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North American Subbasin Groundwater Sustainability Plan

Section 4

Prepared for:

Sacramento Groundwater Authority GSA
RD 1001 GSA
South Sutter Water District GSA
Sutter County GSA
West Placer GSA

Prepared by:

GEI Consultants
2868 Prospect Park Drive, Suite 400
Sacramento, CA 95670

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4. Hydrogeologic Setting

This section describes the geologic conditions that control how groundwater moves in the North American Subbasin (NASb or Subbasin), the Subbasin extent, recharge and discharge areas, general water quality, and defines the principal aquifers.

4.1 Basin Boundaries

The NASb lies in the eastern central portion of the Sacramento Valley Groundwater Basin. A subbasin designation indicates that aquifers beneath the NASb may extend into the adjacent South American, South Yuba, Sutter, and Yolo subbasins.

The NASb is surrounded on three sides by rivers and on one side by bedrock; the Bear River is its northern boundary, the Feather and Sacramento rivers are its western boundary, and the American River is its southern boundary. The eastern boundary, a roughly north-south line extending from the Bear River south to the American River, represents the approximate edge of the alluvial basin, where little or no groundwater flows into or out of the groundwater basin from the bedrock of the Sierra Nevada mountain range (Sierra Nevada) (DWR, 1997).

The bottom of the Subbasin is defined as either bedrock (igneous and metamorphic) that can be found cropping out in the foothills east portion of the Subbasin or the top of the marine sediments (base of fresh water). Fresh water is defined as water having salts that result in an electrical conductivity measurement of less than 3,000 micromhos (Berkstresser, 1973). The base of fresh water occurs near ground surface in the eastern portions of the Subbasin and deepens westward to more than 2,000 feet below mean sea level (msl) near the southwestern corner of the Subbasin. **Figure 4-1** shows the base of fresh water.

