

Merced Subbasin Groundwater Sustainability Plan Hydrogeologic Conceptual Model Draft

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ACRONYMS

AF	Acre-Feet
DWR	Department of Water Resources
GIS	Geographic Information System
gpm	gallons per minute
GSP	Groundwater Sustainability Plan
HCM	Hydrogeologic Conceptual Model
IRWM	Integrated Regional Water Management
mg/L	milligrams per liter
MID	Merced Irrigation District
SGMA	Sustainable Groundwater Management Act
SSURGO	Soil Survey Geographic Database
USACOE	United States Army Corps of Engineers
USDA	United States Department of Agriculture

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

- Hydrogeologic Conceptual Model (HCM) – 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, and 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.

1.1 BASIN SETTINGS

1.1.1 Hydrogeologic Conceptual Model

This section describes the Hydrogeologic Conceptual Model (HCM) for the Merced Subbasin. The HCM is developed to understand and convey the physical conditions by which water moves through in the basin and is used elsewhere in the Groundwater Sustainability Plan (GSP) to support the development of sustainability criteria, monitoring networks, water budgets, programs, and projects.

As defined by the GSP regulations 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.”

1.1.1.1 Regional Geologic and Structural Setting

The Merced Subbasin is located in the San Joaquin Valley, a broad structural trough approximately 200 miles long and up to 70 miles wide. This trough is filled with up to 32,000 feet of marine and continental sediments deposited during periodic inundation by the Pacific Ocean and by erosion of the surrounding mountains. Continental deposits shed from the surrounding mountains form an alluvial wedge that thickens from the valley margins near the eastern boundary of the Subbasin toward the axis of the structural trough near the western boundary of the Subbasin. This depositional axis is below and slightly west of the series of rivers, lakes, sloughs, and marshes that mark the current and historical axis of the surface drainage of the San Joaquin Valley (DWR, 2004).

The Merced Subbasin is generally bounded by the Sierra Nevada Mountain range in the east and other groundwater subbasins of the Central Valley to the north, south, and west (see more detail in Section 1.1.1.5). The southeast portion of the basin is underlain by the Corcoran Clay, a bed of laterally extensive reduced (blue/grey) silt and clay. The Corcoran Clay is a significant confining layer up to 60 feet thick.

This geologic setting is reflected throughout the HCM. The very deep sediments create a large volume of groundwater within the Merced Subbasin. At greater depths, this groundwater is saline, reflective of deposition of the deeper aquifer materials in a marine environment. Shallower depths have fresh groundwater, reflective of deposition in a non-marine environment or flushing with fresh water from higher in the system. The nature of the aquifer materials holding this groundwater is driven by the depositional environment. In higher-energy environments, such as fast-moving streams, larger materials are deposited, such as gravels and sands. In lower-energy environments, such as lakes, smaller materials are deposited, such as clays and silts. Thus, the aquifer system typically has coarser, more conductive materials along current or ancestral river courses and closer to the foothills. Finer, less-conductive materials are present farther from current or ancestral river courses and towards the axis of the valley near the San Joaquin River. In addition to spatial influences on aquifer materials, there is a time component as well. The deposition of continental deposits in alluvial fans emanating from the foothills was interrupted when the valley was inundated by Lake Corcoran, creating a low-energy depositional environment which resulted in the regional clay unit known as the Corcoran Clay. The Corcoran Clay is an important aquitard in that portion of the basin, separating the subsurface into two distinct aquifer systems, one above the clay and one below.

1.1.1.2 Geologic History

The geologic history of the Merced Subbasin is one of deposition of sediments in an environment with changing climate, changing sea levels, and tectonic movement, all of which resulted in the **sediments that form today's aquifer system.**

A summary of the geologic history is provided below. This summary refers to the geologic time scale, which is included in Appendix X as a reference.

As with other areas on the east side of the San Joaquin Valley, the deposition of sediments occurred on a westward-tilted block of crystalline basement composed of Sierra Nevada plutonic and metamorphic rocks under the eastern part of the valley and mafic and ultramafic rocks of a presumed ophiolite of Jurassic age under the central and western parts of the valley (Bartow, 1991). Thus, the bottom of the basin is a westward extension of the materials associated with the Sierra Nevada or is ophiolitic material associated with subducting oceanic crust from the west. In addition to forming the bottom of the basin, the continued tilting of the Sierran block contributed to the ability to accumulate sediments in the basin and resulted in the dipping units and angular unconformities between units.

Pre-Tertiary marine rocks are deposited at the greatest depths and in great thickness. Cretaceous Period marine rocks are as much as 20,000 feet thick in areas of the San Joaquin Valley (Page R. W., 1986).

Most of the materials relevant to groundwater management were deposited in the more recent Cenozoic Era. Near the close of the Mesozoic Era, the San Joaquin Valley area was the southern part of an extensive forearc basin (Bartow, 1991). Tectonic movements elevated many Coast Range areas, including those adjacent to the Sacramento Valley and the northern San Joaquin Valley; these movements created the ancestral Tertiary San Joaquin and Sacramento basins as restricted troughs of deposition lying between the emerging Coast Ranges and the eastern Sierra Nevada (Page R. W., 1986). With significant restriction between what is now the valley and the ocean, the depositional environment varied based on sea level, tectonics, and deposition.

The Lone Formation was deposited in the middle Eocene Epoch discontinuously on pre-Tertiary rocks, dipping gently to the southwest (Bartow, 1991). Overall, the formation is considered deltaic in origin, with fluvial, lacustrine, and lagoonal deposits (Page R. W., 1986). The beginning of the middle Eocene was characterized with lower eustatic sea levels resulting in a non-marine depositional environment for earlier Lone Formation materials. As eustatic sea levels rose through the middle Eocene, the depositional environment became more shoreline or shallow marine. The Merced Subbasin was generally a coastal environment with open ocean to the west. The more southwesterly portions of the Subbasin would be more likely to be shallow marine and the more northeasterly portions of the basin more likely to be non-marine. Towards the end of the middle Eocene, lower eustatic sea levels again moved the lone to more non-marine deposition (Bartow, 1991).

Deformation, driven by tectonic forces, generally resulted in west or southwest tilting. This causes the subtle angular unconformities in the Cenozoic units with discordances of generally less than 1 degree. Discordances appear to be less between Eocene and younger units compared to Eocene and older units, but there is evidence of continued tilting in the Oligocene based on differences in the gradient of depositional surfaces in the Eocene Lone and Miocene Valley Springs Formations. Currently, tilting continues to be present, likely at an accelerated rate (Bartow, 1991).

The Oligocene marks a change in sedimentary history in the Merced area and the San Joaquin Valley, with a change from few, long-lasting, San Joaquin Valley-wide depositional sequences, to shorter sequences of more local extent. This is associated with a regional transition from a convergent continental margin to a transform margin (Bartow, 1991).

During the Oligocene, at the time of maximum regression, the entire Subbasin was above sea level, sloping towards the south. A hiatus representing most of the Oligocene is evidence that there was negligible subsidence in the western part of the block during that interval (Bartow, 1991).

The Subbasin remained above sea level during the Miocene, although uplift to the south resulted in a change in slope towards the southwest. The Valley Springs Formation was deposited in the Upper Oligocene and Lower Miocene unconformably over the Lone, dipping gently to the southwest. The Valley Springs was deposited following a period of low eustatic sea levels. While eustatic sea levels became higher during this period, the depositional environment remained non-marine, with fluvial sequences and ash deposits.

The Mehrten Formation was deposited in the Middle to Upper Miocene unconformably over the Valley Springs, dipping gently to the southwest. The Mehrten Formation is considered to have been laid down by streams carrying andesitic debris associated with the beginning of andesitic volcanism in the Sierra Nevada (Page R. W., 1986). There is no apparent angular discordance between the Mehrten and the Valley Springs, although there is an unconformity with as much as 120 meters of erosional relief in the eastern part of the outcrop area (Bartow, 1991).

By the end of the Pliocene (approximately 2 million years ago), seaway connections were completely closed due to rapid filling of the San Joaquin Valley with sediment (Elam, 2012), marking the end of marine deposition and the beginning of continental deposition.

Interrupting the alluvial deposition of continental deposits, in the Pleistocene Epoch a large lake known as Lake Corcoran was impounded, filling nearly the entire valley (Bartow, 1991). The period coincided with low eustatic sea levels associated with glaciation. The large lake is evidenced by the widespread deposition of the lacustrine clays today known as the Corcoran Clay. Outwash from alpine glaciers was deposited into the lake by Sierra Nevada rivers. The lake drained approximately 600,000 years ago when the present-day drainage outlet of the Carquinez Strait was carved out. However, several other smaller lakes also occupied portions of the valley later during the Quaternary Period (Bartow, 1991).

More recent deposits are alluvial, aeolian, and floodplain deposits derived primarily from the Sierra Nevada (Page R. W., 1986) (Page & Balding, 1973). **The presence of today's Corcoran Clay at depths of** approximately 40 feet to 240 feet is indicative of rates of tectonic subsidence (not related to groundwater withdrawal) that have occurred over the past 600,000 years.

1.1.1.3 Geologic Formations and Stratigraphy

The Merced Subbasin is underlain by consolidated rocks and unconsolidated deposits. The consolidated rocks, from bottom to top, include the Sierra Nevada basement complex, lone Formation and other sedimentary rocks, the Valley Springs Formation, and the Mehrten Formation (Page & Balding, 1973). The unconsolidated deposits include continental deposits, lacustrine and marsh deposits, older alluvium, younger alluvium, and flood-basin deposits.

A description of the consolidated rocks and unconsolidated deposits is provided below, with a map of surficial geology shown as Figure 2-1 and a summary table of the units and their water-bearing characteristics provided as Table 2-1.

Note that the text, table, and maps are taken from different sources and use slightly different terminology. Therefore, Table 2-2 is provided to map terminology between items.

The Merced Groundwater Management Plan (AMEC, 2008) provides the following description of the Subbasin geology in the following subsections. The discussions are supported by a geologic map (Figure 2-2) and cross sections (Figure 2-3 through Figure 2-13) from several sources. Table 2-3 serves to relate differing definitions and groupings of geologic units across the different sources.

Consolidated Rocks

The consolidated rocks include the Sierra Nevada basement complex, lone Formation and other sedimentary rocks, the Valley Springs Formation, and the Mehrten Formation.

The Sierra Nevada bedrock complex consists largely of metasedimentary and metavolcanic rock of pre-Tertiary age (Page & Balding, 1973). These rocks occur as foothill ridges along the eastern edge of the Merced Subbasin. Where the basement complex occurs near the surface, fracture sets and joints within the bedrock complex may contain sufficient groundwater for domestic or stock supplies.

The Eocene lone Formation unconformably overlies the Sierra Nevada bedrock complex and is composed of marine to non-marine clay, sand, sandstone, and conglomerate (Figure 2-1). These rocks occur as foothill ridges along the

eastern edge of the Merced Subbasin. The lone is characterized by a white sandy clay (kaolinite) at its base and beds of conglomerate and yellow, red, and gray sandstone in its upper parts. In localized areas near the Sierra Nevada foothills, the formation contains fresh water; however, well yields are highly variable.

The Miocene Valley Springs Formation overlies the lone Formation and is composed of a fluvial sequence of rhyolitic ash, sandy clay, and siliceous gravel in a clay matrix. These rocks occur as foothill ridges along the eastern edge of the Merced Subbasin (Figure 2-1). Because of the abundant ash and clay matrix, the Valley Springs has a relatively low groundwater yield, sufficient for domestic or stock supplies, but generally insufficient for irrigation.

The Miocene/Pliocene Mehrten Formation overlies the Valley Springs Formation and is composed of fluvial deposits of sandstone, breccia, conglomerate, silt, siltstone and claystone. It contains a large amount of andesitic material, making it easy to distinguish. The Mehrten outcrops over a large area in eastern Merced Subbasin (Figure 2-1). It forms an important aquifer in the Merced Subbasin with relatively high yields.

Unconsolidated Deposits

The unconsolidated deposits, from bottom to top, include continental deposits, lacustrine and marsh deposits, older alluvium, younger alluvium, and flood-basin deposits.

The Pliocene/Pleistocene continental deposits consist of a heterogeneous mixture of poorly sorted gravel, sand, silt and clay derived primarily from the Sierra Nevada. The sediments, which are found throughout the Merced Subbasin, dip gently to the southwest and have variable thickness up to 700 feet. The continental deposits have relatively large yields to wells and are an important part of the aquifer system.

The lacustrine and marsh deposits consist of two beds: the Corcoran Clay Member of the Pleistocene Tulare Formation and a shallow clay bed of Holocene age (Page R. W., 1977). The Corcoran Clay is a bed of laterally extensive reduced (blue/grey) silt and clay that underlies about 437 square miles in the southeast portion of the Merced Subbasin (Figure 2-25). The Corcoran Clay is a significant confining layer up to 60 feet thick. The shallow clay bed of Holocene age is composed of oxidized (brown/red) sandy clay and clay with silica cemented intervals (hardpan). It is found throughout most of the Merced Subbasin at a shallow depth (-35 feet). For more information on the Corcoran Clay, see Section 1.1.1.6.2: Principal Aquifers and Aquitards.

The older alluvium consists of a heterogeneous mixture of poorly sorted gravel, sand, silt and clay up to 400 feet thick derived primarily from the Sierra Nevada. The sediments, which are found throughout the Merced Subbasin, were deposited as a series of interbedded coarse-grained and fine-grained layers and form a leaky-aquifer system.

The flood-plain deposits consist of intercalated lenses of reduced to oxidized fine sand, silt, and clay. These deposits are found in the southwestern portion of the Merced Subbasin and generally are less than 30 feet thick (Figure 2-1).

The younger alluvium consists of well-sorted gravel and sand derived primarily from the Sierra Nevada. The younger alluvium is found in a narrow band along the stream channels throughout the Merced Subbasin (Page & Balding, 1973).

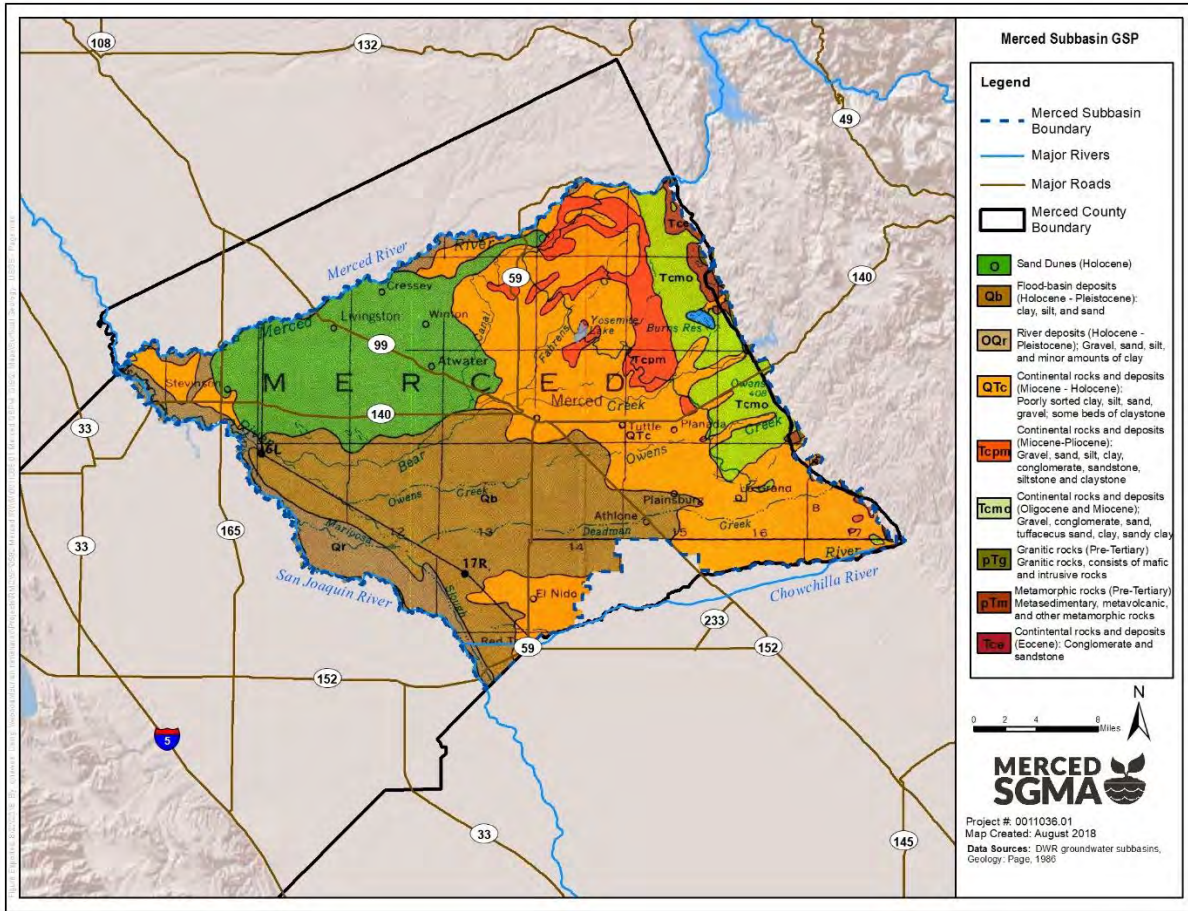
Table 2-1: Generalized Section of Geologic Units and Their Water-Bearing Characteristics

System and Series		Geologic Unit	Lithologic Character	Maximum thickness (feet)	Water-Bearing Character
Unconsolidated Deposits					
Quaternary	Holocene	Flood-basin deposits	Silt, clay, and fine sand, bluish-gray, brown, and reddish-brown.	100	Small hydraulic conductivities and small yields to wells.
	Holocene	Younger alluvium	Gravel, sand, and fine sand, some silt and clay, little or no hardpan; yellow, yellowish-brown, brown.	100	Moderation to large hydraulic conductivities, where saturated yields moderate quantities to wells. Unconfined.
	Pleistocene and Holocene?	Older alluvium	Gravel, sand, silt, and clay, some hardpan; brown, reddish-brown, gray, brownish-gray, white, blue, and black.	400 (in northern part of area) 700 (in southern part of area)	Moderate to large hydraulic conductivities, yields to wells reported as large as 4,451 gpm (gallons per minute); average yield to large wells (1900 gpm). North of study area transmissivities of about 11,700 ft ² /day (cubic feet per day per foot). Unconfined and confined.
	Pleistocene	Lacustrine and marsh deposits	Silt, silty clay, and clay, gray and blue.	100	Confining bed, very small hydraulic conductivities. (includes the Corcoran Clay)
Tertiary and Quaternary?	Pliocene and Pleistocene	Continental deposits	Gravel, sand, silt, and clay; brown, yellow, gray, blue, and black.	+450 (In northern part of area) +700 (in southern part of area)	Moderate to large hydraulic conductivities; yield to wells as large as 2,102 gpm. North of study area transmissivities of about 8,000 ft ² /day. Confined beneath lacustrine and marsh deposits. In extreme western part of area, water contains in excess of 2,000 mg/l (milligrams per liter) dissolved solids.
Consolidated Rocks					
Tertiary	Miocene and Pliocene	Mehrten Formation	Sandstone, breccia, conglomerate, tuff, siltstone, and claystone; brown, yellowish-brown, grayish-brown, pinkish-brown, pink, blue, yellow, green, gray, and black. Large amounts of andesitic material occur in beds.	200 (In northern part of area) +700 (In southern part of area)	Small to moderate hydraulic conductivities. North of study area ranges in hydraulic conductivity from 0.01 to 67 ft/day. Yield to wells as large as 2,102 gpm. In western part of area, water contains in excess of 2,000 mg/l dissolved solids content. Locally in eastern part of area water probably contains in excess of 2,000 mg/l dissolved solids.

System and Series		Geologic Unit	Lithologic Character	Maximum thickness (feet)	Water-Bearing Character
	Miocene and Pliocene	Valley Springs Formation	Ash, sandy clay, and siliceous sand and gravel generally in clay matrix, tuff, siltstone, and claystone; yellow, yellowish-brown, brown, reddish-brown, gray, greenish-gray, white, pink, green, and blue. Rhyolitic material occurs in beds.	900 (In northern part of area) (Unknown in southern part of area)	Probable small hydraulic conductivities. Quality of water ranges from fair to poor.
	Eocene	Ione Formation and other sedimentary rocks	Conglomerate, sandstone, clay and shale; partly marine; yellow, red, gray, and white.	800 (In northern part of area) (Unknown in southern part of area)	Probable small to moderate hydraulic conductivities. In places reported to yield saline water.
Cretaceous		Marine sandstone and shale	Sandstone and shale.	>9, 500 (In northern part of area) (Unknown in southern part of area)	Unknown. Reported to yield saline water.
Pre-Tertiary		Basement complex	Metamorphic and igneous rocks.		Fractures and joints locally yield small quantities of water; otherwise virtually impermeable.

Source: (Page & Balding, 1973)

Figure 2-1: Surficial Geology



The units generally dip to the west; that is, the elevation of the units is higher in the east than in the west. Some units are not present across the entire basin. Notably, this is true of the Corcoran Clay which extends east to near Highway 99, where it is generally shallow and thin, and becomes deeper than thicker to the west where it extends beyond the western boundary of the Subbasin. Details on materials in the subsurface is provided through cross sections and a three-dimensional rendering of the basin.

Five cross sections were developed by Page & Balding (1973) across the Merced Subbasin and neighboring Turlock Subbasin. The locations of the cross-section are shown on Figure 2-2, with the cross-sections themselves shown on Figure 2-3 through Figure 2-7. The cross sections show the units dipping towards the west, highlighting the depth, thickness and extent of the Corcoran Clay as well as the depth of the base of fresh water (short dashed line). Note that these cross sections include vertical exaggeration in order to highlight the small difference in the vertical axis. Distances shown vertically are 52.8 times what they are in reality, allowing visualization of finer detail with depth, but also resulting in dip angles appearing much steeper and the overall aquifer appearing much deeper than in reality.

Four additional cross sections were developed by Page (1977) more specifically for the City of Merced-City of Atwater area. The locations of these cross-sections are shown on Figure 2-8, with the cross sections shown on Figure 2-9 through Figure 2-12.

Table 2-2 provides a lookup table that links the various names used for the formations described in the earlier text of Section 1.1.1.3 with the cross sections shown below (Figure 2-3 through Figure 2-12).

