Cuyama Valley Groundwater Basin Groundwater Sustainability Plan Hydrogeologic Conceptual Model Draft

Prepared by:

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Chapter 2 Basin Setting

This document includes the Hydrogeologic Conceptual Model Section will be included as part of a report section in the Cuyama Basin Groundwater Sustainability Plan that satisfies § 354.8 of the Sustainable Groundwater Management Act Regulations. The Hydrogeologic Conceptual Model section is a portion of the Basin Settings portion of a Groundwater Sustainability Plan. The Basin Settings contains three main subsections:

- Hydrogeologic Conceptual Model – This section, presented here, provides the geologic information needed to understand the framework that water moves through in the basin. It focuses on geologic formations, aquifers, structural features, and topography.
- Groundwater Conditions - This section describes and presents groundwater trends, levels, hydrographs and level contour maps, estimates changes in groundwater storage, identifies groundwater quality issues, addresses subsidence and surface water interconnection.
- Water Budget – This section provides the data used in water budget development, discusses how the budget was calculated, and provides water budget estimates for historical conditions, current conditions and projected conditions.

Groundwater Conditions and the Water Budget section are currently under development and will be released for review when completed.

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Acronyms

Basin	Cuyama Valley Groundwater Basin
bgs	below ground surface
CUVHM	Cuyama Valley Hydrologic Model
DWR	Department of Water Resources
ft.	feet
ft/d	feet per day
gpd/ft	gallons per day per foot
gpm	gallons per minute
GSP	Groundwater Sustainability Plan
GRF	Graveyard Ridge Fault
HCM	Hydrogeological Conceptual Model
InSAR	interferometric synthetic-aperture radar
Ma	mega-annum (million years)
Morales	Morales Formation
MCL	maximum contaminant level
mg/L	milligrams per liter
NW	northwest
NRCS	National Resource Conservation Service
NWIS	National Water Information System
SAGBI	Soil Agricultural Groundwater Banking Index
SBCF	Santa Barbara Canyon Fault
SMCL	secondary maximum contaminant level
TDS	total dissolved solids
TTRF	Turkey Trap Ridge Fault
µg/L	microgram per liter
USGS	United States Geological Survey
USEPA	United States Environmental Protection Agency

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2.1 Hydrogeologic Conceptual Model

This section describes the Hydrogeologic Conceptual Model (HCM) for the Cuyama Valley Groundwater Basin. (Basin).

As defined by the Groundwater Sustainability Plan (GSP) regulations promulgated by the Department of Water Resources (DWR), the HCM:

1. "Provides an understanding of the general physical characteristics related to regional hydrology, land use, geology geologic structure, water quality, *principal aquifers,* and principal aquitards of the *basin setting;*
2. Provides the context to develop water budgets, mathematical (analytical or numerical) models, and monitoring networks, and
3. Provides a tool for stakeholder outreach and communication."

The HCM is developed to understand and convey the physical conditions by which water moves through the basin and is used elsewhere in the GSP to understand the distribution and movement of water within the basin to support the development of water budgets.

2.1.1 Useful Terminology

The HCM conditions section includes descriptions of the geologic formations and structures, aquifers, and properties of geology related to groundwater, among other related components. A list of technical terms and a description of the terms are listed below. The terms and their descriptions are identified here to guide readers through the section and are not a definitive definition of each term:

- **Formation –** A formation, or geologic formation, is a unit of rock of similar properties, such as grain size, mineral composition, or depositional environmental. Geologic formations are distinct from surrounding rock types and are large enough to be mapped regionally. If the formation contains a dominant rock type, such as sandstone, it may be included in the name of the formation.
- **Basement Rocks –** Basement rocks are the oldest and deepest rocks in the subsurface. Basement rocks are typically crystalline and metamorphic or igneous in origin, and groundwater generally only moves through fractures in the rock instead of pore spaces like in sedimentary rocks. No sedimentary layers are found below the basement rocks.
- **Water Bearing Formation –** A water bearing formation is a rock formation that is saturated and contains water within the pores or fractures of the unit. One or more water bearing formations compose an aquifer.
- **Aquifer –** An aquifer is an underground reservoir of water stored within the pores and fractures of rocks and sediments.
- **Unconfined Aquifer –** An unconfined aquifer is an aquifer that does not have an impermeable layer above it (such as a clay layer). With an unconfined aquifer, the upper water surface is defined as the water table and is at atmospheric pressure. Water seeps from the ground surface directly into the aquifer, as there are not impermeable layers to prevent the water from entering the aquifer.
- **Cross Section –** A cross section is a diagram that identifies subsurface layers located beneath a surficial trend. Stratigraphic cross sections depict geologic formations in the subsurface in relation to elevation. Cross sections are useful tools to interpret geology in the subsurface and visualize the relative thickness and distribution of geologic formations. Cross-sections are often presented with an accompanying map that acts as a reference to spatially locate the trend of the cross section at the surface. To read cross-sections, use the location and trend of the surficial lines on the location map as a key. For instance, where A-A' is marked on the map represents where the cross-section named A-A' is located spatially

- **Hydraulic Conductivity** – Hydraulic conductivity is defined as the "measure of a rock or sediment's ability to transmit water," typically measured in feet or meters per unit of time (day, hour, minute) (DWR, 2003). Rocks and sediments with high values of conductivity, such as gravels or coarse sands, are able to sustain groundwater flow better than rocks and sediments with low values of conductivity. Rocks and sediments with near zero values of hydraulic conductivity, such as very fine-grained sandstones, shale, or granites, do not transmit groundwater and are considered to be barriers to flow. Values of conductivity are used in the groundwater model to determine how quickly formations transmit groundwater and where barriers to groundwater flow (i.e. formations with very low values of conductivity) exist.
- **Hydrogeology** – The study of groundwater and aquifer.
- **Primary Aquifer –** Primary aquifers are required to be identified by GSP regulations, and identify which aquifers require specific monitoring and management. Primary aquifers are regionally extensive and are sources groundwater used for beneficial uses.
- **Aquitard –** An aquitard is a layer of strata that has a low conductivity that groundwater flows very slowly through. Aquitards can be regional, such as the Corcoran Clay in the central valley, where it prevents flow from upper strata to lower strata across the western side of the valley, or localized, which is common in most alluvial settings. Localized aquitards restrict vertical flows in a small region of an aquifer, and water will generally move laterally around localized aquitards as it flows by gravity toward the bottom of the aquifer.
- **Piper Diagrams** – A piper diagram is used to characterize the chemical quality of a water sample involves plotting the relative proportions of major ions on a Piper diagram. Piper diagrams show the relative abundance of major cations (Sodium, Potassium, Calcium, Magnesium) and anions (Bicarbonate, Carbonate, Sulfate, Chloride, Fluoride) commonly found in water on a charge equivalent basis, as a percentage of the total ion content of the water, and are useful to understand 'what kind of salts' make up the TDS in a location.

2.1.2 Regional Geologic and Structural Setting

The basin is located at the southeastern end of the California Coast Ranges and north of the Western Transverse Ranges (Figure 2.1-1) and is in an area of high tectonic activity. The basin is bounded on the north and south by faults and is located near major fault zones such as the San Andreas and Santa Maria River fault zones. Because the basin is located in a mountainous region with active tectonic activity, it has a number of structural features generated by tectonic activities. The basin has been deformed by this tectonic activity, and is generally a synclinal basin, with multiple synclines that are oriented to the northwest and a number of faults that cross the basin.

Tectonic activity from the northwest movement of the San Andreas fault system has led to the development of a fold and thrust belt which has driven the deformation of the Cuyama Valley for the past four million years (USGS, 2013c). The Cuyama Valley was formed by a downfaulted block of the earth's crust called a graben. This block is bordered on the north by the Morales and Whiterock faults and on the south by the South Cuyama and Ozena faults. Along these borders the faults have thrust older rocks of pre-Pliocene age over the rocks of Pliocene age and younger. In the eastern part of the valley the north-bordering faults approach the San Andreas fault zone and the south-bordering faults approach the Big Pine fault. (Singer and Swarzenski, 1970)

2.1.3 Geologic History

The Cuyama Basin has a long history of deformation and deposition, most influenced by tectonic activity and cycles of marine transgression and regression. Formations in the Basin reflect variable depositional environments, from the middle bathyal shales and siltstones to the nonmarine sandstone, conglomerate, and mudstones. Marine rocks are dominant in the western part of the basin and interfinger to the east with nonmarine rocks (Ellis, 1994).

A major late Eocene/early Oligocene (38 – 28 million years (Ma)) unconformity affected all regions south of the San Andreas fault, shown in the geologic record by nonmarine Oligocene (23 Ma) rocks overlying a thick section (several kilometers) of upper Eocene (56 Ma) marine rocks (Kellogg et al., 2008; Ellis, 1994). The unconformity is a result of the Ynezian orogeny (around 30 Ma) during which pre-Oligocene marine rocks were folded and uplifted above younger, Oligocene-age sediments (Kellogg et al., 2008).

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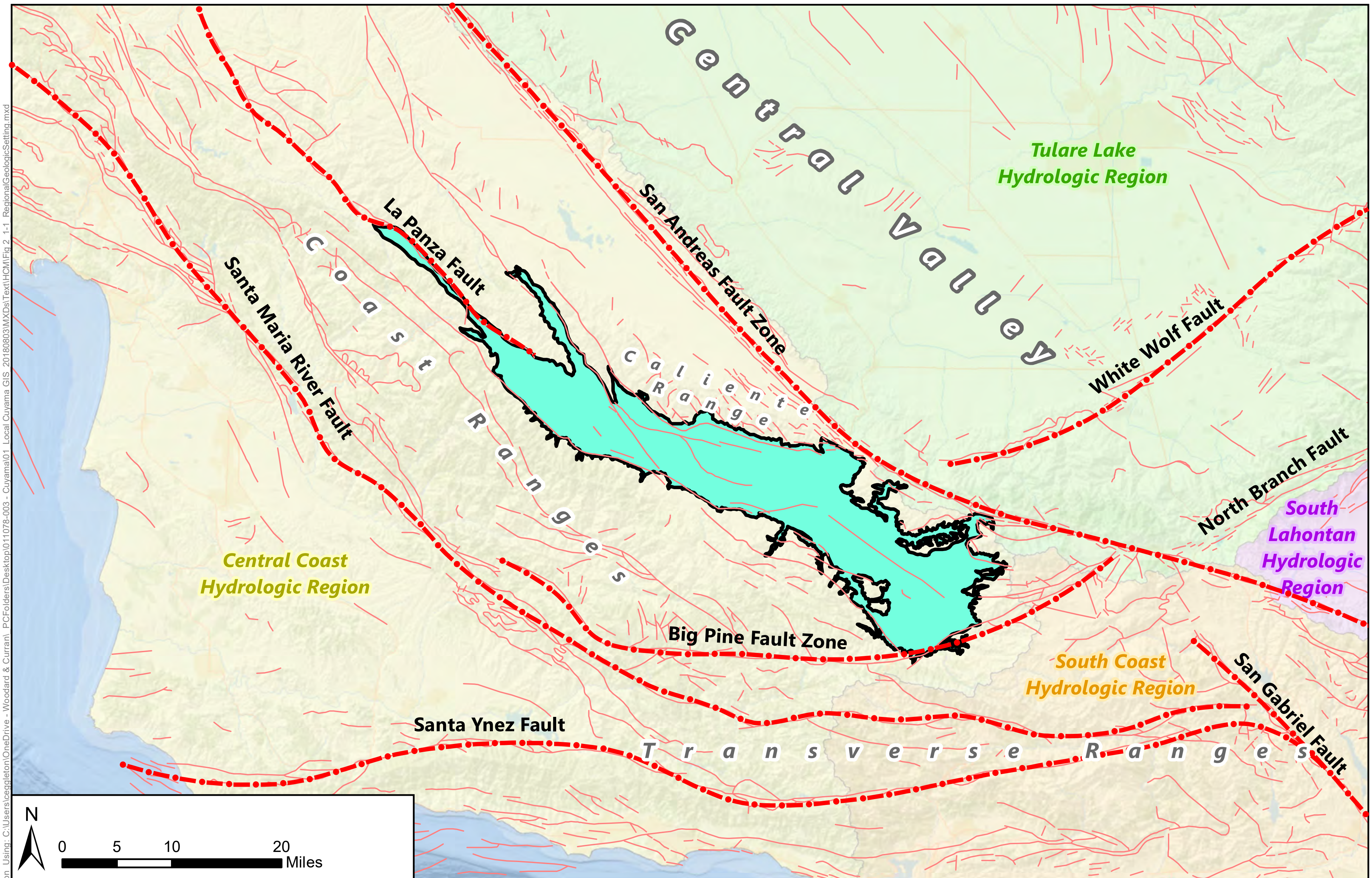

Figure 2.1-1: Regional Geologic Setting

Cuyama Basin Groundwater Sustainability Agency

Cuyama Valley Groundwater Basin Groundwater Sustainability Plan

August 2018

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Legend

Cuyama Basin

Faults

Fault Data Sources:
Fault Activity Map of California (2010) from the California Department of Conservation. Retrieved 6/13/2018.
<http://maps.conservation.ca.gov/cgs/fam/>
California Geologic Map Data from United States Geologic Survey. Retrieved 2/8/2018.
<https://mrdata.usgs.gov/geology/state/state.php?state=CA>

Figure Exported: 10/18/2018 By: ceggleton Using: C:\Users\ceggleton\OneDrive - Woodard & Curran\PCFolders\Desktop\011078-003 - Cuyama\01 Local Cuyama GIS 20180803\MXDs\Text\HCM\Fig 2.1-1 RegionalGeologicSetting.mxd

Following a period of orogeny, deformation changed to extension from the late Oligocene and early Miocene (around 23 Ma) and the Cuyama Basin became a major extensional basin (Ellis, 1994). This period also correlated with two transgressive-regressive cycles, where the sea advanced and retreated over geologic time over the sediments now in the basin due to tectonic subsidence (Bazeley, 1988). Sediments deposited during this period reflect the cyclical nature of sea level rise and are generally categorized by marine strata in the west and nonmarine strata to the east. Formations deposited during ocean transgression are thick marine sediments, including the Vaqueros Formation, Monterey Formation, Branch Canyon Sandstone, and Santa Margarita Sandstone (Kellogg et al., 2008; Lagoe, 1981). Many of the marine units interfinger with terrestrial units and eventually pinch out to zero thickness in the east. During the late Miocene (8 Ma), the sea regressed from the western part of the region, evident in the geologic record where the nonmarine Caliente Formation interfingers with the similarly aged marine Santa Margarita Sandstone and unconformably overlies the Branch Canyon Sandstone (Kellogg et al., 2008). By the middle Miocene (15 Ma), the eastern Cuyama Valley area was characterized by a shelf and nonmarine deposition. Deformation by the middle Miocene changed from extension to right-lateral strike slip motion, resulting in the development of the Russell fault.

Deformation from Oligocene extension and Miocene strike-slip faulting regimes was buried by the folding, uplift, and thrust faulting during the Pliocene through Pleistocene compression (beginning around 4 Ma) (Ellis, 1994). Compression led to the uplift of the Coast and Transverse mountain ranges surrounding the current topographic valley and the converging thrust faults that surround the present day topographic basin, including the Whiterock, Morales, and South Cuyama faults (United States Geological Survey [USGS], 2013b). The transition to a predominantly compressional system led to the development of a thrust system across the older extensional basin and began thrusting older sediments above younger sediments through the Cuyama Valley (Davis et al., 1988). Older, inactive faults and rocks were buried by the deposition of the younger Morales Formation, older alluvium, and younger alluvium. Thrust and compression continued into the Quaternary (3 – 2.5 Ma) and uplifted the Caliente Range and thrusted Miocene-aged rocks of the Caliente Range southward over Quaternary alluvium on the Morales fault (USGS, 2013b; Ellis, 1994). The Morales Formation and older alluvium are folded into synclines along the north and south margins of the valley near the bounding thrust faults (USGS, 2013b). The end of the Pliocene (around 2 Ma) marks the complete withdrawal of the sea from the area and the final sea regression marks the change in deposition of marine sediments to the continental clay, silt, sand, and gravel of the Morales Formation and alluvium (Singer and Swarzenski, 1970; Ellis, 1994). Fluvial deposits of claystone, sandstone, and conglomerate became the primary forms of sedimentation.

2.1.4 Geologic Formations/Stratigraphy

The Cuyama Valley Groundwater Basin is composed of a sequence of unconsolidated to partly consolidated nonmarine deposits of Pliocene to Pleistocene age unconformably overly consolidated marine and nonmarine sedimentary rocks of late Cretaceous to middle Cenozoic age on top of Mesozoic crystalline granitic and gneissic bedrock (Davis et al., 1988). The unconsolidated to partly consolidated nonmarine deposits are the primary water-bearing units in the Cuyama Basin and are described in further detail in Section 2.1.7. Individual geologic units found in the Cuyama Basin are described in detail below, in order of youngest to oldest in deposition. Geologic units mapped at the surface are shown in Figure 2.1-2. A generalized stratigraphic column of the Valley is shown in Figure 2.1-3.