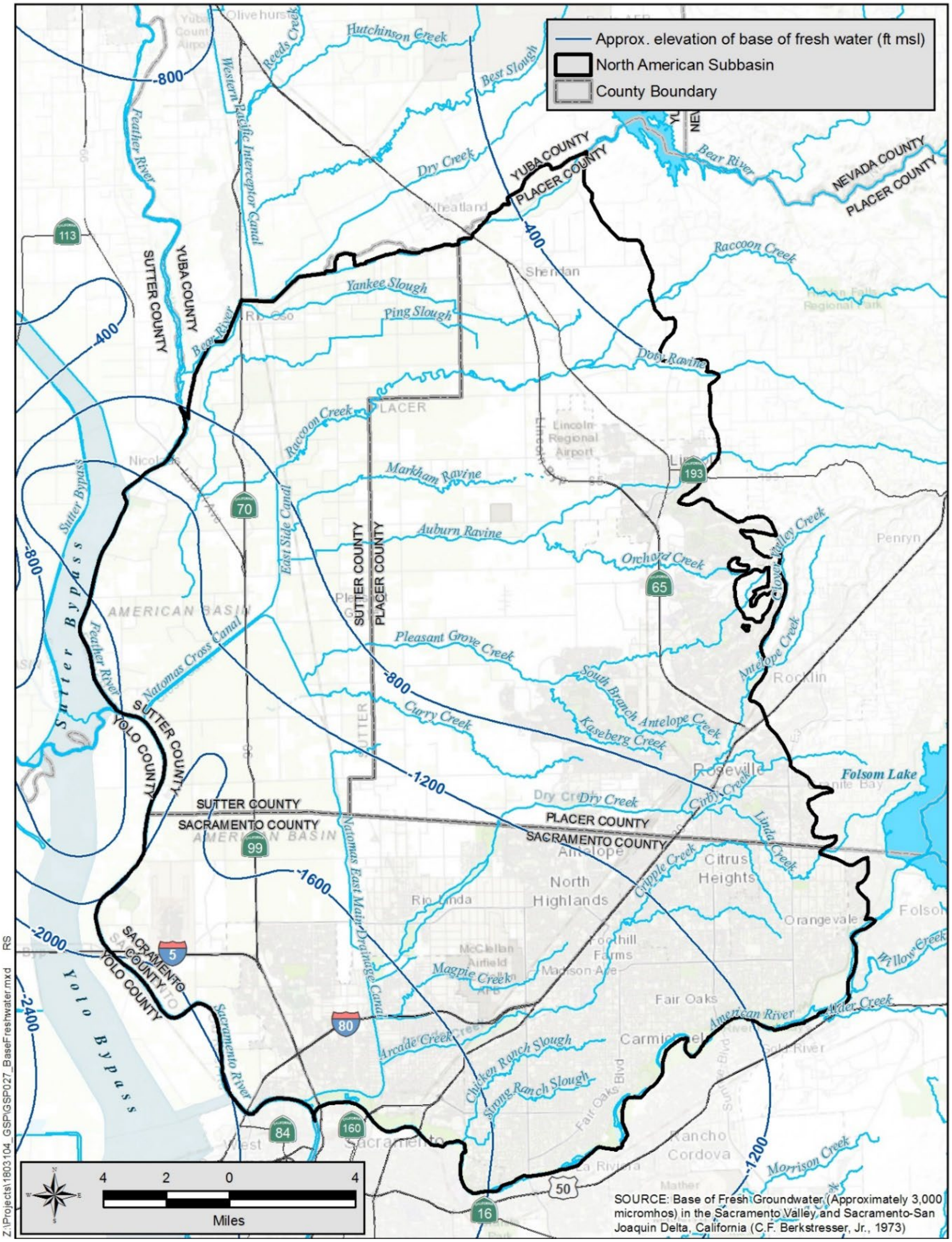

Figure 4-1. Base of Fresh water

4.2 Topography

The topography in the NASb is irregular in the eastern portion of the Subbasin whereas the western portion of the Subbasin is nearly flat. The elevation in the Subbasin ranges from about 20 to 300 feet above mean sea level (msl). In the eastern portion of the NASb, ground surface is characterized by low rolling dissected uplands. The western half of the Subbasin is nearly flat, with elevations ranging from 20 feet above msl near the Feather and Sacramento rivers to about 50 feet above msl in the central portion of the Subbasin. The lowest land elevations are located near the southwestern corner of the Subbasin, near the confluence of the Sacramento and American rivers. The topography of the Subbasin is shown in **Figure 4-2**.

4.3 Surface Water Bodies

There are no large lakes or reservoirs in the NASb. There are numerous lakes and reservoirs within the Bear and American watersheds that contribute water to the NASb. The lowest elevation reservoirs in the watershed are Folsom and Camp Far West, which control flows in the American River and the Bear River, respectively. There are numerous smaller reservoirs above both Folsom and Camp Far West reservoirs.

Below Folsom Reservoir and within the NASb is Lake Natomas, which is a small lake that ponds water and may provide some recharge to the Subbasin. Outside of the Subbasin and watershed, to the north, are Lake Oroville and Shasta reservoirs, which regulate flow to the Feather and Sacramento rivers, respectively. Flows in these rivers, especially during the summer months, are predominantly due to regulated releases through dams that created these reservoirs and lakes.

The Subbasin is drained by numerous creeks and ravines that are tributary to the American, Bear, Feather, and Sacramento rivers (**Figure 4-2)**. Most of the creeks and ravines drain either to the East Side Canal and Natomas Cross Canal or the Natomas East Main Drainage Canal. These canals were constructed to reclaim and provide flood protection for lands west of the canals.

Water in the tributaries is present due to rain (winter months), tailwater from Placer County Water Agency and Nevada Irrigation District canal systems, conveyance of transferred water, and treated water from wastewater treatment plants. In the western portion of the Subbasin, groundwater may discharge seasonally to drainage canals and the Feather and Sacramento rivers.