Table 2-2: Formation Name Lookup for Geologic Text, Tables, and Figures

Formation Name in Report Text		Formation Name in Surficial Geology Map (Page 1986)	Formation Name in Page & Balding 1973 Cross Sections	Formation Name in Page 1977 Cross Sections
Sierra Nevada bedrock complex		pTm (Metamorphic rocks [Pre-Tertiary])	pTb (Basement complex)	-
Eocene lone Formation		Tce (Continental rocks and deposits [Eocene])	Ti (lone Formation)	-
Miocene Valley Springs Formation		Tcmo (Continental rocks and deposits [Oligocene and Miocene])	Tvs (Valley Springs Formation)	-
Micoene/Pliocene Mehrten Formation		Tcpm (Continental rocks and deposits [Miocene-Pliocene])	Tm (Mehrten Formation)	Tm (Mehrten Formation - Fluvialite deposits of sandstone, breccia, conglomerate, tuff, silt, siltstone, and claystone)
Lacustrine and marsh deposits	Corcoran Clay Member	N/A – not surficial	E-clay or Ql	Qc (Corcoran Clay Member of the Tulare Formation - Lacustrine and marsh deposits)
	Shallow clay bed (Holocene age)	N/A – not surficial	-	Qs (Shallow Clay Bed - Lacustrine and marsh deposits)
Pliocene/Pleistocene continental deposits		QTc (Continental rocks and deposits [Oligocene and Miocene])	QTc (Continental deposits)	QTc (Continental deposits)
Older alluvium			Qoa (Older alluvium)	Qoa (Older alluvium)
Flood-plain deposits		Qb (Flood-basin deposits [Holocene-Pleistocene])	Qb (Flood basin deposits)	Qb (Flood basin deposits)
Younger alluvium		Qr (River deposits [Holocene-Pleistocene])	Qya (Younger alluvium)	Qya (Younger alluvium)

A three-dimensional representation of the Subbasin (Figure 2-13) provides the capability to understand geologic conditions at different depths and locations throughout the Subbasin. The three-dimensional representation allows for the development of cross sections at any location, with examples shown in Figure 2-14 and Figure 2-15. Originally developed for the MercedWRM, the three-dimensional representation incorporates information from the Page & Balding (1973) cross sections and the surficial geologic map, in addition to subsurface texture data from the United States Geological Survey (USGS). Model layers were aligned with the formations and are described in detail in Section 1.1.1.6 - Principal Aquifers and Aquitards. More information on the MercedWRM can be found in [Appendix X](#).

Figure 2-2: Location of Geologic Cross Sections (Page & Balding 1973)

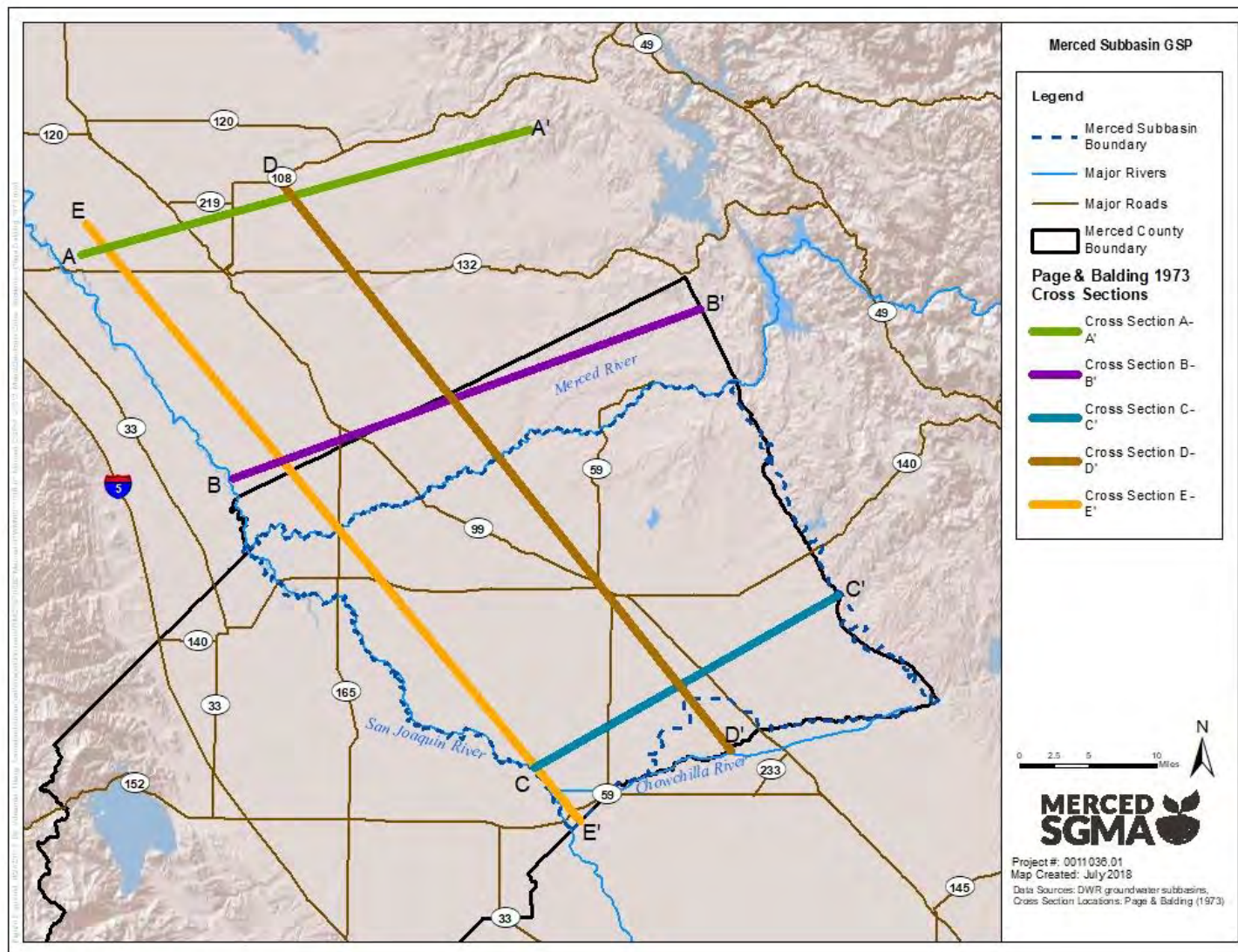
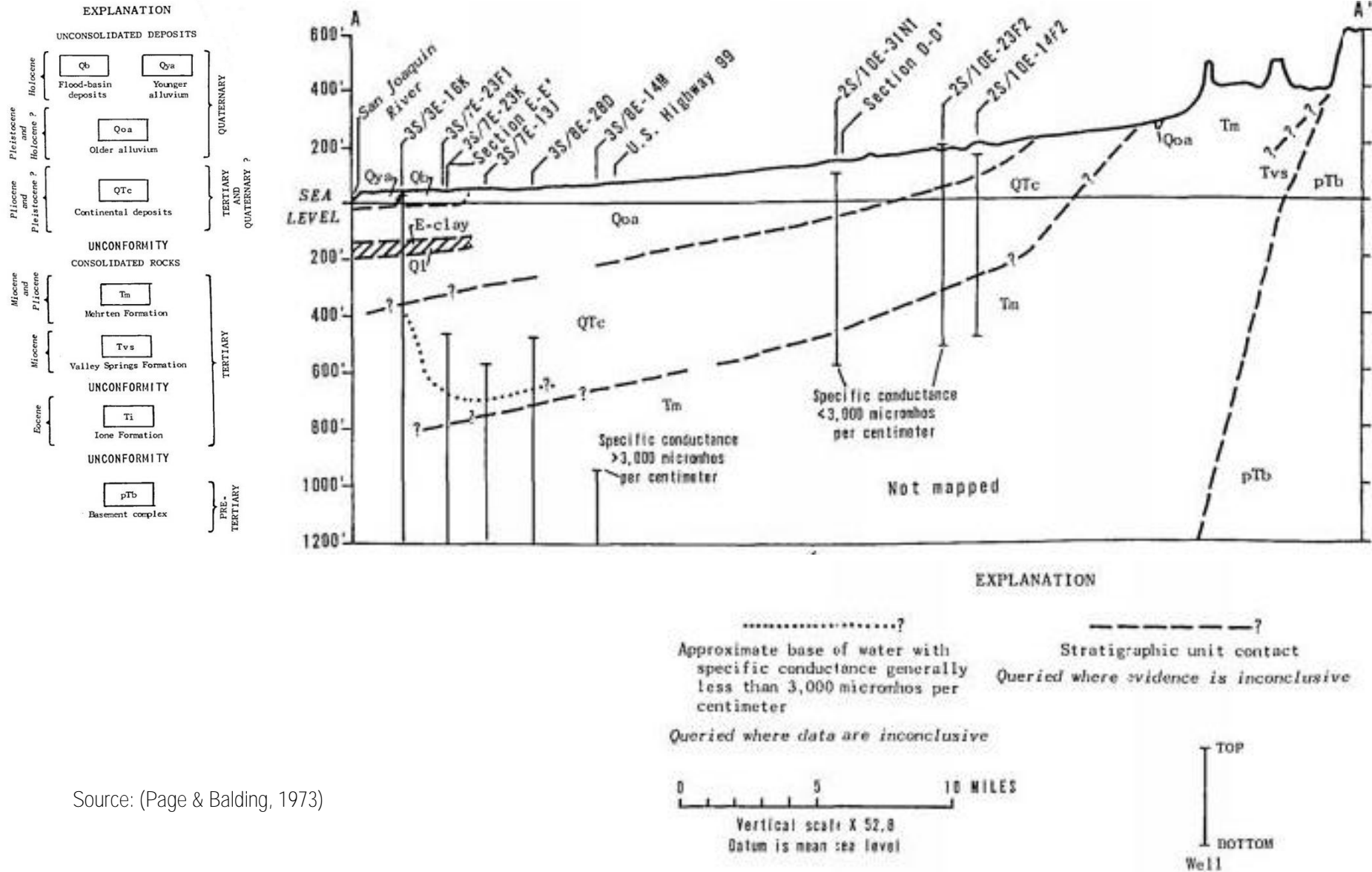
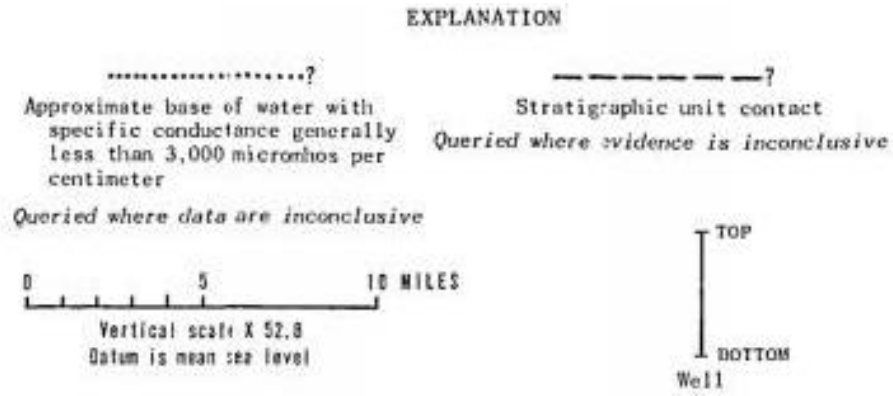
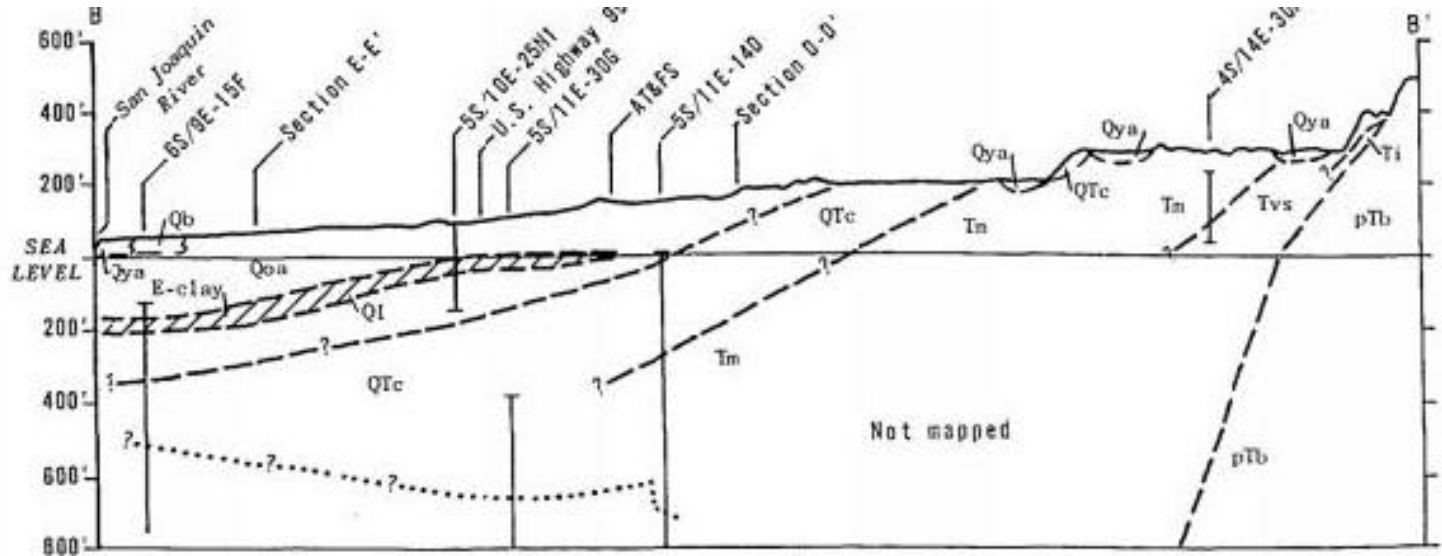
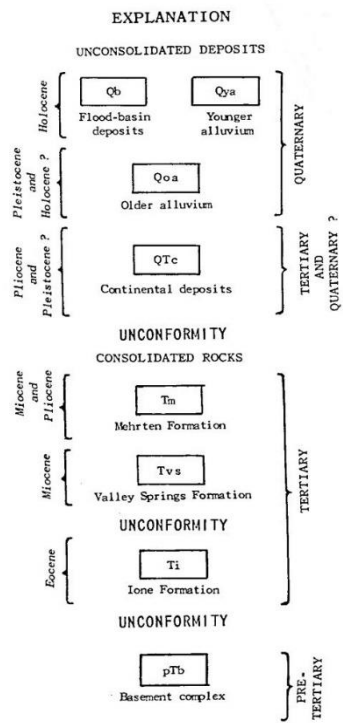


Figure 2-3: Geologic Cross-Section A (Page & Balding 1973)



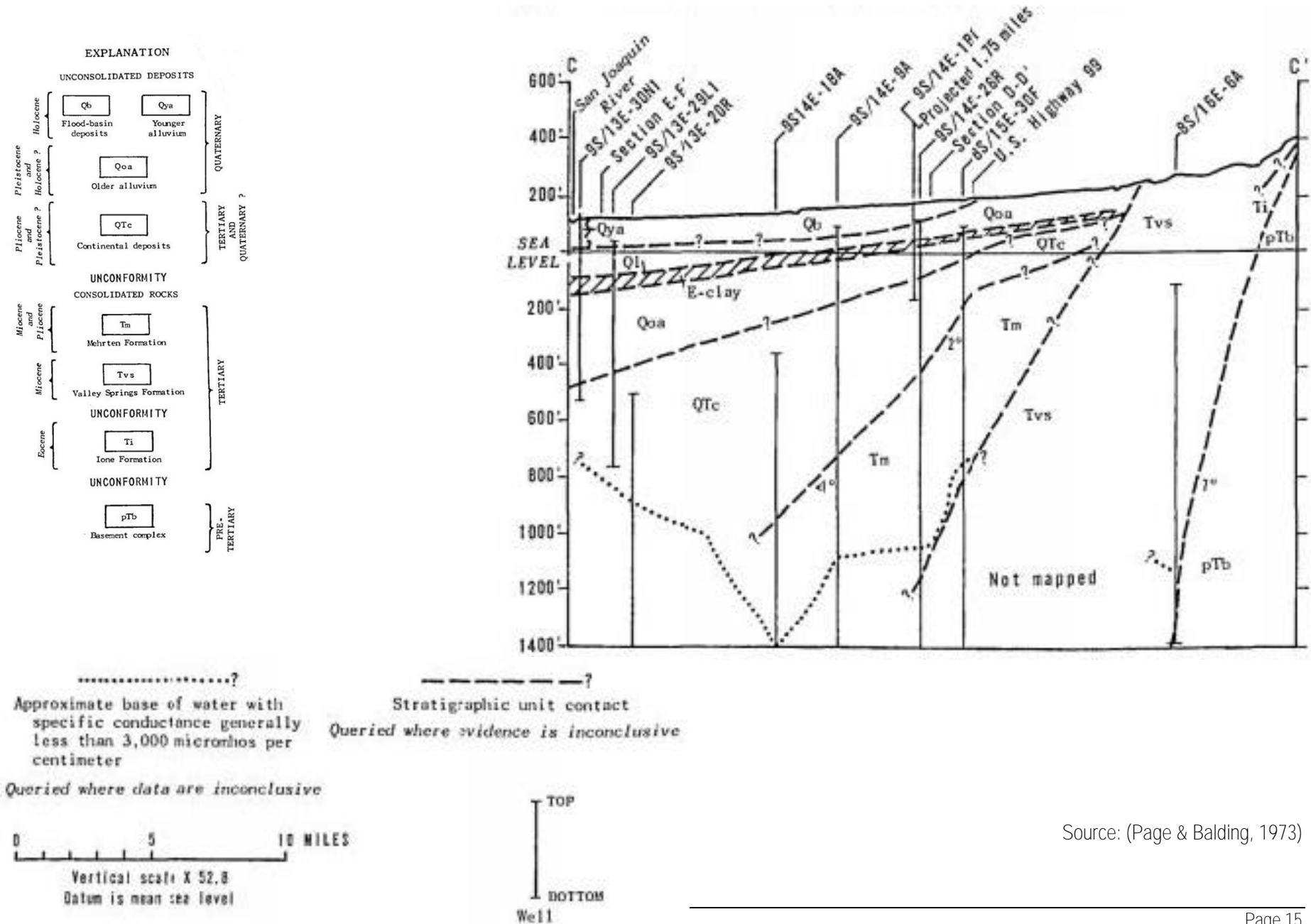
Source: (Page & Balding, 1973)

Figure 2-4: Geologic Cross-Section B (Page & Balding 1973)



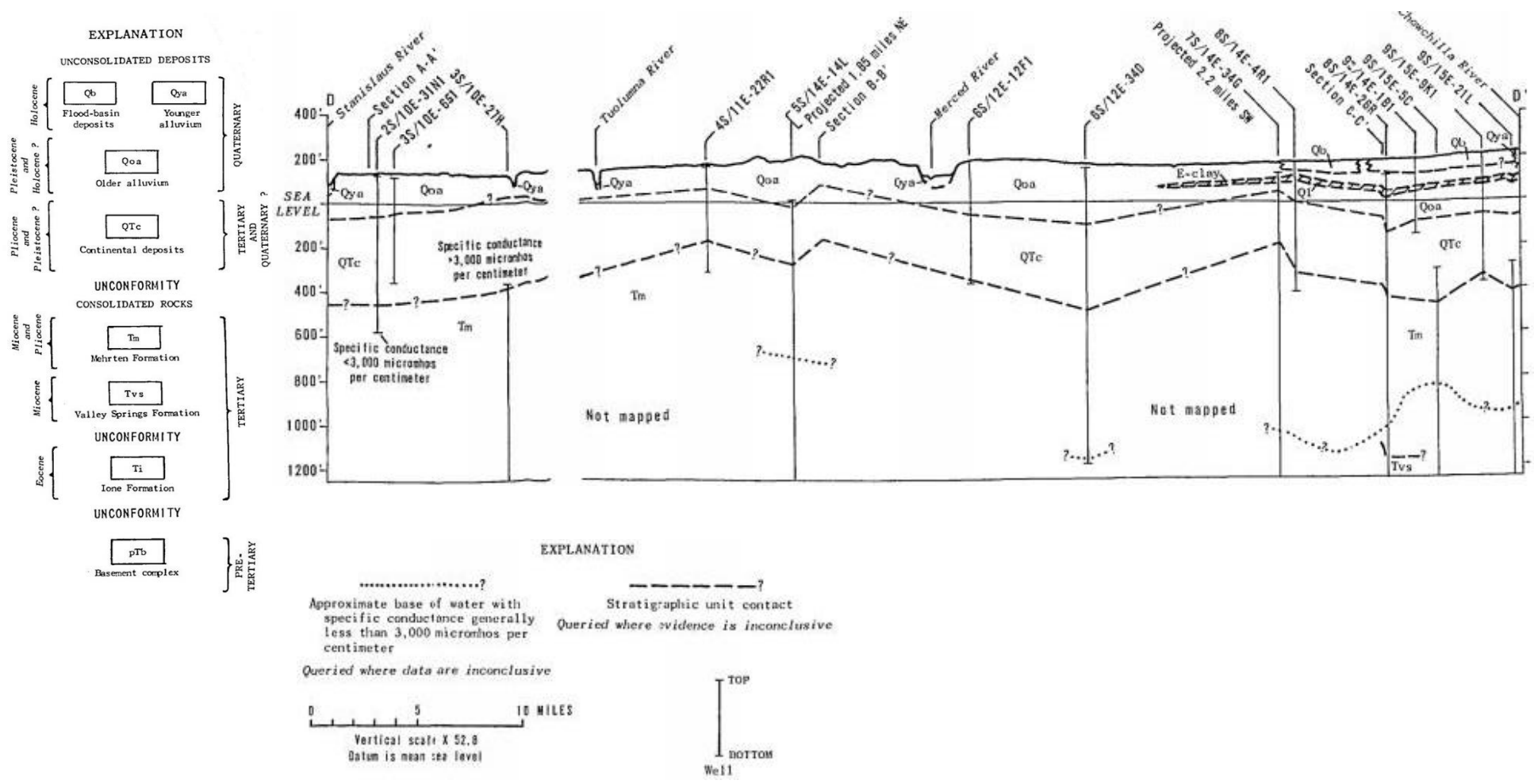
Source: (Page & Balding, 1973)

Figure 2-5: Geologic Cross-Section C (Page & Balding 1973)



