Cuyama Valley Groundwater Basin Groundwater Sustainability Plan Hydrogeologic Conceptual Model Draft

Prepared by:

June 2018

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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 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) 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)

2.1.2 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.

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

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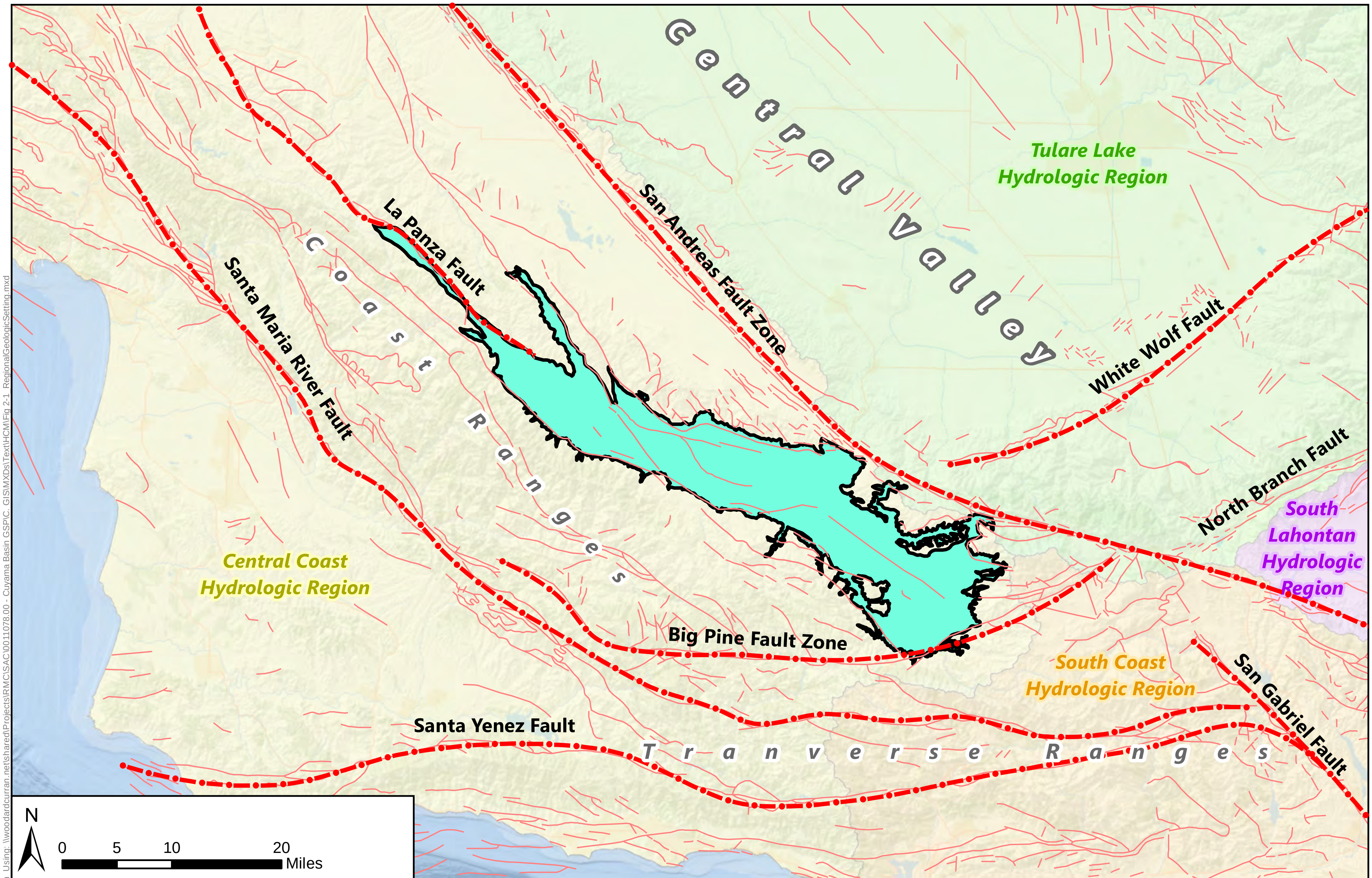

Figure 2-1: Regional Geologic Setting

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Cuyama Valley Groundwater Basin Groundwater Sustainability Plan

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Legend

Cuyama Basin

Faults

Fault locations and names use data from the Fault Activity Map of California (2010) from the California Department of Conservation. Retrieved 6/13/2018. <http://maps.conservation.ca.gov/cgs/fam/>

Figure Exported: 6/13/2018 By: ceggleton Using: \\woodardcurran.net\shared\Projects\RMC\SAC\0011078.00 - Cuyama Basin GSP\C_GIS\MXDs\Text\HCM\Fig 2-1_RegionalGeologicSetting.mxd

Following a period of orogeny, deformation changed to extension from the late Oligocene and early Miocene and the Cuyama Basin became a major extensional basin. 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. 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, 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, 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. 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 and uplifted the Caliente Range and thrusted Miocene-aged rocks of the Caliente Range southward over Quaternary alluvium on the Morales fault (USGS, 2013b). 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 Pliocene 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). Fluvial deposits of claystone, sandstone, and conglomerate became the primary forms of sedimentation.

2.1.3 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 2.1.6. 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 2-2. A generalized stratigraphic column of the Valley is shown in Figure 2-3.

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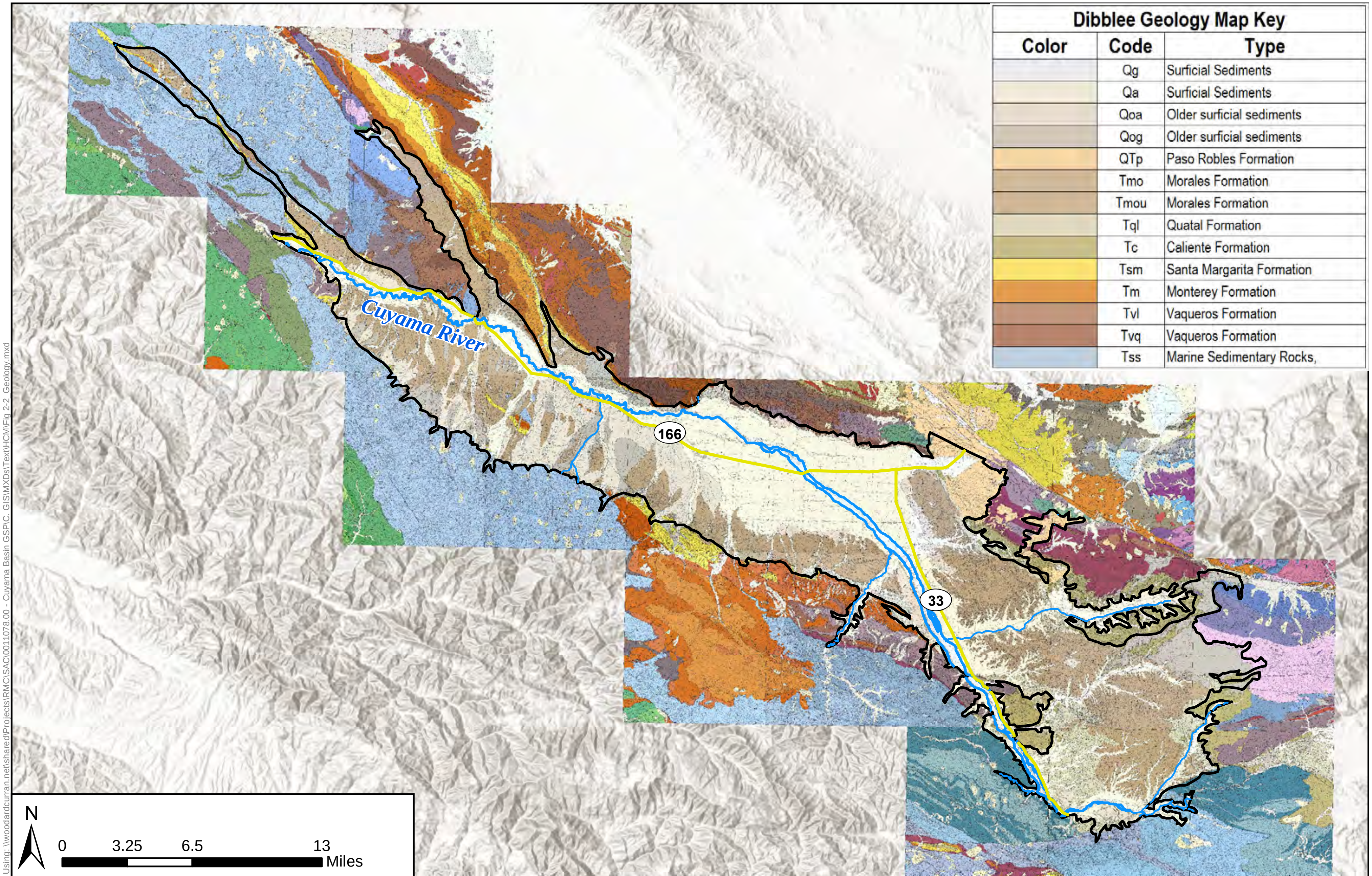