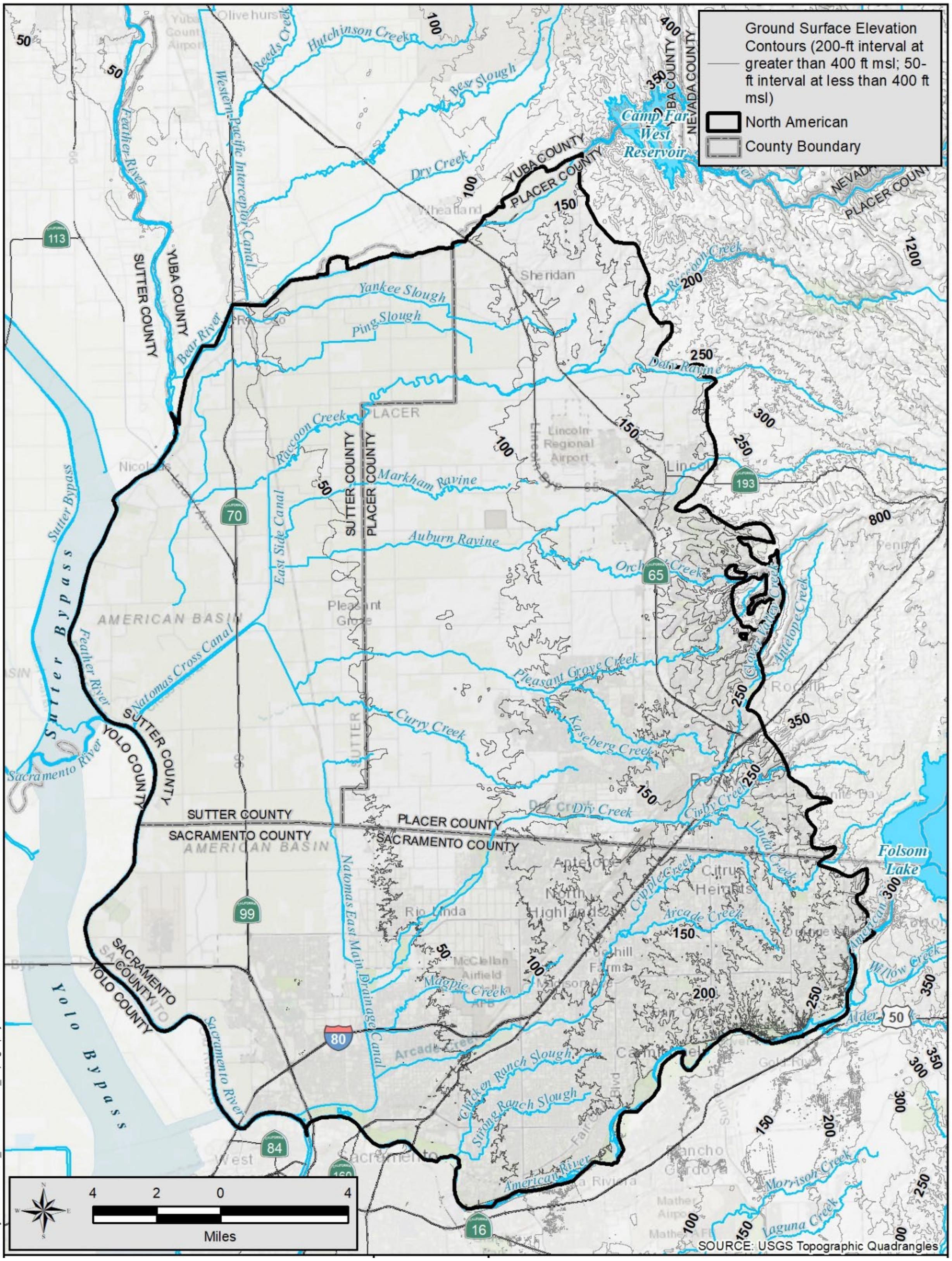

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Figure 4-2. Topography

4.4 Soils

The NASb is covered by soils whose age, in general, corresponds with the relative age of the geologic units. The oldest soils lie along the eastern margin of the study area, with progressively younger soils toward the west. Most of the soils in the eastern three-fourths of the study area have well-developed profiles, usually with claypans and hardpans (U.S. Soil Conservation Service, 1980 and 1987). The dense subsoil in these areas may limit deep percolation of precipitation and applied irrigation water.