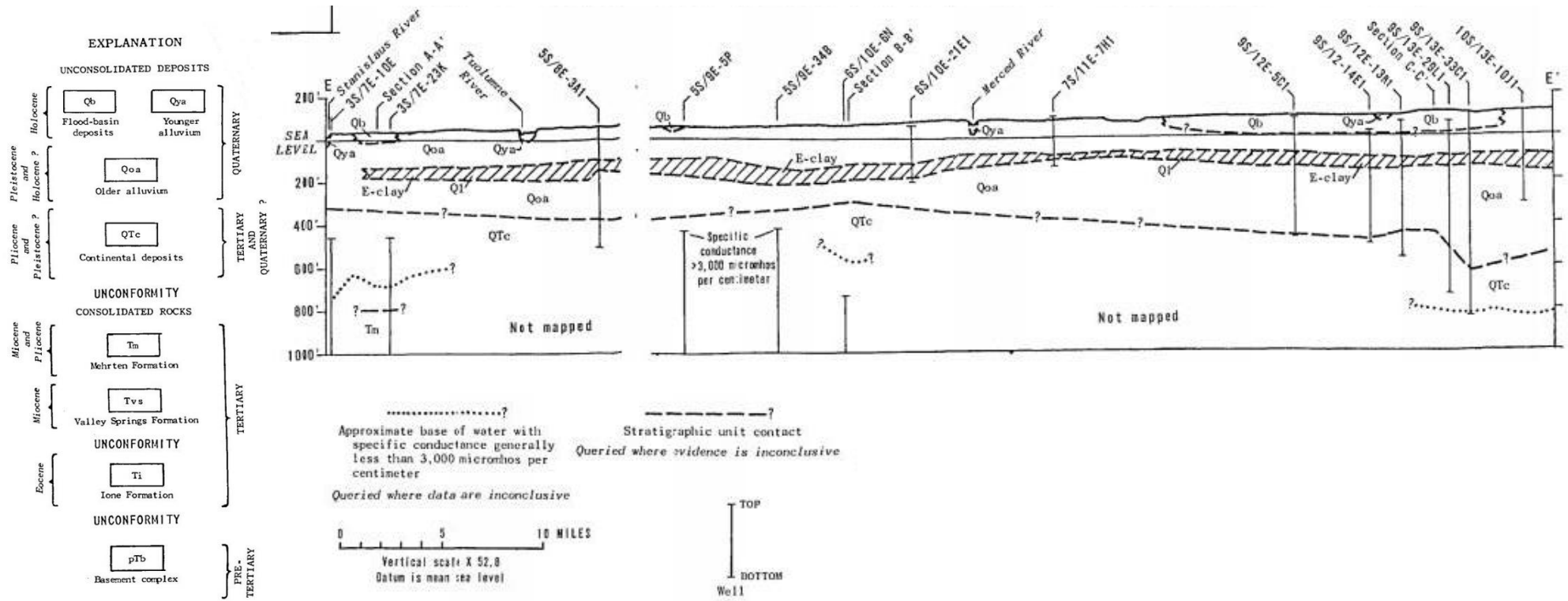
Source: (Page & Balding, 1973)

Figure 2-6: Geologic Cross-Section D (Page & Balding 1973)



Source: (Page & Balding, 1973)

Figure 2-7: Geologic Cross-Section E (Page & Balding 1973)



Source: (Page & Balding, 1973)

Figure 2-8: Location of Geologic Cross Sections (Page 1977)

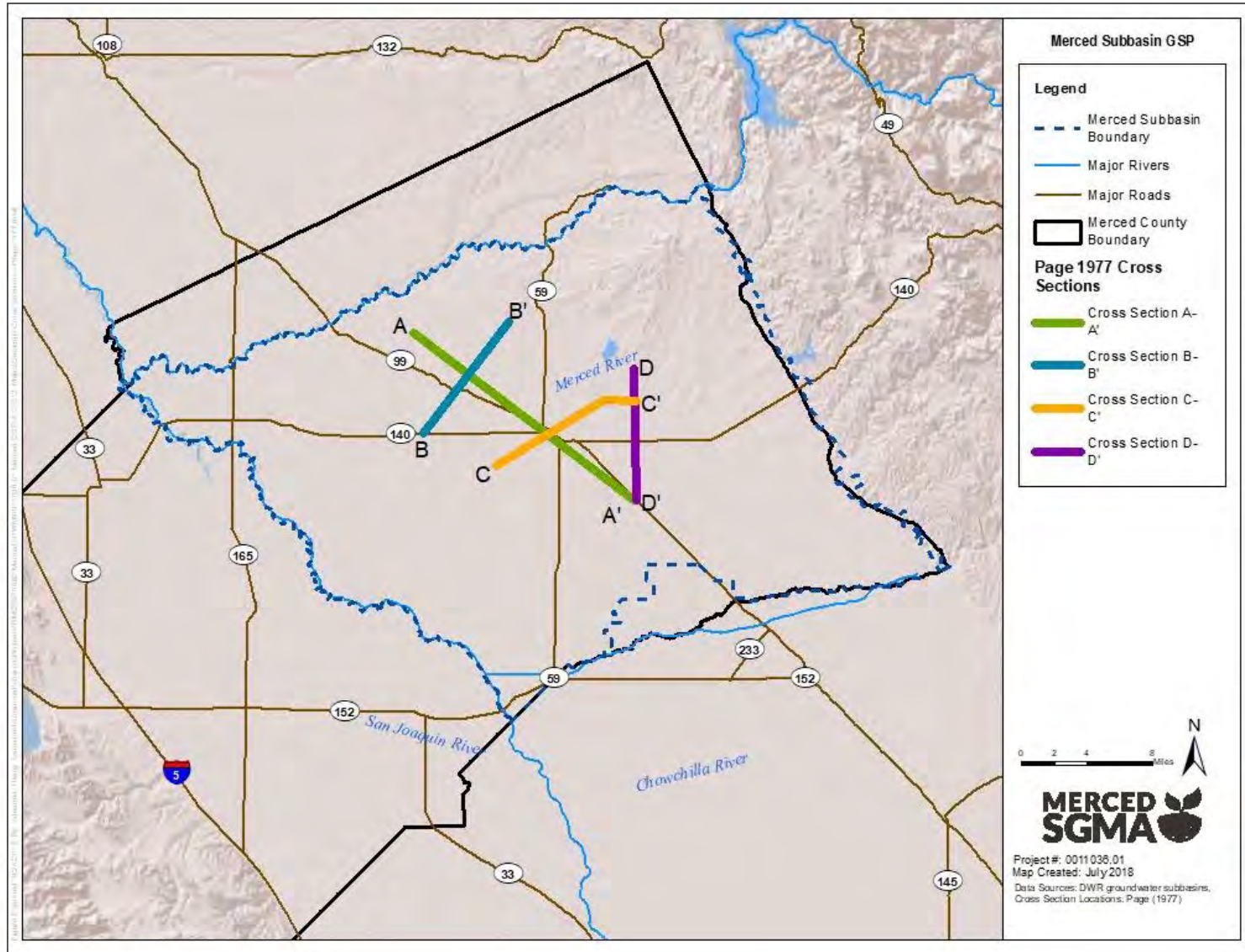
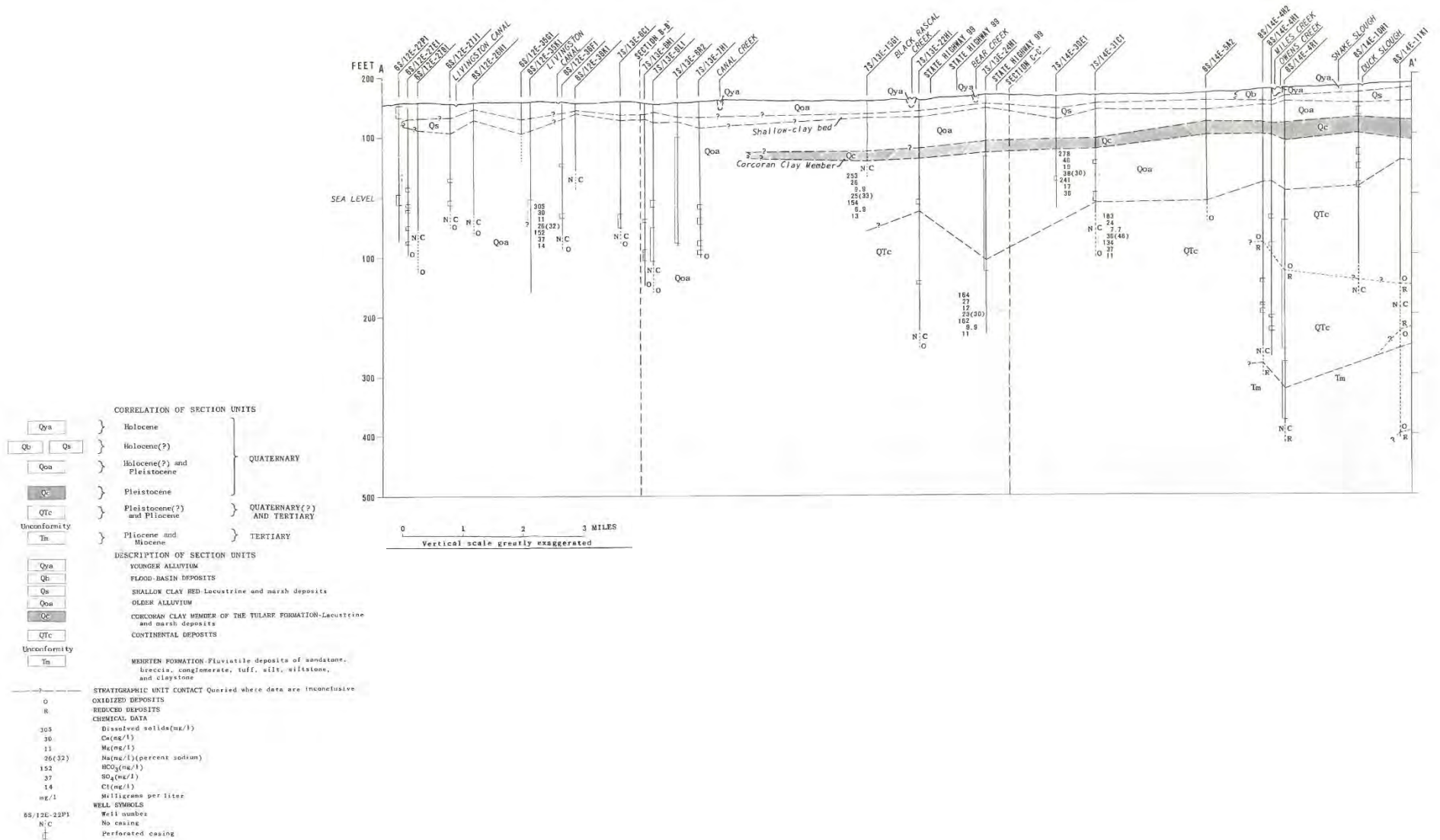
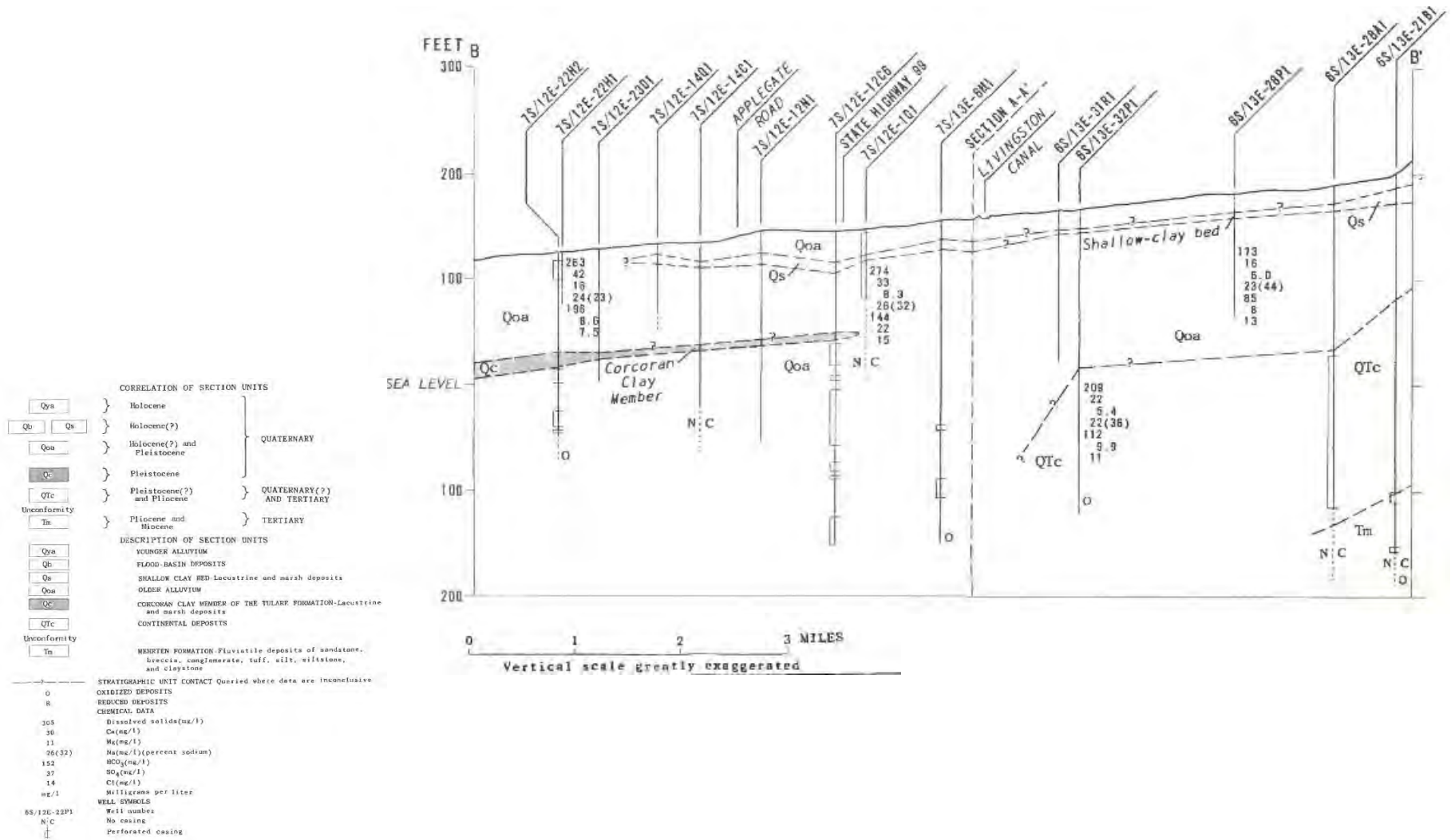


Figure 2-9: Geologic Cross-Section A (Page 1977)



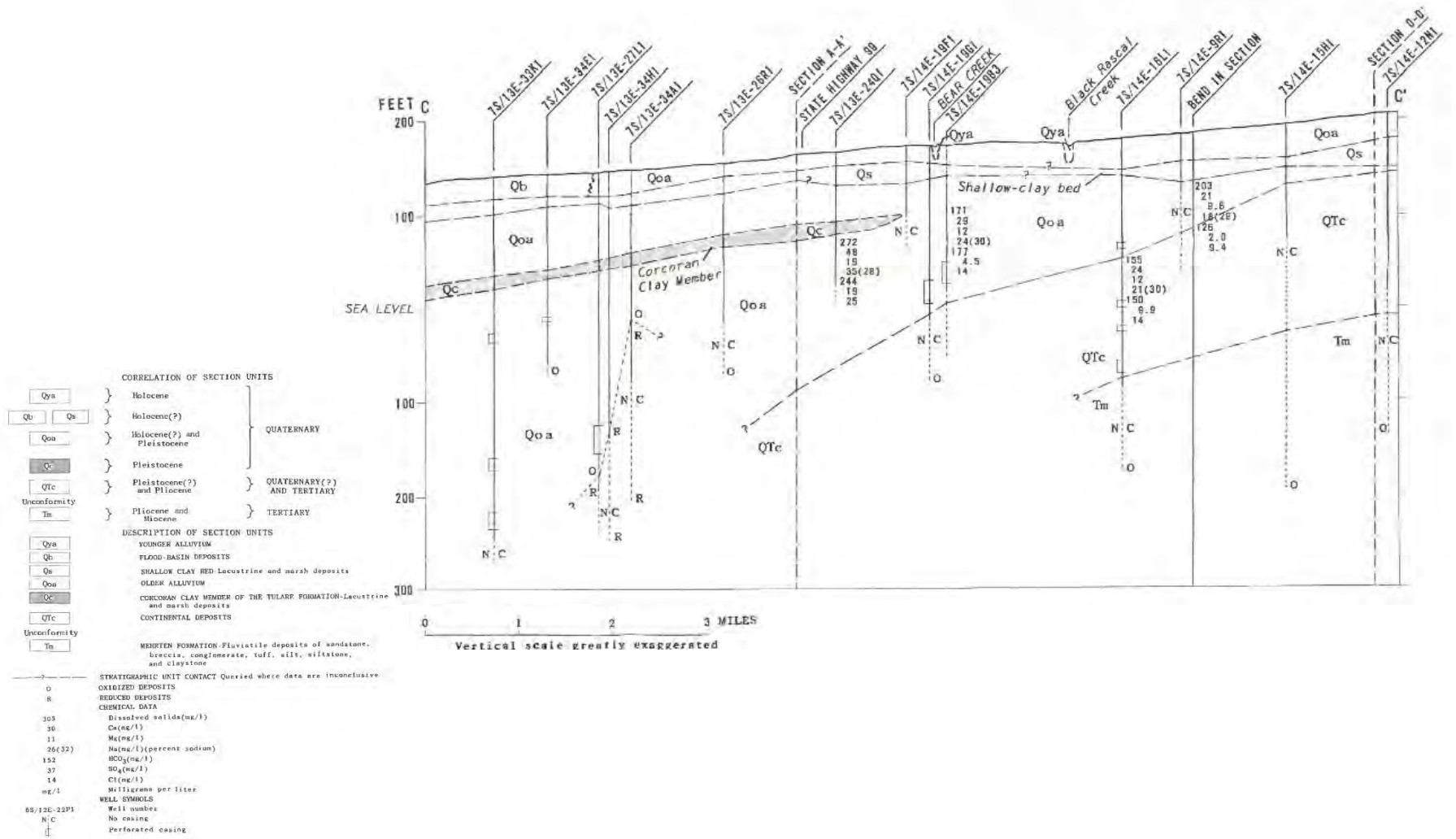
Source: (Page R. W., 1977)

Figure 2-10: Geologic Cross-Section B (Page 1977)



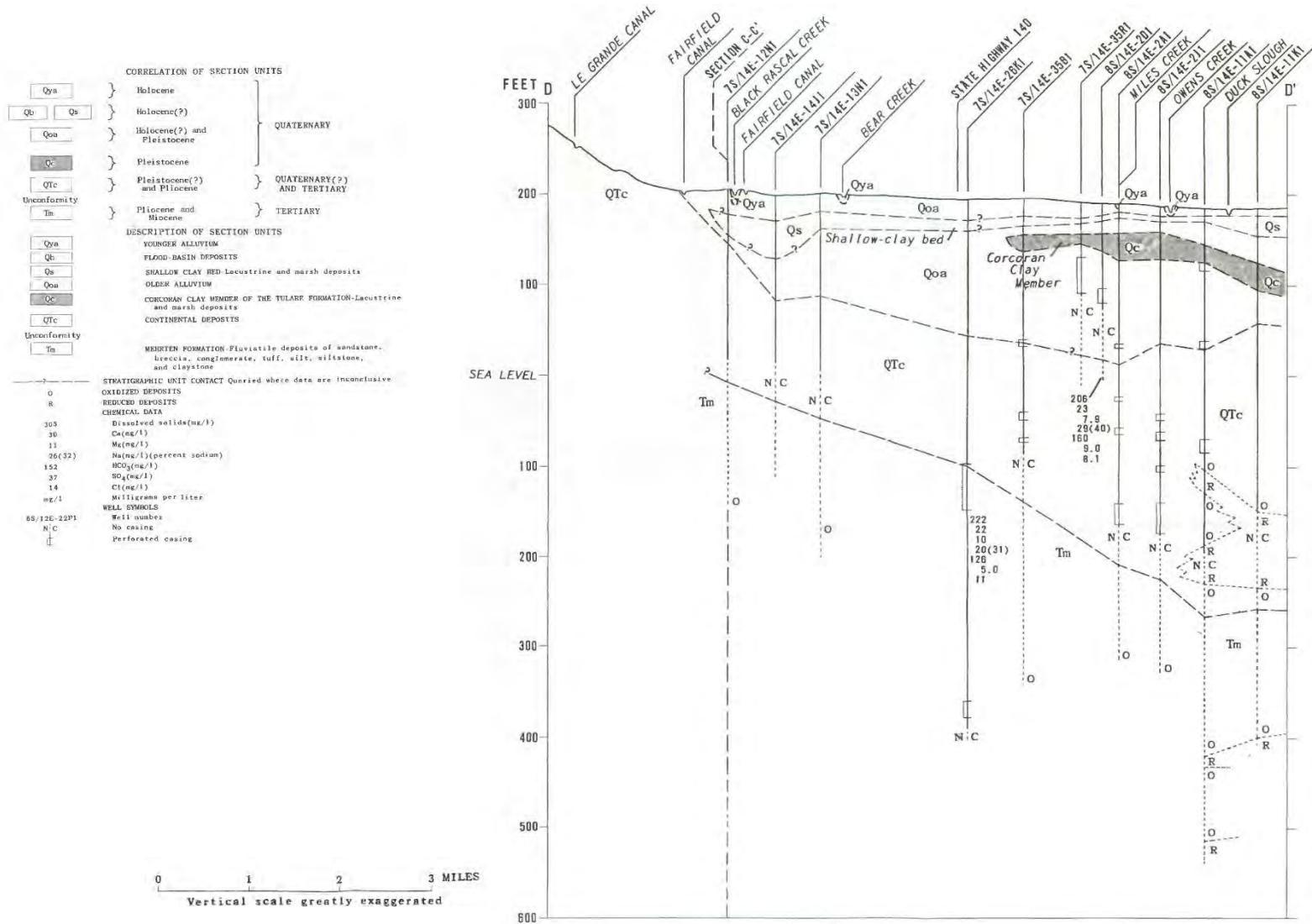
Source: (Page R. W., 1977)

Figure 2-11: Geologic Cross-Section C (Page 1977)



Source: (Page R. W., 1977)

Figure 2-12: Geologic Cross-Section D (Page 1977)



Source: (Page R. W., 1977)