Figure 2-2: Geologic Map

Cuyama Basin Groundwater Sustainability Agency

Cuyama Valley Groundwater Basin Groundwater Sustainability Plan

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- Cuyama Basin
- Highways
- Cuyama River
- Streams

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

Figure Exported: 6/5/2018 By: ceggleton Using: \\woodardcurran.net\shared\Projects\RMC\SAC\0011078.00 - Cuyama Basin GSP\C. GIS\MXDs\Text\HCM\Fig 2-2 Geology.mxd

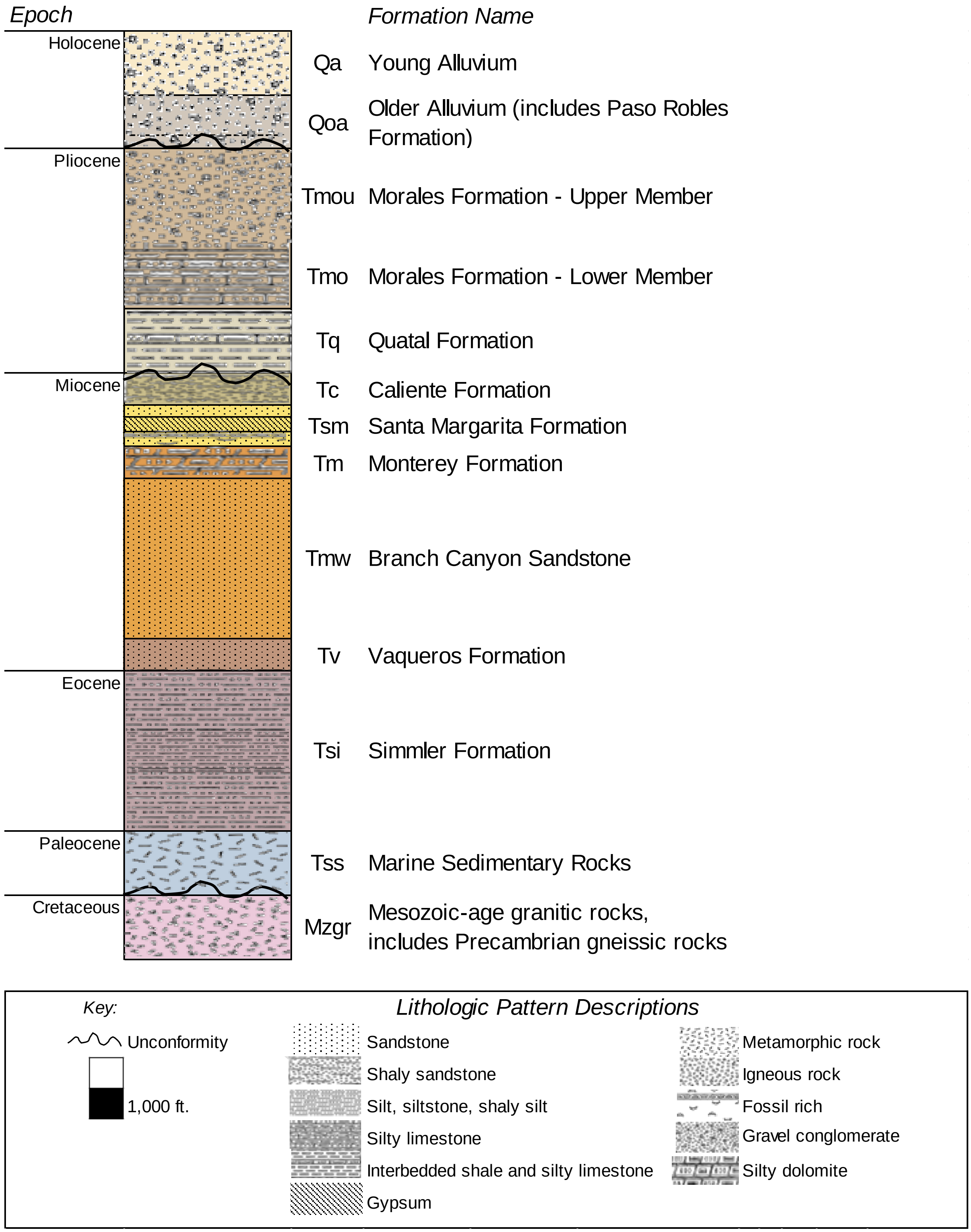

Figure 2-3: Generalized Stratigraphic Column of the Cuyama Valley

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 (USGS, 2013a).

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). 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 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 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 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 (USGS, 2013a). 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.

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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 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 underlies the Morales Formation in the northwest of the Valley and grades into the Caliente Formation to the east. 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 to siliceous shale. 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 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.

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 shoreline and is defined by the gradational change into the nonmarine Caliente Formation to the east (Davis et al., 1988).

Vaqueros Formation

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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). To the east, the Vaqueros Formation grades into the lower part of the nonmarine Caliente Formation. 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).

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).

Basement Rocks

The crystalline basement 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.

The USGS prepared a generalized stratigraphic diagram of the central portion of the basin in 2013. The location of the diagram is shown in Figure 2-4, and the diagram is shown in Figure 2-5. 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).

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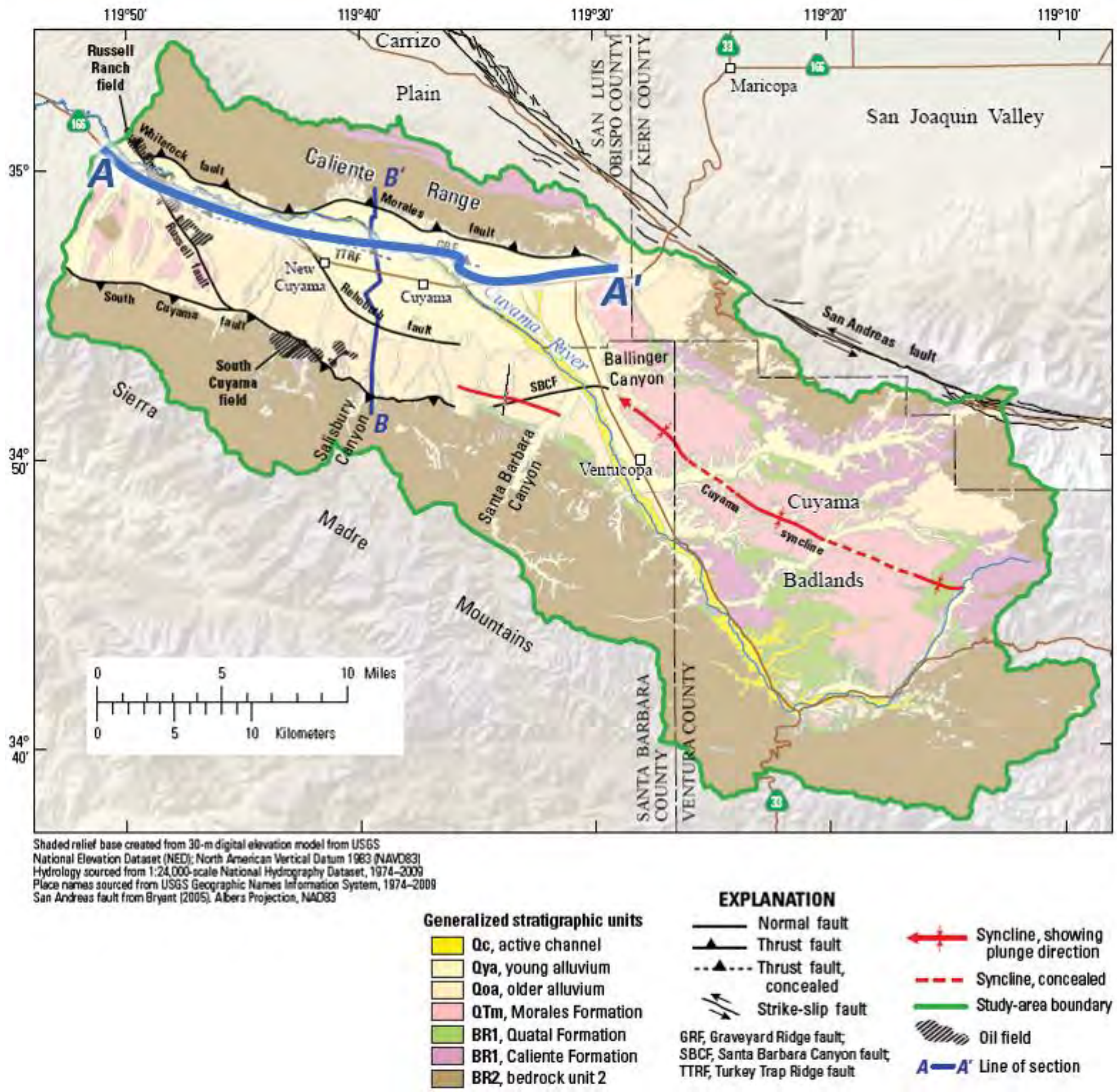
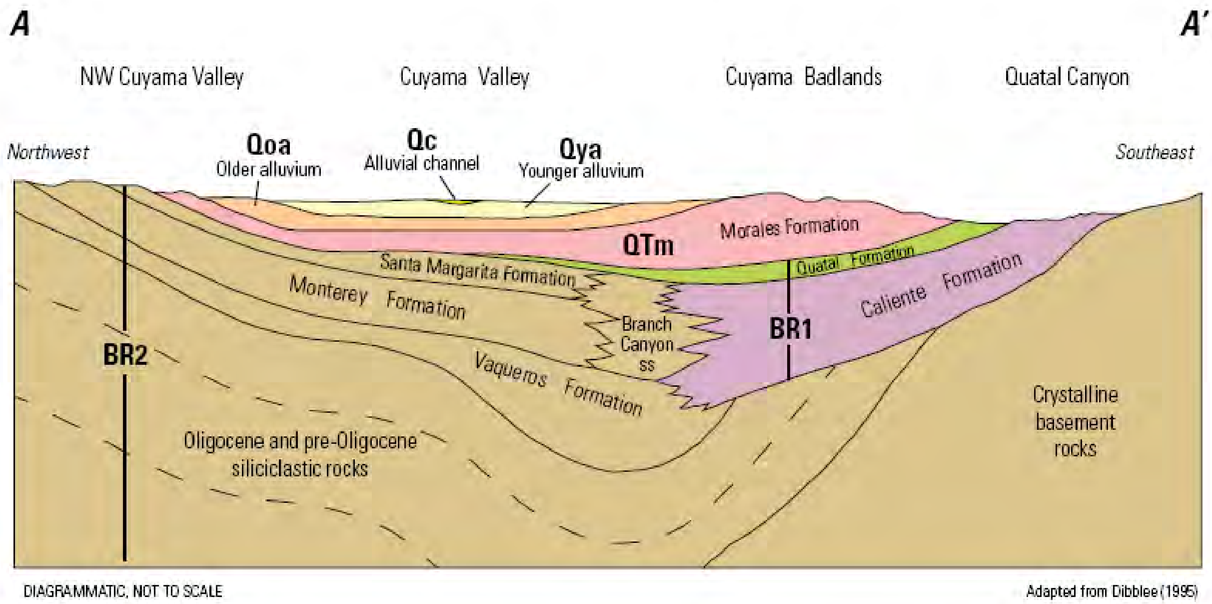