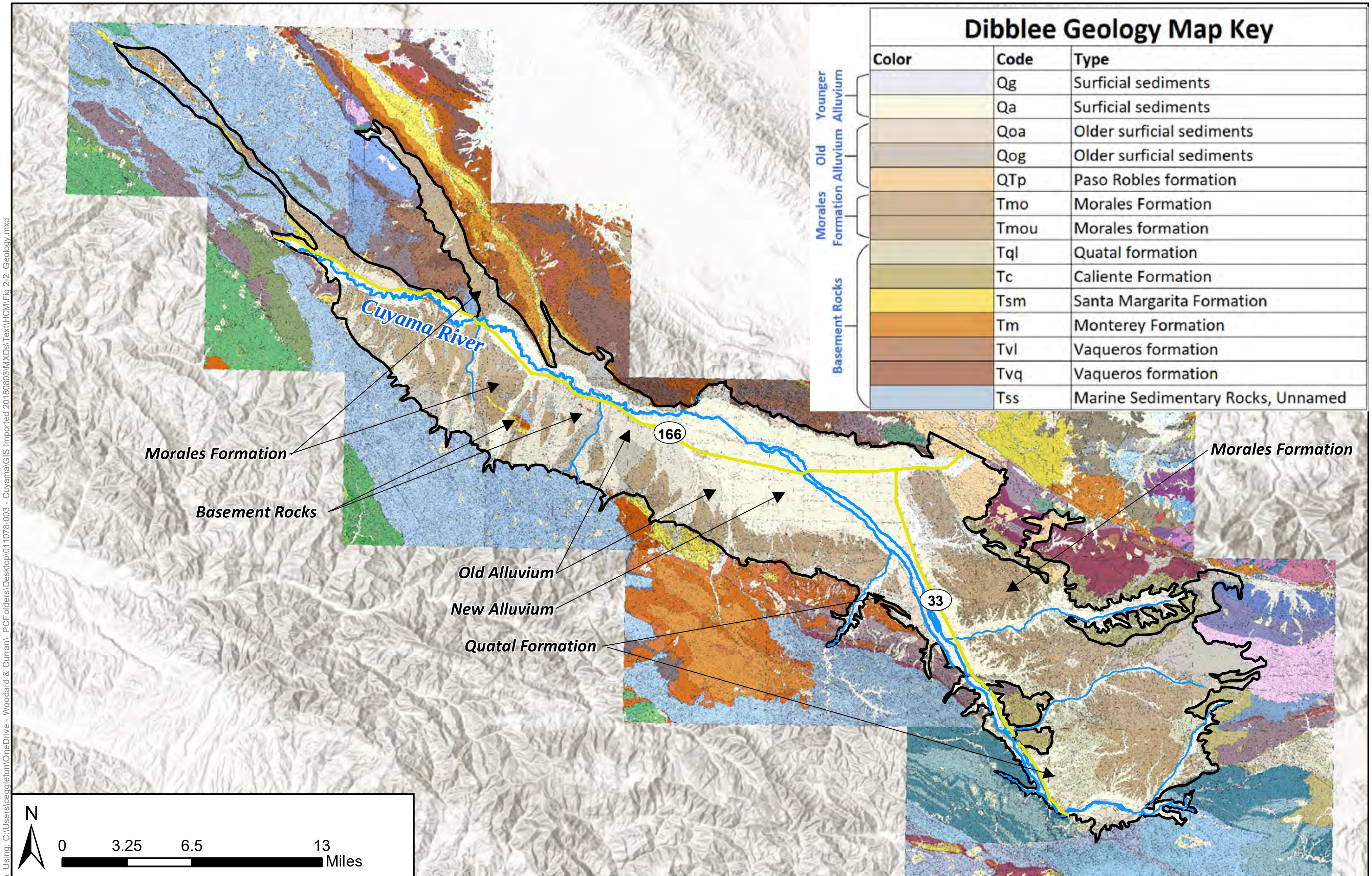

Figure 2.1-2: Geologic Map

Cuyama Basin Groundwater Sustainability Agency

Cuyama Valley Groundwater Basin Groundwater Sustainability Plan

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Legend

- Cuyama Basin
- Cuyama River
- Streams
- Highways

Data Source: Thomas W. Dibblee, Jr., Dibblee Foundation Relased in June 2012, Purchased from AAPG as GeoTIF 28 March 2018.

Figure Exported: 8/21/2018 By: ceggleton Using: C:\Users\ceggleton\OneDrive - Woodard & Curran\ PCFolders\Desktop\011078-003 - Cuyama\GIS Imported 20180803\MXDs\Text\HCM\Fig 2-2 Geology.mxd

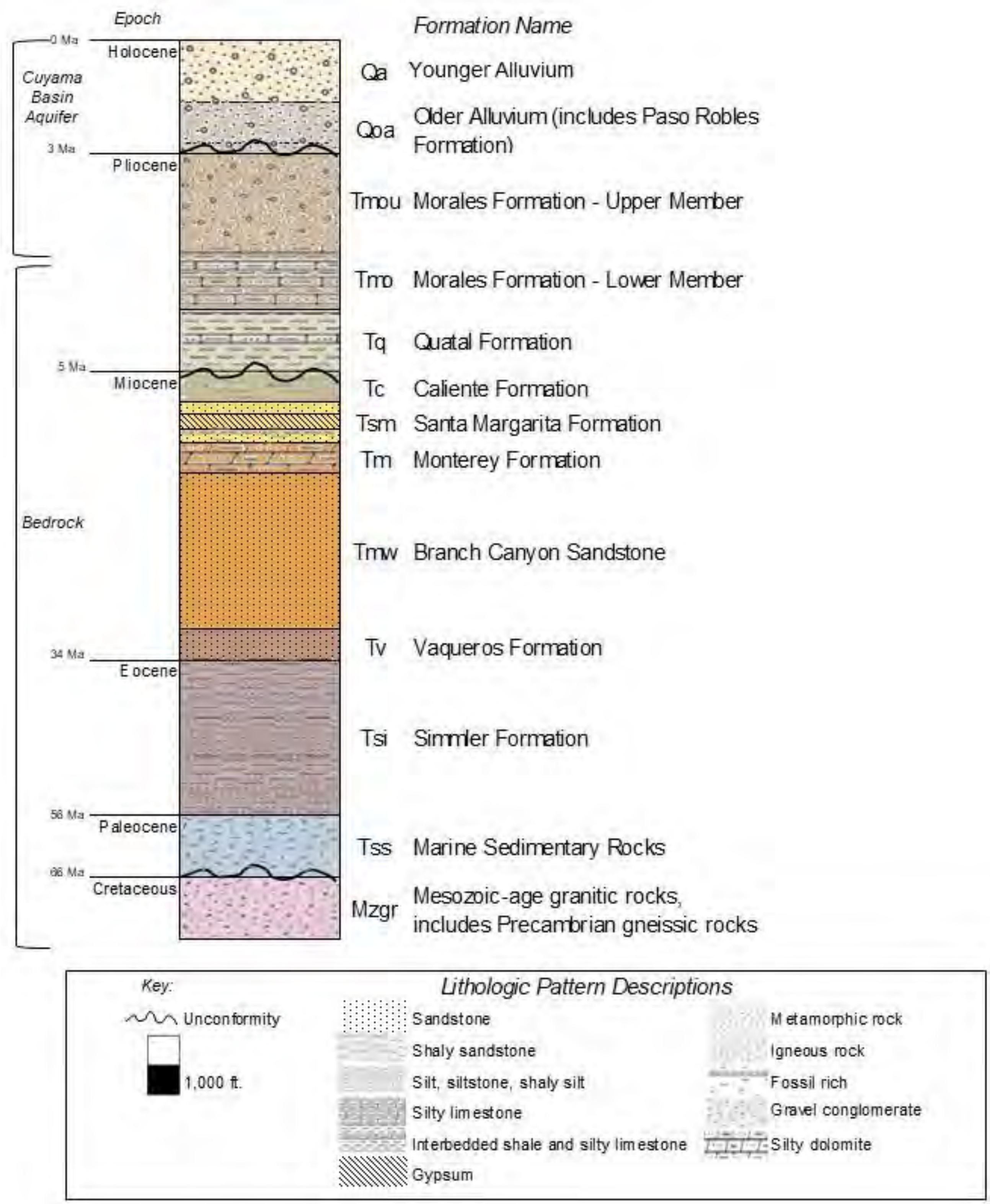
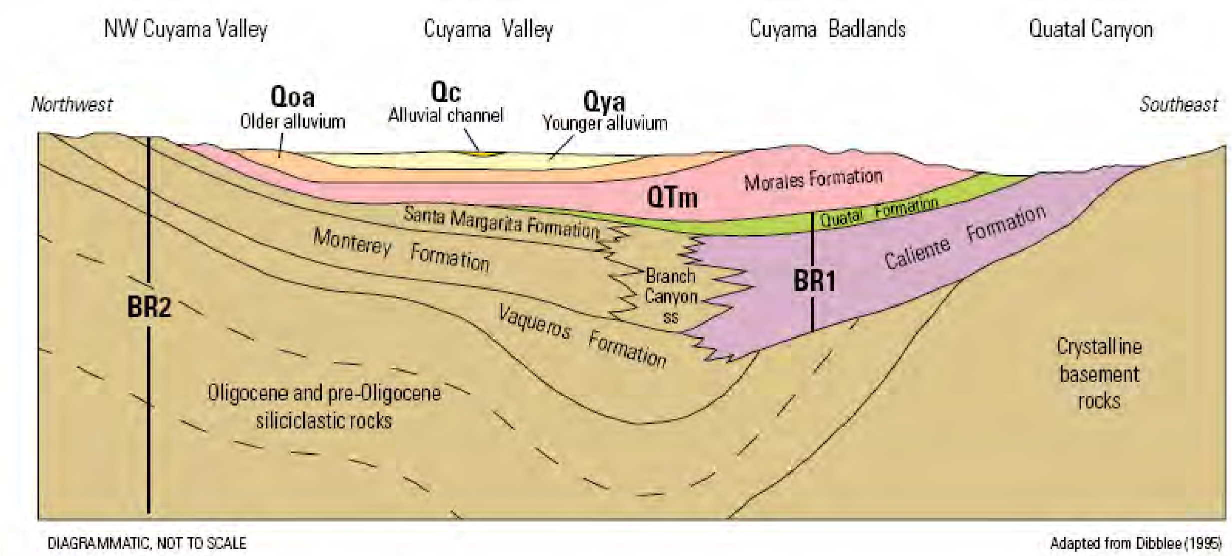


Figure 2.1-3: Generalized Stratigraphic Column of the Cuyama Valley

Stratigraphic Units of the Cuyama Basin Aquifer

Stratigraphic units in this section are presented in order from youngest to oldest. The USGS prepared a generalized stratigraphic diagram of the basin and surrounding area in 2013 (Figure 2.1-4). The diagram shows the relationship of the Young Alluvium, Older Alluvium, Morales Formation, and basement rocks in and near the basin. The diagram shows that the Morales formation is thicker to the east, and that the Caliente Formation is interfingered with a number of other basement rock formations (Santa Margarita, Monterey, Vaqueros) beneath the basin (USGS 2013a). This diagram shows the general relationship of formations in the Cuyama area and is not a precise representation of unit thickness.



Source: USGS, 2013a.

Figure 2.1-4: Generalized Stratigraphic Diagram

Recent and Younger Alluvium

The youngest deposit of the Cuyama Basin is the recent and young alluvium. Recent alluvium is made up of active fluvial channel deposits associated with the Cuyama River and other active channels. Deposits include river-bed gravels and grain sizes range from silt to boulder size and are found along active fluvial channels in the Basin. The younger alluvium is inactive fluvial deposits consisting of unconsolidated to partly consolidated sand, gravel, and boulders, with some clay deposited as part of stream channels, floodplains, alluvial fans, or stream terraces (USGS, 2013c). Younger alluvium is exposed throughout the central portion of the Valley and along the active channels and flood plains of the Cuyama River and other streams. The deposits thicken to the east; typically ranging from 5 to 50 feet (ft.) in the west and thicken up to 630-1,100 ft. in the east (Singer and Swarzenski, 1970). Recent and younger alluvium are primarily Holocene in age, but the younger alluvium can date back to the Pleistocene (USGS, 2013c). The younger and recent alluvium are the principal water-bearing formations in the Cuyama Basin.

Older studies do not distinguish the younger alluvium from the older alluvium (Upson and Worts, 1951; Singer and Swarzenski, 1970), but more recent studies (Kellogg et al., 2008) mapped the two alluvium units as distinguishable mappable units at the surface and the USGS identified differences in the two units using electric log signatures in 2013. A greater degree of consolidation, dissection, and local deformation distinguishes the older alluvium deposits from the younger alluvium.

Older Alluvium

Older alluvium is primarily Pleistocene in age and is composed of unconsolidated to partly consolidated sand, gravel, and boulders with some clay (USGS, 2013a). The percentage of clay increases in the western part of the valley. Older alluvium deposits are typically more consolidated and deformed than younger alluvium deposits and contain a higher clay content. The older alluvium is dissected alluvial fans, colluvial deposits and sediments on multiple terraces and alluvial surfaces and is found exposed on uplifted alluvial surfaces along the south side of the Cuyama Valley and on the caps of the Turkey Trap and Graveyard ridges (USGS, 2013a). Older alluvium is typically 400 to 600 ft. in thickness but increases in thickness up to 1,000 ft. near the axis of the Cuyama Valley and decreases in thickness west of the Russell fault (USGS, 2013a; Cleath-Harris, 2018). The older alluvium overlies the Morales Formation unconformably, west of the Cuyama Badlands (Ellis, 1994).

Paso Robles Formation

The Paso Robles Formation is part of the Quaternary alluvium series and is commonly grouped with the older alluvium. The Paso Robles Formation is a gray, crudely bedded alluvial gravel derived from Miocene rocks and basement rocks of western San Emigdio Mountains east of San Andreas Fault (Davis et al., 1988). The Formation is composed of pebbles, gravel, sand, and some cobbles. The Paso Robles Formation is sandwiched between two unconformities; it rests uncomformably below the older alluvium and with angular discordance above the Morales Formation (Davis et al., 1988; Ellis, 1994). The Paso Robles Formation is present only in a small northeastern portion of the basin.

Morales Formation

The Pliocene to Pleistocene-aged Morales Formation (Morales) is divided into two members, the upper and lower. The Morales Formation is the oldest formation to respond to the modern topography of the Cuyama Basin, indicating its deposition simultaneous to acceleration of tectonic-driven subsidence (Yeats et al., 1989). The contact between the upper and lower members of the Morales is used to define the base of water-bearing units of the Cuyama Basin (USGS, 2013a).

The Morales is massively bedded and ranges from 1,000 to 5,000 ft. in thickness east of the Russell fault and up to 1,200 ft. thick west of the Russell fault (USGS, 2013a; Cleath-Harris, 2018). Thickness of the Morales Formation is disputed amongst published references. In 1970, Singer and Swarzenski reported the Morales Formation to be up to 10,000 feet in thickness along the northern margin of the Valley (Singer and Swarzenski, 1970). The Morales Formation is found throughout the Valley and is widely exposed to the east of the Cuyama River near Ventucopa and the Cuyama Badlands. Its lateral extent is generally limited by faults. The Morales Formation is overlain unconformably by the older and younger alluvium (Hill, 1958).

Upper Morales

The upper member of the Morales is composed of partly consolidated, poorly sorted deposits of gravelly arkosic sand, pebbles, cobbles, siltstone, and clay of Pleistocene age (Davis et al., 1988). The upper Morales is a water-bearing unit and the base of this member marks the base of aquifer materials in the basin. The upper Morales is thickest to the east near the Cuyama Badlands, approximately 2,200 ft., and shallows to the west, less than 800 feet west of the Russell fault (Hill, 1958; Cleath-Harris, 2018). In the central portion of the Basin, south of the Cuyama River, the upper Morales is around 1,500 feet thick (Ellis, 1994). In some areas, such as near Ballinger Canyon, the Morales shows some degree of angular unconformity (Ellis, 1994).

Stratigraphic Units Below the Cuyama Basin Aquifer

Lower Morales

The lower member of the Morales consists of clay, shale, and limestone with lacustrine clay beds with distinct coarse-grained intervals, boulder trains, and gravelly channel deposits (USGS, 2013a). The lower member of the Morales finer grained than the upper Morales and is less permeable. The lower Morales is not considered a water bearing unit. South of the Cuyama River, the lower part of the Morales consists of about 1,300 feet of gray, gypsiferous, lacustrine claystones (Hill, 1958). The lower Morales lies conformably on the Quatal Formation and, in western areas of the Basin, unconformably on other marine units (Ellis, 1994).

Quatal Formation

The Quatal Formation is a sequence of fluvial and lacustrine claystone, siltstone, and sandstone which unconformably underlies the Morales Formation. Near the Cuyama Badlands, the formation is up to 820 ft. of gypsiferous claystone while in other areas the unit is nonmarine sandstones interbedded with the claystone (USGS, 2013a). The Quatal Formation thins to the west and pinches out to zero in thickness near the town of Cuyama. In the eastern and central parts of the Basin, the Quatal Formation is a distinct stratigraphic marker that defines the bottom of the Morales Formation (USGS, 2013a). The Quatal Formation is not a water bearing unit and is not considered a part of the Cuyama Basin groundwater system.