Soil permeability provides an initial indication of where recharge to the underlying aquifers may occur. Soil types and attributes have been mapped in the NASb by the U.S. Department of Agriculture's Natural Resources Conservation Service and are contained in a database (SSURGO, 2019). The Hydrologic Soils Grouping describes the soil's drainage characteristics. The groups range from Type A soils, which are well drained (high infiltration rates), Type B that are moderately drained, Type C that are poorly drained, and Type D soils that are very poorly drained (very slow infiltration rates). **Figure 4-3** shows the soil types by hydrologic groupings in the Subbasin. Much of the Subbasin is covered with poorly drained Type C and D soils. While these poor infiltration rate soils often inhibit flow to the subsurface, these soils classifications are generalizations of soil types and localized windows of connection to the underlying aquifers can exist, particularly when streams are incised through the soil profile. Most of the coarse-grained, well-drained soils occur along rivers and major stream channels and some along the eastern margins of the Subbasin.

While the Hydrologic Soils groups shown on **Figure 4-3** indicate the hydrologic characteristics of the soils, the Soil Agricultural Groundwater Banking Index (SAGBI), developed by researchers at UC Davis (O'Geen, et al., 2015), also considers factors that affect the suitability of active agricultural lands for groundwater recharge, including root zone residence time, topography, chemical limitations, and soil surface condition. The UC Davis researchers developed an index that ignores restrictive layers in the first 6 feet. This "modified SAGBI" is shown on **Figure 4-4** and assumes that tillage practices could break up the shallow restrictive layers. These kinds of tillage (or ripping) practices may already have been used in certain areas that may have greatly enhanced the soil's hydrologic characteristics and increased their permeability. **Figure 4-4** shows a much larger area of more permeable soils than shown on the SSURGO soils map in **Figure 4-3**. Note that the white/gray areas do not contain the data necessary to calculate the SAGBI.