Source: USGS, 2013a.

Figure 2-4: Geologic Map and Location of Stratigraphic Diagram A-A'



Source: USGS, 2013a.

Figure 2-5: Generalized Stratigraphic Diagram

2.1.4 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 2-6. Outcrops of basement rocks are shown on the geologic maps (Figure 2-2 and Figure 2-4).

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 and plunges to the northwest (Singer and Swarzenski, 1970). 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, 2016). 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 and Minch. (Dibblee and Minch, 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 2-6.

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 in the center 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 million years (Ma) (USGS, 2013a). 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 are thinner than the water bearing units to the east of the Russell 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. 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, 2013a). 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 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, 2016). 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).

Due to the lack of a consensus as to the impact of the Russell Fault on groundwater flow, we believe it is prudent to further evaluate the impacts of the fault on groundwater flow through additional monitoring, monitoring will be addressed in Section XX

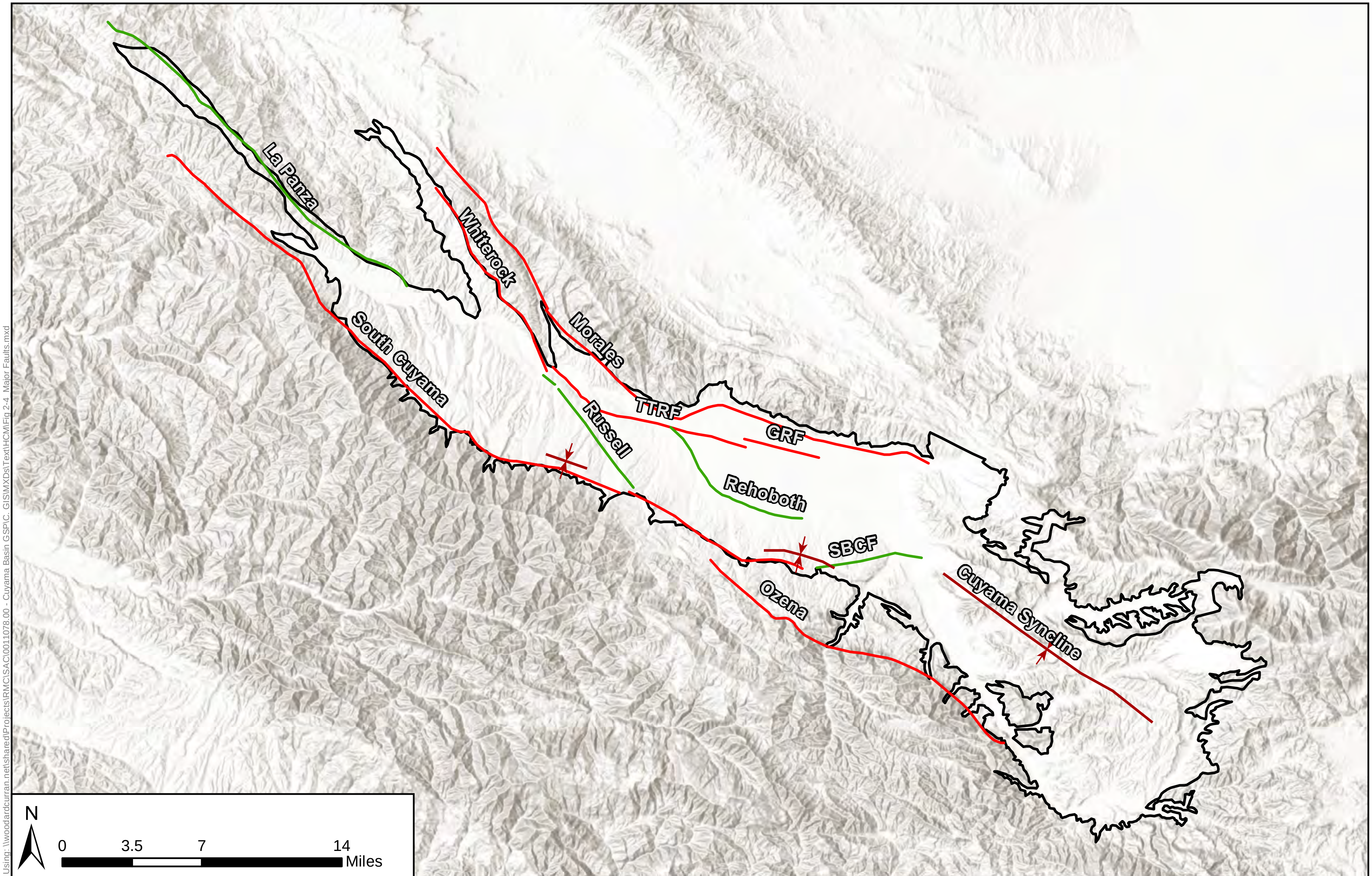


Figure 2-6: Major Faults

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Cuyama Valley Groundwater Basin Groundwater Sustainability Plan

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Legend

- Cuyama Basin
- **Fault Types**
- Normal
- Reverse Fault
- Reverse Fault, Concealed
- Syncline
- Thrust
- Thrust Fault, Concealed

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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 (USGS, 2013b). The USGS determined the fault to be "not a significant barrier to groundwater flow" as symmetrical subsidence and uplift was observed on both sides of the fault (USGS, 2013b).

In 2013, the USGS concluded the fault only offsets formations older than the older alluvium. The top of the Morales Formation is offset by 160 feet on the northeast side of the fault and the offset increases with depth. 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, 2013c).

Whiterock Fault

The Whiterock fault is a surficial thrust fault that runs 11 miles along the northern finger of the Cuyama Basin. 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). The Whiterock fault is a barrier to groundwater and is a defining feature of the lateral boundary of the Cuyama Basin.

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.

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. 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

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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 (USGS, 2013b). 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 as a dip of approximately 30 (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. 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. Outcrops in the western portion are likely tied to tectonic activity and faulting.

Outcrops of basement rock in the eastern upland portion of the basin are shown in Figure 2-4. 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 2-2.