Caliente Formation

The Caliente Formation is composed of nonmarine sandstones, claystones, and conglomerates of Miocene age (Davis et al., 1988). Layers of volcanic ash and basalt sills and dikes are commonly found in the formation and tertiary basalt is found interbedded with the formation in the Caliente Range (Davis, 1988; Dudek, 2016). The formation is exposed on the eastern half the Valley, along the basin edge in the Caliente Ranges and in a footwall block of the Pine Mountain fault (Kellogg et al., 2008). The fluvial Caliente Formation was deposited in the east at the same time the marine Branch Canyon Sandstone and Santa Margarita Formation were being deposited to the west (Ellis, 1994). The Caliente Formation conformably overlies and interfingers with the marine sedimentary rocks of the Santa Margarita Formation and pinches out to zero thickness to the west (Kellogg et al., 2008; Davis et al., 1988).

Santa Margarita Formation

The Santa Margarita Formation is composed of shallow-marine, consolidated sandstones from the middle to late Miocene (USGS, 2013b). The formation contains a gypsum member and a sandstone-mudstone member. The gypsum member consists of a greenish-gray, medium to thin bedded gypsum, up to 82 ft. thick (Kellogg et al., 2008). The sandstone and mudstone member consists of interbedded layers of arkosic sandstone, mudstone, and siltstone, up to 400 ft. thick (Kellogg et al., 2008). The sandstone sequence is rich in shallow marine molluscan fossils. The formation unconformably underlies the Morales Formation in the northwest of the Valley and grades into the Caliente Formation to the east (Hill, 1958). Locally, the formation contains layers of volcanic ash, basalt sills, dikes and flow units (Davis et al., 1988). The Santa Margarita Formation is the youngest marine unit in the Cuyama Basin and marks the final phase of marine sedimentation and sea transgression (Lagoe, 1981).

Monterey Formation

The Monterey Formation consists of intervals of dolomitic marine shale, mudstone, and siltstone. The formation is subdivided into two members: the upper Whiterock Bluff Shale member and the lower Saltos Shale member (Davis et al., 1988). The Whiterock Bluff Shale is a calcareous in the lower two-thirds and becomes gradually siliceous in the upper one-third and is found up to 1,200 feet in thickness (Bazeley, 1988; Hill, 1958). The Saltos Shale member is a calcareous shale with turbiditic sandstones and was deposited at the same time as the fluvial Caliente Formation, but in the western, bathyal portion of the Basin (Davis et al., 1988; USGS, 2013b). The Saltos Shale member is found up to 2,250 feet thick (Hill, 1958). The formation is middle Miocene in age and is cut with layers of volcanic ash and Miocene-age basalt sills (Davis et al., 1988). In the Caliente Mountain Range, tertiary basalt is found interbedded with the Monterey Formation (Davis et al., 1988). To the east, the Monterey Formation grades into the Branch Canyon Sandstone. The formation is conformably overlain by the Santa Margarita Formation.

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Branch Canyon Sandstone

The Branch Canyon Sandstone is Middle Miocene in age and is a shallow marine sandstone (Davis et al., 1988). Like the Monterey and Santa Margarita formations, the Branch Canyon Sandstone contains layers of volcanic ash and is cut by basalt sills and dikes (Davis et al., 1988). The sandstone grades into the Caliente Formation to the east and is up to 2,500 ft. thick (Kellogg et al., 2008). The easternmost extent of the Branch Canyon Sandstone represents an early Miocene wave-dominated shoreline and is defined by the gradational change into the nonmarine Caliente Formation to the east (Davis et al., 1988; Bazeley, 1988).

Vaqueros Formation

Most of the oil produced in the Cuyama Basin comes from the Vaqueros Formation. The formation is late Oligocene to early Miocene in age and is a marine clastic unit that is subdivided into three members: the upper, shallow-marine Painted Rock Sandstone member, the middle, bathyal Soda Lake Shale member, and the lower, shallow-marine Quail Canyon Sandstone member (Davis et al., 1988). The Vaqueros Formation represents a shallow-marine, high-energy, shoreface environment where the lower half represents a transgressive environment and the upper half represents a regressive environment (Bazeley, 1988). To the east, the Vaqueros Formation grades into the lower part of the nonmarine Caliente Formation. In the Cuyama Badlands, the Vaqueros Formation rests on the Simmler Formation and crystalline basement rocks, while in the central portion of the Basin, the Vaqueros Formation rests on Paleogene sedimentary rocks (Ellis, 1994). The Branch Canyon Sandstone and Monterey Formation are conformably above the Vaqueros Formation (Davis et al., 1988).

Simmler Formation

The Simmler Formation is a terrestrial sandstone, siltstone, and conglomerate of the Oligocene epoch (Davis et al., 1988). The Simmler Formation contains a shale member containing intervals of claystones and siltstones interbedded with coarse sandstones and a sandstone member containing sandstones interbedded with siltstones and claystones (Kellogg et al., 2008). The formation is as thick as 2,800 ft. and overlies the Eocene-Oligocene unconformity (Kellogg et al., 2008). To the east, the Simmler Formation interfingers with a thin section of the marine Vaqueros Formation, marking the beginning of marine regression in the early to middle Miocene (Kellogg et al., 2008). Sediments of the Simmler Formation were sourced from the erosion of the Santa Barbara Canyon area and were deposited on a wide, delta plain (Bazeley, 1988). Though rare, the Simmler Formation can contain interbedded mafic volcanics (Yeats et al., 1989).

Marine Sedimentary Rocks

Late Cretaceous to Eocene marine rocks are unnamed but are part of the crystalline basement of the Cuyama Valley (Davis et al., 1988). The strata are unconformably overlain by a thick section of middle and upper Cenozoic rocks and are primarily exposed in the La Panza and Sierra Madres ranges and the hanging walls of the South Cuyama, La Panza, and Ozena faults (Davis et al., 1988).

Formations Older Than Marine Sedimentary Rocks

The crystalline rocks of the Cuyama Valley are composed of Mesozoic age granitic rocks and Precambrian age gneissic rocks (Davis et al., 1988). Cretaceous granitic rocks are exposed in the La Panza Range and near the San Andreas Fault, 12-18 miles southeast of the Cuyama Valley (USGS, 2013b). Precambrian granitic gneissic rocks outcrop east of the Cuyama Badlands and the La Panza Range (USGS, 2013b). Total thickness is unknown.

Figure 2.1-5 shows the locations of cross sections across the central portion of the basin prepared by USGS in 2013. Figure 2.1-5 shows an west-east cross section that runs near the towns of New Cuyama and Cuyama labeled A-A', and a south-north cross section labeled B-B'. Figure 2.1-6 shows the A-A' cross section and Figure 2.1-7 shows the B-B' cross-section. Cross-section A-A' shows the layering of the recent

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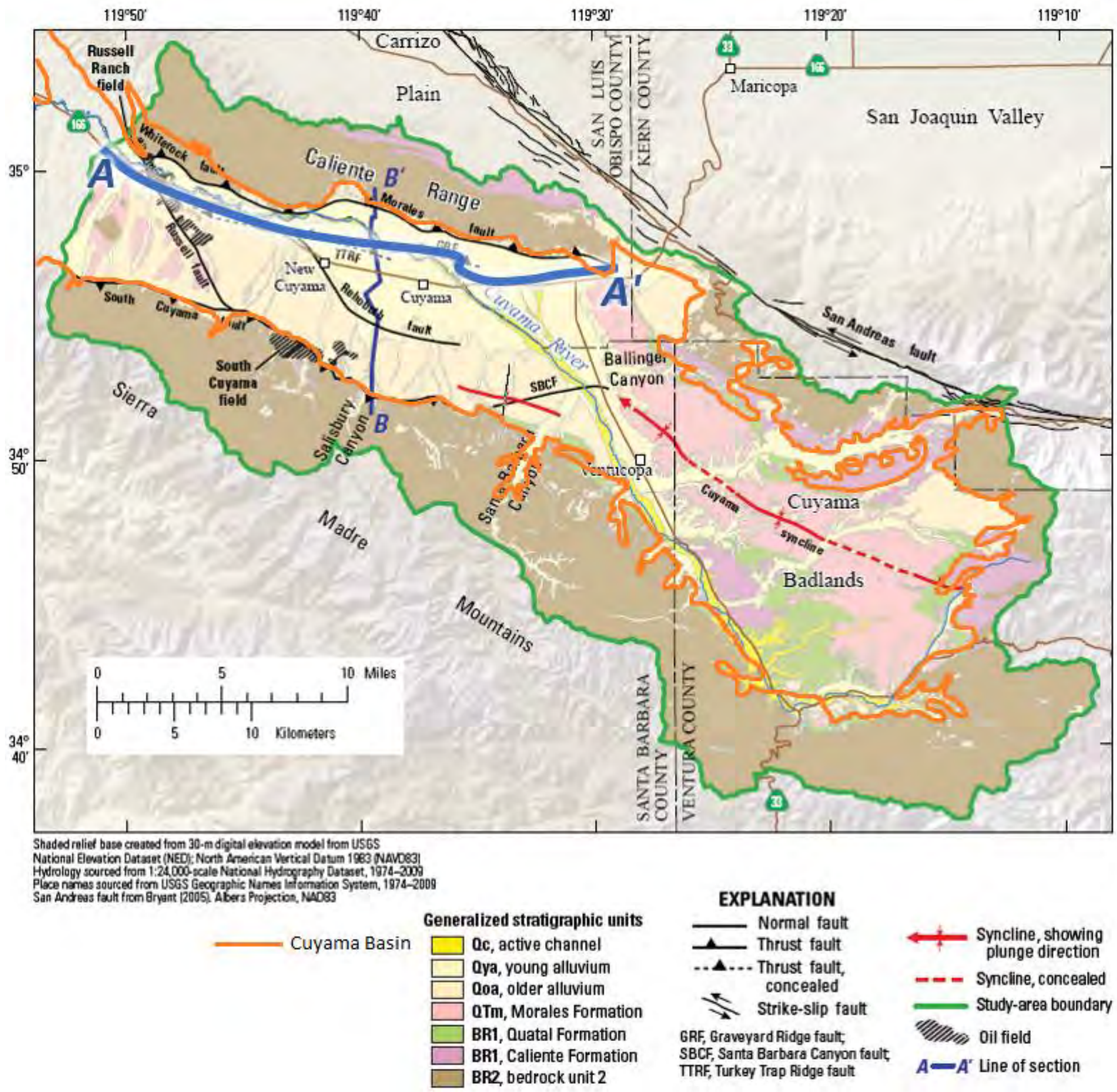
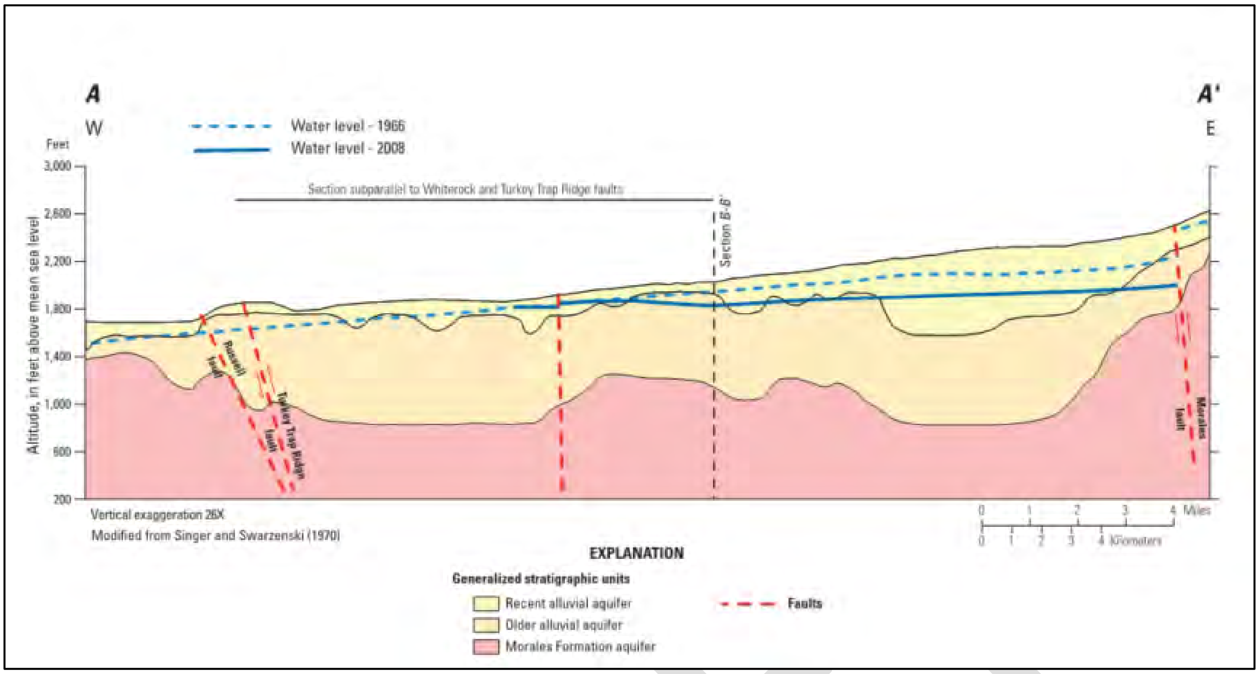


Source: USGS, 2015.

Figure 2.1-5: Location of USGS 2015 Cross-sections



Source: USGS, 2015

Figure 2.1-6: USGS Cross Section A-A'

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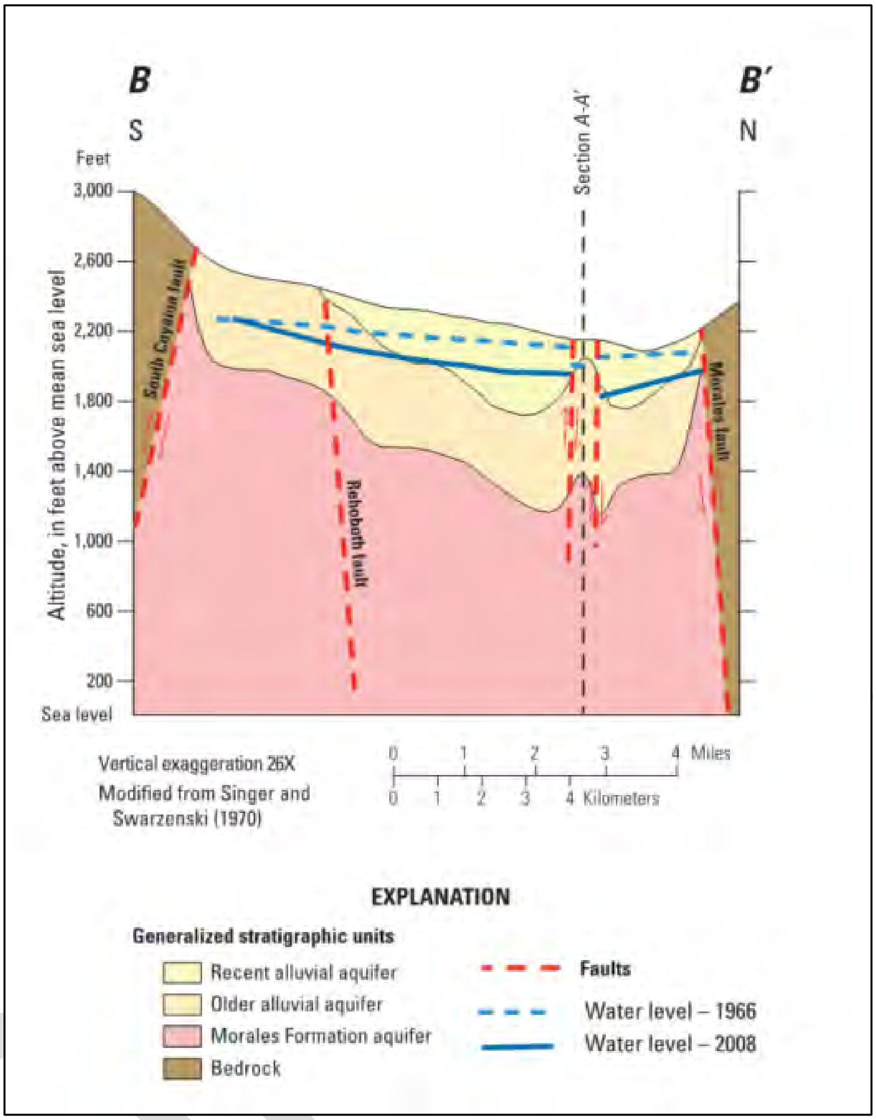

Source: USGS, 2015

Figure 2.1-7: USGS Cross Section B-B'

and older alluvial aquifers and the Morales Formation aquifer, as well as where the Russell Fault, and Turkey Trap Ridge Fault cross the cross-section, and groundwater elevation. Figure 2.1-7 shows cross-section B-B' which shows layering of the aquifers and the locations where the Rehoboth and Graveyard Ridge fault cross the cross section.