Figure 2-13: 3D Rendering Cross Section Overview

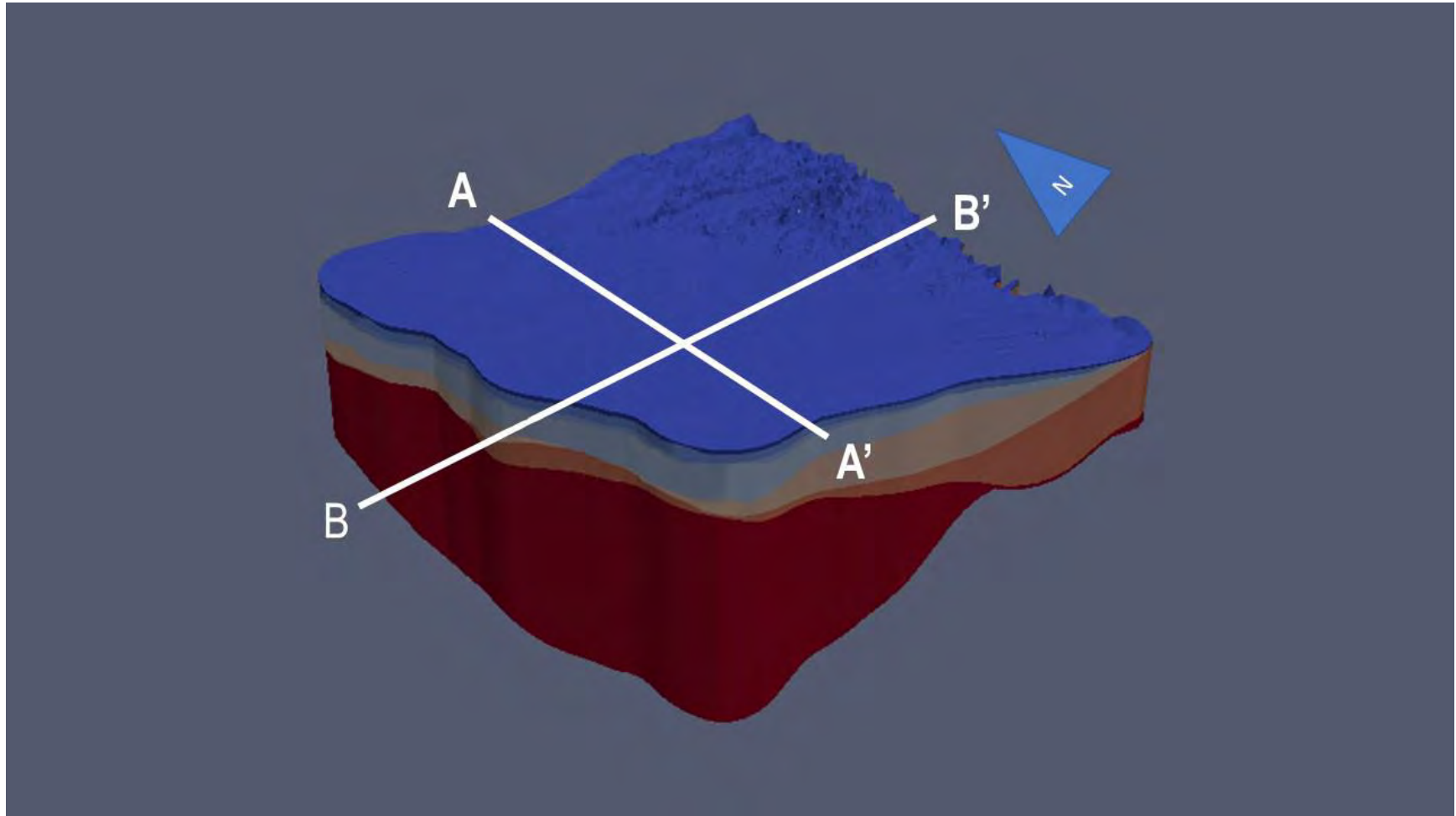


Figure 2-14: 3D Rendering A-A'

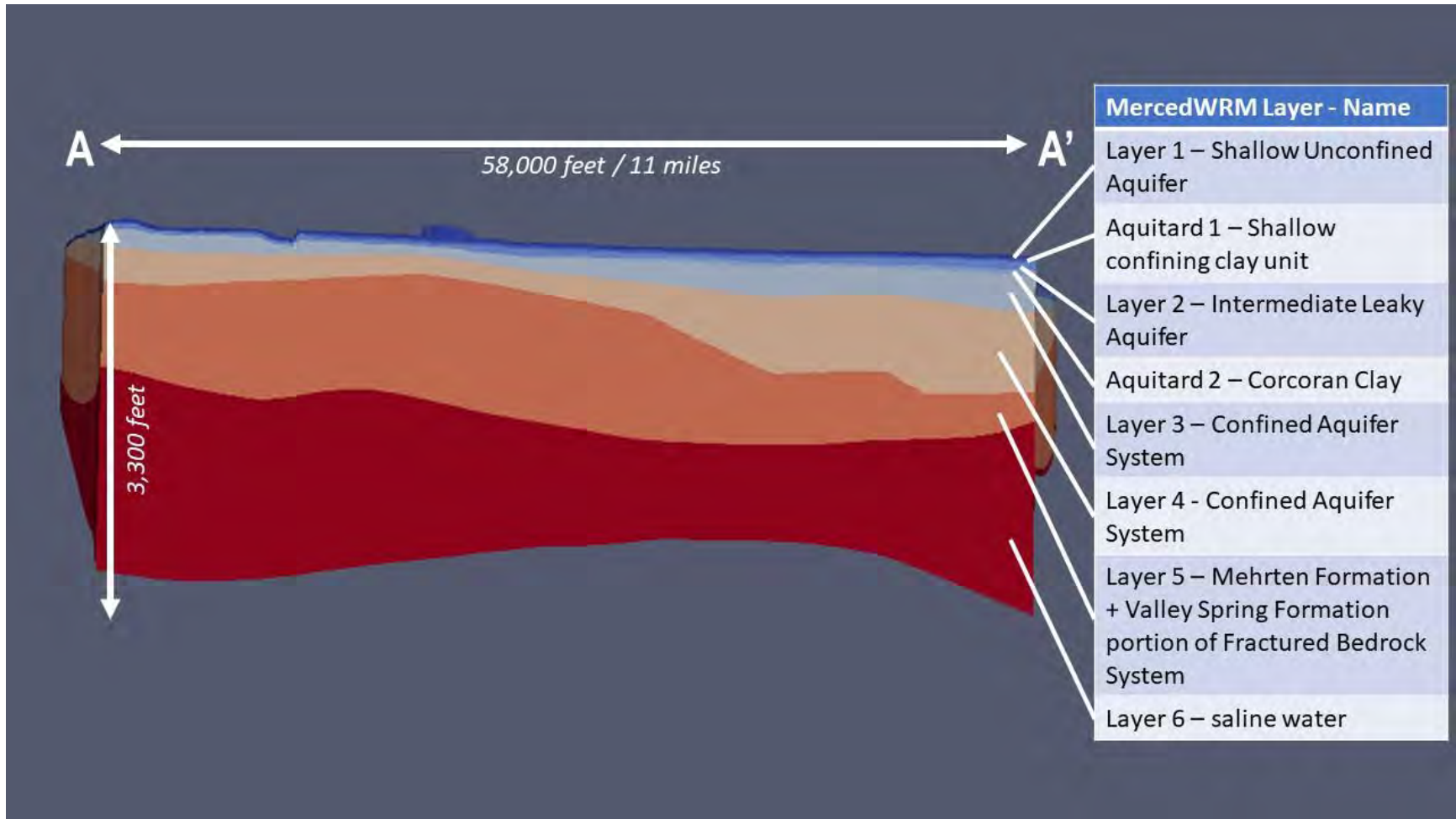
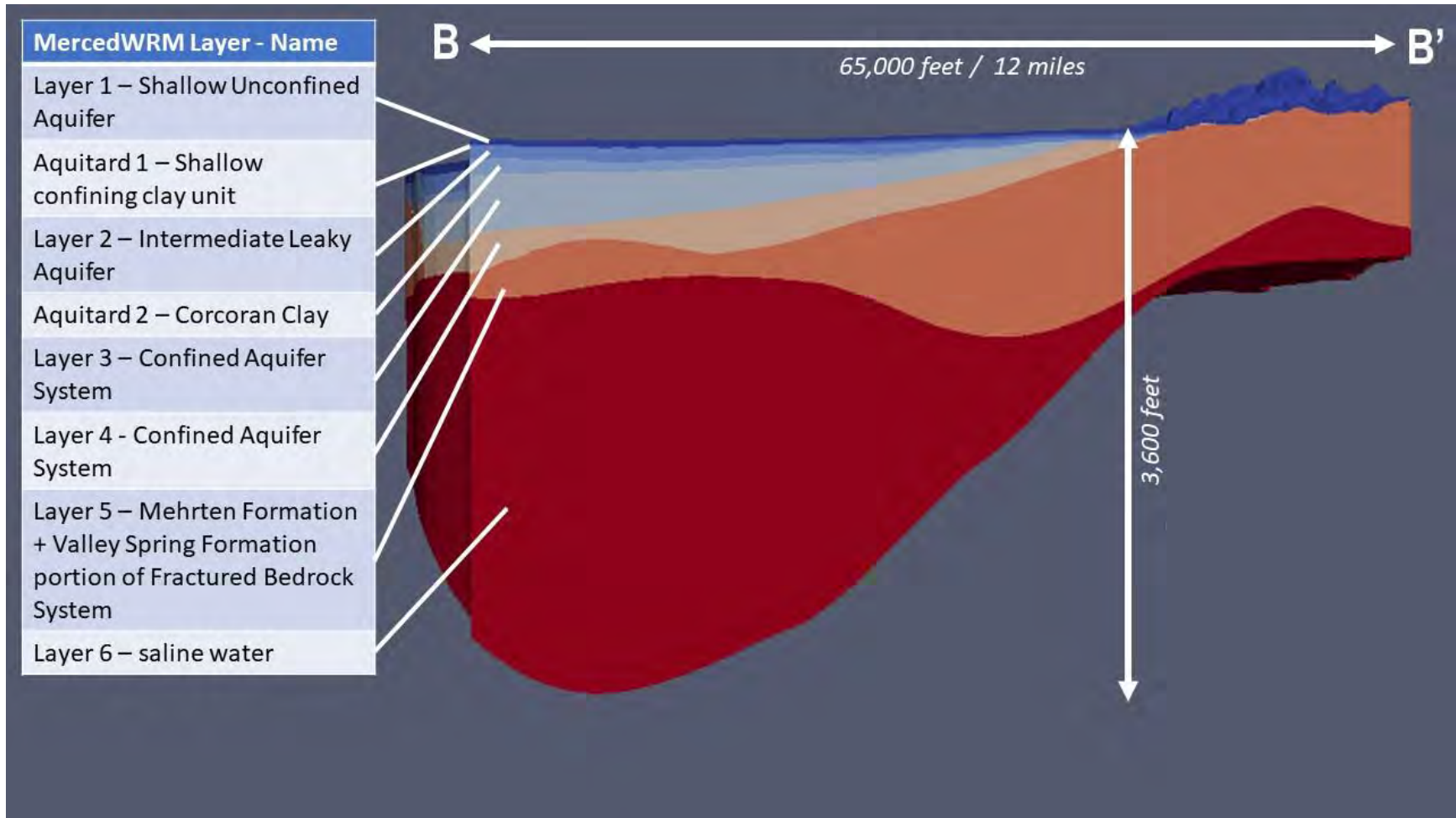


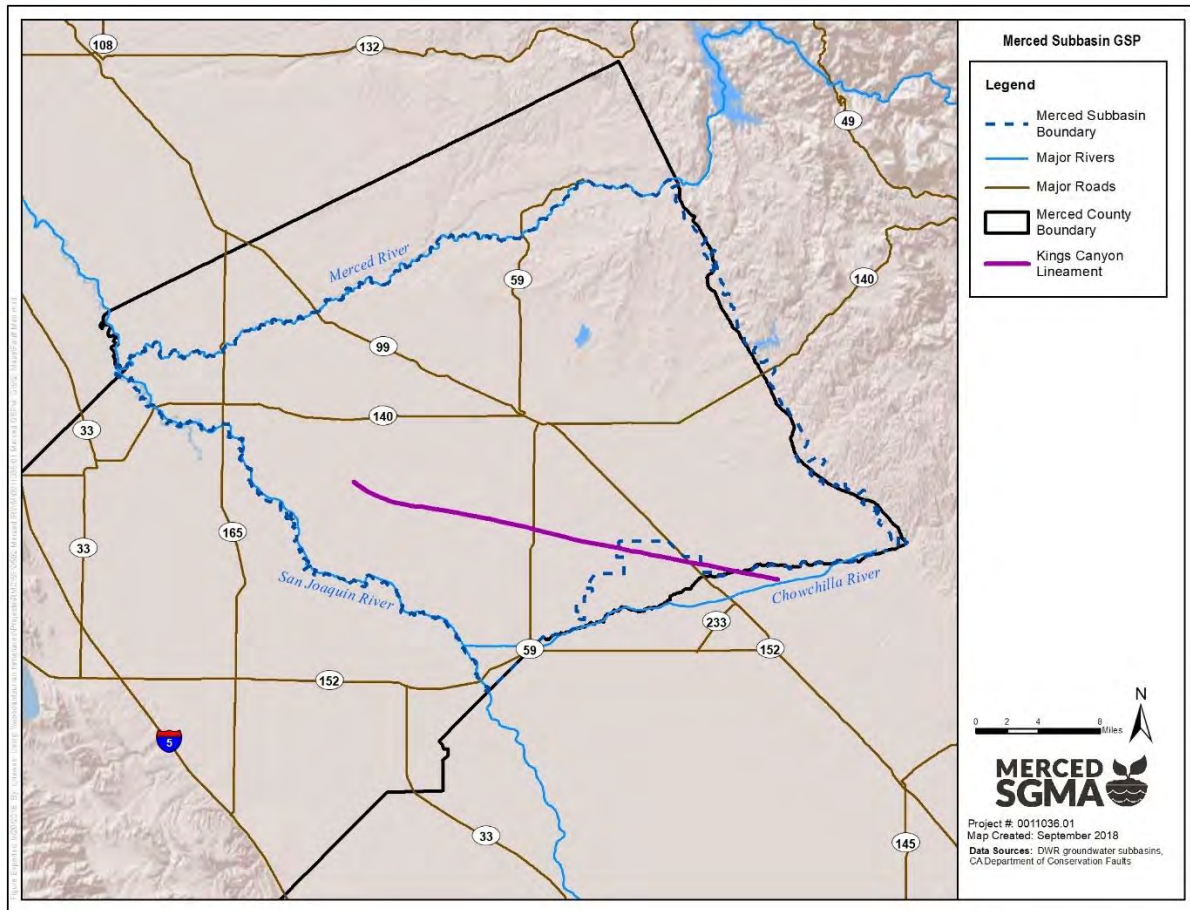
Figure 2-15: 3D Rendering B-B'



1.1.1.4 Faults and Structural Features

There are no major faults, anticlines, or synclines in the Merced Subbasin. The only minor feature present in the Subbasin is the Kings Canyon Lineament, shown in Figure 2-16 (California Geological Survey, 2010). This feature is not known to effect groundwater flow in the basin. The key geologic feature that affects groundwater flows is the Corcoran Clay, which is described above.

Figure 2-16: Fault Map



1.1.1.5 Subbasin Boundaries

The horizontal and vertical boundaries of the Merced Subbasin are described below.

1.1.1.5.1 Lateral Boundaries and Boundaries with Neighboring Subbasins

The Merced Subbasin includes lands south of the Merced River between the San Joaquin River on the west and the crystalline basement rock of the Sierra Nevada foothills on the east. The Subbasin boundary on the south stretches westerly along the Chowchilla River (Merced-Madera County boundary) and then along the northern edge of the sphere of influence boundary of Chowchilla Water District.

DWR defines boundaries based on the following restrictions on groundwater flow: impermeable bedrock, constructions in permeable materials, faults, low permeability zones, groundwater divides, and adjudicated basin boundaries (DWR, 2003). The boundaries of the Merced Subbasin are described below in Table 2-3 based on these boundary types.

Table 2-3: Basin Boundary Description and Type

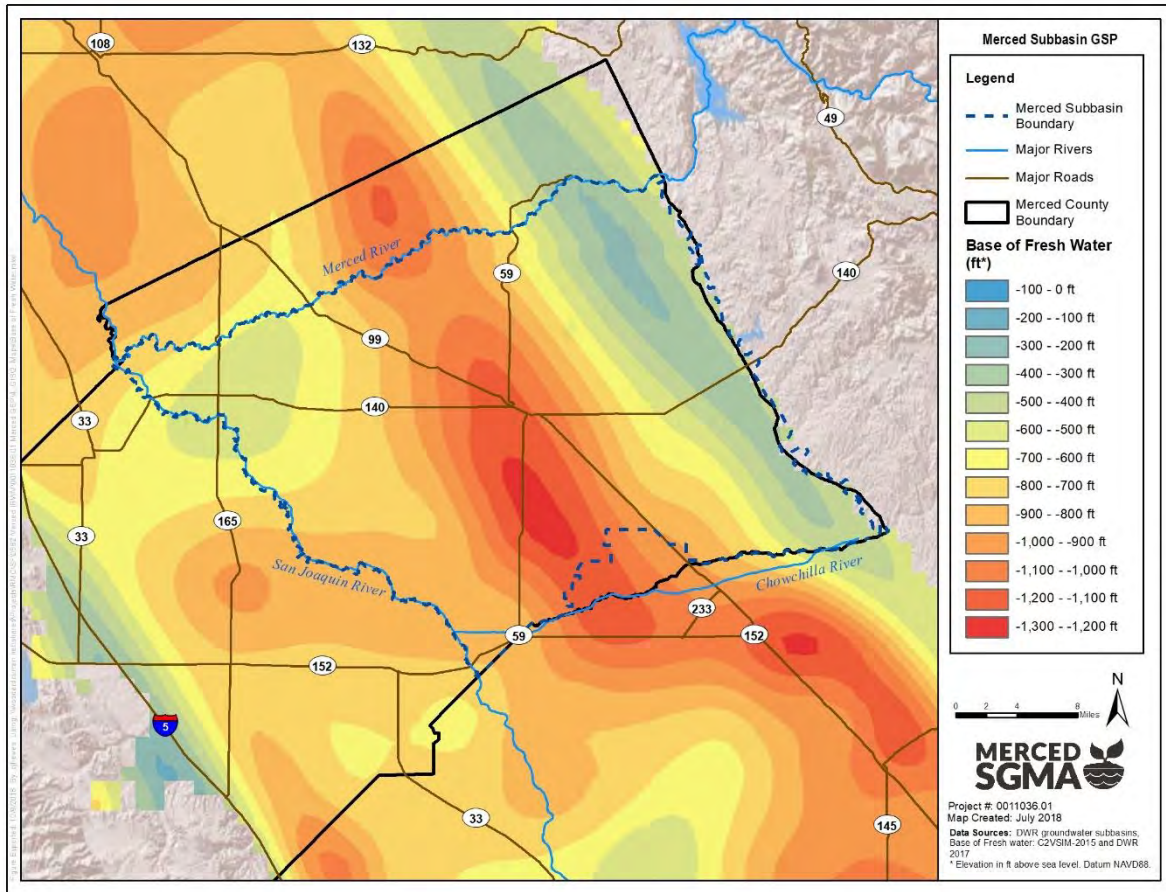
Boundary	Boundary Type	DWR Definition	Boundary Description
Eastern	Impermeable Bedrock	“Impermeable bedrock with lower water yielding capacity. These include consolidated rocks of continental and marine origin and crystalline/or metamorphic rock.” (DWR, 2003)	Bounded by the crystalline bedrock of the Sierra Nevada mountain range.
Northern	Groundwater Divide	“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. The location of the divide may change as water levels in either one of the basins change, making such a “divide” less useful. Such a boundary is often used for subbasins.” (DWR, 2003).	The Merced River forms northern boundary of Merced Subbasin (Bulletin 118 Basin Number 5-022.04) and divides the Subbasin from the Turlock Subbasin (Bulletin 118 Basin Number 5-022.03).
Southern (eastern side)	Groundwater Divide	(defined above)	The Chowchilla River divides the Merced Subbasin from the Chowchilla Subbasin (Bulletin 118 Basin Number 5-022.05) along the eastern edge of the southern boundary. The Chowchilla River also generally forms the boundary between Merced and Madera Counties in this area.

Boundary	Boundary Type	DWR Definition	Boundary Description
Southern (western side)	Jurisdictional Boundary	Not defined.	The boundary generally follows the sphere of influence boundary of Chowchilla Water District. Starting from the intersection of the Chowchilla River at the northwest corner of Section 13, Township 9 South, Range 15 East, it runs north and west along the east and north boundary of Section 11, Township 9 South, Range 15 East until it reaches the Southern Pacific Railroad tracks. Then northwesterly along the Southern Pacific Railroad tracks until it reaches the northeast corner of Section 4, Township 9 South Range 15 East. Then west along the north boundary of Sections 4, 5, and 6, Township 9 South, Range 15 East. Then southwest along the boundary of the Chowchilla Water District until it reaches the northern boundary of Madera County (County of Madera, 2016).
Western	Groundwater Divide	(defined above)	Based on the San Joaquin River which divides the Merced Subbasin from the Delta-Mendota Subbasin (Bulletin 118 Basin Number 5-022.07).

1.1.1.5.2 Bottom of the Merced Basin

As discussed above, the San Joaquin Valley is filled up to 32,000 feet of marine and continental sediments. However, only the uppermost portion of these sediments are saturated with fresh groundwater. Deeper sediments contain saline groundwater. The bottom of the Merced Basin is defined as the lowest elevation of fresh water. This elevation is called the **“base of fresh water” and is defined here as specific conductance of less than 3,000 micromhos per centimeter.** The depth of the base of fresh water is defined by Page (1973) who mapped the base of fresh water based on measurements at wells of specific conductance of less than 3,000 micromhos per centimeter. **Page’s interpretation of the base of fresh water is incorporated into the California Central Valley Groundwater-Surface Water Simulation Model, which includes this information in the definition of model layers and was last updated by DWR in 2017 (see Figure 2-17).**

Figure 2-17: Base of Fresh Water



1.1.1.6 Principal Aquifers and Aquitards

Three principal aquifers are present, which are a combination of five different aquifer systems that have been identified in the subbasin.

1.1.1.6.1 Aquifers in the Basin

Five aquifer systems have been identified in the Merced Subbasin by the Merced Groundwater Management Plan (AMEC, 2008), including, in order of decreasing depth: a fractured bedrock aquifer, the Mehrten Formation, a confined aquifer, an intermediate "leaky" aquifer, and a shallow unconfined aquifer. These aquifer systems interact with each other throughout the basin, except where the Corcoran Clay exists.