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 2-7 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 2-7, 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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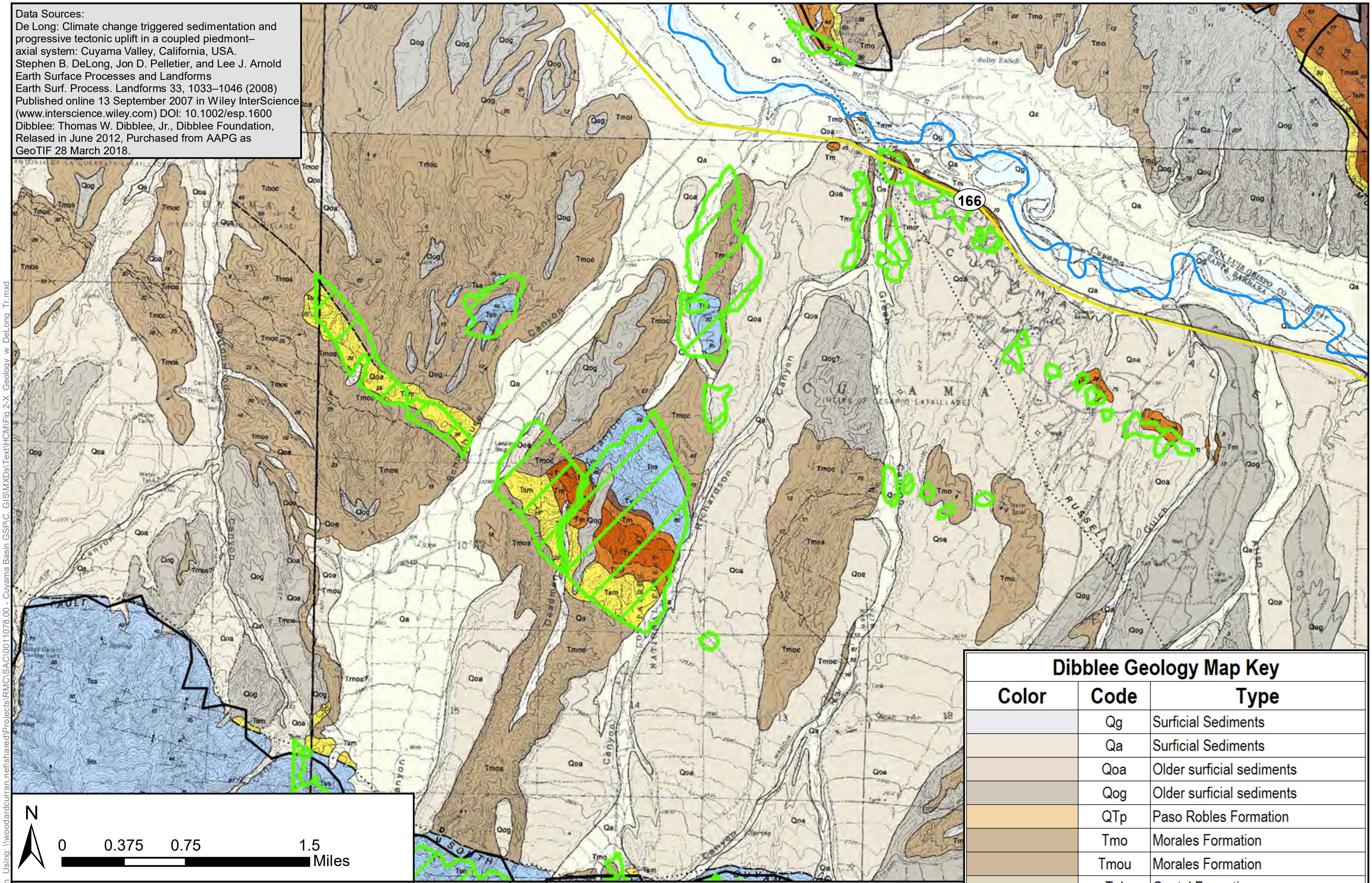
Data Sources:
De Long: Climate change triggered sedimentation and progressive tectonic uplift in a coupled piedmont–axial system: Cuyama Valley, California, USA.
Stephen B. DeLong, Jon D. Pelletier, and Lee J. Arnold
Earth Surface Processes and Landforms
Earth Surf. Process. Landforms 33, 1033–1046 (2008)
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 GeoTIFF 28 March 2018.



N

0 0.375 0.75 1.5 Miles

Figure 2-7: 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: 6/5/2018 By: ceggleton Using: \\woodardcurran.net\shared\Projects\RMC\SAC\0011078.00 - Cuyama Basin GSP\C. GIS\MXDs\Text\HCM\Fig 2-X Geology w DeLong Tr.mxd

2.1.5 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. 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 (Cleath-Harris, 2016). 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).

2.1.6 Principal Aquifers and Aquitards

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." Within the Cuyama Basin, there is one principal aquifer composed of the younger alluvium, older alluvium, and the Morales Formation. 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.

Aquifer Formations

The formations 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. 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 are shown in Figure 2-8 through Figure 2-11. Figure 2-8 shows the location of both aquifer cross sections. Cross sections were created using the layering of the Cuyama Basin groundwater model, which is described in Section 2.3 [Note: section to be added later]. Figure 2-9 shows a cross section of the three formations that make up the principal aquifer along A-A'. Figure 2-10 shows a cross section of the three formations that make up the principal aquifer along B-B'. Figure 2-11 shows a cross section of the three formations that make up the principal aquifer along C-C'. A detailed description of each formation that comprises the principal aquifer are provided below.

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 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 outcrops, the formation is coarse grained and moderately permeable, but land is topographically unsuited to agricultural development and few wells have been installed.

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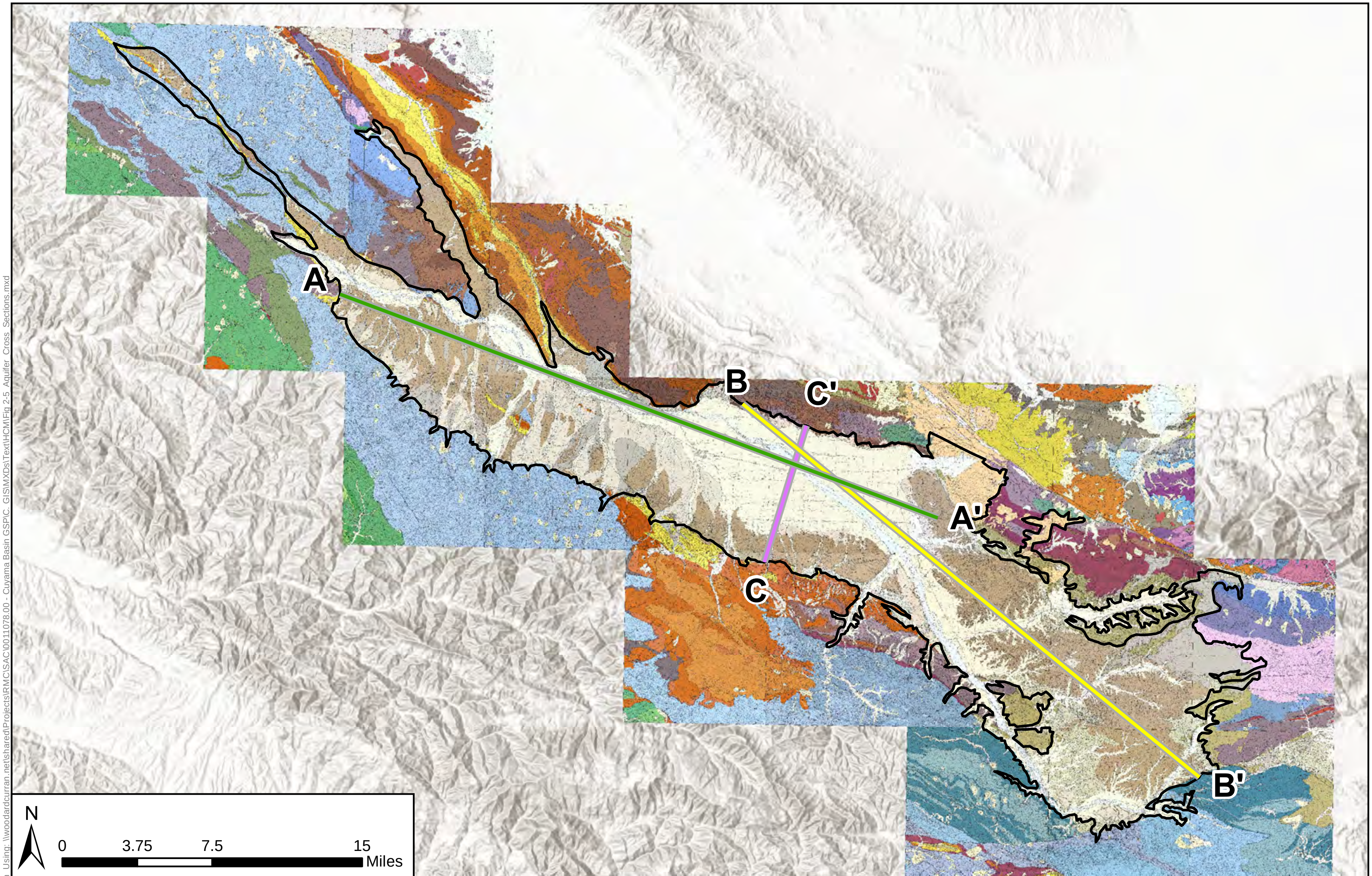

Figure 2-8: Aquifer Cross Sections

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Legend

- Cuyama Basin
- Cross Section A-A'
- Cross Section B-B'
- Cross Section C-C'