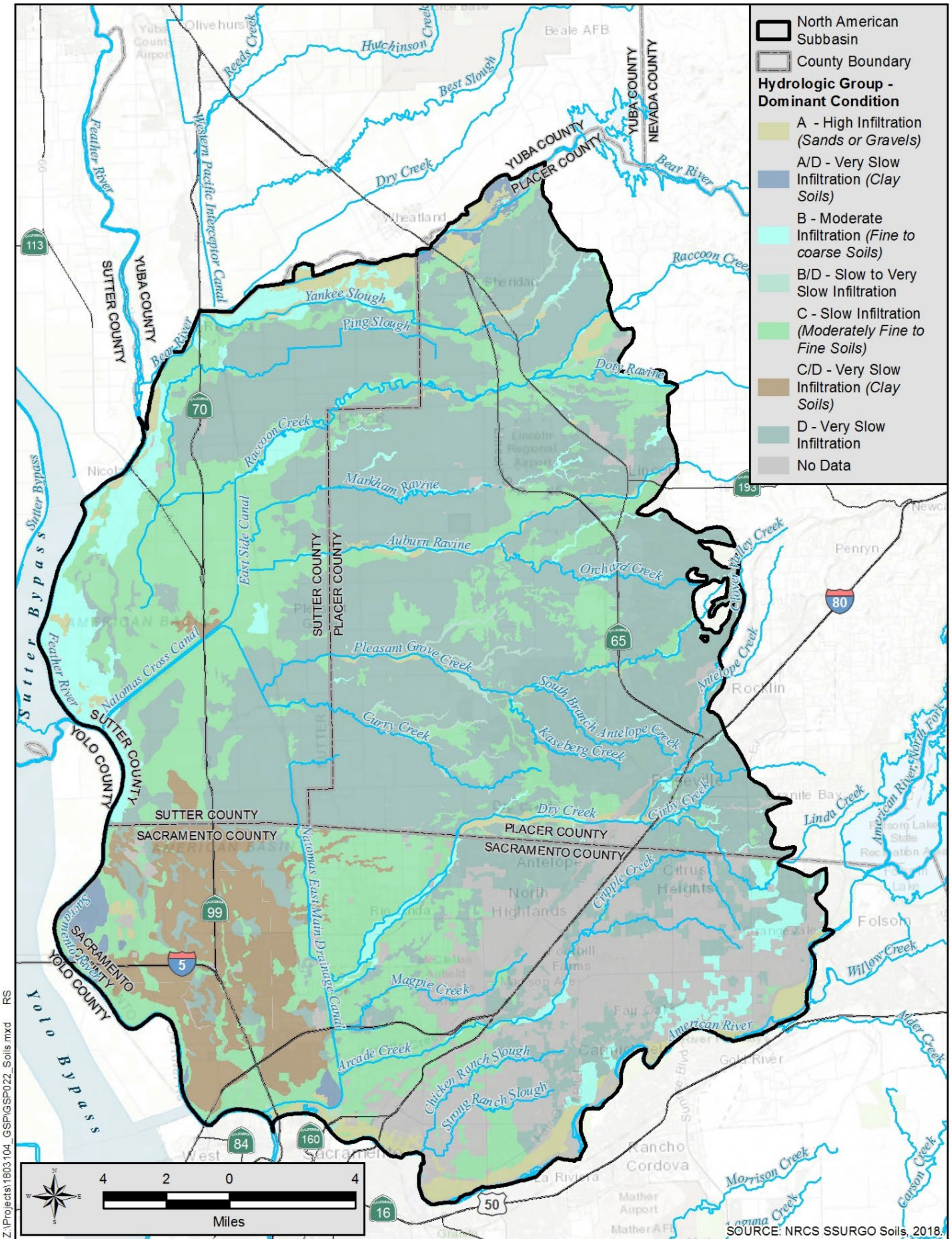

Figure 4-3. Hydrologic Soils Classification

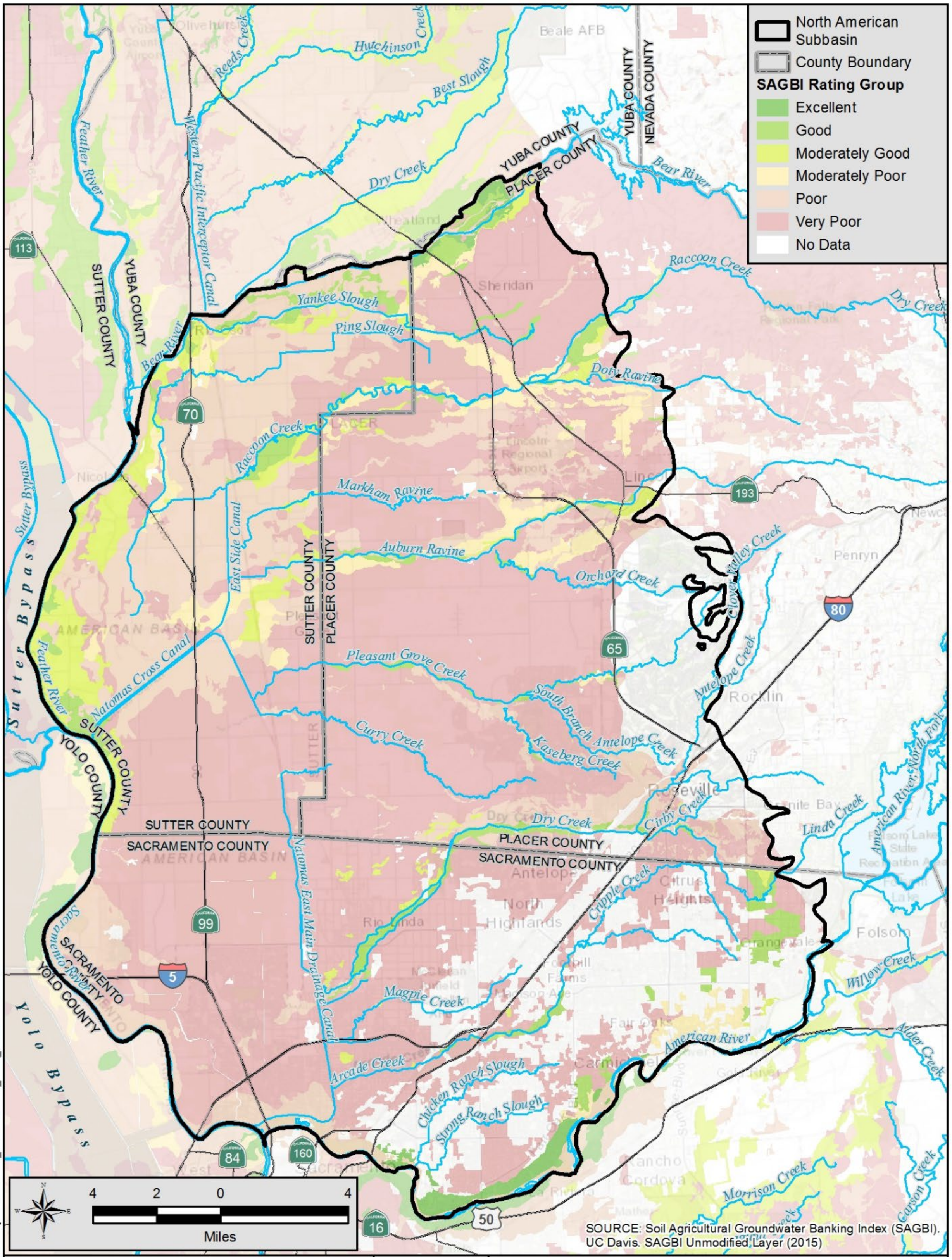

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Figure 4-4. SAGBI Soils

4.5 Regional Geology

The Sacramento Valley is a large depression bounded on the east by the Sierra Nevada, a block mountain range faulted upward on the east and dipping westward beneath the Sacramento Valley. The Sierra Nevada consists of metamorphic rocks intruded by igneous rocks. The Sacramento Valley is bounded on the west by the Coast Range mountains.

Younger river and creek-lain deposits comprise the major portion of the freshwater aquifer system in the Sacramento Valley. The sediments beneath the NASb depict a regional change in the environments, from one previously dominated by marine sedimentary processes to one with continental sedimentary processes. The Sacramento Valley, including the NASb, is filled with marine sedimentary rocks that contain ancient seawater and traps of natural gases. The Valley Springs and Ione formations were deposited during the conversion from marine to continental environments. These formations contain both fresh and brackish water (having salts that result in an electrical conductivity measurement of greater than 3,000 micromhos). Both formations are overlain by younger, continentally derived sediments that have been grouped into the Younger Alluvium and the Modesto, Riverbank, Turlock Lake, Laguna, and Mehrten formations. **Figure 4-5** shows the distribution of these sediments in the Subbasin at ground surface. These formations contain fresh, mostly potable water. Clear distinctions and confining layers that separate formations often do not exist and water movement between formations can occur.