In addition to the descriptive information from the Merced Groundwater Management Plan, the MercedWRM (see [Section X](#)) provides information on aquifer characteristics by aggregating available data and calibrating selected characteristics to closely match observed and simulated groundwater elevation and streamflows. The model uses five distinct fresh-water aquifer layers, one saline aquifer, and two confining units. The fresh water aquifer layers correspond closely with the aquifer formations described below from the Merced Groundwater Management Plan. Hydraulic conductivity is defined and mapped separately for each aquifer layer (Figure 2-18 through Figure 2-22). During a sensitivity analysis, specific storage (Figure 2-23) and specific yield (Figure 2-24) were determined to not vary significantly between aquifer layers and thus are defined across the entire Subbasin for all aquifer layers (RMC Water and Environment, 2017).

These aquifer systems are described from deepest to shallowest, and Section 1.1.1.6.2 describes the principal aquifers to be used in this GSP. Table 2-4 shows the relationship between MercedWRM layer, formation name, and principal aquifer name.

Fractured Bedrock - Along the eastern edge of the Merced Subbasin, wells have been completed within the Valley Springs and Lone Formations (Page & Balding, 1973), (Page R. W., 1977). These wells appear to be completed in fractured bedrock with limited and variable yields. Because of the limited extent (and poor yields) of the fractured bedrock aquifer, the fractured aquifer is not a significant source of water in the Merced Subbasin (AMEC, 2008).

Hydraulic conductivity is shown in Figure 2-18 as part of the MercedWRM Layer 5 which contains both the Valley Springs Formation portion of the Fractured Bedrock system where it underlies the Mehrten Formation as well as the Mehrten Formation itself (described below).

The Mehrten Formation - The Mehrten Formation outcrops over a large area in the Merced Subbasin. Many water supply wells in the eastern portion of the Merced Subbasin penetrate the formation, and it is a significant source of groundwater. Where the Mehrten occurs beneath the Corcoran Clay, it is considered a confined aquifer. Where the Mehrten does not underlie the Corcoran Clay, there is insufficient data to determine the degree of confinement of the formation (AMEC, 2008).

Laboratory and field tests made by the United States Army Corps of Engineers (USACOE) and DWR in other areas indicate a range in hydraulic conductivity in the Mehrten Formation range from 0.01 to about 67 ft/day. Yields from the Mehrten, therefore, can be expected to differ greatly from place to place. Based on another DWR regional study, the Mehrten formation has a yield of about 1,000 gallons per minute (gpm) and a horizontal transmissivity of about 9,100 ft²/day (Page & Balding, 1973).

Hydraulic conductivity is shown in Figure 2-18 as part of the MercedWRM Layer 5 which contains both the Mehrten Formation and the Valley Springs Formation portion of the Fractured Bedrock system (described above).

Confined Aquifer - The confined aquifer occurs in older alluvium (and Mehrten Formation) deposits that underlie the Corcoran Clay (Figure 2-25). Many water supply wells in the western portion of the Merced Subbasin penetrate the Corcoran Clay into the confined aquifer, and it is a significant source of groundwater (AMEC, 2008).

In the older alluvium, yields to wells were as large as 4,450 gpm with an average 1,900 gpm. The specific capacity of 101 sampled wells ranged from 1.1 ft²/min to 18 ft²/min with a mean of 5.6 ft²/min and a median of 4.9 ft²/min. Specific capacities in the eastern part of the area, where wells penetrate older rocks and deposits, were generally smaller than those in the west. Because specific capacity is a rough indicator of transmissivity, the pattern indicates smaller transmissivities in the eastern part of the area near where the consolidated rocks crop out (Page & Balding, 1973).

The Confined Aquifer's hydraulic conductivity is shown in both Figure 2-19 and Figure 2-20 as part of the MercedWRM Layers 3 and 4 which together describe the Confined Aquifer. Layer 3 consists of older alluvium while layer 4 consists of continental deposits.

Intermediate Leaky-Aquifer - The intermediate aquifer occurs in older alluvium deposits that overlie the Corcoran Clay or are east of the Corcoran Clay. Where the Corcoran Clay is absent, the intermediate aquifer extends to the Mehrten Formation. In the eastern portion of the Merced Subbasin the intermediate aquifer consists of a series of interbedded coarse-grained (gravel and sand) layers separated by fine-grained (silt and clay) layers. The fine-grained layers inhibit, but do not prevent vertical groundwater flow between layers and thus form a leaky-aquifer system. Many water supply wells in the Merced Subbasin are completed in the intermediate leaky-aquifer, and it is a significant source of groundwater (AMEC, 2008).

The intermediate leaky-aquifer is the most extensively developed aquifer in the Merced Subbasin. Measured well yields within the Merced Subbasin range from 670 to 4,000 gpm (Page & Balding, 1973). Estimates of specific capacity of

supply wells throughout the Merced Subbasin range from about 20 to 40 gpm per foot of drawdown and indicate that the specific capacity increases from east to west.

Hydraulic conductivity is shown in Figure 2-21 as part of the MercedWRM Layer 2.

Shallow Unconfined Aquifer - The shallow unconfined aquifer occurs in older and younger alluvium deposited above the shallow clay bed. Because of its shallow depth, few water supply wells are completed in the shallow unconfined aquifer. Where water levels in the intermediate leaky aquifer fall below the base of the shallow clay bed, groundwater in the intermediate aquifer becomes unconfined and water in the overlying shallow aquifer becomes perched (AMEC, 2008).

Hydraulic conductivity is shown in Figure 2-22 as part of the MercedWRM Layer 1.

The sixth layer of the model (not mapped) consists of saline water below the base of fresh water (described in Section 1.1.1.5.2) and was implemented as a refinement to the water quality model and for the potential use of scenario development for the simulation of deep well production (RMC Water and Environment, 2017).

Table 2-4: Formation and Aquifer Name Lookup

Formation/Aquifer Name	Principal Aquifer for GSP	MercedWRM Layer Number
Ione Formation	N/A	N/A
Valley Springs Formation	Outside Corcoran Clay	5
Mehrten Formation (outside of Corcoran Clay extent)	Outside Corcoran Clay	5
Mehrten Formation (within Corcoran Clay extent)	Below Corcoran Clay	5
Confined Aquifer	Below Corcoran Clay	4 (continental deposits)
	Below Corcoran Clay	3 (older alluvium)
Intermediate Leaky-Aquifer (within Corcoran Clay extent)	Above Corcoran Clay	2
Intermediate Leaky-Aquifer (outside of Corcoran Clay extent)	Outside Corcoran Clay	2
Shallow Unconfined Aquifer (outside of Corcoran Clay extent)	Outside Corcoran Clay	1
Shallow Unconfined Aquifer (within Corcoran Clay extent)	Above Corcoran Clay	1

Figure 2-18: Hydraulic Conductivity – Mehrten Formation and Valley Springs Portion of Fractured Bedrock System (MercedWRM Layer 5)

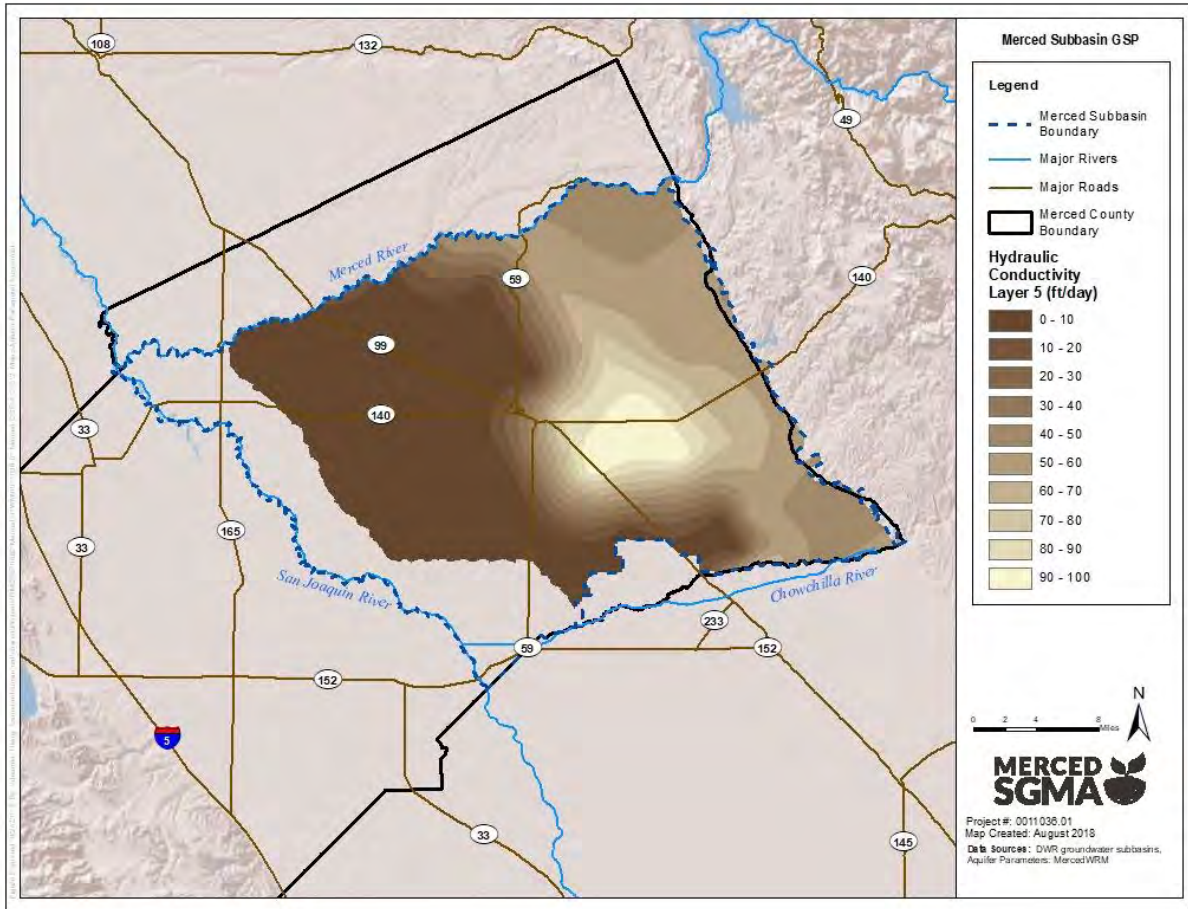


Figure 2-19: Hydraulic Conductivity – Confined Aquifer (MercedWRM Layer 4)

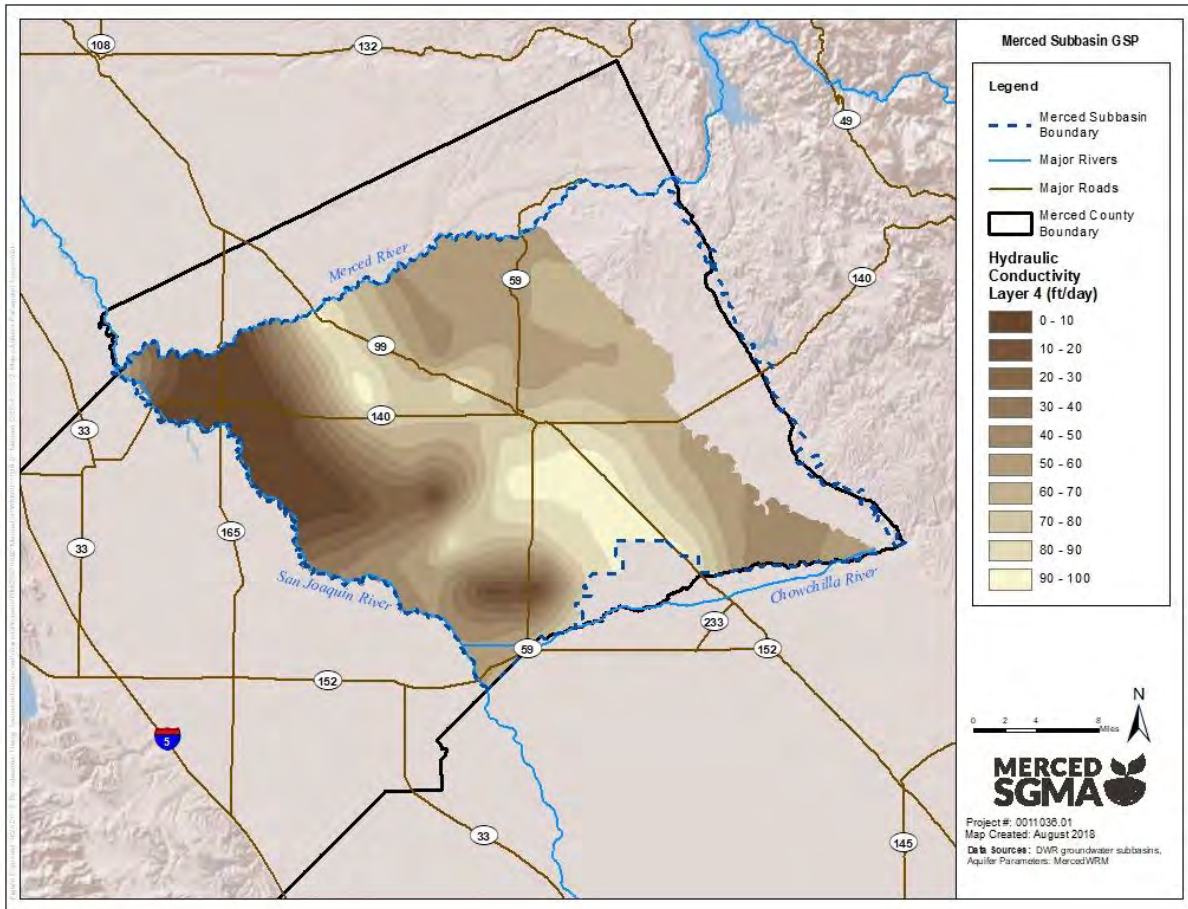


Figure 2-20: Hydraulic Conductivity – Confined Aquifer (MercedWRM Layer 3)

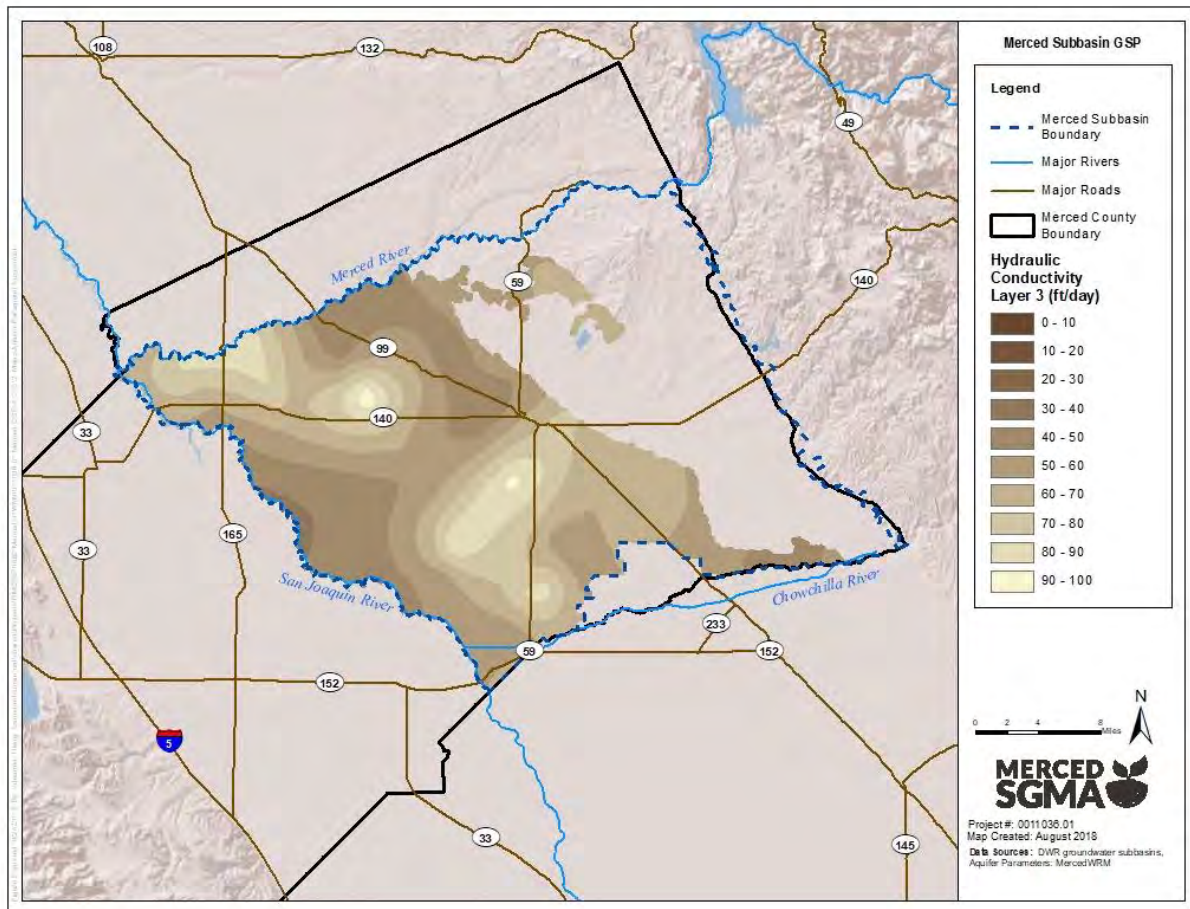


Figure 2-21: Hydraulic Conductivity – Intermediate Leaky-Aquifer (MercedWRM Layer 2)

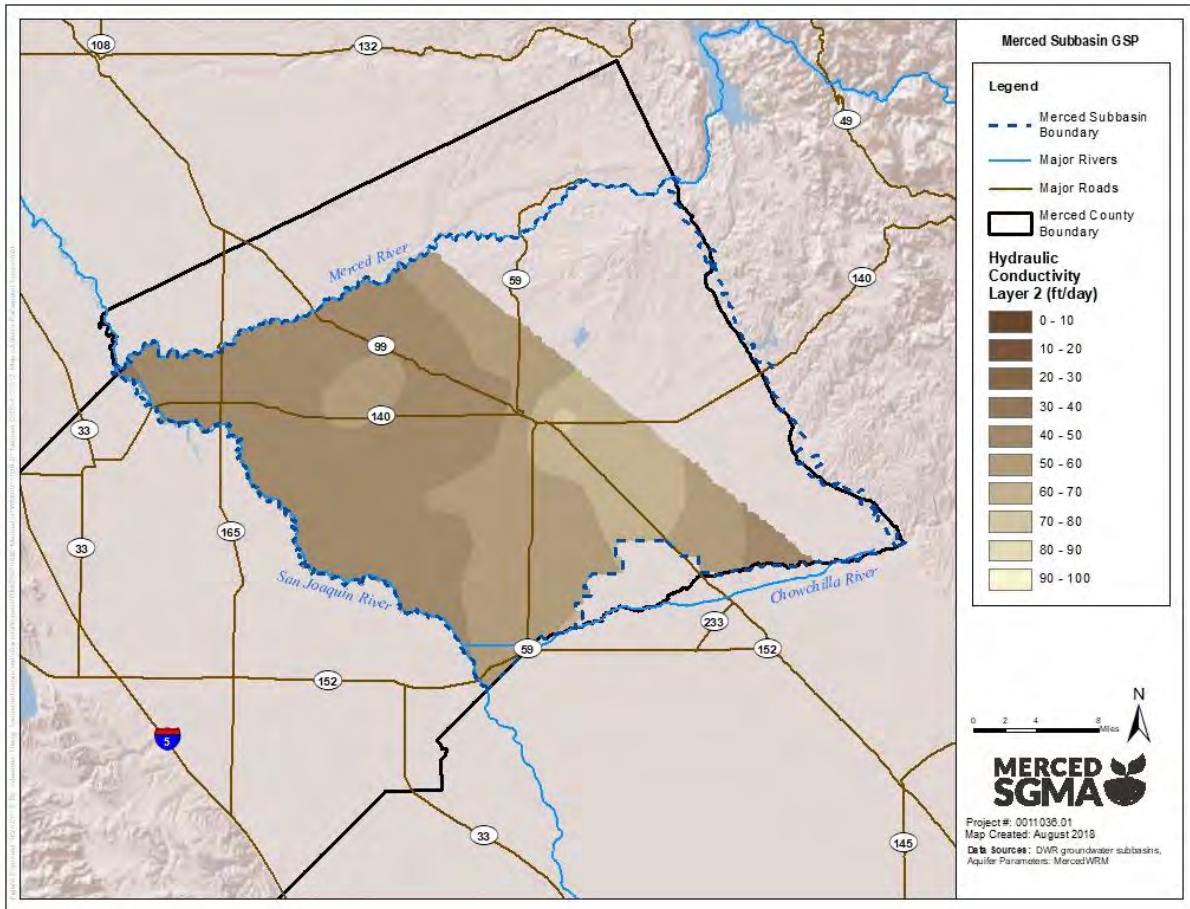


Figure 2-22: Hydraulic Conductivity – Shallow Unconfined Aquifer (MercedWRM Layer 1)