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

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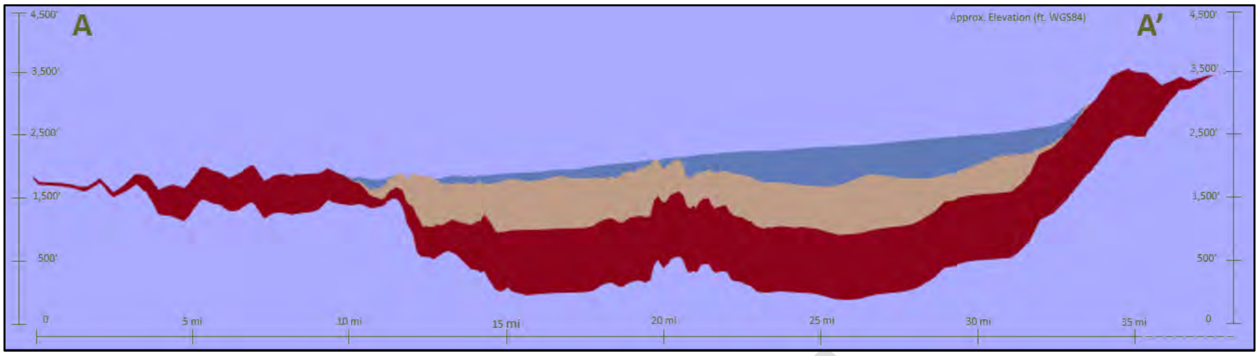

Figure 2-9:Cross Section A-A'

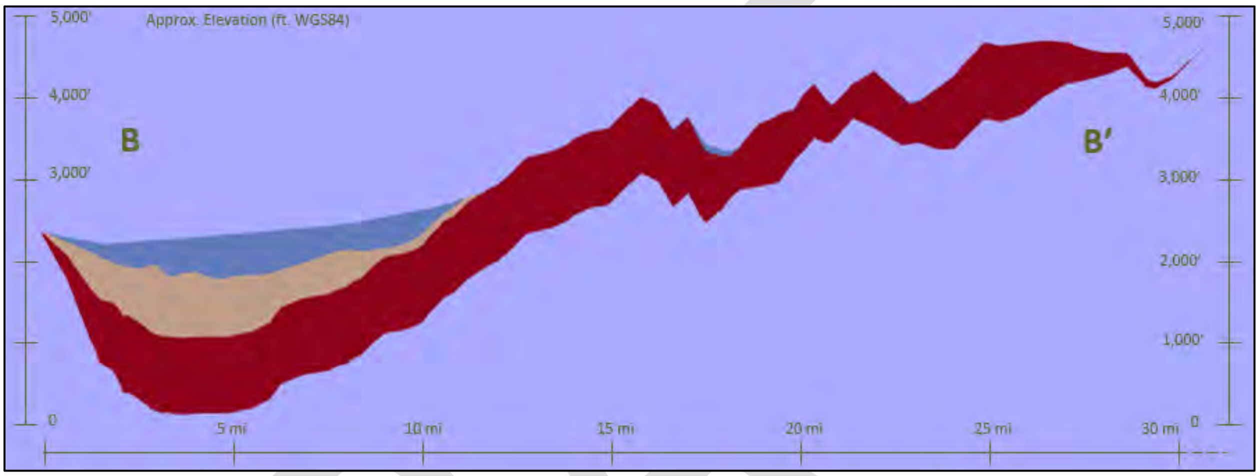

Figure 2-10: Cross Section B-B'

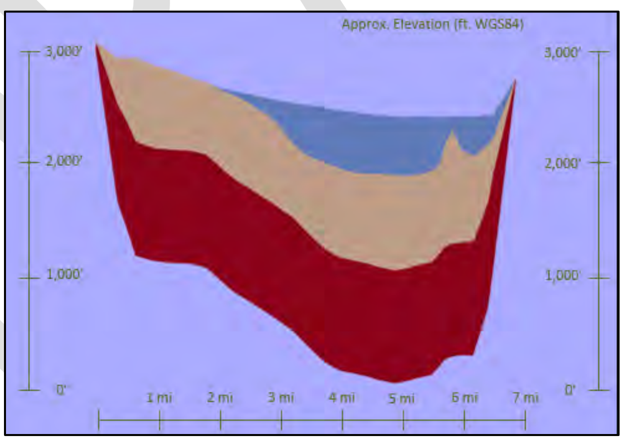

Figure 2-11: Cross Section C-C'

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. Using aquifer tests from 63 wells (Figure 2-12), estimates of horizontal hydraulic conductivity range from 1.5 to 28 feet per day (ft/d) and decrease with depth (USGS, 2013c). The younger alluvium generally has the highest hydraulic conductivity and the Morales Formation has the lowest. The median estimated hydraulic conductivity for the older alluvium (15 ft/d) is about five times the estimated value for the Morales Formation (3.1 ft/d) (USGS, 2013c). 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 moving west (Singer and Swarzenski, 1970).

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[1]. The dewatered alluvium has an average specific yield of 15 percent (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 (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).

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

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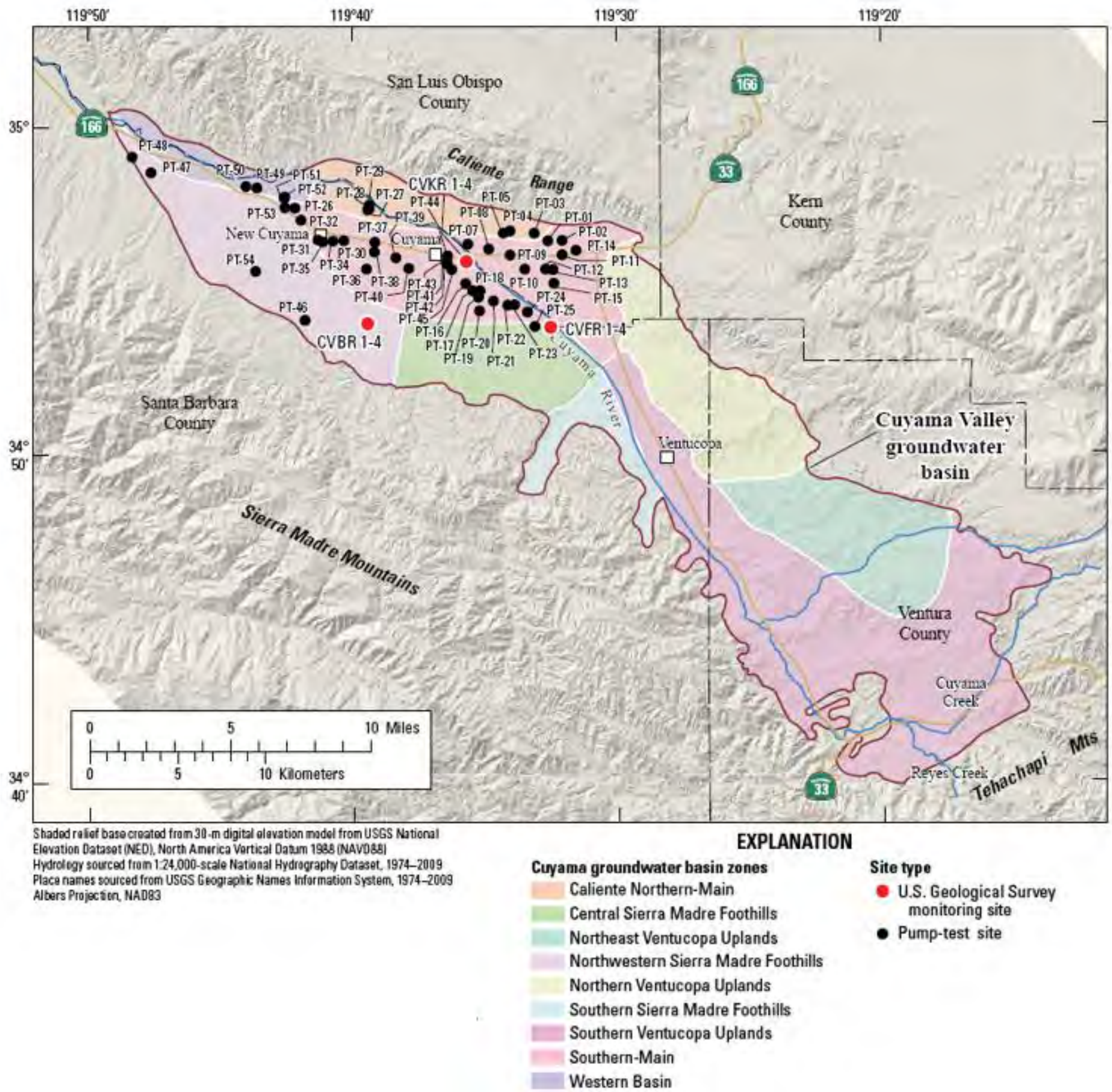


Source: USGS, 2013c.

Figure 2-12: Location of Aquifer Testing Well Sites

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 2-12), 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 fluctuate 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.