2.1.5 Faults and Structural Features

The basin is bounded by faults and contains a number of tectonic features including synclines, faults, and outcrops of basement rocks within the basin. Major faults and synclines are shown in Figure 2.1-8. Outcrops of basement rocks are shown on the geologic maps (Figure 2.1-2 and Figure 2.1-5).

Synclines

There are a number of synclines in the basin, they are generally oriented to the northwest/southeast consistent with how the majority of the basin is oriented.

Cuyama Syncline

The Cuyama Syncline is located in the southeastern portion of the basin. It stretches from the Ballinger Canyon south into the Cuyama Badlands, ending along the Cuyama River. The Cuyama Syncline plunges from the Ventucopa area northwestward to beneath the valley from the Ventucopa area to the southeast. The syncline is known from subsurface data from oil exploration wells beneath the valley and exposed near the town of Ventucopa and in the Cuyama Badlands. (USGS, 2013a). The axis of the syncline strikes roughly parallel to the San Andreas Fault (N50°W) and plunges to the northwest (13°NW) (Singer and Swarzenski, 1970; Ellis, 1994). The Cuyama syncline was a depocenter (a site of sediment accumulation) during the deposition of the Morales Formation (Ellis, 1994). The syncline has folded water and non-water bearing formations and is favorable to the transmission of water from the southeast end of the valley but otherwise has no pronounced effect on the occurrence of groundwater (Upson and Worts, 1951).

Syncline Near the Santa Barbara Canyon Fault

Near the Santa Barbara Canyon Fault, A syncline is indicated by the USGS. The syncline runs generally east-west and is roughly five miles long. It ends near the southern edge of the South Cuyama fault (USGS, 2013a).Syncline in the Northwestern Portion of the Basin

There is a syncline in the western portion of the basin, that roughly follows a west-northwest (WNW) direction near the southern border of the basin, located southwest of the Russel fault, near an outcrop of the Santa Margarita formation. (Cleath-Harris, 2018). The full extent of this syncline, and its length are not documented at this time, but likely extends 5 to 10 miles, which is the length of documented faults in the area, as mapped by Dibblee. (Dibblee, 2005)

Major Faults

There are a number of faults within the basin, many of which take the form of ‘fault zones’ where there are multiple individual faults close together oriented in the same direction. This section describes each major fault individually, with consideration that there are often additional small faults near each major fault. Major faults are shown in Figure 2.1-8.

Russell Fault

The Russell fault is a subsurface, right lateral, strike-slip fault that is seven miles long and runs roughly parallel to the Russell Ranch oil field through the western portion of the basin.

The Russell fault offsets the top of bedrock by as much as 1,500 feet (Nevins, 1982), and has had approximately 18 miles of right-lateral offset documented on the NW-striking Russell fault in the NW part of the Cuyama Valley have occurred between 23 and 4 Ma (USGS, 2013a; Ellis, 1994). The fault is referred to as strike-slip by several authors, and normal fault by others, and is sometimes referred to as both strike slip and normal within the same document (USGS, 2013a). Water bearing units on the western (upthrown) side of the Russell fault become thinner to the west of the Russell Fault and become thicker to the east of the Russel Fault due to this uplift. Alluvium is generally limited to stream channels and the Cuyama River bed on the western side of the fault.

The Russell fault has been analyzed by a number of authors who have come to differing conclusions regarding the fault’s potential to be a barrier to groundwater flow. In 1989, Yeats stated that “the base of the Morales Formation is not cut by the fault” (Yeats et al., 1989). Using tectonic activity and decreasing offset of younger beds, Yeats concluded that the Vaqueros Formation is primarily impacted as it was deposited during the fault’s most active period and that by the time the Morales Formation was deposited 19 million years later, activity on the fault had ceased (Yeats et al., 1989). The USGS in 2008 initially concluded that the fault was not a barrier to flow (USGS, 2013c). The USGS in 2013 studied the fault using interferometric synthetic-aperture radar (InSAR) data and concluded that “the Russell fault did not appear to be acting as a barrier to groundwater flow” (USGS, 2013c). In 2015 the USGS identified the Russell fault as a barrier to flow and used it as a no flow boundary in the CUVHM model (USGS, 2015). Based on

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the conclusions of the USGS, Dudek stated that the fault has indicators that it obstructs groundwater flow due to truncation of older geologic formations and standing moisture near the fault and prepared a basin boundary modification request based on the conclusion that the fault is a barrier to flow (Dudek, 2016). In addition, Cleath-Harris determined that the fault is a barrier to flow and prepared a technical memorandum to document their study of the fault's behavior (Cleath-Harris, 2018). In 2016, DWR denied a request for a basin boundary modification motivated by claims that the Russell Fault is a barrier to groundwater flow and divides groundwater in the central portion of the basin from groundwater in the west. DWR rejected the basin boundary modification request, citing a lack of hydrogeologic data that supported evidence of barrier. EKI reviewed the USGS's work in 2017 and concluded the fault potential to be a barrier is not understood and recommended additional study to refine the fault's properties (EKI, 2017).

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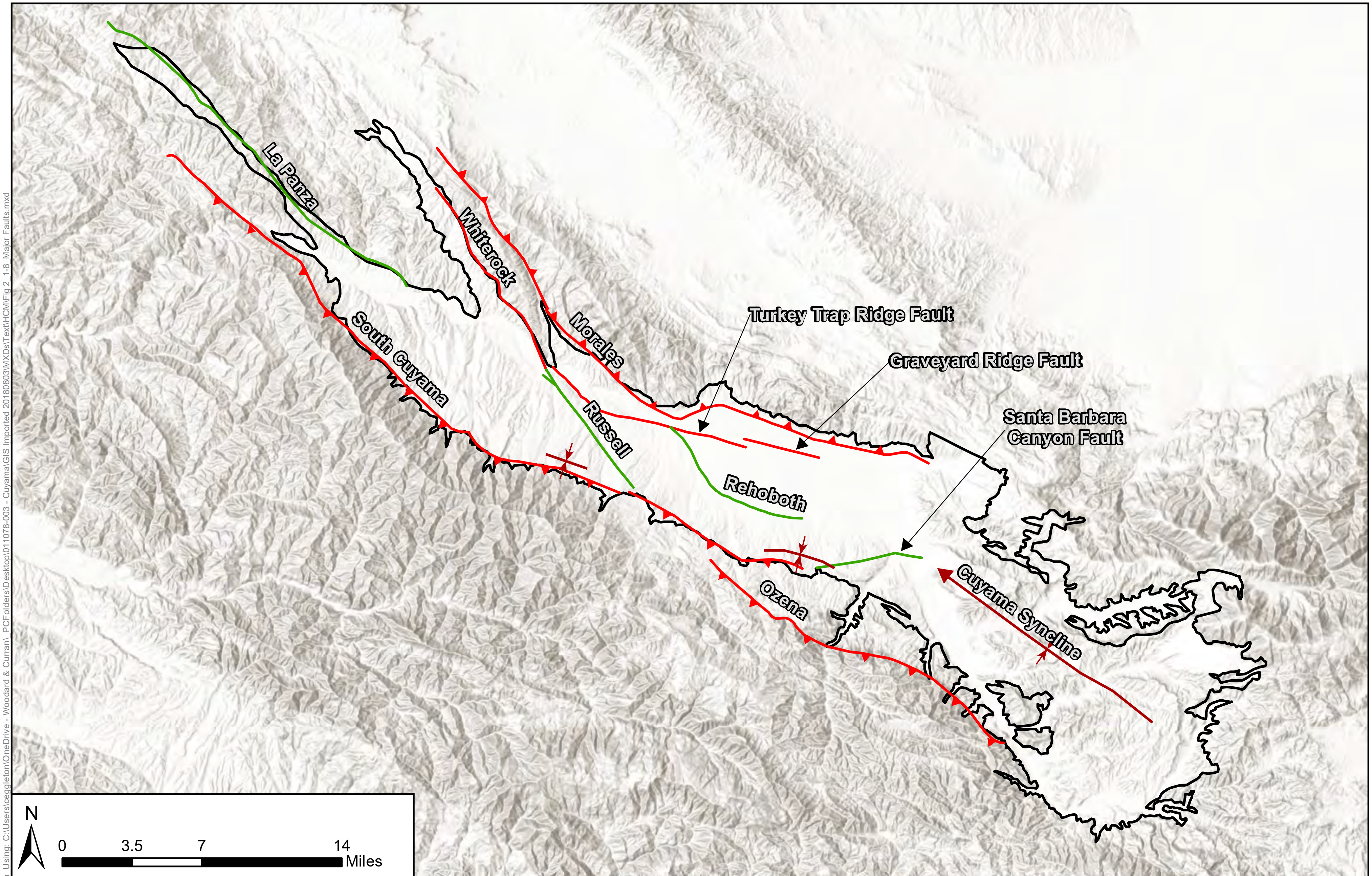

Figure 2.1-8: Major Faults

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Cuyama Valley Groundwater Basin Groundwater Sustainability Plan

August 2018

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Legend

Fault Types

- Normal
- Syncline
- Thrust
- Thrust Fault, Concealed

Cuyama Basin

Figure Exported: 8/21/2018 By: ceggleton Using: C:\Users\ceggleton\OneDrive - Woodard & Curran\ PCFolders\Desktop\011078-003 - Cuyama\GIS Imported 20180803\MXDs\Text\HCM\Fig 2 1-8 Major Faults.mxd

Rehoboth Fault

The Rehoboth fault is a normal, subsurface fault that bisects the central portion of the basin. The fault is approximately eight miles long and trends to the southeast. The USGS concluded that evidence of the fault is inferred based on water level-changes in the west-central part of the valley and offset of the Morales Formation (USGS, 2013b; USGS, 2013a). The top of the Morales Formation is offset 160 feet on the northeast side of the fault and the offset increases with depth (USGS, 2013a). Surface exposures of the older alluvium do not appear to be offset along the trace of the fault, indicating the motion of the Rehoboth fault ceased prior to the deposition of the older and younger alluvium (USGS, 2013a).

Despite stating that the Rehoboth fault does not "have a discernible effect on the elevation" of the older alluvium and younger alluvium and that the fault was "not a significant barrier to groundwater flow" as symmetrical subsidence and uplift was observed on both sides of the fault, the USGS included the Rehoboth fault as a leaky, horizontal barrier to groundwater flow in the CUVHM (USGS, 2013a; USGS, 2013b; USGS, 2015). In the CUVHM, the Rehoboth fault impedes underflow in the older alluvium and Morales Formation along the Sierra Madre Foothills region (USGS, 2015). The USGS also listed the Rehoboth fault as affecting the younger and older alluviums and the Morales Formation in a summary table of "Geologic Units affected by Cuyama Valley faults" (USGS, 2013a).

Whiterock Fault

The Whiterock fault is a surface and subsurface thrust fault that runs along the northern finger of the Cuyama Basin. The fault can be traced further south under the basin near the Cuyama River and Highway 166, though it is subsurface (Calhoun, 1985). The fault dips northeast and is late Oligocene to early Miocene in age (Davis et al., 1988). The Whiterock fault is exposed at the surface where it thrusts the Monterey Formation over the Morales Formation (Davis et al., 1988). Activity along the fault began after movement ceased on the Russell fault and tectonically overrides the Russell fault (Nevins, 1982; Calhoun, 1985). The fault cuts the Morales Formation south of the Cuyama River but does not affect the younger or older alluviums (DeLong et al., 2011; Nevins, 1982).

Turkey Trap Ridge Fault and Graveyard Ridge Fault

The Turkey Trap Ridge fault (TTRF) and the Graveyard Ridge fault (GRF) are normal, subsurface faults that trend slightly north of west in the center of the Cuyama Valley (USGS, 2013a). The primary difference between the two faults is that the TTRF is 11 miles long and located southwest of the GRF and the GRF is four miles long. Both faults are located north of Highway 166 and are oriented in a "left-stepping, echelon pattern" (USGS, 2013a). Seismic reflection profiles collected along the ridges indicate they are bounded by north-dipping, south-directed, reverse faults along the south sides (USGS, 2013a). Both faults are considered to be barriers to groundwater. Evidence of the faults and their no-flow zones include springs and seeps along the base of the faults in the 1940-50s and water-level changes across the faults of 80 to 100 feet in the area near these ridges (Upson and Worts, 1951; Singer and Swarzenski, 1970).

In 1970, Singer and Swarzenski reported that water removed by pumping from this region was slow to replenish because faults restrict movement of water from neighboring areas. The impediment to flow could be related to the hydraulic properties of the faults themselves or fault juxtaposition of older, slightly less permeable older alluvium to the north against younger alluvium to the south of the faults (USGS, 2013a).

South Cuyama Fault

The South Cuyama fault is a surficial, thrust fault that defines a 39-mile stretch of the Cuyama Basin's southwestern boundary. The fault thrusts the Eocene-Cretaceous aged marine sediments against the older alluvium and Morales Formation and impedes groundwater flow across the fault zone.

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Ozena Fault

The Ozena fault is a 17-mile long surficial, thrust fault located three miles south of the Cuyama Basin and locally cuts through the southeastern canyons of the Basin. Less than one mile of the Ozena fault is within the Cuyama Basin boundary. The fault trends west to northwest and runs parallel to the Basin boundary.

Santa Barbara Canyon Fault

The Santa Barbara Canyon fault (SBCF) is a normal, subsurface fault that runs five miles perpendicular to the Santa Barbara Canyon. The fault is east-west striking and offsets basin deposits with impermeable Eocene-Cretaceous marine rocks (typically the Simmler and Vaqueros Formations) (Bazeley, 1988). Evidence of the fault comes from reported seasonal springs, a steep hydraulic gradient in the southeastern part of the Cuyama Valley near the fault, and the truncation of distinct gravel beds (Singer and Swarzenski, 1970). Water levels in the Ventucopa area have been reported 98 feet higher than water levels to the north (Singer and Swarzenski, 1970). The fault is considered a barrier to groundwater flow as it prevents groundwater flow from moving across the boundary bounded by the marine rocks (USGS, 2015). The USGS in 2013 also concluded that the SBCF was a barrier to groundwater flow: "Relatively small amount of vertical offset in the SBCF indicates changes in water levels across the fault documented in previous studies are perhaps the result of distinct fault-zone properties rather than juxtaposition of units of differing water-transmitting ability" (USGS, 2013a).

La Panza Fault

The La Panza fault is a surficial thrust fault that trends west to northwest along 22 miles of the western margin of the Cuyama Basin (USGS, 2013b). The present day thrust fault is a reactivated Oligocene extensional fault that was once part of the same system with the Ozena fault (USGS, 2013b; Yeats et al., 1989). The fault defines the west-central margin of the Cuyama Basin as it juxtaposes older non-water bearing Eocene to Cretaceous marine rocks and the Simmler Formation against the younger, water bearing alluvium and Morales Formation, impeding groundwater flow across the fault.

Morales Fault

The Morales fault is a 30-mile-long thrust fault that forms the boundary along the north central portion of the basin. The Morales thrust fault has a dip of approximately 30 degrees (Davis et al., 1988).

Unnamed Fault Near Outcrop of Santa Margarita Formation

A fault located southwest of the Russell fault runs southeast to northwest and is located next to an outcrop of the Santa Margarita formation inside the basin (Dibblee, 2005). The fault runs parallel to the long side of the outcrop and bounds the syncline that is to the south of the outcrop. The fault's extent is not well documented, and its surficial exposure is roughly five miles long.

Outcrops of Bedrock Inside the Cuyama Basin

There are a number of outcrops of non-aquifer material within the basin. The outcrops occur primarily in the eastern upland portion of the basin and the western portion, near and to the west of the Russell Fault. Outcrops of basement rock in the western portion of the basin occur in a different manner than those in the eastern portion, outcrops in the eastern portion are likely depositional contacts with the Morales Formation that were missed during basin delineation by DWR[1]. Outcrops in the western portion are likely tied to tectonic activity and faulting.

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[1] DWR delineates basins based on the type of restrictions to groundwater flow. The boundaries of the Cuyama Basin were delineated by DWR because they were the boundary between permeable sedimentary materials (within the Basin) and impermeable bedrock (outside the Basin). DWR defines this boundary as "*Impermeable bedrock with lower water yielding capacity. These include consolidated rocks of continental and marine origin and crystalline/or metamorphic rock.*"

Outcrops of basement rock in the eastern upland portion of the basin are shown in Figure 2.1-2. The Quatal Formation, and the Caliente Formation are present within the basin boundary near the edges of the basin. The Quatal formation is exposed at the surface near the Cuyama River, and in the higher elevation portions of the basin, and in a band near the Quatal Canyon. The Caliente Formation is exposed at the surface within the basin in the northeast portion of the basin, near and along the Quatal Canyon. Another outcrop of Caliente Formation is present near the Cuyama River, but that outcrop has been excluded from the basin during the basin's delineation by DWR and is visible in Figure 2.1-2.

Outcrops of basement rock in the western portion of the basin are exposed at the surface in limited areas and are tied to tectonic activity in the area.