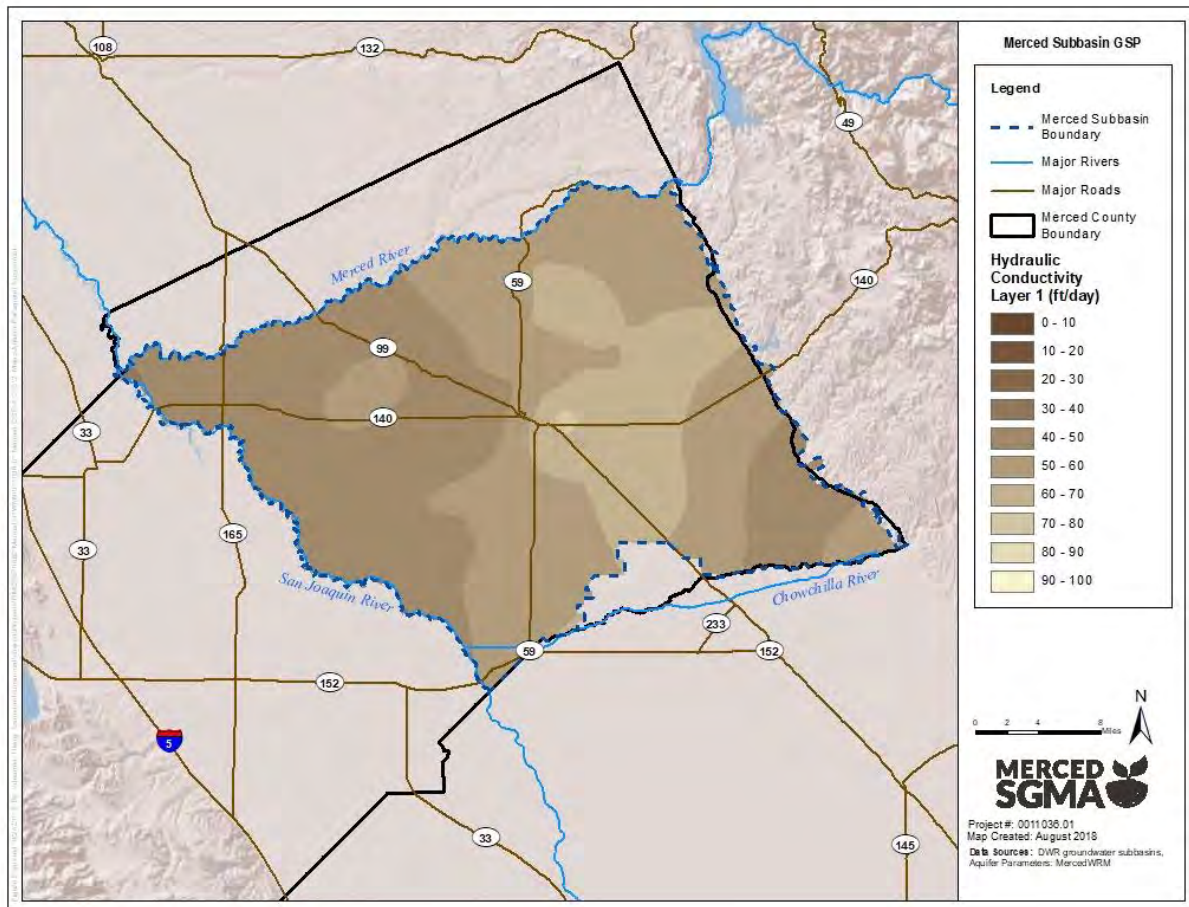


Figure 2-23: Specific Storage (all aquifer layers)

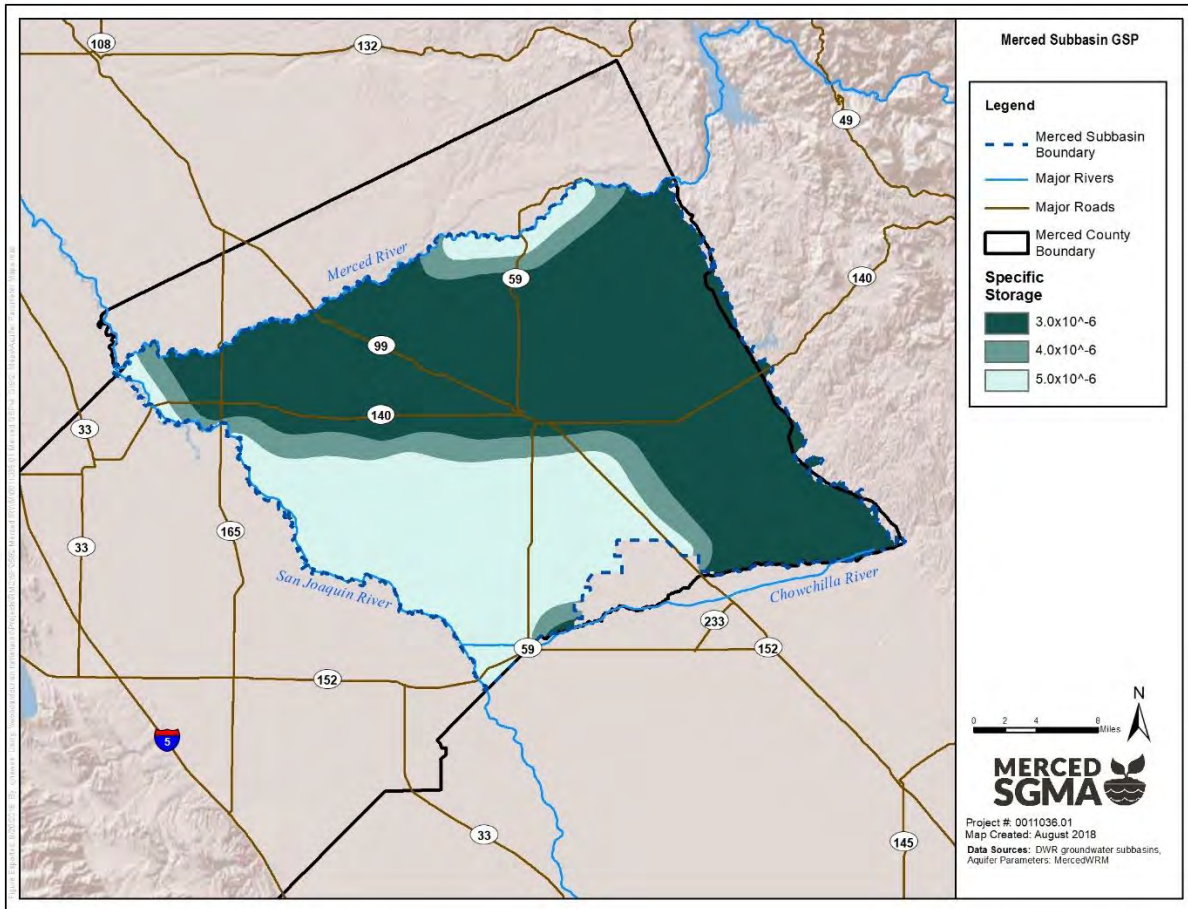
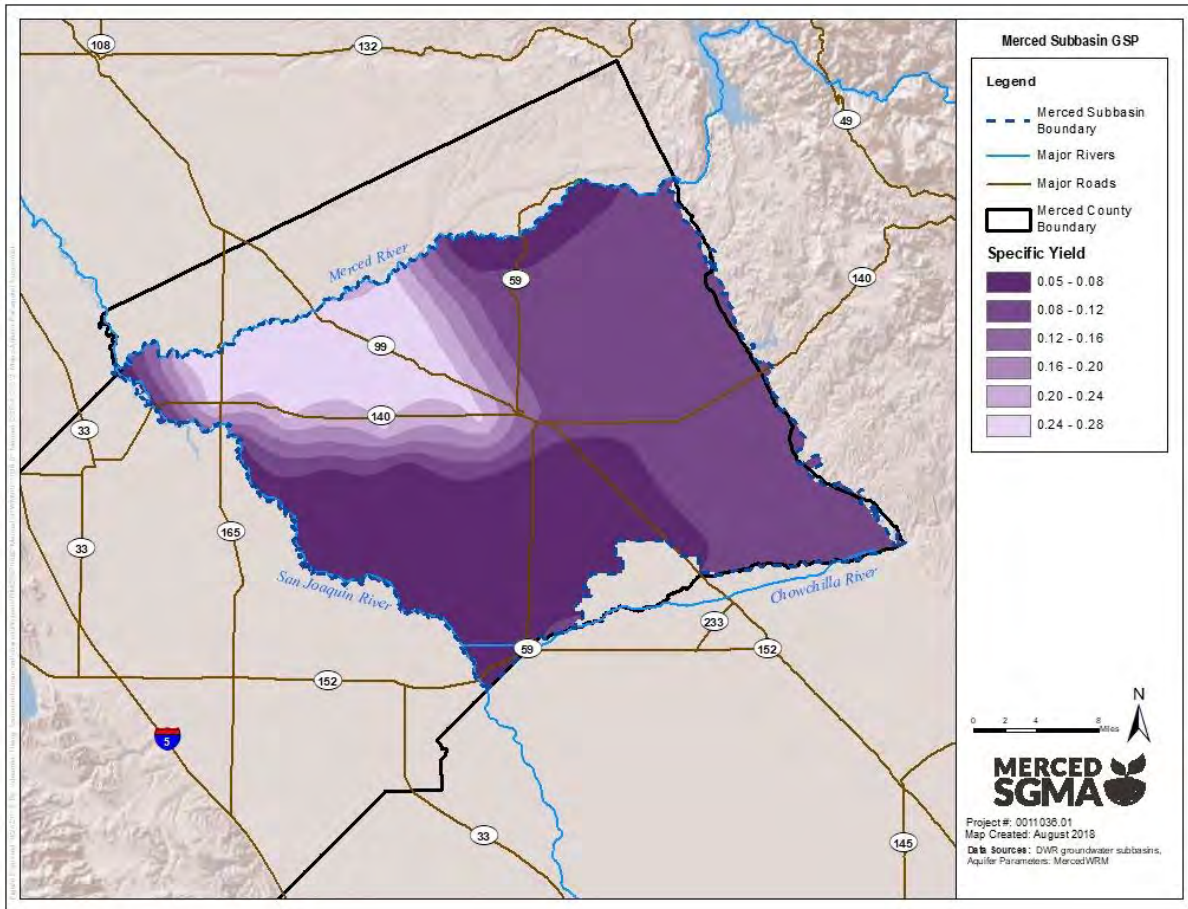


Figure 2-24: Specific Yield (all aquifer layers)



1.1.1.6.2 Principal Aquifers and Aquitards

The aquifer systems described in Section 1.1.1.6.1 interact with each other throughout the basin, except where the Corcoran Clay exists. The three principal aquifers in the Merced Subbasin and their associated characteristics are described below by referencing the specific formations defined earlier. Included in the sections below is a description of general water quality characteristics for the principal aquifers based primarily on the work of Page & Balding (1973). Specific constituents of concern with values and spatial distributions (where applicable) are described later in Section X – Section Name under Section X – Section Name.

The Above Corcoran Principal Aquifer includes all aquifers that exist above the Corcoran Clay Aquitard, namely the Intermediate Leaky-Aquifer (where it overlies the Corcoran Clay) and the Shallow Unconfined Aquifer, both described above. This excludes areas that are located east of the extent of the Corcoran Clay. Major uses of water in the Above Corcoran Principal Aquifer include domestic and irrigation uses.

The general chemical composition of groundwater in the unconfined aquifers (including both the Above Corcoran Clay and Outside of Corcoran Clay Principal Aquifers) changes spatially across the basin; moving downgradient from east to west, the water quality generally changes from a calcium bicarbonate type to a calcium sodium or calcium magnesium bicarbonate type to a sodium bicarbonate type. In terms of hardness, groundwater was generally moderately hard (61-120 mg/L) east of Highway 99 and hard to very hard (121-180 or >180 mg/L) west of Highway 99 (Page & Balding, 1973).

The Corcoran Clay Principal Aquitard is a member of the Pleistocene Tulare Formation. It is a laterally extensive reduced (blue/grey) silt and clay that underlies about 437 square miles in the southeast portion of the Merced Subbasin. The Corcoran Clay is a significant confining layer up to 60 feet thick (Page & Balding, 1973). Numerous silt and clay beds occur above and below the Corcoran Clay, but they could not be correlated over large areas and are therefore only of local importance to the confinement of groundwater (Page & Balding, 1973). The depth (and lateral extent) of the Corcoran Clay is shown on Figure 2-25. Thickness of the Corcoran Clay is shown on Figure 2-26.

The Below Corcoran Principal Aquifer includes all aquifers that exist below the Corcoran Clay Aquitard, namely the Confined Aquifer and any portion of the Mehrten Formation or Fractured Bedrock system that underlies the Corcoran Clay, described above. Major uses of water in the Below Corcoran Principal Aquifer include irrigation as well as some domestic and municipal use.

Water quality of the Below Corcoran Clay Principal Aquifer is mostly a sodium or calcium bicarbonate type. In terms of hardness, groundwater was found to range from soft (>60 mg/L) to very hard (>180 mg/L) (Page & Balding, 1973).

The Outside Corcoran Principal Aquifer includes all aquifers that exist outside of the eastern lateral extent of the Corcoran Clay, namely portions of the Mehrten Formation, Fractured Bedrock, Intermediate Leaky-Aquifer, and Shallow Unconfined Aquifer. This aquifer is connected laterally with the Above Corcoran Principal Aquifer at shallower depths and the Below Corcoran Principal Aquifer at deeper depths. Major uses of water in the Outside Corcoran Principal Aquifer include irrigation, domestic, and municipal use.

General water quality of the Outside of Corcoran Clay Principal Aquifer is described above under the section for **Above Corcoran Clay where the literature references both together as the “unconfined aquifers”**. In general, groundwater salinity is lowest in the easterly portion of the Subbasin. Salinity increases westward toward the San Joaquin River and southward toward the Chowchilla River. A small area of predominantly sodium-chloride type water has been identified near the confluence of the Merced and San Joaquin Rivers.

Data gaps and uncertainties related to the principal aquifers are primarily related to water quality and to the extent to which the Corcoran Clay reduces the vertical flow of water. Both the depth and thickness of the clay varies throughout the basin (Figure 2-25 and Figure 2-26), and there are areas where the clay may be thin or not present. Additionally, the presence of numerous wells that penetrate the Corcoran Clay provides conduits for flow. Some of these wells are screened above and below the Corcoran Clay, although this practice is not currently allowed by Merced County Code, greatly increasing opportunities for vertical flow when pumps are not operating. With regards to water quality, there is limited depth-specific water quality data for the basin. The most recent, comprehensive study on general water quality types in the Subbasin dates from the 1970s and should be updated in the future.

Figure 2-25: Corcoran Clay Depth

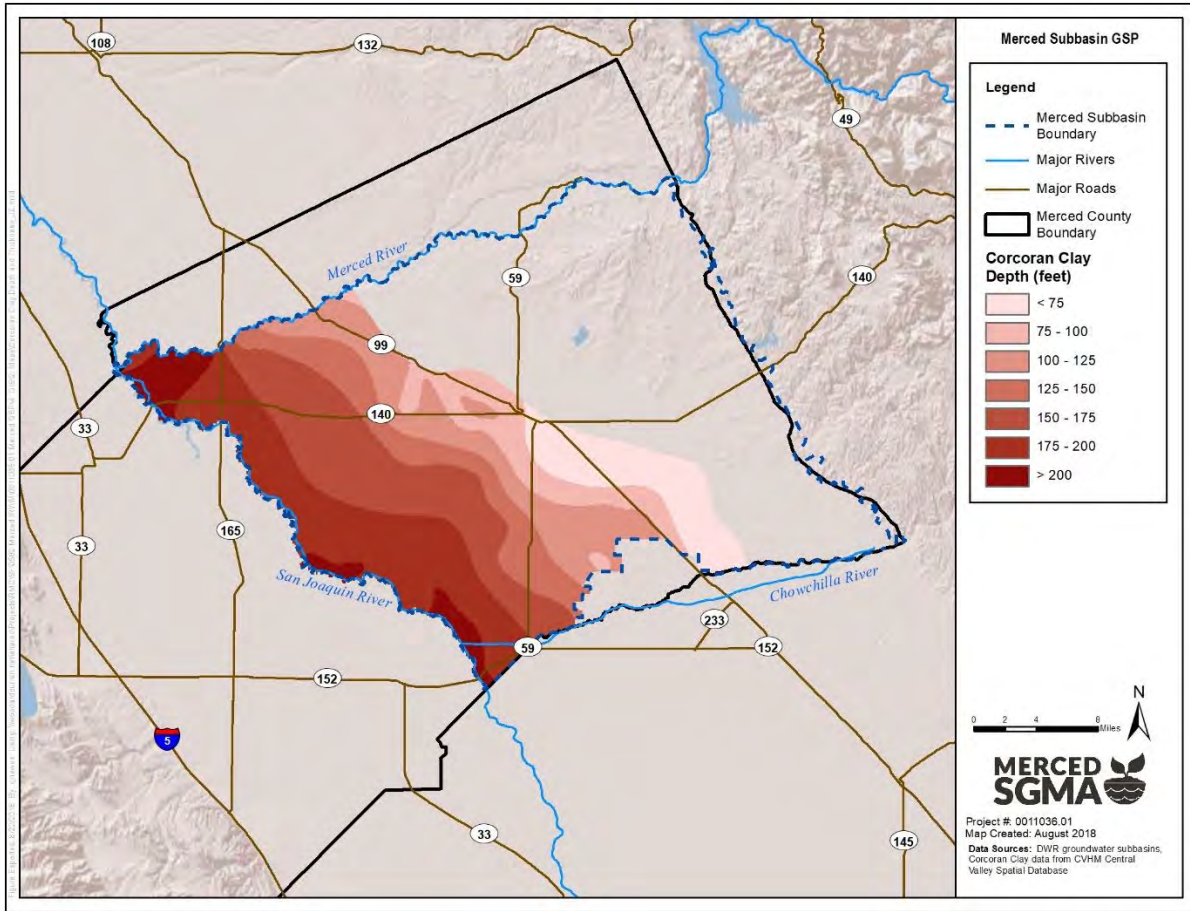
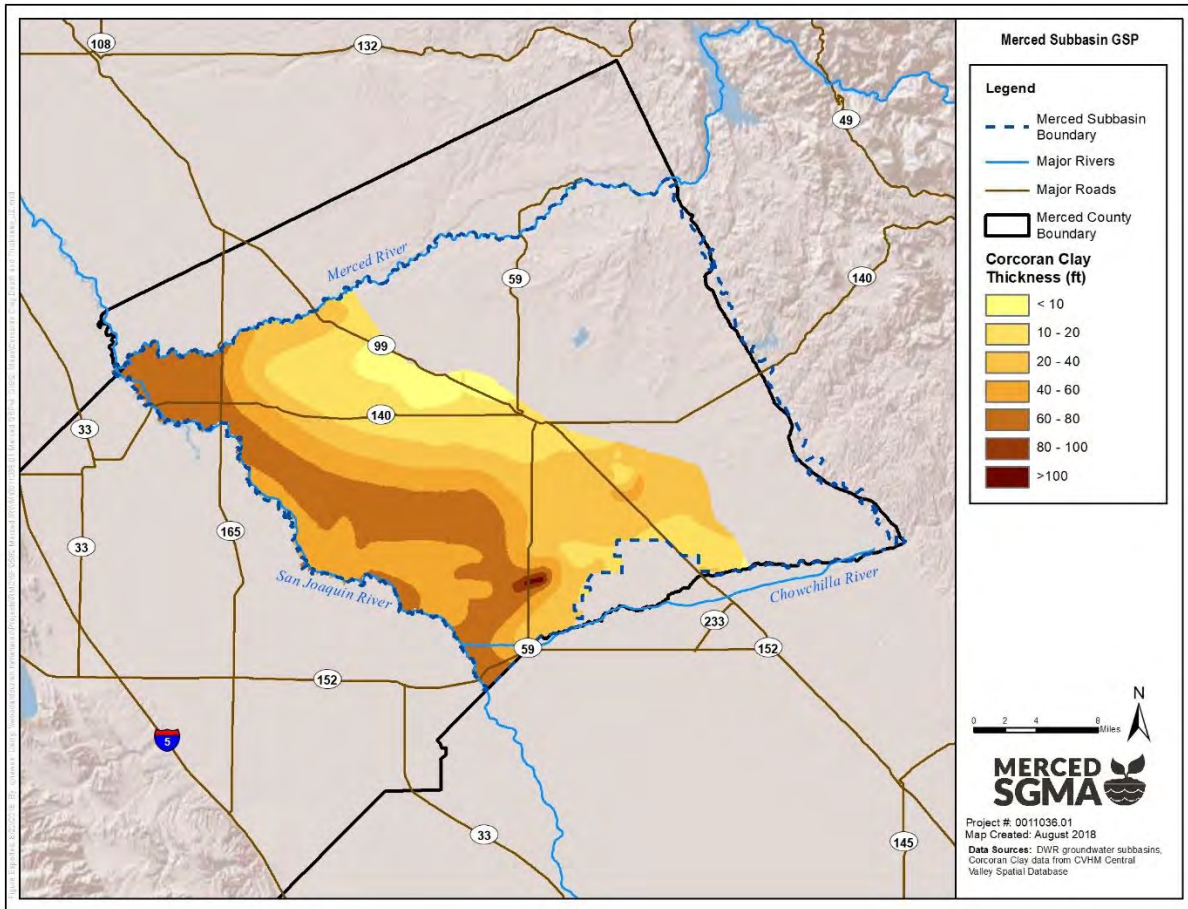


Figure 2-26: Corcoran Clay Thickness



1.1.1.7 Surface and Near-Surface Conditions

This section describes the topography, surface water, imported water supplies, soils, and recharge areas in the basin.

Topography and Physiography

The Merced Subbasin is largely flat, with a minimum elevation of approximately 50 feet, near the confluence of the Merced and San Joaquin Rivers and a maximum elevation of 836 feet, in the foothills near the northern corner of the Subbasin. Figure 2-27 shows a map of elevation within the Subbasin.

The topography is driven by the physiography of the area. The following description of the physiography and geomorphology of the Merced Subbasin is provided to add context to the topography and is based on geomorphic descriptions and maps by the USGS (Davis, Green, Olmsted, & Brown, 1959) as referenced in the Merced Groundwater Management Plan (AMEC, 2008).

The physiographic units in the Merced Subbasin area include the Sierra Nevada, dissected uplands, low alluvial plains and fans, river floodplains and channels, and overflow lands (Page & Balding, 1973). These physiographic units are presented on Figure 2-28. The Sierra Nevada unit, which can be found along the eastern border of the Merced Subbasin, consists of metamorphic and granitic mountains that have deep river-cut canyons and highly dissected foothills.

The dissected uplands unit has a width ranging between 5 and 18 miles and covers a significant portion of the Merced Subbasin. Local relief may be up to 200 feet. Within the uplands, the Merced River has developed two terraces and a broad floodplain while the Chowchilla River is only slightly entrenched into the upland surface.

The low alluvial plains and fans unit, which consists primarily of coalescing alluvial fans, has a width ranging between 14 and 20 miles and also covers a significant portion of the Merced Subbasin. Local relief may be up to 10 feet. Between Atwater and Turlock, northwest trending sand dunes underlie the surface of the plains and fans.

The river floodplains and channels unit flank the channels of the major rivers including the Merced and Chowchilla Rivers. In the dissected uplands unit, the floodplain of the Merced River ranges in width between 0.25 and 1 mile. In the Cressey area, natural levees are present. Near the valley trough, the Merced River floodplain becomes indistinguishable from the surrounding alluvial plains. The Chowchilla River, which is entrenched about 40 feet near where it leaves the Sierra Nevada, has developed a thin floodplain through the dissected uplands. The river has deposited natural levees throughout the low alluvial plains and fans unit.