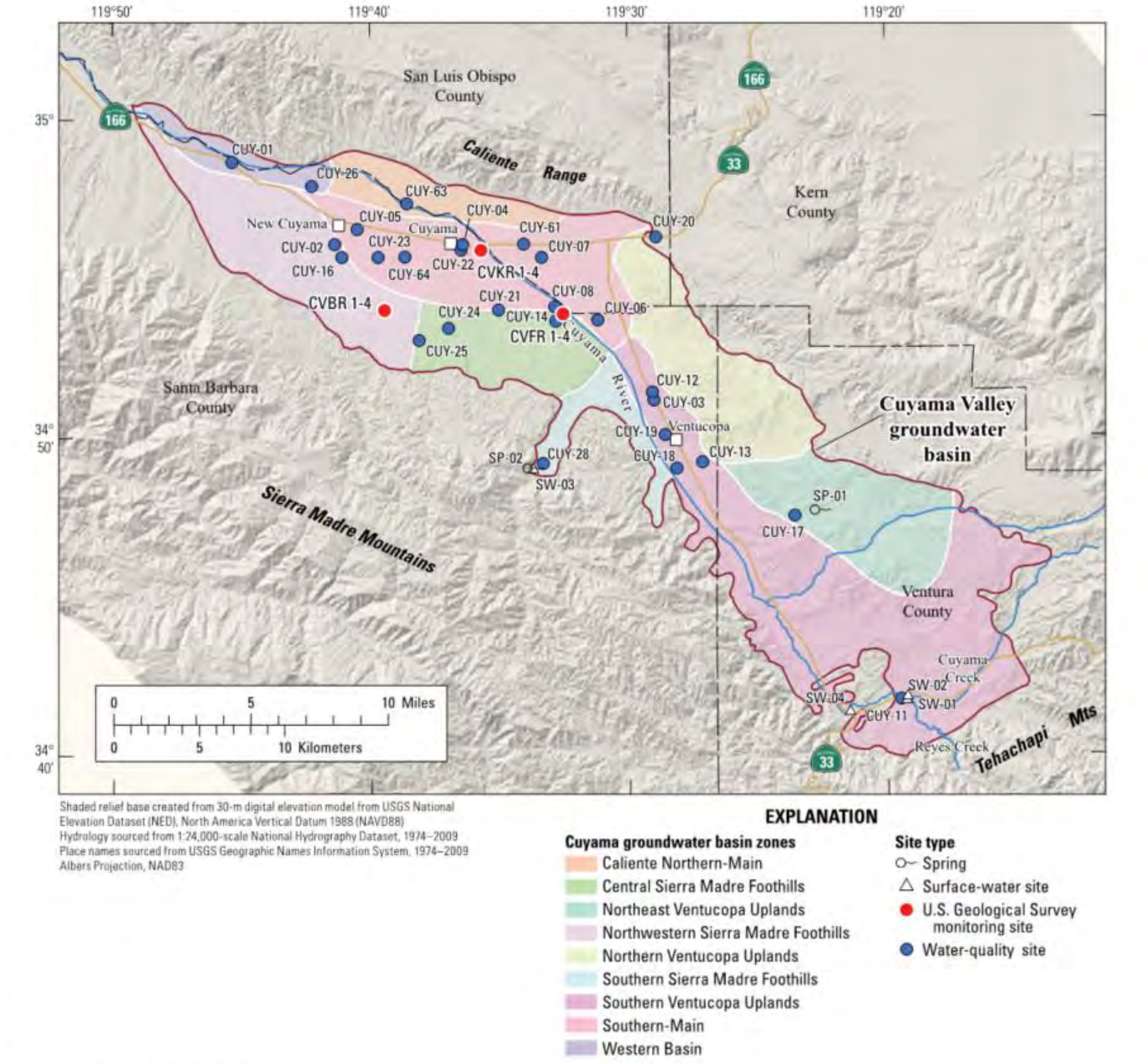
2.1.7 Water Quality

Historic Groundwater Quality

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 are shown in Figure 2-13.

Singer and Swarzenski studied groundwater in the basin in 1970. Groundwater ranges 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.



Source: USGS, 2013c.

Figure 2-13: Location of USGS 2013 Groundwater Quality Sites

Recent Groundwater Quality

In 2013, the USGS collected groundwater from 39 wells and two springs for 53 constituents including nitrate, major and minor ions, field parameters (dissolved oxygen, temperature, alkalinity, pH, and specific conductance), arsenic, iron, and chromium (USGS, 2013c). Concentrations of nitrates, sulfates, arsenic, TDS, and hexavalent chromium were compared to the United States Environmental Protection Agency (USEPA) secondary drinking-water standards (SMCL) and maximum contaminant levels (MCL) to identify samples that exceeded drinking water standards. Groundwater quality data indicated that the groundwater has high concentrations of TDS and sulfates Basin-wide and localized spikes in arsenic, nitrates, hexavalent chromium, boron, and chloride (USGS, 2013c). Results found that:

- TDS concentrations exceeding the SMCL (greater than 500 mg/L) were found in 97 percent of samples.
- Sulfate concentrations exceeding the SMCL (greater than 250 mg/L) were found in 95 percent of groundwater quality samples.
- Nitrate concentrations ranged from 0.02 mg/L up to 45.3 mg/L, exceeding the SMCL (10 mg/L) in 13 percent of samples. Wells along the edges of agricultural land-use areas reported the lowest nitrate levels and wells within agricultural land use areas reported the highest levels of nitrate. Nitrate concentrations decreased with depth, indicating the source was near the surface and likely a result of agricultural activities.
- Arsenic concentrations exceeding the MCL (greater than 10 micrograms per liter (µg/L)) were found in 12 percent of groundwater quality samples and ranged from 0.51 to 67.1 µg/L. High concentrations of arsenic correlated with groundwater older than 25,000 years.
- Hexavalent chromium concentrations exceeding the Public Health Goal[2] of 0.02 µg/L were observed in 95 percent of groundwater quality samples and ranged from below detection limit (0.1 µg/L) to 1.7 µg/L.

Aquifer Use

The Cuyama Valley is dependent on groundwater as its sole source of supply. Groundwater is used primarily for irrigation (USGS, 2013c). The majority of agricultural activity occurs between the New Cuyama and Ventucopa areas.

2.1.8 Topography, Surface Water and Recharge

This section describes the topography, surface water, soils, and groundwater recharge potential in the basin.

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 2-14 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

[2] The USEPA does not list a SMCL for hexavalent chromium. Public Health Goals are typically orders of magnitude lower than a SMCL.

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to the small watershed and storms that provide precipitation onto the surrounding Coastal Range Mountains. Peak flows through the Cuyama River thus 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 Wells 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 2-15 shows the locations of surface water bodies in the basin.

No standing bodies of water such as lakes or ponds are present within Cuyama Valley. 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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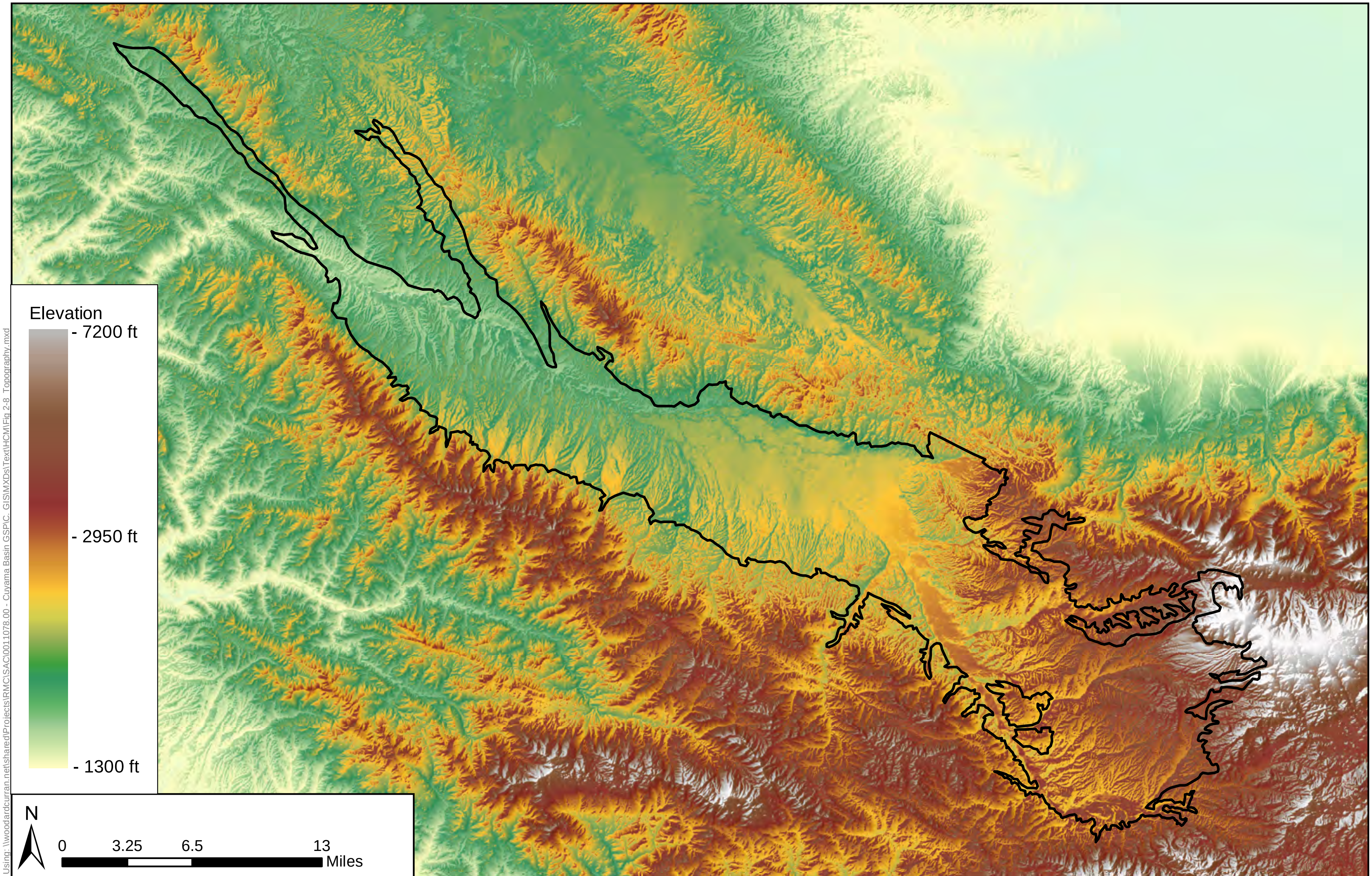