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Figure 2.1-9 shows the outcrops of bedrock near the Russell Fault with an overlay of areas identified by DeLong as “Tr”, or out of basin bedrock, overlain on the geologic mapping performed by Dibblee. In general, the outcrops identified by DeLong and Dibblee largely overlap and indicate that in separate field study efforts, the outcrops were identified independently by different geologists. As shown in Figure 2.1-9, outcrops of non-aquifer materials are present near the Russell Fault, next to the Cuyama River, as well as to the south of the Cuyama River, both in small outcrops that are partially linear in nature, and larger outcrops that are located next to faults, such as where the Santa Margarita, Monterey and Marine Sedimentary Formations are present. The presence of these non-aquifer materials in this area likely restricts groundwater movement by limiting the extent of permeable materials in this portion of the basin.

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Data Sources:
De Long: Climate change triggered sedimentation and progressive tectonic uplift in a coupled piedmont–axial system: Cuyama Valley, California, USA.
Stephen B. DeLong, Jon D. Pelletier, and Lee J. Arnold
Earth Surface Processes and Landforms
Earth Surf. Process. Landforms 33, 1033–1046 (2008)
Published online 13 September 2007 in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/esp.1600
Dibblee: Thomas W. Dibblee, Jr., Dibblee Foundation, Relased in June 2012, Purchased from AAPG as GeoTIF 28 March 2018.

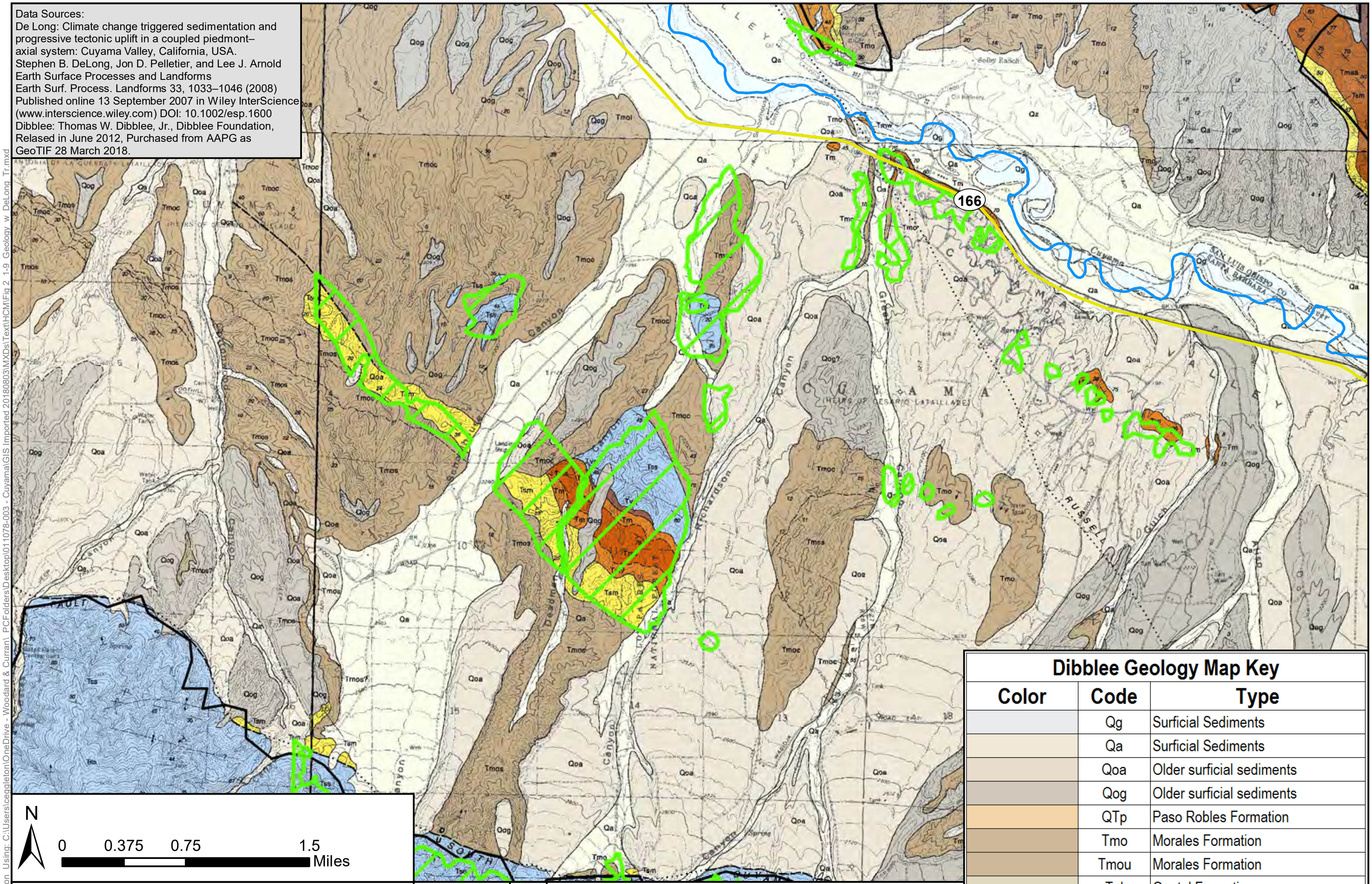

Figure 2.1-9: Geology with De Long "Tr" Overlay

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Legend

- Cuyama Basin
- De Long Geology "Tr" - Out of Basin Bedrock
- Highways
- Cuyama River

Dibblee Geology Map Key

Color	Code	Type
	Qg	Surficial Sediments
	Qa	Surficial Sediments
	Qoa	Older surficial sediments
	Qog	Older surficial sediments
	QTp	Paso Robles Formation
	Tmo	Morales Formation
	Tmou	Morales Formation
	Tql	Quatal Formation
	Tc	Caliente Formation
	Tsm	Santa Margarita Formation
	Tm	Monterey Formation
	Tvl	Vaqueros Formation
	Tvq	Vaqueros Formation
	Tss	Marine Sedimentary Rocks,

Figure Exported: 8/21/2018 By: ceggleton Using: C:\Users\ceggleton\OneDrive - Woodard & Curran\ PCFolders\Desktop\011078-003 - Cuyama\GIS Imported 20180803\MXDs\Text\HCM\Fig 2 1-9 Geology w DeLong Tr.mxd

2.1.6 Basin Boundaries

The basin has multiple types of basin boundaries. The majority of the boundaries are in contact with impermeable bedrock and faults, and a small portion is bounded by a groundwater divide between this basin and the Carrizo Plain groundwater basin.

Lateral boundaries

The Cuyama Basin is geologically and topographically bounded; to the north by the Morales and Whiterock faults and the Caliente Range, to the west by the South Cuyama and Ozena faults and the Sierra Madre Range, to the east within the Los Padres National Forest and Caliente Range, and to the south by the surface outcrops of Pliocene and younger lithologies, which are surrounded by Miocene and older consolidated rocks (Dudek, 2016). The boundaries of the Cuyama Basin were delineated by DWR in Bulletin 118 because they were the boundary between permeable sedimentary materials and impermeable bedrock. DWR defines this type boundary as: "*Impermeable bedrock with lower water yielding capacity. These include consolidated rocks of continental and marine origin and crystalline/or metamorphic rock*" (DWR, 2003). The thrust faults bounding the Cuyama Basin juxtapose younger, water-bearing lithologies against older, impermeable rocks. The consolidated continental and marine rocks and shales of the bordering mountain ranges mark a transition from the permeable aquifer sediments to impermeable bedrock.

Boundaries with Neighboring Subbasins

The Cuyama Basin shares a boundary to the east with the Carrizo Plain Groundwater Basin (Carrizo Plain Basin) and the Mil Potrero Area Groundwater Basin, as shown in Figure 1-3. The Cuyama and Carrizo Plain basins share a four-mile boundary along Caliente Ranges, which is a groundwater divide basin boundary. DWR defines this type of boundary as: "*A groundwater divide is generally considered a barrier to groundwater movement from one basin to another for practical purposes. Groundwater divides have noticeably divergent groundwater flow directions on either side of the divide with the water table sloping away from the divide*" (DWR, 2003).

The Cuyama and Mil Potrero basins are share a less than one mile boundary along the San Emigdio Canyon. The division between the Cuyama and Mil Potrero basins is also a groundwater divide basin boundary.

Bottom of the Cuyama Basin

The bottom of the Cuyama Basin is generally defined by the base of the upper member of the Morales Formation (USGS, 2015). The lower member of the Morales Formation is composed of clay, shale, and limestone and is less permeable than the upper member of the Morales Formation (USGS, 2013a). The USGS describes the Morales Formation (both the upper and lower member combined) as up to 5,000 feet thick (USGS, 2013a). The top of the Morales Formation is generally encountered 750 feet below ground surface (bgs) but ranges up to 1,750 feet bgs in the Sierra Madre Foothills (USGS, 2013a). When referring to the Morales Formation in the context of the Cuyama aquifer, this is a reference to only the upper member of the Morales Formation.

2.1.7 Principal Aquifers and Aquitards

There is one principal aquifer in the basin composed of the younger alluvium, older alluvium, and the Morales Formation. The DWR's *Groundwater Glossary* defines an aquifer as "a body of rock or sediment that is sufficiently porous and permeable to store, transmit, and yield significant or economic quantities of groundwater to wells and springs." Most of the water pumped in the valley is contained in the younger and older alluviums. These two units are indistinguishable in the subsurface and are considered, hydrologically, one unit. There are no major stratigraphic aquitards or barriers to groundwater movement, amongst the alluvium and the Morales Formation. The aquifer is considered to be continuous and unconfined with the exception of locally perched aquifers resulting from clays in the formations.

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Aquifers

The aquifers making up the principal aquifer in the Cuyama Basin are:

- Younger alluvium,
- Older alluvium, and the
- Upper Member of the Morales Formation.

These units consist of unconsolidated to partly consolidated sand, gravel, silt, clay, and cobbles within alluvial fan and fluvial deposits and in total range from 3,000 to 4,000 ft. in thickness (Upson and Worts, 1951). Rocks older than the upper Morales Formation are generally considered either non-water bearing or contain water, but the water is released too slowly or of quality that is too poor for domestic and irrigation uses (USGS, 2013a). Historically, most of the water pumped in the Cuyama Valley has been extracted from the younger and older alluvium. Cross sections showing the extents and depths of the three formations making up the principal aquifer as used in the numerical model are under development and will be included in Section XXX [Note: section under development].

Recent and Younger Alluvium

Historically, most of the water pumped in the Cuyama Basin was sourced from the saturated portions of the younger and older alluvium (Singer and Swarzenski, 1970). Groundwater is found in the permeable Holocene alluvial fill and in the underlying, less permeable, Pliocene-Pleistocene continental deposits. Younger alluvium deposits thicken to the east, typically ranging from 5 to 50 ft. in the west and thicken up to 630-1,100 ft. in the east (Singer and Swarzenski, 1970).

The younger alluvium varies compositionally across the basin (Upson and Worts, 1951). The recent and younger alluvium is the primary source of groundwater on the western side of the Basin. In the west, younger alluvium consists of interbedded layers of sand and gravel and thick beds up clay (ranging from 1 to 36 ft. thick) (Upson and Worts, 1951). Clay beds, found 100 to 150 ft. bgs, define the base of the younger alluvium (Upson and Worts, 1951). Wells in the western part of the basin that are screened in the younger alluvium are shallow but have moderately large yields as the sands and gravels have high permeabilities (Singer and Swarzenski, 1970).

In the south-central part of the valley, the alluvium contains more gravel and is less fine grained compared to western alluvium. The alluvium is predominantly sand and silt with some beds of gravel and clay, though no continuous layers of any material exist (Upson and Worts, 1951).

Older Alluvium

Older alluvium consists of unconsolidated to partly consolidated sand, gravel, boulders, and some clay. Similar to the younger alluvium, clay content increases to the west (Upson and Worts, 1951). Like the younger alluvium, historically most of the water pumped in the Cuyama Basin was sourced from the saturated portions of the younger and older alluvium (Singer and Swarzenski, 1970). More wells are perforated in the older alluvium in the western portion of the basin than to the east (USGS, 2013c). In most regions of the basin, the top of the saturated zone (the water table) is either deep in the alluvium or below its base (Upson and Worts, 1951).

Upper Morales Formation

The Pliocene to Pleistocene-aged Morales Formation is divided into two members, the upper and lower. The upper member of the Morales is composed of partly consolidated, poorly sorted deposits of gravelly arkosic sand, pebbles, cobbles, siltstone, and clay and is considered water bearing (USGS, 2013a). Water bearing properties of the Morales Formation are not well defined, but available data indicate that the hydraulic conductivity of the formation varies greatly laterally and with depth (USGS, 2013c). Permeabilities of the upper Morales Formation vary greatly laterally and with depth; the highest values occur in the syncline beneath the central part of the valley and decrease to the west (Singer and Swarzenski, 1970). In the east and southeastern parts of the valley where the Morales Formation crops out, the formation is coarse grained and moderately permeable, but land is topographically unsuited to agricultural development and few wells have been installed.

Aquifer Properties

The highest yielding wells are screened in the alluvium and located in the north-central portion of the basin. Pumping in the alluvium also occurs in the eastern part of the Cuyama Valley, along the Cuyama River and its tributary canyon as far as a few miles upstream from Ozena (Singer and Swarzenski, 1970).

Hydraulic Conductivity

The DWR defines hydraulic conductivity as the "measure of a rock or sediment's ability to transmit water" (DWR, 2003). The hydraulic conductivity is variable within the principal aquifer, varying laterally, vertically, and amongst the three aquifer formations. In general, conductivity is highest near the center of the Basin and decreases to the west and east with the highest values associated with the younger alluvium and the Morales Formation with the lowest. Conductivity data is widely available for the central portion of the Basin (near the cities and New Cuyama) and near the western vineyards and sparse elsewhere. Available data from field tests (including pump and slug tests) were reviewed from the following sources: three multi-completion USGS wells (USGS, 2013c), 51 PG&E wells (USGS, 2013c), 66 private landowner wells in the central portion of the Basin, , and 12 private landowner wells in the western portion of the Basin, and the locations of these wells are shown in Figure 2.1-10. Dates of field tests range from 1942 (PG&E tests) to 2018 (Grapevine Capital tests) and wells are screened in all three of the main aquifer formations, including the younger alluvium, older alluvium, and Morales Formation. Additional sources include the USGS's 2015 *Hydrologic Models and Analysis of Water Availability in Cuyama Valley, California,* which describes conductivity values used in the CUVHM, along with Singer and Swarzenski (1970) and a 2011 USGS study. The CUVHM characterizes the recent and younger alluvium as having the highest hydraulic conductivity of all aquifer units (USGS, 2015). Conductivity values calculated from field tests for the wells are used to characterize each aquifer formation, as described below and summarized in Table 2.1-1.

Recent & Younger Alluvium – As shown in Table 2.1-1, wells screened exclusively in the younger alluvium in the central portion of the Basin have hydraulic conductivities ranging from 1 – 31.9 ft/day and a median conductivity of 9.5 ft/day. Wells screened in both the younger and older alluvium in the central portion of the Basin had a higher median conductivity of 10.1 ft/day. Field tests are lower than those reported by the USGS in 2015 which reported hydraulic conductivity for the recent and younger alluvium ranged from 5.2 to 85 ft/day (USGS, 2015). Within the recent and younger alluvium, the highest horizontal conductivity is near the Cuyama River. Vertical conductivity ranges from 0.2 ft/day in tributaries crossing the alluvium in areas west of the Russell fault up to 49 ft/day in the Cuyama River in the Ventucopa Uplands (USGS, 2015).

Older Alluvium – In the central portion of the Basin, hydraulic conductivity in the older alluvium ranges from 0 to 81.2 ft/day, with a median conductivity of 16 ft/day. Field tests are higher than those reported by the USGS in 2015 which reported conductivity for the older alluvium ranges from 0.3 to 28 ft/day in the central Basin (USGS, 2015; USGS, 2011). West of the Russell fault, conductivity ranges from 0.77 to 1.79 ft/day with a median value of 1.24 ft/day in areas west of the Russell Fault, near the vineyards. Conductivity generally decreases with depth. Field data shows that while the range in hydraulic conductivity for wells screened in both the older alluvium and Morales Formation is lower than wells screened exclusively in the older alluvium (ranging from 0 to 61.2 ft/day), the median value is higher at 21.4 ft/day. The USGS calculated the median hydraulic conductivity for the older alluvium (15 ft/d) to be about five times the estimated value for the Morales Formation (3.1 ft/d) (USGS, 2013c).

Morales Formation – The Morales Formation has the lowest hydraulic conductivity of all aquifer units. In the central portion of the Basin, conductivity for wells exclusively screened in the Morales Formation range from 1.6 to 9.9 ft/day, with a median value of 3.15 ft/day. Only two wells were interpreted to be

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screened exclusively in the Morales Formation west of the Russell fault; hydraulic conductivity for these wells ranges from 1.6 – 1.98 ft/day. The hydraulic conductivity of the Morales Formation decreases with depth and the lower member of the formation (the clay and limestone unit) has a lower conductivity than the upper member (sandstone). The highest values in the Morales Formation occur in the central portion of the valley and decrease west (Singer and Swarzenski, 1970).