4.6 Geologic Structure

During the deposition of sediments, the valley has been gently down-warped due to tectonic activities and consolidation of the sediments. Sediments generally dip toward the center of the valley at about a 4-degree dip. Therefore, near the eastern edge of the Subbasin, older sediments such as the Mehrten Formation are exposed at the ground surface while to the west these sediments occur as deep as 2,000 feet below ground surface.

Faults may affect groundwater flow by bringing geologic materials with different hydraulic properties into contact across the fault plane or by fracturing the sediments, which could either increase or decrease permeability. Faults might, therefore, act as a boundary or barrier affecting the lateral flow of groundwater between adjacent areas and could act as a conduit allowing vertical upward flow within the fault zone. There are no known active faults within the Subbasin (DWR, 1997), but there are older inactive faults that may affect groundwater quality. One of these older faults is the Willows Fault, which is a northwest-southeast trending reverse fault that dips 74 degrees to the east and extends from the Stockton area through the NASb and to the north end of the Sacramento Valley (Harwood and Helley, 1987). **Figure 4-5** shows the location of the fault. Displacement along the Willows Fault is approximately 1,600 feet and displaces older marine sediments up to the time of deposition of the Ione Formation (Harwood and Helley, 1987). It does not continue into the fresh water-bearing sediments and therefore is not a barrier to groundwater flow. Although the fault is not designated by the state as active, the fault does