Figure 2-14: Topography

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Legend

Cuyama Basin

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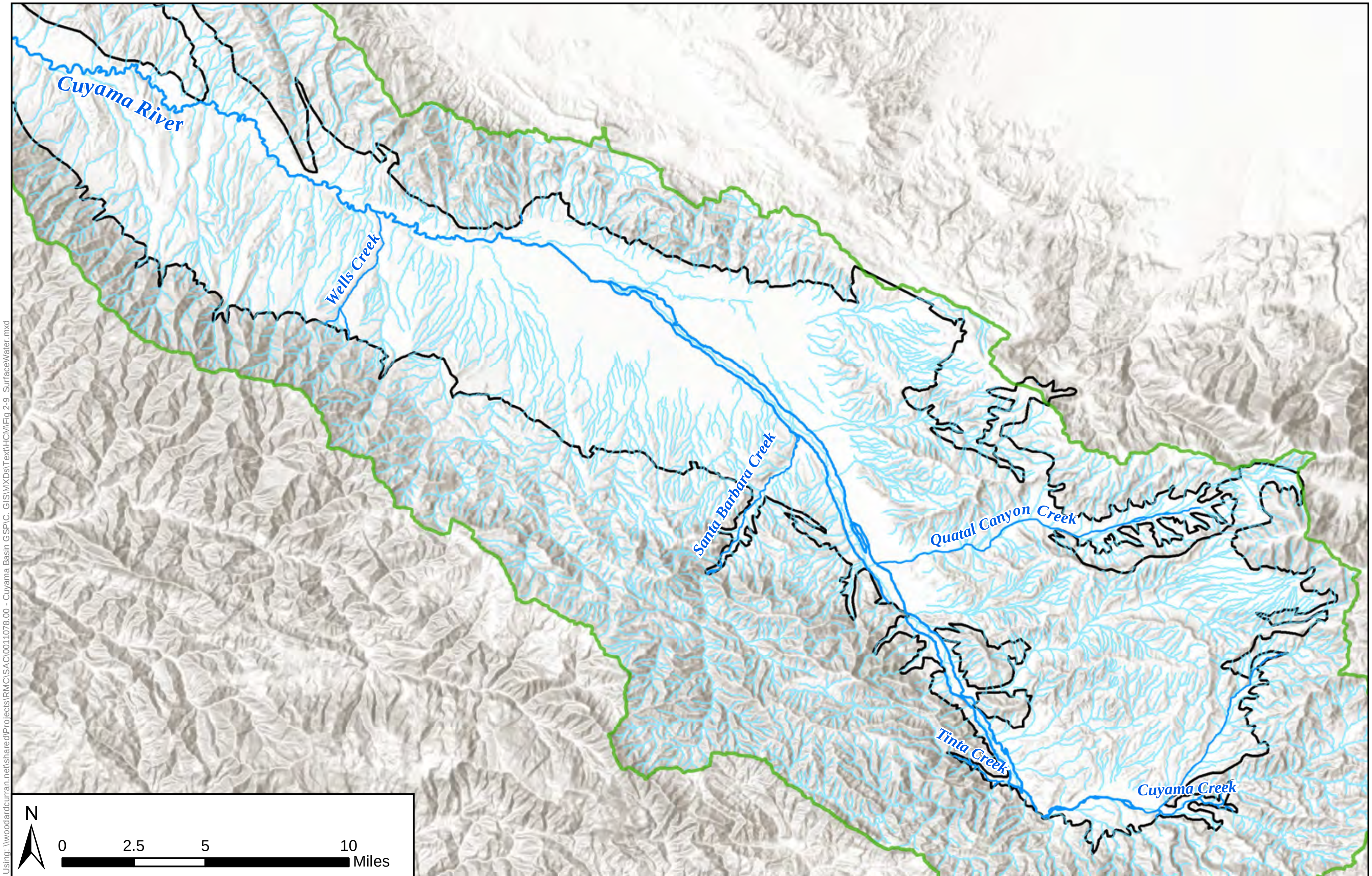

Figure 2-15: Surface Water

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Legend

- 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. Approximately 25 miles of the eastern portion of the Cuyama River is categorized as a wetland by the U.S. Fish & Wildlife Service's National Wetlands Inventory. These wetlands are considered areas of recharge during flow events due to precipitation within the basin.

Agricultural and open space lands are also considered areas of potential recharge. Figure 2-16: 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 2-16 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 2-16 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 2-17, 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 2-18 shows soils by hydrologic soil group. Hydrologic soil groups were calculated by the NRCS on a by-county basis. As shown in Figure 2-18, 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 2-18 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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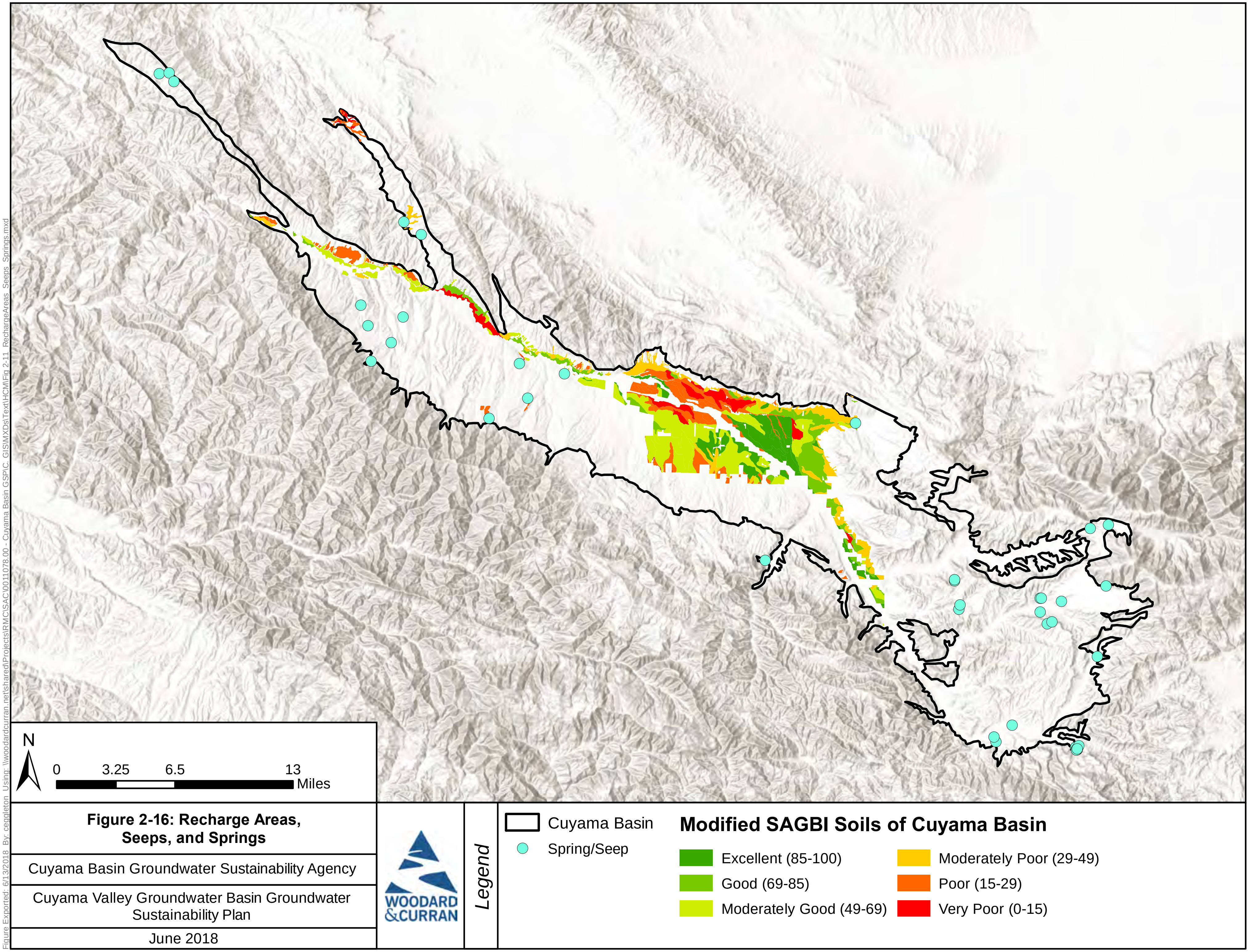