Table 2.1-1: Summary of Hydraulic Conductivities in Aquifer Formations

Well Owner	No. of Wells	Formation(s) Well is Screened in	Conductivity Range (ft/day)	Median Conductivity (ft/day)
USGS	6[a]	Older alluvium	1.5 – 18.1	15
	6[a]	Upper Morales Formation	1.6 – 9.9	3.15
PG&E[b]	22	Younger alluvium	1 - 30	9
	19	Younger & older alluvium	0.1 - 37	4.5
	8	Older alluvium	0.1 – 17	4
	2	Older alluvium & Upper Morales Formation	0.1 – 4	2
Private Landowners, Central Portion of the Basin[c]	2	Younger alluvium	28.9 – 31.9	30.4
	19	Younger alluvium & Older alluvium	3.9 – 68.6	17.1
	6	Younger alluvium & Upper Morales Formation	1 – 21.3	12
	16	Older alluvium	3.2 – 81.2	17.15
	23	Older alluvium & Upper Morales Formation	3.6 – 61.2	23
Private Landowners, Western Portion of the Basin[c]	4	Older alluvium	0.77 – 1.79	1.47
	6	Older alluvium & Upper Morales Formation	0.64 – 1.59	1.22
	2	Upper Morales Formation	1.6 – 1.98	1.79

Notes:

a. 3 wells with 4 completions each – each well completion is reported as a single well.
b. Conductivity estimated using transmissivity field tests.
c. Conductivity estimated using specific capacity field tests.

Specific Yield

The DWR defines specific yield as the "amount of water that would drain freely from rocks or sediments due to gravity and describes the portion of groundwater that could actually be available for extraction" (DWR, 2003). Specific yield is a measurement specific to unconfined aquifers, such as the primary aquifer in the Cuyama Basin[2]. The dewatered alluvium has an average specific yield of 0.15 (Singer and Swarzenski, 1970). The USGS estimated the specific yields of the three aquifer formations during the Cuyama Valley Hydrologic Model (CUVHM) calibration, calculating that the recent alluvium had the lowest specific yield ranging from 0.02 to 0.14, the older alluvium has a specific yield ranging from 0.05 to 0.19, and the Morales Formation has the highest specific yield ranging from 0.06 to 0.25 (USGS, 2015).

Specific Capacity

Specific capacity is defined as "the yield of the well, in gallons per minute, divided by the pumping drawdown, in feet" (Singer and Swarzenski, 1970). Specific capacity in the aquifer varies laterally and vertically but is typically highest in the younger alluvium and lowest in the Morales Formation. Wells perforated in the younger alluvium have a median specific capacity of 60 gallons per minute (gpm) per foot

[2] For confined aquifers, the measurement of "storativity" is used instead of specific yield.

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(USGS, 2013c). Wells perforated in both the younger and older alluvium have a median specific capacity of 40 gpm per foot (USGS, 2013c). Wells perforated in the older alluvium have a median specific capacity of 20 gpm per foot (USGS, 2013c). The silt and clay content of the older alluvium increases to the west and corresponds to a decrease in specific capacity in the alluvium; specific capacities are less on the western half of the valley compared to the eastern half. However, a greater percentage of wells in the western part are perforated in the older alluvium (USGS, 2013c). The specific capacity of the Morales Formation varies laterally but is generally less than the specific capacity of the younger and older alluvium. In the western part of the valley, the Morales Formation has a specific capacity ranging from 5 to 25 gpm per foot. In the north north-central portion of the basin the specific capacity increases to 25 to 50 gpm per foot (Singer and Swarzenski, 1970).

Transmissivity

The DWR defines transmissivity as the "aquifer's ability to transmit groundwater through its entire saturated thickness" (DWR, 2003). Using aquifer tests from 63 wells (shown in Figure 2.1-10), estimates of transmissivity ranged from 560 to 163,400 gallons per day per foot (gpd/ft) and decreased with depth (USGS, 2013c). Amongst the aquifer units, wells screened in the younger alluvium had the highest transmissivity, a median value of 15,700 gpd/ft (USGS, 2013c). Wells screened in older alluvium had a transmissivity three times less than the younger alluvium wells, at a median value of 5,000 gpd/ft (USGS, 2013c). Wells screened in both the younger and alluvium had a median transmissivity of 11,300 gpd/ft (USGS, 2013c). Data from the 61 wells were not available for the Morales Formation, but a transmissivity estimate from two wells screened in both the older alluvium and Morales Formation averaged 4,900 gpd/ft (USGS, 2013c). Using groundwater level contours, Singer and Swarzenski determined the range of transmissivity values in the Morales Formation to change much more than the transmissivity values of the younger and older alluvium; in general, values are highest in the central portion of the valley and decline to the west as the thicknesses of the younger and older alluvium become more shallow.

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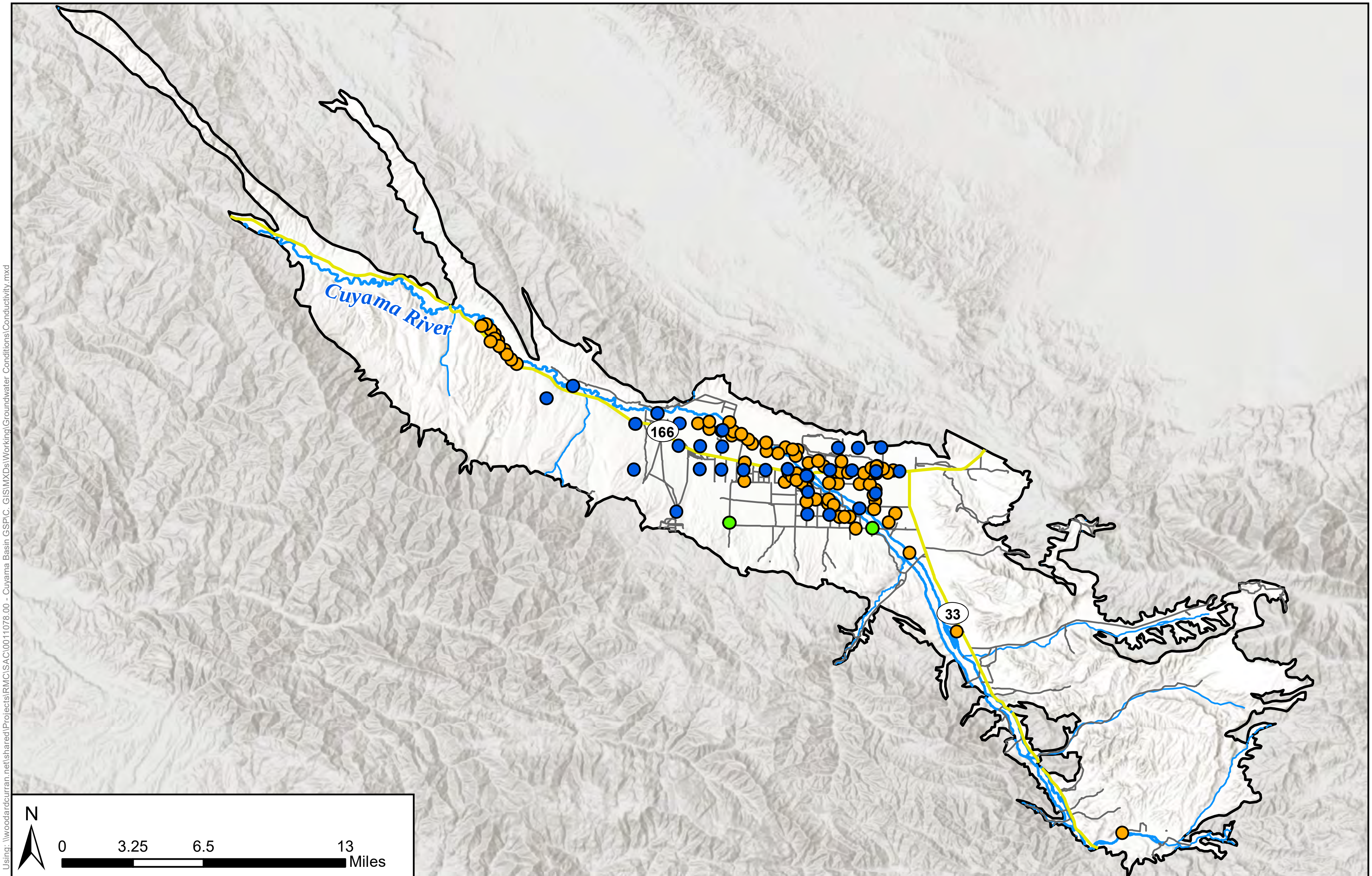

Figure 2.1-10 Location of Aquifer Testing Wells

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Legend

- Highways
- Local Roads
- Cuyama River
- Streams
- Cuyama Basin

Well Owner

- Private Landowners
- PG&E
- USGS

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2.1.8 Natural Water Quality Characterization

Water quality in the Cuyama Basin has historically had high total dissolved solids (TDS) and sulfates. High concentrations of other constituents, such as nitrate, arsenic, sodium, boron, and hexavalent chromium are localized (USGS, 2013c). Locations where water quality measurements were taken by the USGS are shown in Figure 2.1-11.

Singer and Swarzenski studied groundwater in the basin in 1970. Groundwater ranged from hard to very hard and is predominately of the calcium-magnesium-sulfate type (Singer and Swarzenski, 1970). Averages of concentrations include 30 milligrams per liter (mg/L) chloride, 0.20 mg/L of boron, and 1,500 to 1,800 mg/L TDS (Singer and Swarzenski, 1970). Along the periphery of the basin, groundwater quality is variable. Along the southern boundary and near the eastern badlands, the groundwater quality reflects the recharge from springs and runoff from the Sierra Madre Mountains; TDS concentrations range from 400-700 mg/L and most of the water is sodium calcium bicarbonate (Singer and Swarzenski, 1970). Along the eastern edge of the valley, near the Caliente Range, water quality declines as concentrations of sodium, chloride, TDS, and boron increase. Concentrations of boron range up to 15 mg/L, concentrations of chloride increase up to 1,000 mg/L, and TDS concentrations range from 3,000 to 6,000 mg/L (Singer and Swarzenski, 1970).

Singer and Swarzenski in 1970 also concluded that the basin's water quality potentially results from the mixing of water from the marine rocks: *"This water quality presumably results from the mixing of water from the marine rocks of Miocene age with the more typical water from the alluvium and is characterized by increased sodium, chloride, and boron. Although chloride and boron concentrations commonly are less than 30 and 0.20 mg/1, respectively, in the central part of the valley, the water from many wells is close to the Caliente Range contains several hundred to nearly 1,000 mg/L of chloride and as much as 15 mg/1 of boron."* (Singer and Swarzenski, 1970). Singer and Swarzenski did not provide a map showing their sampling locations.

In 2011, the USGS published the *Kirschenmann Road Monitoring Well Site Open File Report* (USGS 2011), which included analysis of major-ion composition for samples collected from the multiple-well monitoring site CVKR, and samples from selected water supply and irrigation wells in the Cuyama Valley. Figure 2.1-12 shows a piper diagram of the major-ion analysis. Figure 2.1-12 shows that groundwater in the central portion of the basin shares similar major-ions, and is largely chloride, Fluoride, Sulfate and Calcium Magnesium type water. Figure 2.1-13 shows the locations USGS sampled to perform this analysis.

In 2017 EKI compiled water quality data contained in the appendices of the USGS report *Geology, Water-Quality, Hydrology, and Geomechanics of the Cuyama Valley Groundwater Basin, California, 2008-12* (USGS 2013c). and prepared a piper diagram with the data (Figure 2.1-14). The locations of the data used in this piper diagram are shown in Figure 2.1-15. The piper diagram shows the majority of samples indicate that water in the basin can be characterized as calcium-magnesium sulfate waters, which agrees with conclusions made by USGS in 2013.

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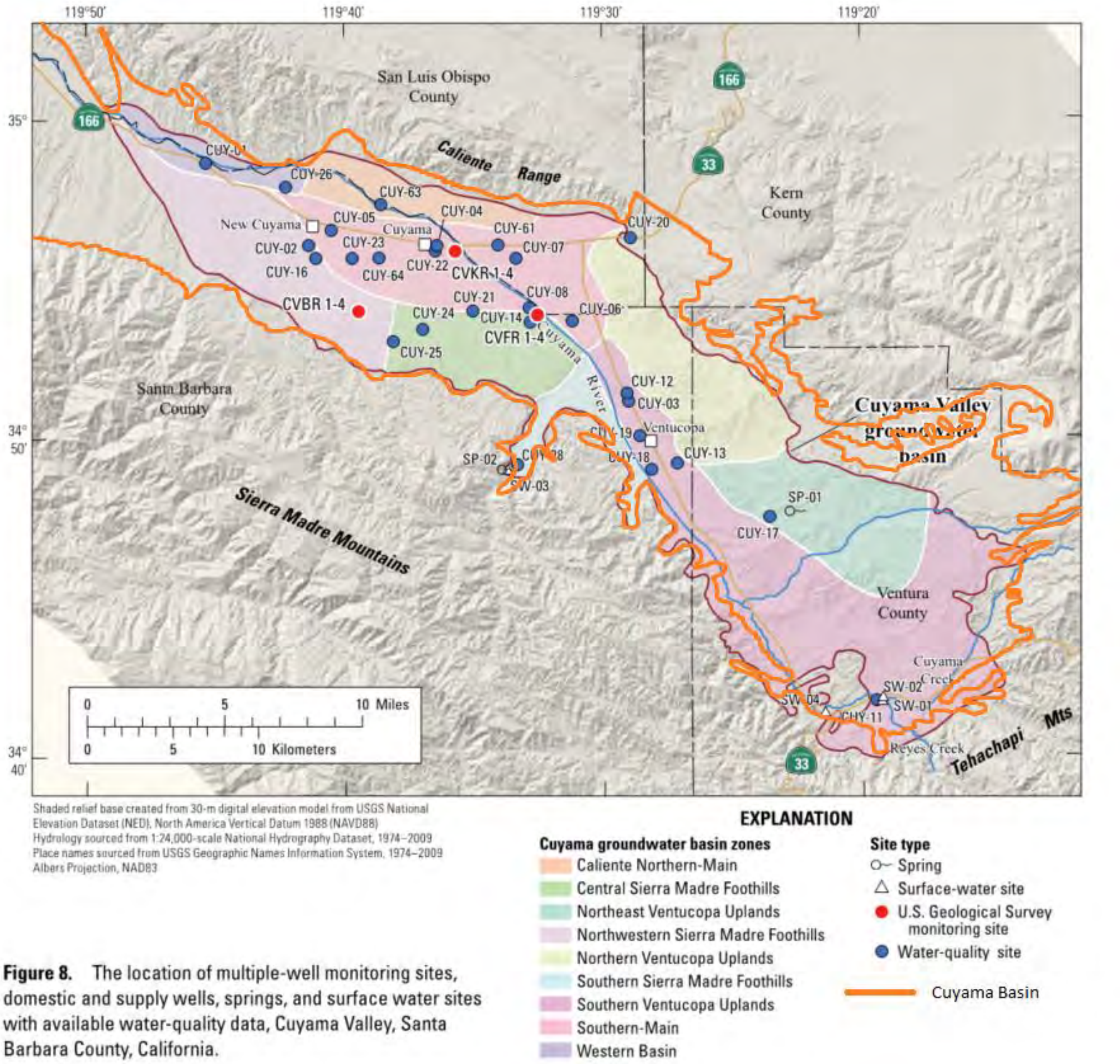

Figure 8. The location of multiple-well monitoring sites, domestic and supply wells, springs, and surface water sites with available water-quality data, Cuyama Valley, Santa Barbara County, California.

Source: USGS, 2013c.