Figure 2-27: Topography

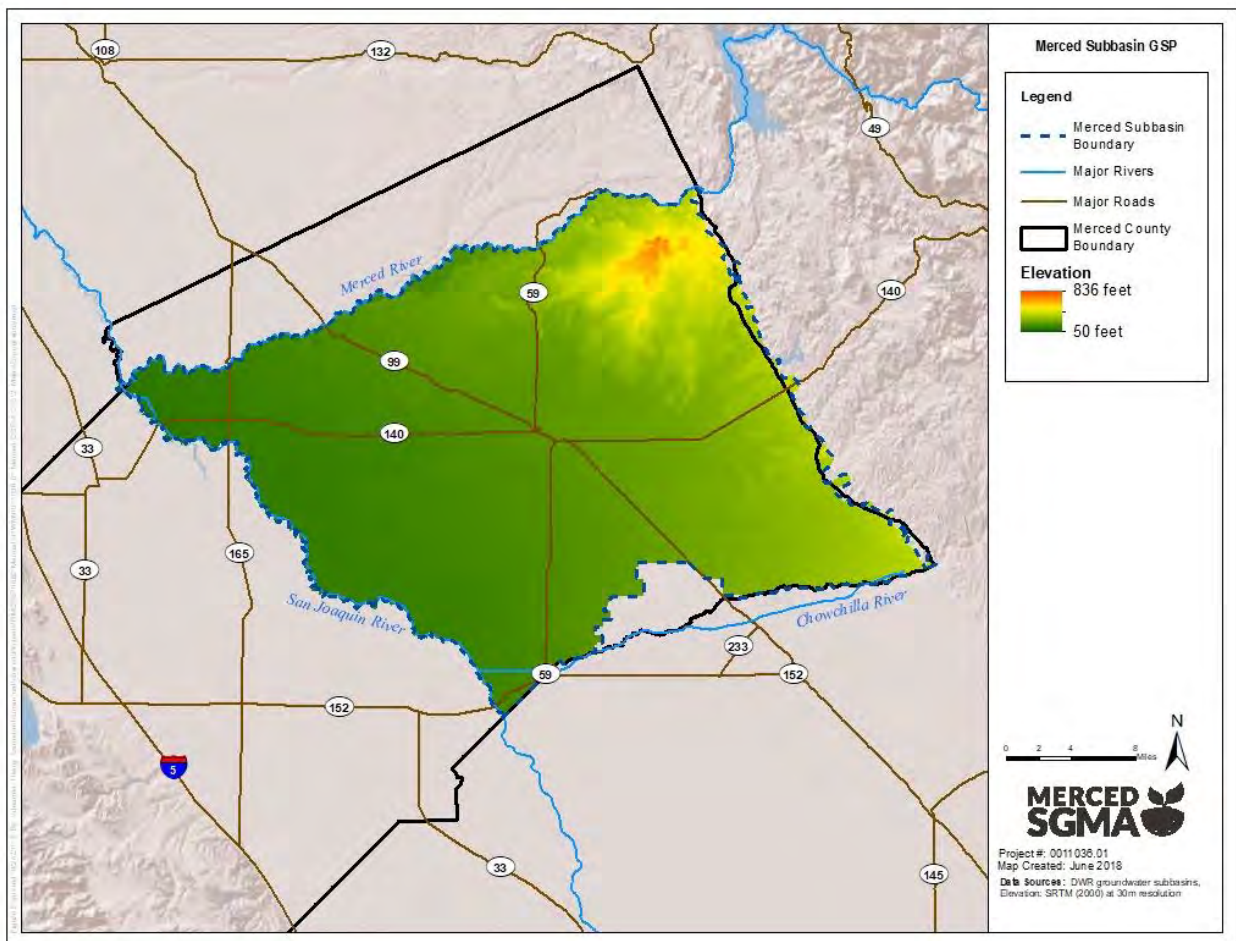
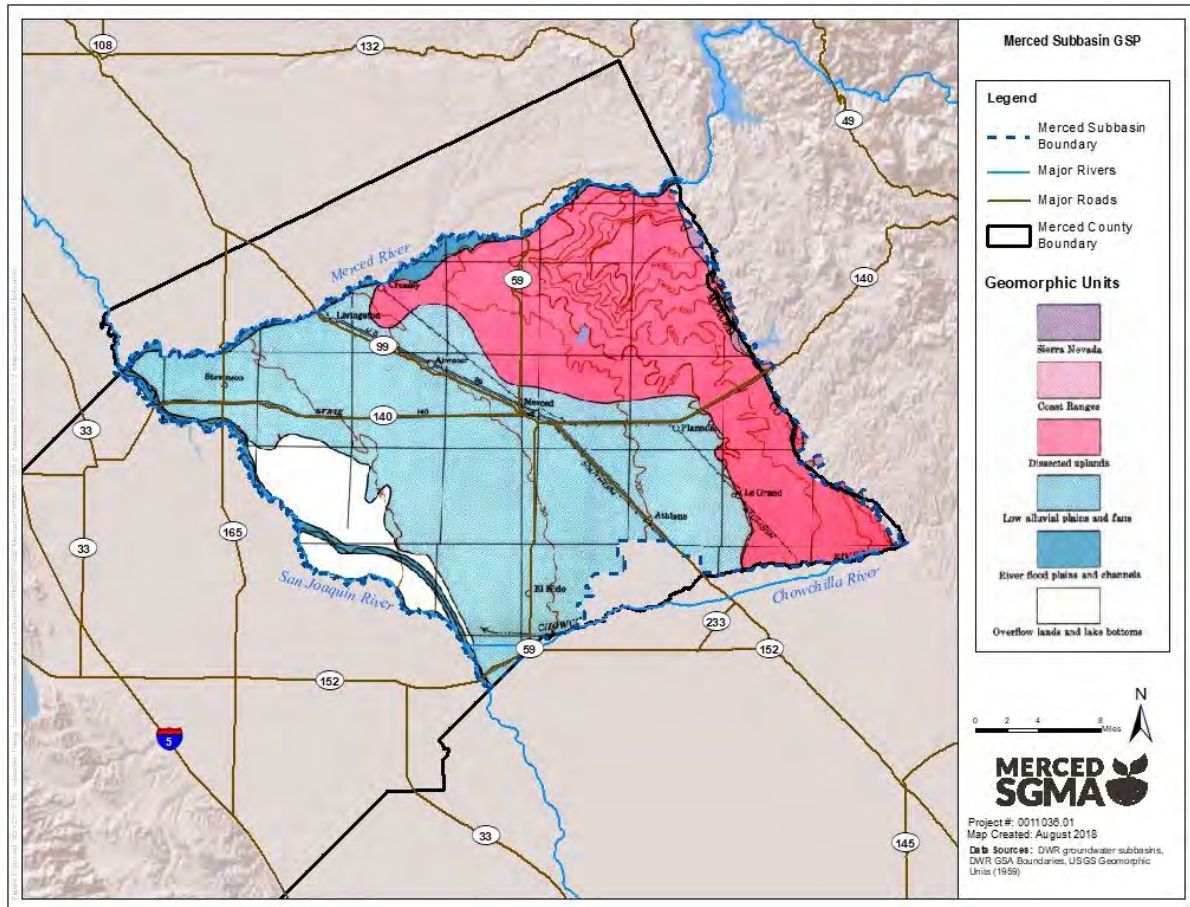


Figure 2-28: Geomorphic Units



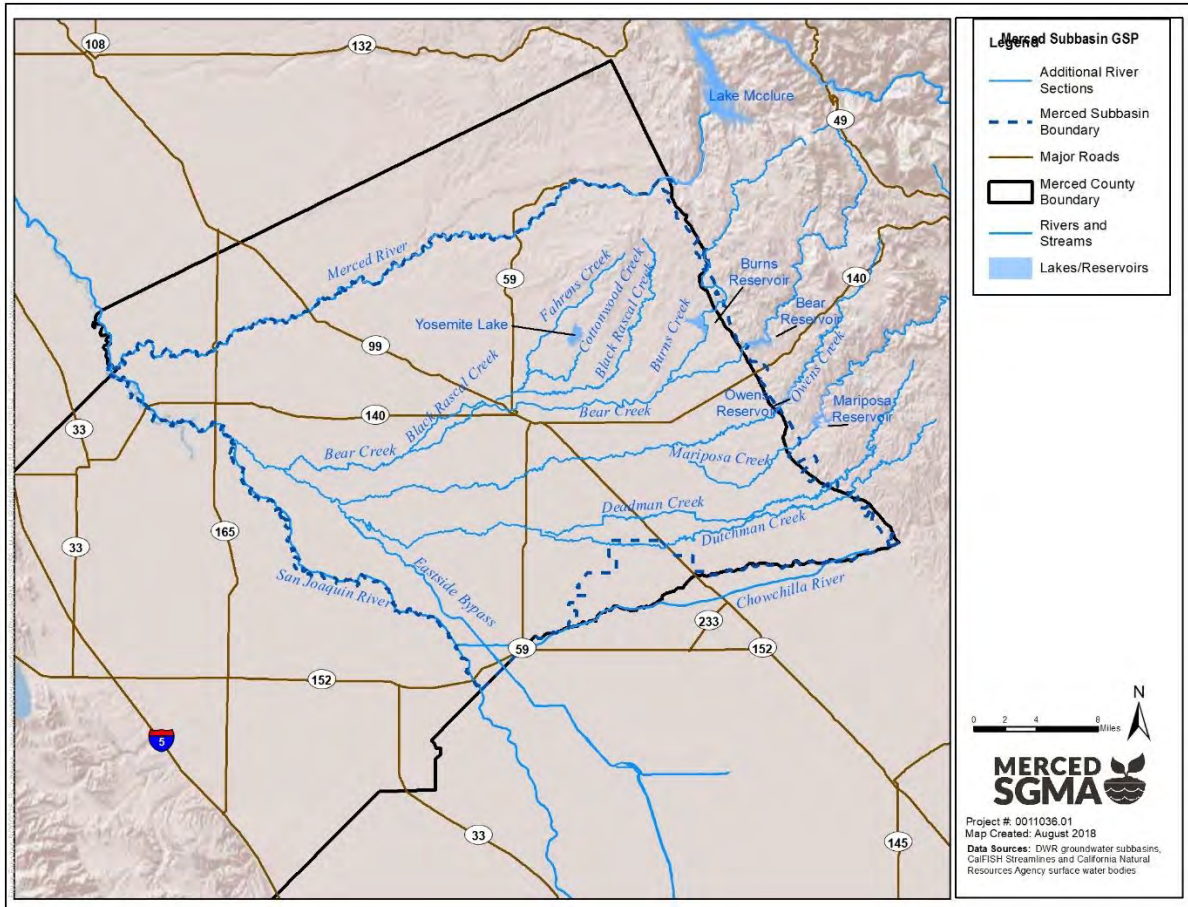
Source: (Davis, Green, Olmsted, & Brown, 1959)

Surface Water

Many surface water courses cross the Merced Subbasin, generally flowing from the uplands in the northeast towards the San Joaquin River in the southwest. The San Joaquin River is an exception, flowing northwest towards the Sacramento-San Joaquin Delta. The San Joaquin and Merced Rivers are the largest rivers in the subbasin. Chowchilla River is also a significant water course.

Other surface water bodies within the Merced Subbasin include the following permanent and ephemeral streams: Bear Creek, Black Rascal Creek, Burns Creek, Canal Creek, Cottonwood Creek, Deadman Creek, Dutchman Creek, Fahrens Creek, Little Dutchman Creek, Mariposa Creek and Owens Creek (Figure 2-29). Most of these features are utilized for conveyance of irrigation water. Gauging stations are located at flood control structures on Burns, Bear, Mariposa, and Owens Creeks.

Figure 2-29: Surface Waters



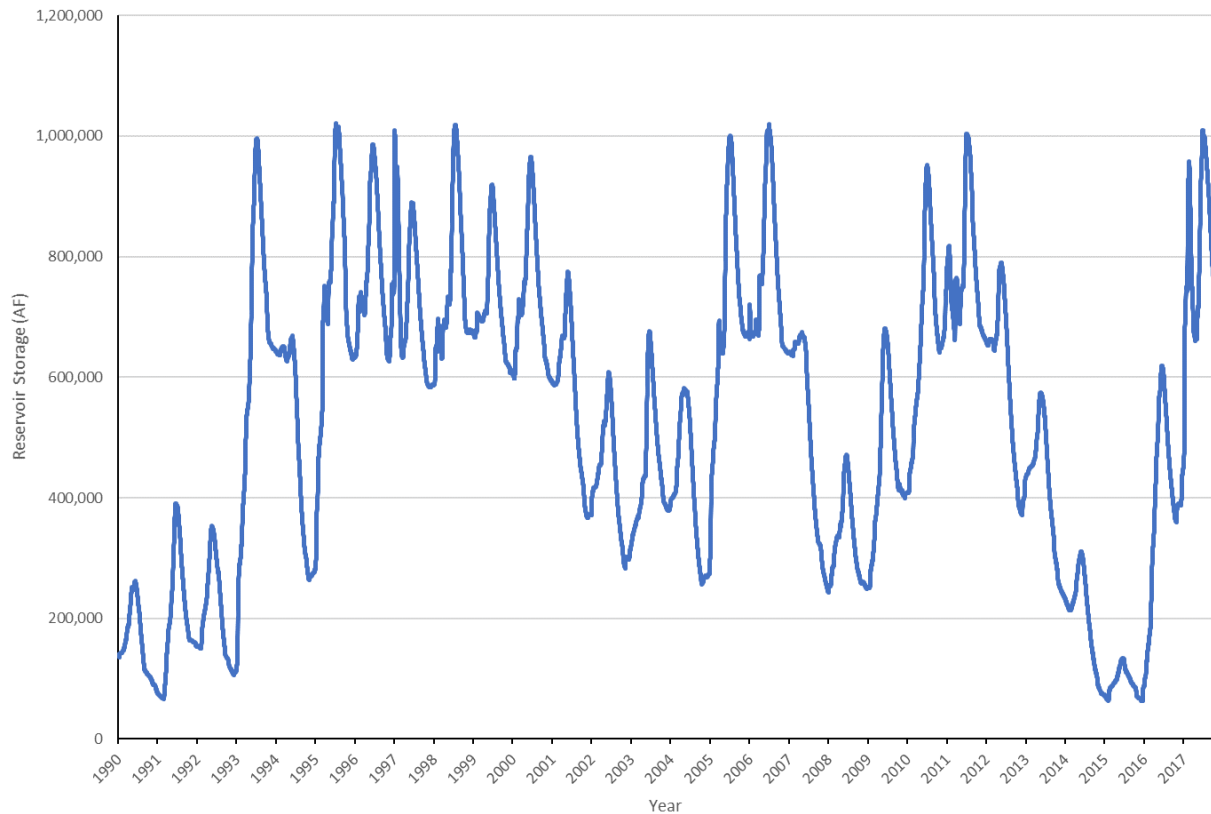
The Merced River is the principal renewable surface water supply in the Merced Subbasin (see Figure 2-29). The Merced River is impounded by New Exchequer Dam, forming Lake McClure. Lake McClure has a storage capacity of over 1 million acre-feet (AF) and is used for flood control and storage of irrigation water. Under agreement with the USACOE, each spring the storage pool in Lake McClure is reduced to a maximum of 675,000 AF for flood control purposes (AMEC, 2008).

From 1990-2017, storage in Lake McClure has ranged from about 63,300 AF (February 2015) to 1,022,000 AF (July 1995) and averaged about 524,000 AF (Figure 2-30).

Diversions from the Merced River include:

- Merced Irrigation District (MID) – 430,000 AF/yr (2003 - 2015 average)
- Stevinson Water District (SWD) – 18,000 AF/yr (2003 – 2013 average)
- Merquin County Water District (MCWD) – 16,000 AF/yr (2003 – 2013 average)

Figure 2-30: 1990-2017 Lake McClure Reservoir Storage



Source: USGS Data for Site 11269500 LK MCCLURE A EXCHEQUER CA

The Chowchilla River drains a 254 square-mile watershed on the western slope of the Sierra Nevada and is regulated by Buchanan Dam. Some flows downstream of the dam are diverted at Chowchilla Water District canals. Average annual natural flows from 1912 to 2008 at Buchanan Dam were approximately 70,000 AF. Chowchilla Water District has been able to take delivery of approximately 43,000 AF annually from the dam. The remaining 27,000 AF have been released as flood flows from the dam (RMC Water and Environment, 2015).

The San Joaquin River is regulated by Millerton Reservoir and other reservoirs on upstream tributaries. In the Merced Subbasin, the river is a source of water supplies for Turner Island Water District which diverts 20,000 AF/yr (2003 to 2013 average) using the San Luis Canal Company conveyance. Turner Island Water District also receives periodic flood flows from the East Side Bypass at 5,000 AF/yr only when available.

There are no significant active springs or seeps within the Merced Subbasin. Wetlands within the subbasin are generally supplied supplemental water and are not dependent on shallow groundwater.

Imported Water

No agencies in the Merced Subbasin benefit from imported water supplies from outside the Subbasin, such as from the Central Valley Project or State Water Project. The Turner Island Water District is split into two GSAs. Turner Island

Water District GSA #1 is the portion of the water district that falls within the Merced Subbasin while #2 falls within the Delta-Mendota Subbasin. There is some transfer of groundwater between the two GSAs, though the exact volume is unknown.

Surface Soils

The United States Department of Agriculture (USDA) Soil Conservation Service (now the USDA Natural Resource Conservation Service) conducted a soil survey in Merced County and identified more than 200 unique soil types within the Merced Subbasin. Data on soils can assist in the understanding of how water may infiltrate or run off the surface as well as how chemical constituents may interact with soils. The soil types can be grouped into 25 associations based on general soil type (Figure 2-31 and Table 2-5) and permeability (Figure 2-32), along with other characteristics identified by the USDA. Soil types and permeability were mapped using the Soil Survey Geographic (SSURGO) database last updated 2017.

Figure 2-31: Soil Types

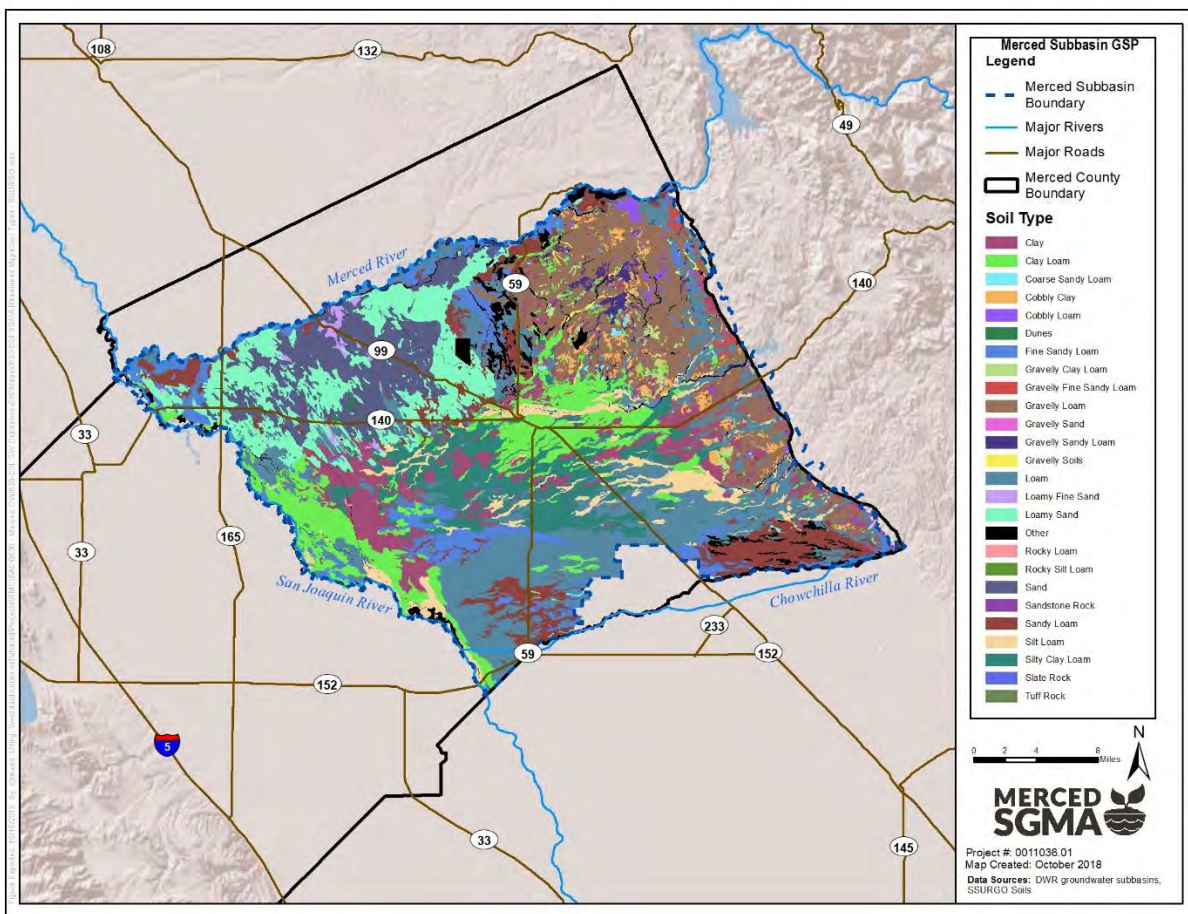
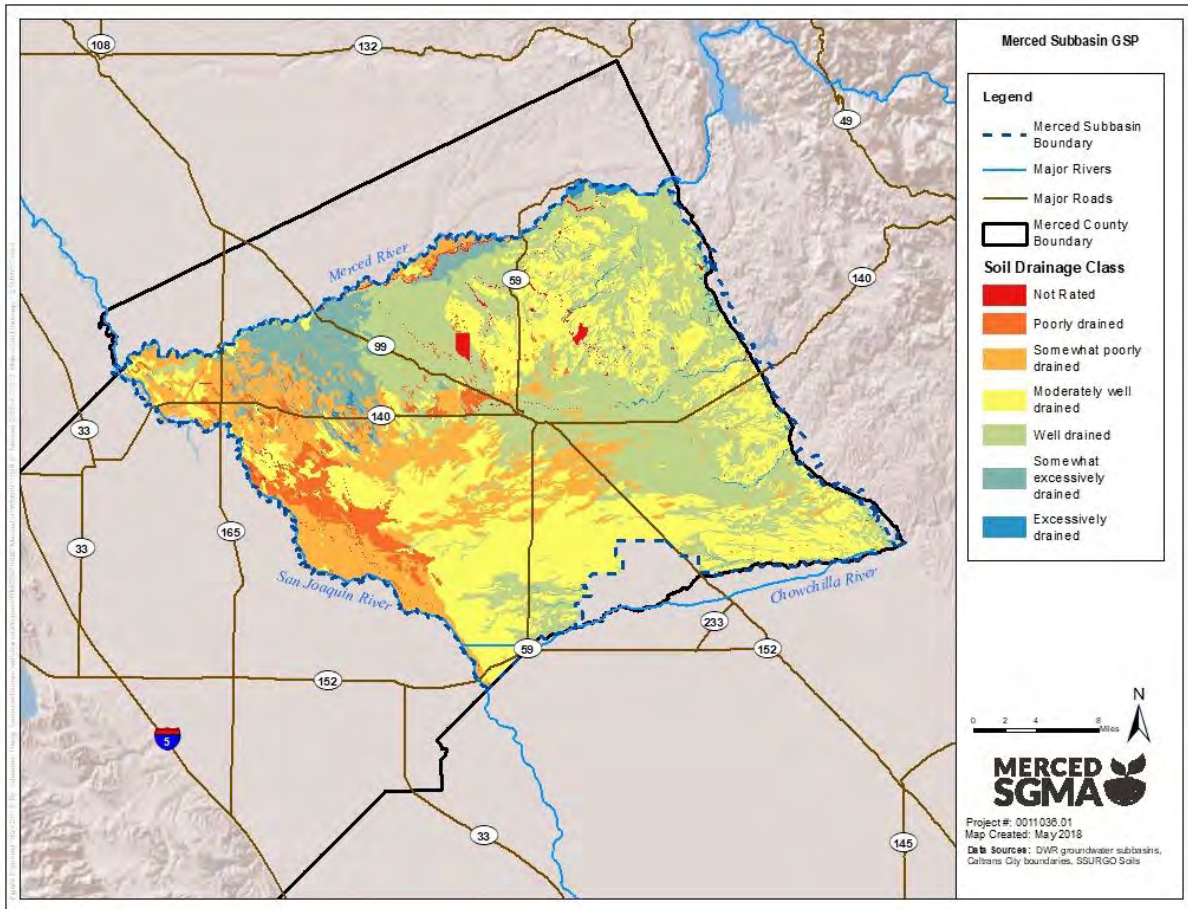