Figure 2-16: Recharge Areas, Seeps, and Springs

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Figure Exported: 6/13/2018 By: cappleton Using: \\woodardcurran.net\shared\Projects\RMC\SAC\0011078.00 - Cuyama Basin GSP\C_GIS\MXDs\Text\HCM\Fig 2-11_RechargeAreas_Seeps_Springs.mxd

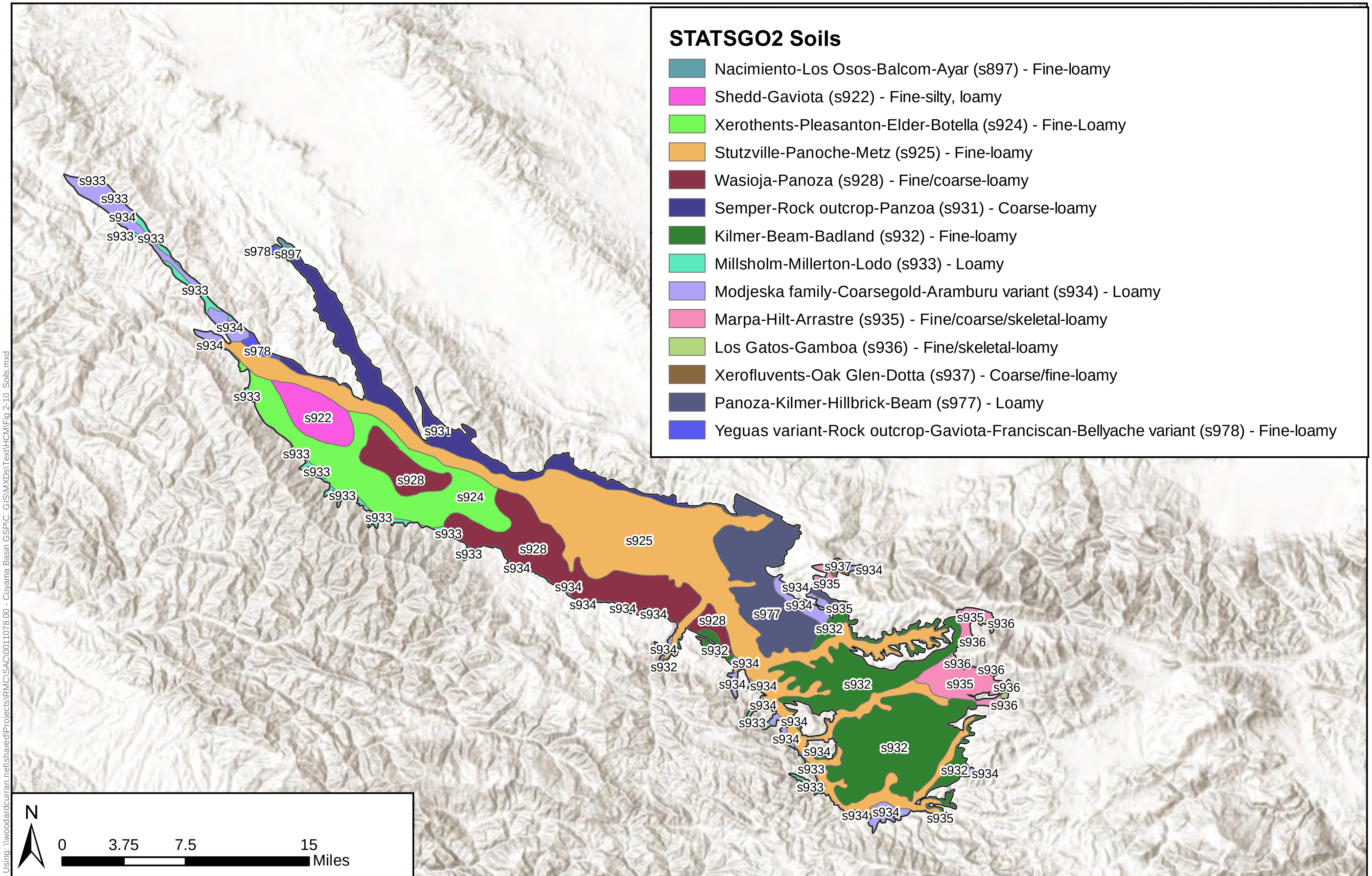

Figure 2-17: Soils

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Legend

Cuyama Basin

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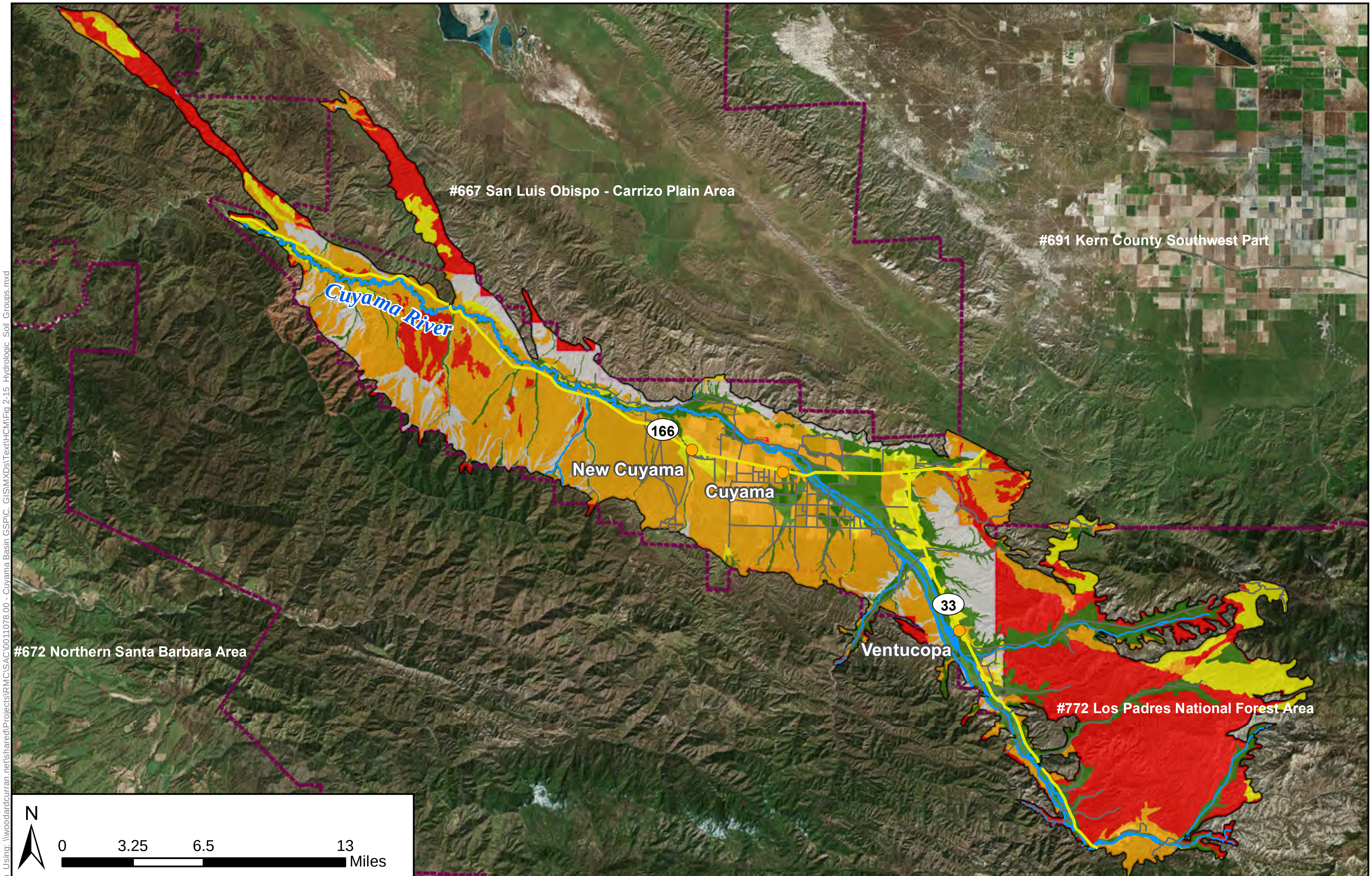

Figure 2-18: Hydrologic Soil Groups

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Legend

- 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

Figure Exported: 6/12/2018 By: ceggleton Using: \\woodardcurran.net\shared\Projects\RMC\SAC\0011078.00 - Cuyama Basin GSP\C_GIS\MXDs\Text\HCM\Fig 2-15_Hydrologic_Soil_Groups.mxd

2.1.9 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.

- Russell Fault
- Boundary of the Upper and Lower Units of the Morales Formation
- Groundwater Quality
- Portions of basin not well understood (far west and east portions)
- Plans to fill data gaps in understanding

To be completed after further research and GSP development

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