Figure 2.1-11: Location of USGS 2013 Groundwater Quality Sampling Sites

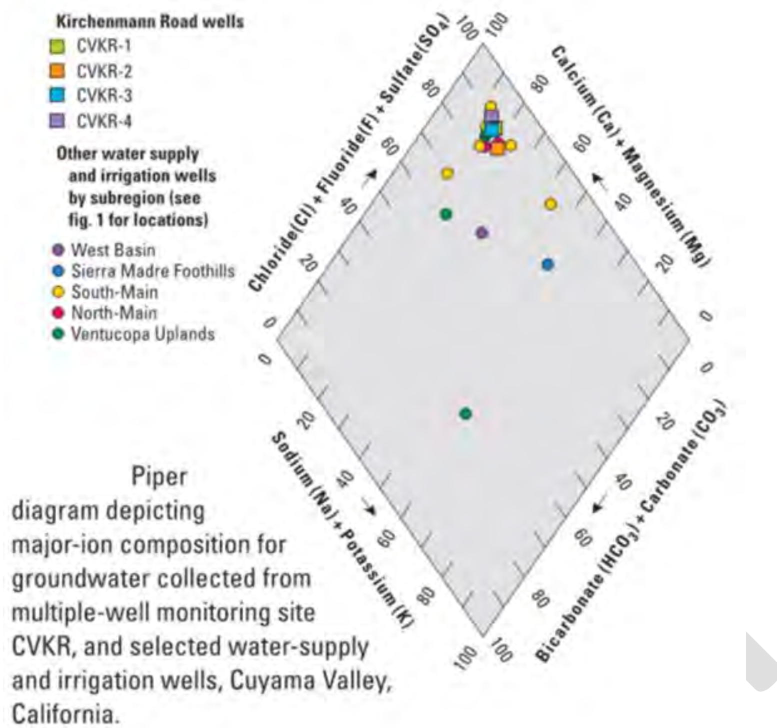

Figure 2.1-12 – Piper Diagram for Well CVKR1-4

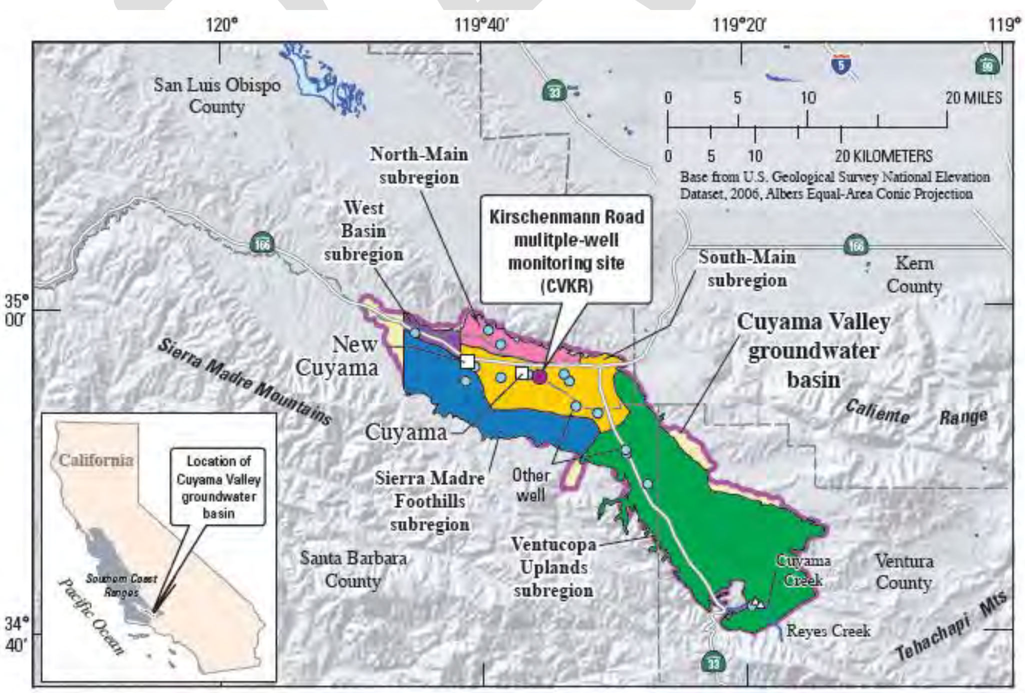

Figure 2.1-13 – Location Map for Samples Used in Figure 2.1-12

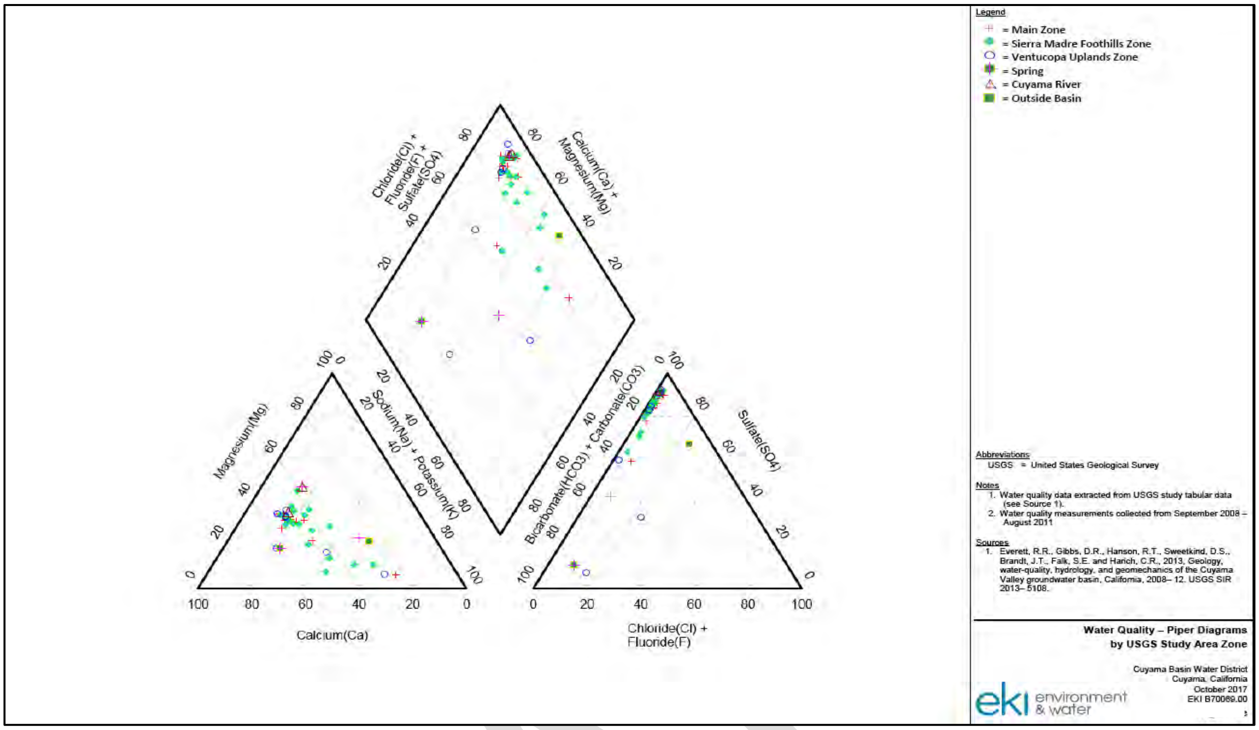

Figure 2.1-14: Piper Diagram of USGS 2013 Water Quality Sampling

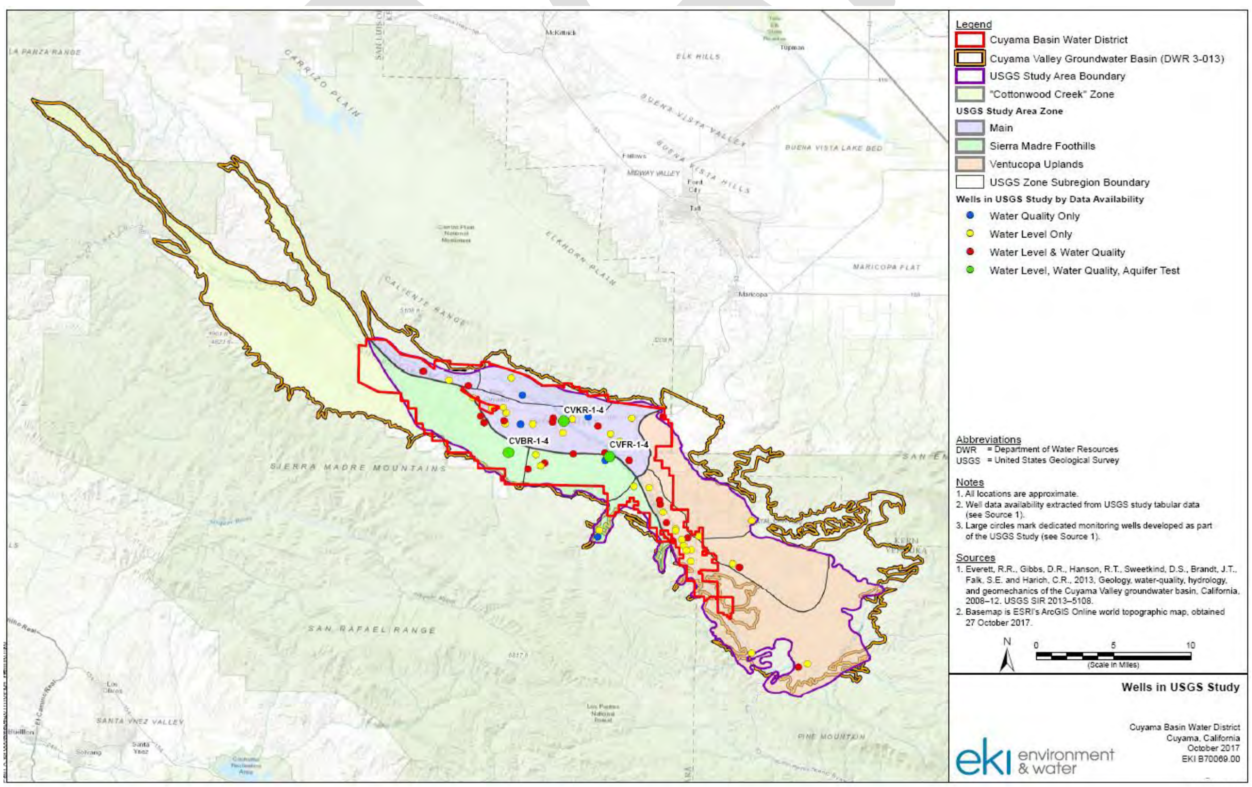

Figure 2.1-15: Location Map of USGS 2013 Sampling

Aquifer Use

The Cuyama Valley is dependent on groundwater as its sole source of supply. Groundwater is used for irrigation, domestic and municipal use (USGS, 2013c). The majority of agricultural activity occurs between the New Cuyama and Ventucopa areas, and west of the Russell fault near the north fork.

2.1.9 Topography, Surface Water and Recharge

This section describes the topography, surface water, soils, and groundwater recharge potential in the basin. There are no imported water supplies to the Cuyama Basin and are not discussed in this section.

Topography

The basin is lowest in the northwest, and highest in the southeast. The lowest elevation in the Basin is located at the west edge where the Cuyama River exits at approximately 1,300 ft, while the highest point is approximately 7,250 ft on the eastern boundary. Figure 2.1-16 shows the topographic characteristics of the Cuyama Basin. The south facing northern slopes of the valley are generally steeper than the north facing south slopes. The eastern portion of the basin along the valley walls becomes steep, characterized by mountainous runoff-cut topography.

Surface Water Bodies

The Cuyama River is the primary surface water feature in the valley and flows from an elevation of 3,800 ft on the eastern side to the west of the basin to 1,300 ft at the western outlet of the basin. The Cuyama River travels approximately 55 miles through the basin and has a slope ratio of approximately 1:125. The river is perennial with most dry seasons seeing little to no flows. Large flows usually occur in flashes due to the small watershed and storms that provide precipitation onto the surrounding Coastal Range Mountains. Peak flows through the Cuyama River, dated between 1929 and 2017, range from approximately 6,000 to the highest recorded flow of 15,500 cubic feet per second on February 18, 2017 (National Watershed Information System [NWIS], 2018). There are approximately four main perennial streams that feed the Cuyama River including Aliso Creek, Santa Barbara Creek, Quatal Canyon Creek, and Cuyama Creek. However, during precipitation events many more smaller streams flow from the valley walls and surrounding mountains. Figure 2.1-17 shows the locations of surface water bodies in the basin.

Downstream on the Cuyama River lies Twitchell Reservoir, however this is an artificial body of water outside of the Cuyama Groundwater Basin.

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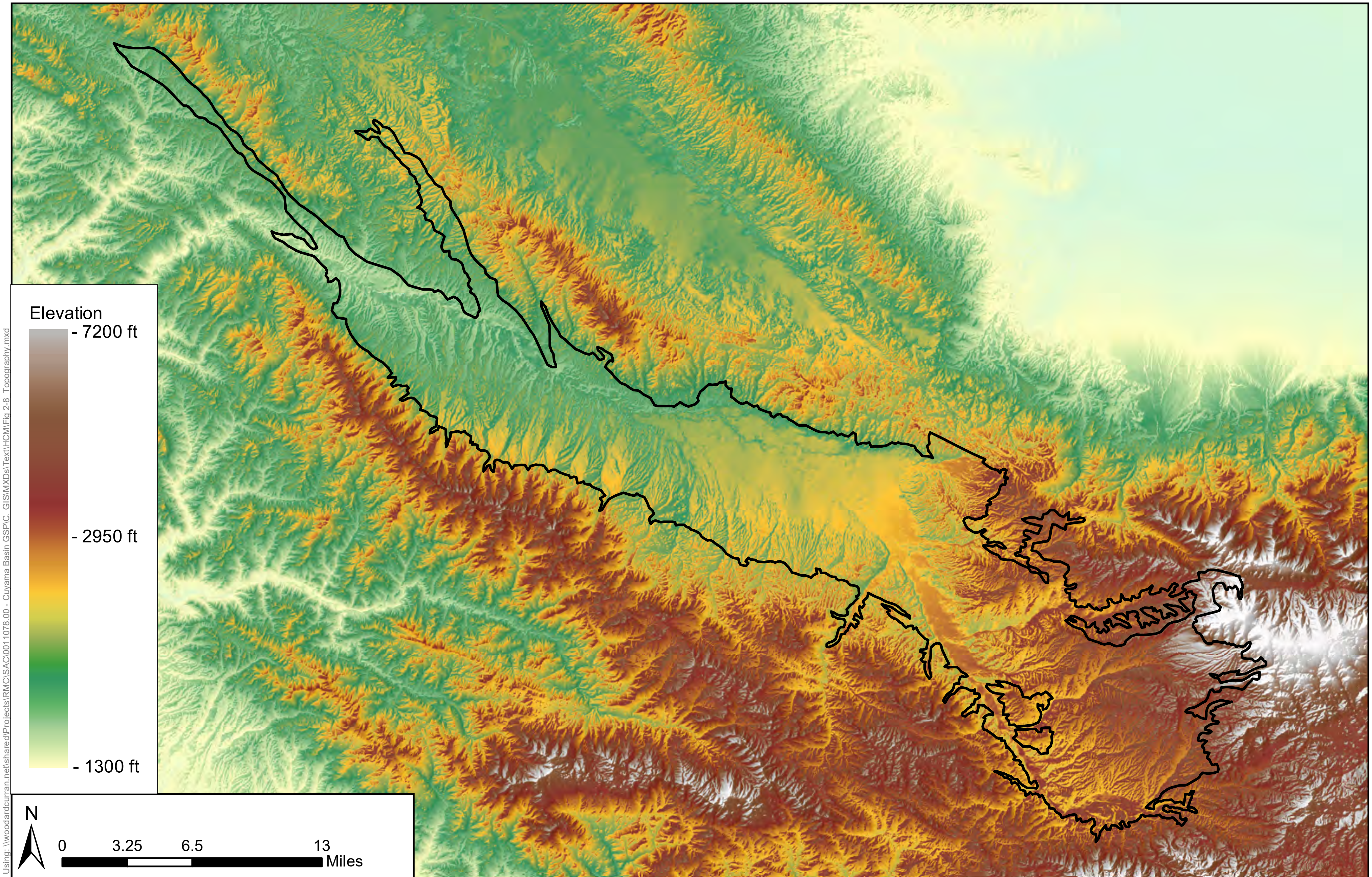