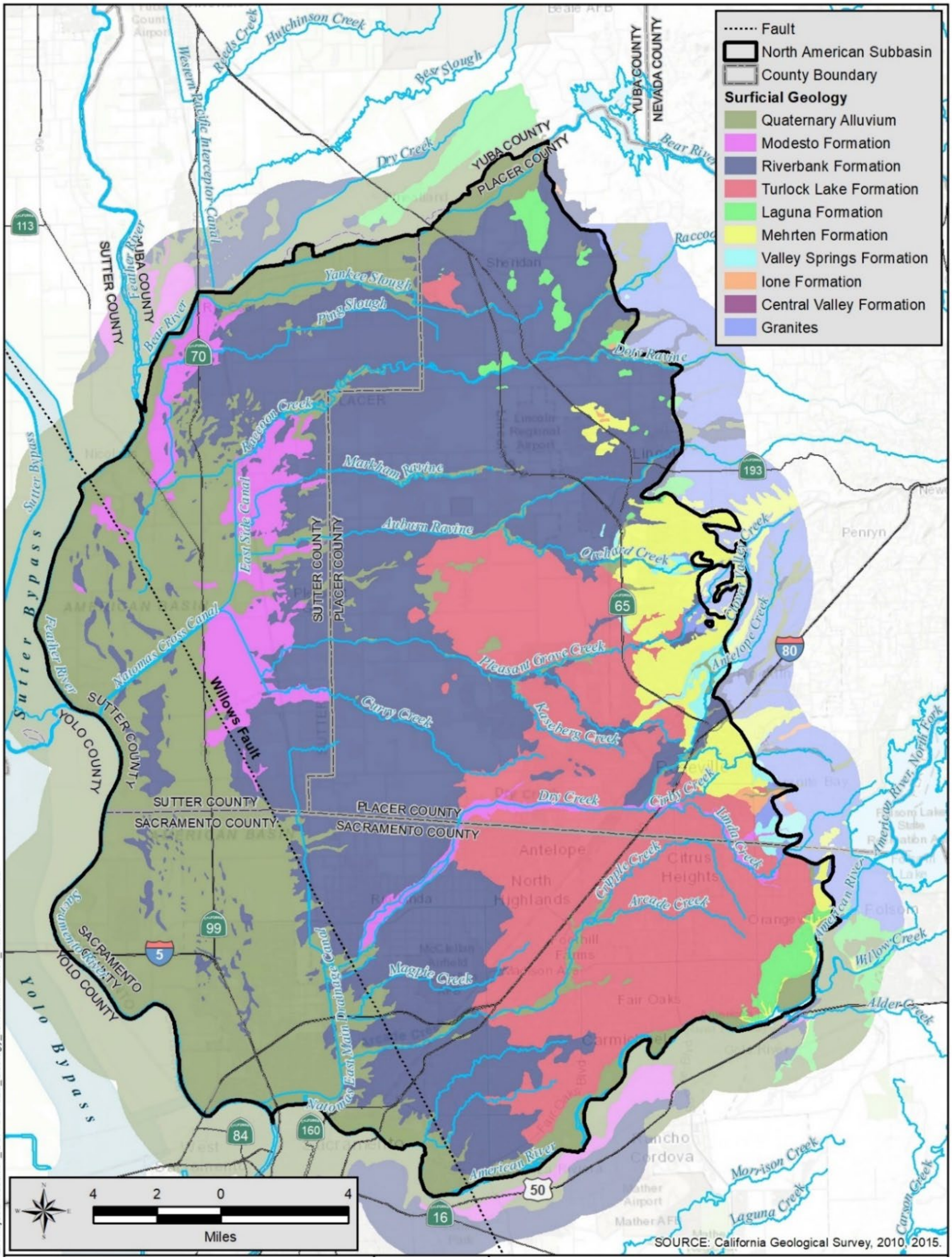


Figure 4-5. Surface Geology

appear to have some movement. The slip rate on the Willows Fault is very small, estimated to be 0.00055 inches per year (McPherson and Garven, 1999, reference in DWR, 2014), but still suggests some activity.