Table 2-5: Soil Type Summary

Soil Type	Area (sq miles)	% of total
Loam	145.8	18%
Gravelly Loam	96.3	12%
Clay Loam	77.8	10%
Loamy Sand	74.5	9%
Sand	66.9	8%
Silty Clay Loam	63.9	8%
Clay	62.2	8%
Sandy Loam	54.5	7%
Fine Sandy Loam	48.0	6%
Silt Loam	32.6	4%
Other (Includes Water, Fill, No Data Available)	28.2	4%
Cobbly Clay	10.9	1%
Gravelly Sandy Loam	6.7	1%
Gravelly Clay Loam	4.7	1%
Gravelly Fine Sandy Loam	4.0	1%
Loamy Fine Sand	3.8	<1%
Cobbly Loam	3.7	<1%
Coarse Sandy Loam	1.6	<1%
Gravelly Soils	1.4	<1%
Dunes	1.2	<1%
Sandstone Rock	1.1	<1%
Rocky Silt Loam	1.0	<1%
Rocky Loam	0.2	<1%
Slate Rock	0.0	<1%
Tuff Rock	0.0	<1%
Gravelly Sand	0.0	<1%
Total	791.3	100%

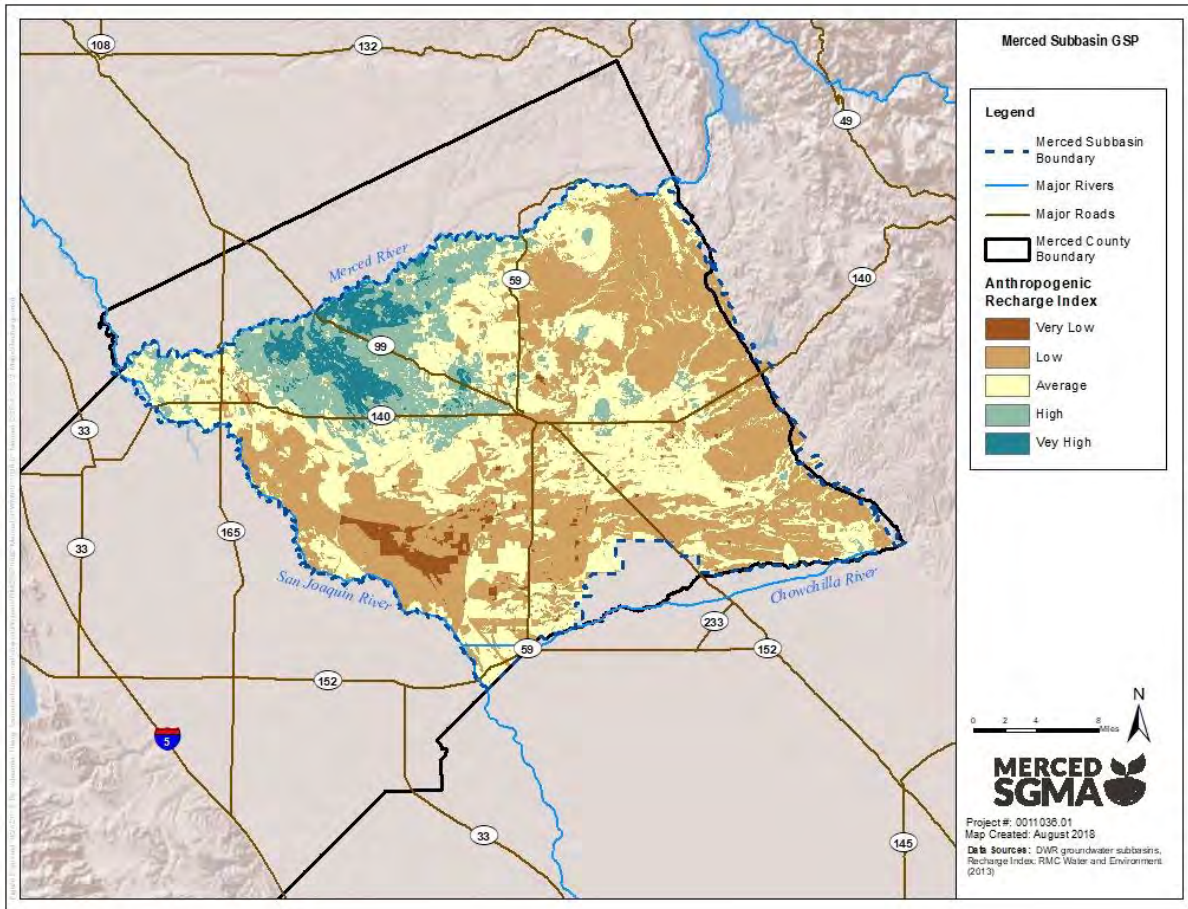
Figure 2-32: Soil Drainage Class



Groundwater Recharge and Discharge Areas

Groundwater recharge and discharge is driven by both natural and anthropogenic (human-influenced) factors. Anthropogenic recharge, particularly deep percolation from agricultural irrigation and earthen-lined canals, is a key source of recharge in the Merced Subbasin. A Groundwater Recharge Study was conducted as part of the Merced Integrated Regional Water Management (IRWM) Plan Development in 2013 to identify where recharge is occurring. The study used a Geographic Information System (GIS) overlay method to analyze spatial data and integrate information to interpret recharge areas (RMC Water and Environment, 2013). The Subbasin was divided into five different categories, relating the relative amount of recharge occurring in the area (see Figure 2-33). The map shows recharge is occurring in areas with coarser materials in the upper subsurface and in areas with extensive applied water to support irrigated agriculture. The map does not show the recharge occurring from surface water courses, including rivers and canals. Estimates of the quantities of these recharge components are provided in the water budget discussion in Section X.

Figure 2-33: Areas of Recharge



Groundwater discharge is primarily through groundwater production wells. However, groundwater also discharges to rivers and streams where groundwater elevations are higher than river stage. This occurs in limited areas in the lower portions of the Subbasin. Figure 2-34 shows gaining streams in red where groundwater discharges to rivers, while losing streams are shown in blue where streams lose water to groundwater. This analysis was based on modeling results from the MercedWRM for approximately 1,500 stream nodes in the Merced Subbasin. The stream nodes within the MercedWRM contain information on the quantity of stream gains and losses on a monthly basis. Using the historical simulation (see Appendix X), the median value of monthly stream gains and losses was calculated over the 2005 to 2015 time period. Figure 2-34 indicates where these stream nodes indicate gaining conditions (groundwater contributing to streamflow) and where they indicate losing conditions (surface water recharging groundwater). Any stream nodes that are disconnected from the principal aquifer (see Figure 2-35) are noted as losing.

The groundwater elevation data indicate that there is groundwater discharge along the San Joaquin River (gaining stream). There is a trough in the water table elevations that follows the San Joaquin River. Groundwater inflow to the river and surrounding areas occurs from both sides of the San Joaquin Valley. Apart from groundwater pumping, this river and the surrounding areas are the primary groundwater discharge area for the valley (Amec, 2013).

On the north side of the Merced Subbasin west of State Highway 99, the lower reaches of the Merced River appear to be a groundwater discharge area (where the Merced River is a gaining stream). East of the highway, the river may be acting as a constant head source and supplying water to the pumping depression centered approximately 17 miles

northwest of Merced. East of Oakdale Road (Township 5 South, Range 12 East, Section 36), the river is higher than the groundwater and probably provides some recharge to the groundwater (Amec, 2013).

Comparison of Chowchilla River elevations with groundwater levels indicates that the river is higher than the groundwater. Consequently, the river probably contributes some recharge to groundwater along the reach south of the study area. The pumping depressions near the Chowchilla River do not appear to be affected by the presence of the river (Amec, 2013).

Figure 2-34: Losing and Gaining Streams

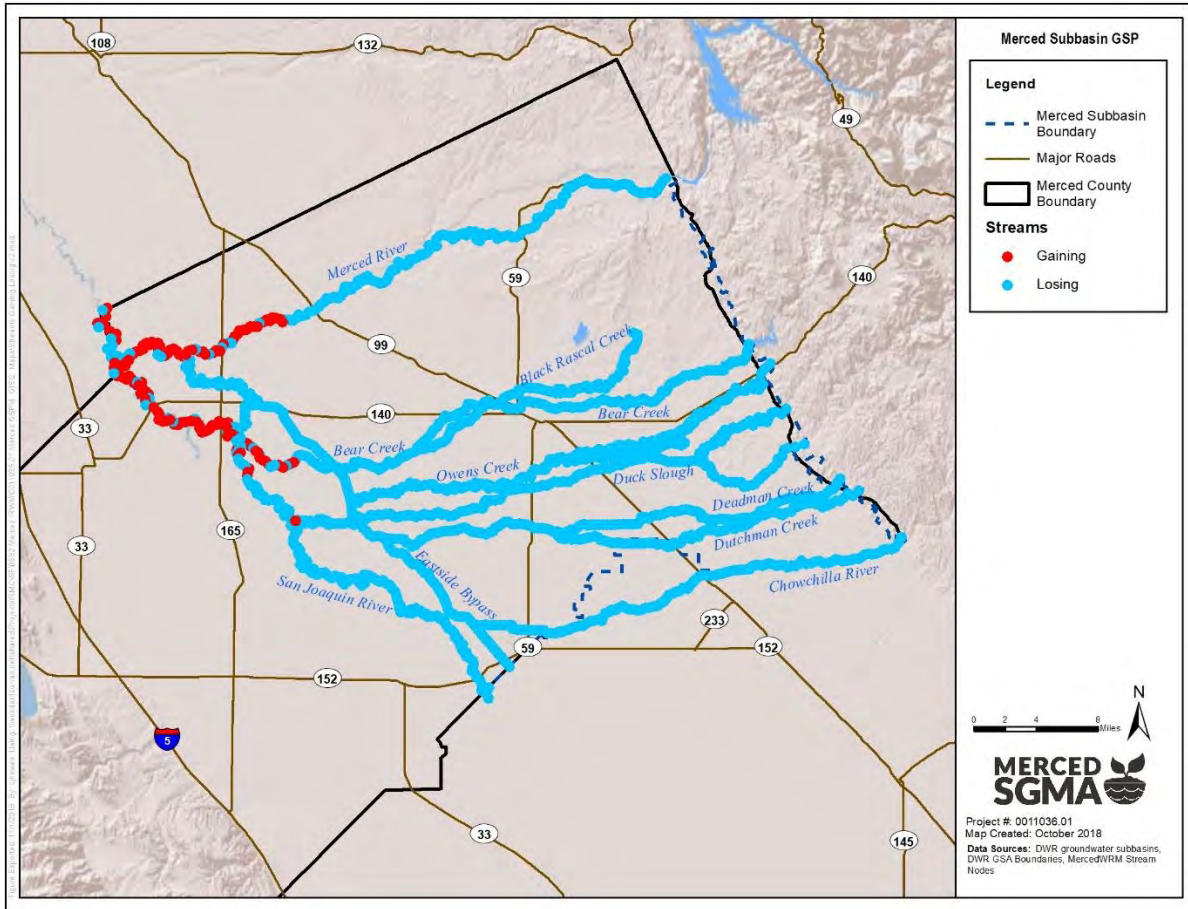
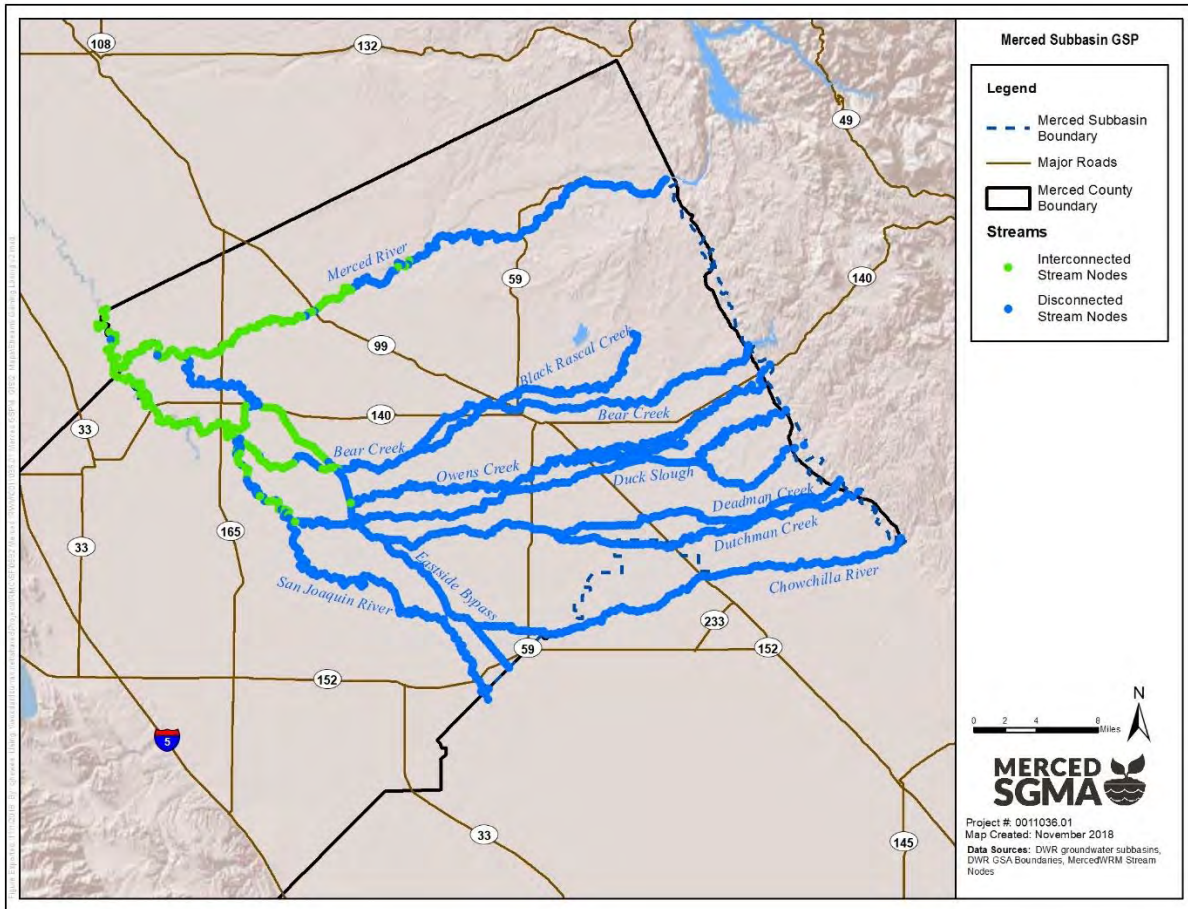


Figure 2-35: Interconnected and Disconnected Streams



1.1.1.8 HCM 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. These data gaps will be revised after further research and GSP development:

- Water quality of principal aquifer

2. REFERENCES

- AMEC. (2008, July 29). Merced Groundwater Basin Groundwater Management Plan Update. *Merced Groundwater Basin Groundwater Management Plan Update, Merced County, CA*.
- Amec. (2013). *Salt and Nutrient Study (from MIRWMP)*.
- Bartow, J. A. (1991). *The Cenozoic Evolution of the San Joaquin Valley, California (USGS Professional Paper 1501)*. USGS.
- California Geological Survey. (2010). Fault Activity Map of California. Retrieved from <http://maps.conservation.ca.gov/cgs/fam/>
- California Regional Water Quality Control Board Central Valley Region. (2016, July). The Water Quality Control Plan (Basin Plan) - Sacramento River Basin and San Joaquin River Basin.
- Catalyst. (2018, February 7). Merced Basin Groundwater Sustainability Stakeholder Engagement Strategy.
- City of Livingston. (2016). *2015 Urban Water Management Plan*.
- City of Merced. (2017). *2015 Urban Water Management Plan*.
- City of Merced. (n.d.). Code of Ordinances: Chapter 8.12 - Water Wells. Retrieved April 5, 2018
- City of Merced Development Services Department. (2011). Merced Vision 2030 General Plan.
- County of Madera. (2016, March 29). Chowchilla Subbasin - Modified Boundary Description.
- Davis, G. H., Green, J. H., Olmsted, F. H., & Brown, D. W. (1959). *Ground-Water Conditions and Storage Capacity in the San Joaquin Valley California (USGS Water Supply Paper 1469)*. USGS.
- DWR. (2003). *California's Groundwater Bulletin 118*.
- DWR. (2004). *Bulletin 118: San Joaquin Valley Groundwater Basin Merced Subbasin*.
- DWR. (2016, January 7). Groundwater Sustainability Agency Frequently Asked Questions. Retrieved May 3, 2018, from <https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Groundwater-Sustainability-Agencies/Files/GSA-Frequently-Asked-Questions.pdf>
- DWR SGMP. (2016). *Groundwater Sustainability Plan (GSP) Annotated Outline*. Sacramento, CA.
- DWR SGMP. (2016). *Preparation Checklist for GSP Submittal*. Sacramento, CA.
- Elam, T. (2012, August 1). *The San Joaquin Valley Through Time*. Retrieved from Buena Vista Museum of Natural History & Science, Bakersfield: http://www.sharktoothhill.org/index.cfm?fuseaction=news_full_view&news_id=7
- Harter, T., Lund, J. R., Darby, J., Fogg, G. E., Howitt, R., Jessoe, K. K., . . . Rosenstock, T. S. (2012). *Addressing Nitrate in California's Drinking Water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater*. Report for the State Water Resources Control Board Report to the Legislature. Center for Watershed Sciences, University of California, Davis.
- Luhdorff and Scalmanini Consulting Engineers. (2016). *Region 5: Updated Groundwater Quality Analysis and High Resolution Mapping for Central Valley Salt and Nitrate Management Plan*.
- Merced County. (2013). *2030 Merced County General Plan*.
- Merced County. (2015). *Well Construction, Destruction, Mining, and Export Application/Permit User Guide*. Retrieved April 5, 2018, from <http://www.co.merced.ca.us/DocumentCenter/View/10905>
- Merced County Department of Public Health, Division of Environmental Health. (2018). *Adverse Groundwater Quality by Area in Merced County*.
- Merced County. (n.d.). Merced County Code. *Chapter 9.28 - Wells*. Retrieved April 5, 2018, from http://www.qcode.us/codes/mercedcounty/view.php?topic=9-9_28&frames=on
- Merced Irrigation District. (2013). *Agricultural Water Management Plan*.
- Merced Irrigation District. (2017). *Attachment 5: Budget for 2017 Merced Groundwater Subbasin Sustainability (DWR Grant Application)*.
- Merced Subbasin GSA, MIUGSA, Turner Island Water District GSA-#1. (2017, October 13). Memorandum of Understanding.
- Merced Subbasin GSA, MIUGSA, Turner Island Water District GSA-#1. (2018, January 8). Notification of Intent to Develop a Groundwater Sustainability Plan for Merced Subbasin.

MID. (2016, July 5). *Agricultural Water Management Plan*. Retrieved from <http://www.water.ca.gov/wateruseefficiency/sb7/docs/2016/Merced%20ID%202015%20AWMP.pdf>

MIUGSA. (2017). Memorandum of Understanding Forming the Merced Irrigation-Urban Groundwater Sustainability Agency.

MSGSA. (2016). Joint Powers Agreement Creating the Merced Subbasin Groundwater Sustainability Agency.

Pacific Municipal Consultants. (2000). City of Atwater General Plan. Retrieved April 6, 2018, from http://www.atwater.org/dept_communitydevelopment.html#5

Page, R. W. (1973). *Base of Fresh Ground Water (Approximately 3,000 Micromhos) in the San Joaquin Valley, California*. USGS.

Page, R. W. (1977). *Appraisal of Ground-Water Conditions in Merced, California, and Vicinity*.

Page, R. W. (1986). *Geology of the Fresh Ground-Water Basin of the Central Valley, California, with Texture Maps and Sections*. Washington: United States Geological Survey.

Page, R. W., & Balding, G. O. (1973). *Geology and Quality of Water in the Modesto-Merced Area, San Joaquin Valley, California, with a Brief Section on Hydrology*.

Quad Knopf, Inc. (1999, December). Livingston General Plan.

Reclamation. (2016). *Draft Environmental Assessment/Initial Study: Water Year 2016-2026 Transfer and Exchange from Madera Irrigation District and Chowchilla Water District to the Red Top Area*.

RMC Water and Environment. (2013). *Groundwater Recharge Feasibility Study (part of MIRWMP)*.

RMC Water and Environment. (2013). *Merced Integrated Regional Water Management Plan*.

RMC Water and Environment. (2015). *Creating and Opportunity: Groundwater Recharge through Winter Flooding of Agricultural Land in the San Joaquin Valley*.

RMC Water and Environment. (2017, December). Merced Water Resources Model (MercedWRM) DRAFT Report.

Wilde, F. (2015). *National Field Manual for the Collection of Water-Quality Data*. USGS. Retrieved from https://water.usgs.gov/owq/FieldManual/compiled/NFM_complete.pdf