Figure 2.1-16: Topography

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Legend

Cuyama Basin

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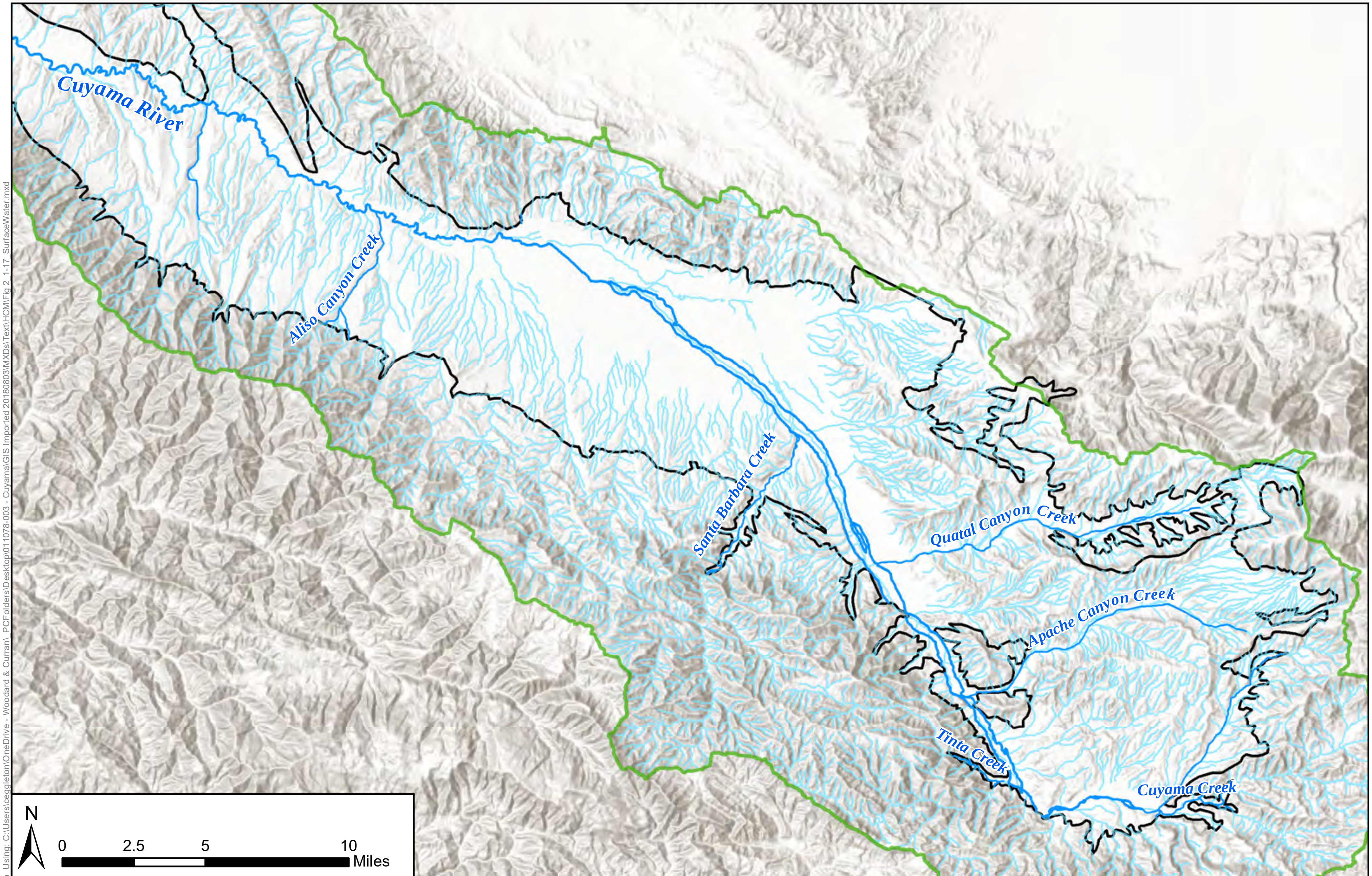

Figure 2.1-17: Surface Water

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- Cuyama Basin
- Cuyama Watershed
- Cuyama River
- Major Cuyama GW Basin Streams
- All Other NHD Flow Lines, Creeks, and Streams in the Cuyama Watershed

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Areas of Recharge, Potential Recharge, and Groundwater Discharge Areas

Areas of recharge and potential recharge lie primarily within the central and low-lying areas of the Cuyama Valley. Agricultural and open space lands are considered areas of potential recharge. Figure 2.1-18: Recharge Areas and Springs shows areas with their potential for groundwater recharge, as identified by the Soil Agricultural Groundwater Banking Index (SAGBI). SAGBI provides an index for the groundwater recharge for agricultural lands by considering deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition. SAGBI data categorizes 22,675 acres out of 37,568 acres (60%) of agricultural and grazing land within the basin as moderately good, good, or excellent for groundwater recharge (University of California, Davis [UCD], 2018). SAGBI data shown in Figure 2.1-18 is "modified" SAGBI data. "Modified" SAGBI data shows higher potential for recharge than unmodified SAGBI data because the modified data assumes that the soils have been or will be ripped to a depth of six feet, which can break up fine grained materials at the surface to improve percolation.

Groundwater discharge areas are identified as springs located within the basin. Figure 2.1-18 shows the location of historic springs identified by the USGS (NWIS, 2018). The springs shown in represent a dataset collected by the USGS and are not a comprehensive map of springs in the basin.

Soils

Soils in the basin were categorized by the National Resource Conservation Service (NRCS). The basin is comprised mostly of fine- to coarse-loamy soils (NRCS STATSGO2, 2018). As shown in Figure 2.1-19, the valley bottom and primary soil surrounding the Cuyama River and its tributaries is primarily fine-loamy soils, while the northern boundary of the basin has coarse-loamy soils.

Figure 2.1-20 shows soils by hydrologic soil group. Hydrologic soil groups were calculated by the NRCS on a by-county basis. As shown in Figure 2.1-20, interpretations of soil groups varied by county in each study. In general, hydrologic soil groups are sorted by permeability, with class A being the most permeable and class D being the least permeable. Figure 2.1-20 shows that in general most of the soils in the basin have lower permeabilities and are listed as class C or D, with higher permeabilities being located near streams and rivers.

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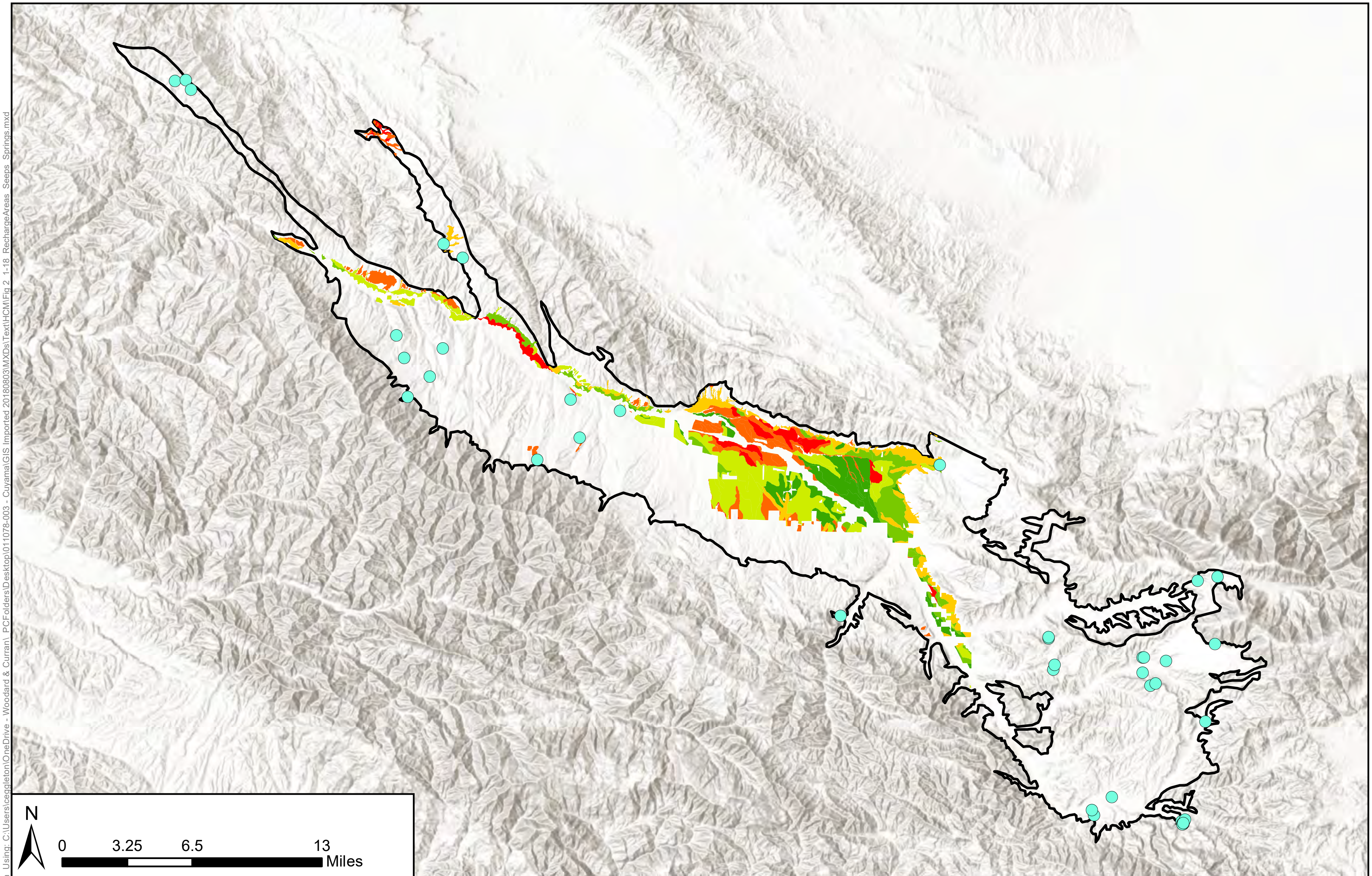

Figure 2.1-18: Recharge Areas, Seeps, and Springs

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Cuyama Basin

Spring/Seep

Modified SAGBI Soils of Cuyama Basin

- Excellent (85-100)
- Good (69-85)
- Moderately Good (49-69)
- Moderately Poor (29-49)
- Poor (15-29)
- Very Poor (0-15)

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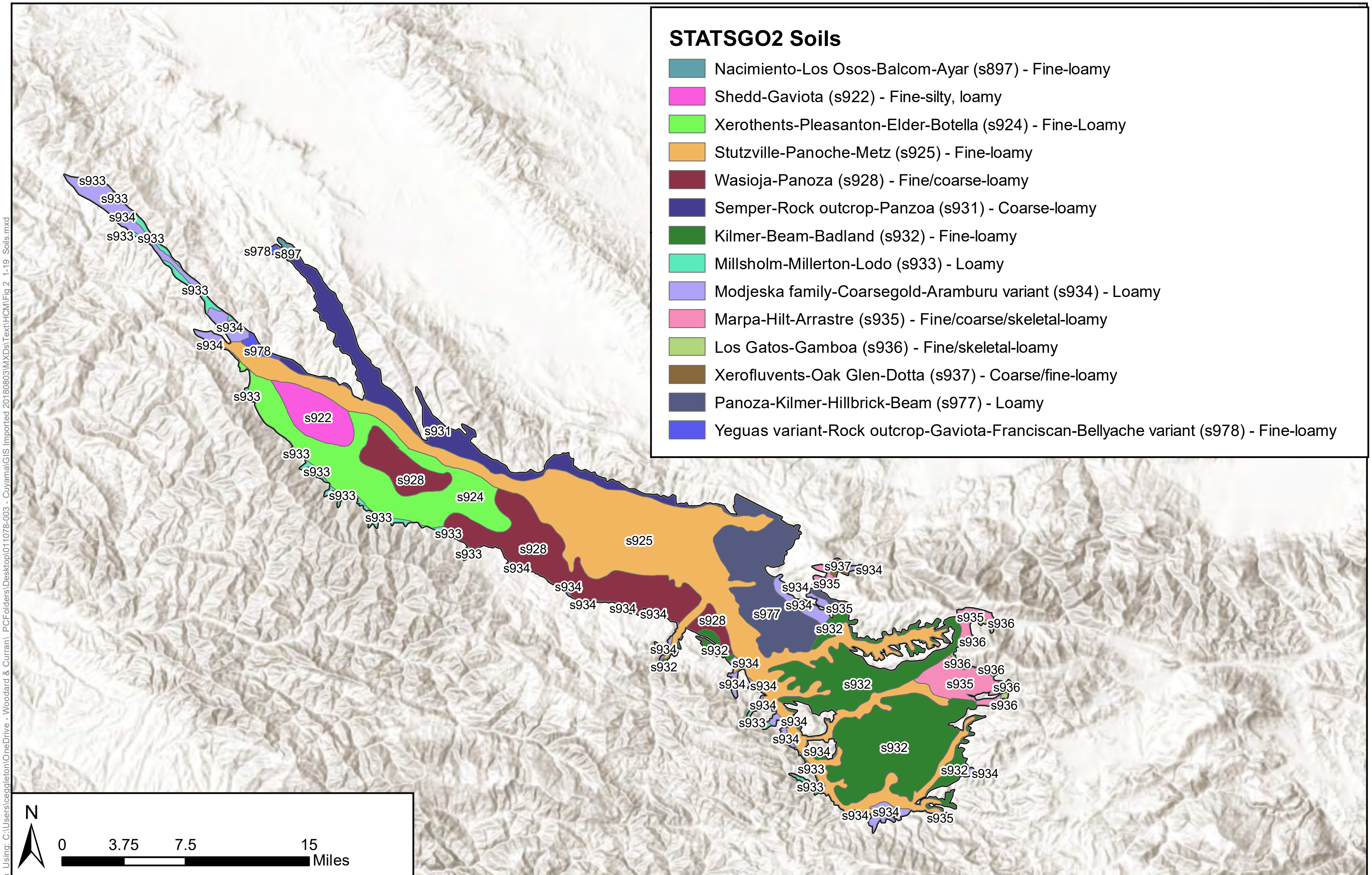

Figure 2.1-19: Soils

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Cuyama Basin

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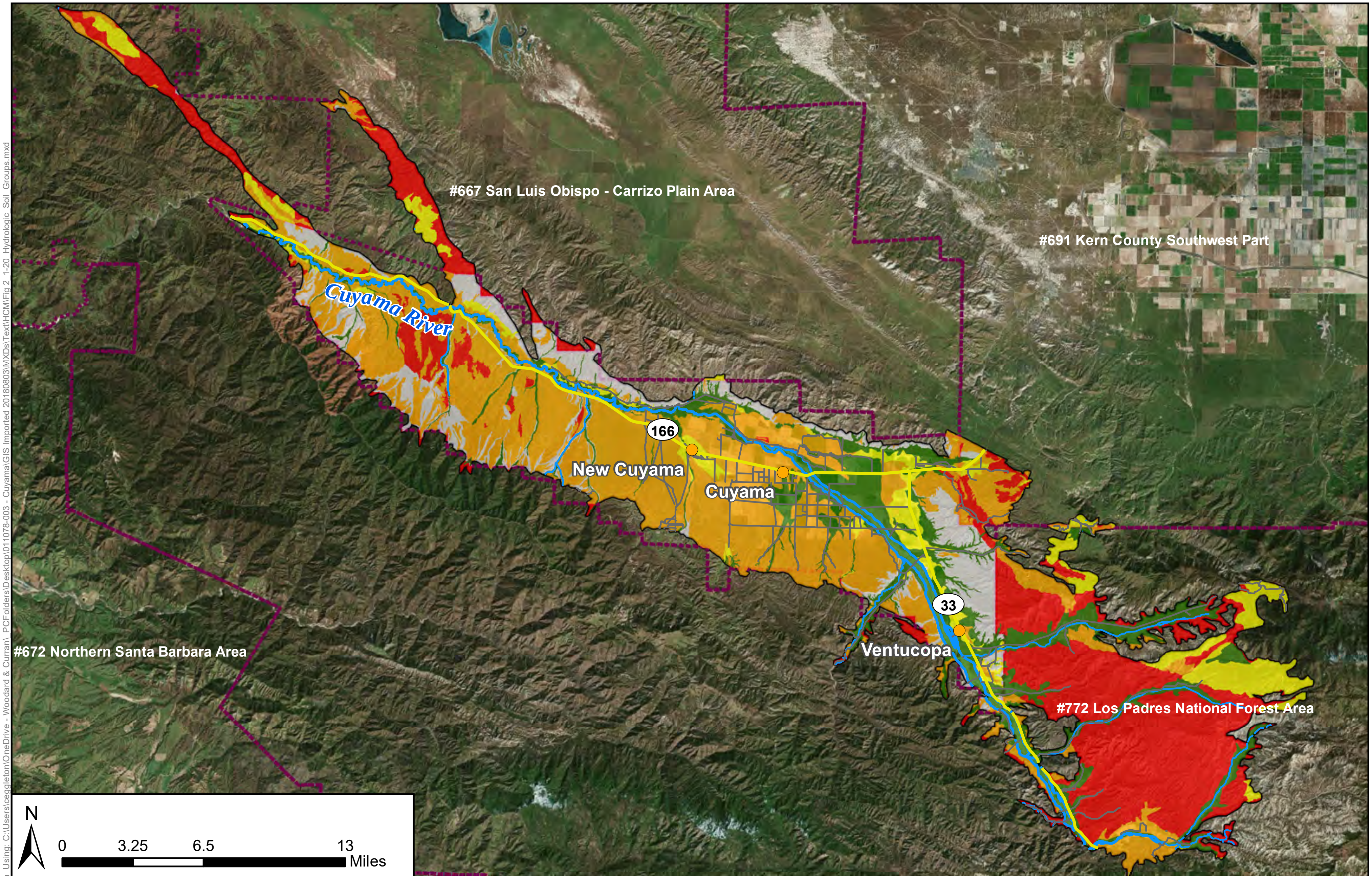

Figure 2.1-20: Hydrologic Soil Groups

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Cuyama Basin
Cuyama River
Streams
Towns
Highways

Hydrologic Soil Group
A
B
C
D
Not classified

Soil Survey Boundary

Soil Survey Key:
#772 Los Padres National Forest Area
Soil Survey Number
Survey Name

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2.1.10 Hydrogeologic Conceptual Model Data Gaps

HCM data gaps are present in the understanding of the HCM presented in this GSP. Initial draft subjects considered data gaps are listed below and will be refined and updated during the preparation of the rest of the GSP. The following data gaps will be revised after further research and GSP development:

- Effects of the Russell Fault
- Extent of synclines
- Conductivity of basement rocks
- Effects of other faults
- Boundary of the Upper and Lower Units of the Morales Formation
- Thickness of the Morales Formation
- Portions of basin not well understood (far west and east portions)
- Plans to fill data gaps in understanding (Management Actions and/or Projects)

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