4.7 Fresh Water-Bearing Formations

Fresh water-bearing sediments in the NASb from shallow/youngest to deepest/oldest sediments include the Quaternary Alluvium and the Modesto, Riverbank, Turlock Lake, Laguna, and Mehrten formations. These formations are of similar ages and have been grouped together for discussion purposes below. Surface outcrop formations are shown in **Figure 4-5**.

4.7.1 Quaternary Alluvium

Quaternary Alluvium is the youngest geologic unit (current to 10,000 years old) in the Subbasin. Laterally extensive outcrops of the Quaternary Alluvium deposits occur along the American, Bear, Feather, and Sacramento rivers. The alluvium is separated into three types: those associated with stream channels, with flood basins, and with alluvial fans (sediments deposited by streams as they emerge onto the valley floor).

The stream channel deposits originate in the channels of active streams and as overbank deposits of those streams, terraces, and local dredge tailings. Alluvium consists of sand, gravel, silt, and minor clay. The most extensive deposits occur along the American, Bear, Feather, and Sacramento rivers. Near the junction of the Bear and Feather rivers, coarse-grained sediments are present at depths up to 140 feet. However, the deeper sediments probably belong to the Modesto and Riverbank formations. Along the Bear River, the thickness of the alluvium is estimated to be 25 to 60 feet thick (Olmstead and Davis, 1961). The alluvium is also exposed along the smaller streams draining the Subbasin and is probably only a few tens of feet thick.

Flood basin deposits consist primarily of poorly drained silts and clays, although local lenses of sand and gravel may occur from the deposition of migrating ancestral river channels. The thickness of each of these units may be up to 100 feet (Olmstead and Davis, 1961). Flood basin deposits crop out on the western margin of the Subbasin, immediately east of the Sacramento River.

Alluvial fan deposits are derived from the Sierra Nevada and are generally coarse-grained. They are present along the eastern edge of the Sacramento Valley where they overlie the Mehrten, Ione, and Valley Springs formations.

4.7.2 Modesto and Riverbank Formations

The Pleistocene-age (10,000 to 2 million years) Modesto and Riverbank formations are the most widely exposed geologic units in the study area. They unconformably overlie the Turlock Lake, Laguna, and Mehrten formations and the metamorphic and igneous rocks near the eastern margin of the Subbasin. The Modesto and Riverbank formations were derived from similar parent rocks and are indistinguishable (lithologically) in the subsurface, composed of mixtures of silt, sand, gravel, and clay that are very heterogeneous both laterally and vertically. The combined thickness of these two formations can be up to 75 feet. These two formations are moderately permeable but include highly permeable coarse zones (Olmstead and Davis 1961).

4.7.3 Turlock Lake and Laguna Formations

Underlying the Modesto and Riverbank formations are the early Pleistocene-age (2 to 10 million years) Turlock Lake Formation and Pliocene-age Laguna Formation. The Turlock Lake and Laguna formations unconformably overlie the Mehrten Formation. The units underlie dissected uplands along the eastern margin of the study area and dip westward beneath the land surface toward the axis of the valley. The exposures of the Laguna Formation are small and discontinuous, generally less than a few square miles in area, and limited to the northeastern corner of the NASb. The Turlock Lake Formation is exposed on ground surface in a wide band near the southeastern corner of the NASb.

The Turlock Lake and Laguna formations are lithologically indistinguishable. They are differentiated in outcrop by the presence of a preserved clay soil horizon in the Turlock Lake Formation (Helley and Harwood, 1985). The Turlock Lake and Laguna formations consist of a heterogeneous mixture of tan to brown interbedded silt, clay, and sand. Gravel lenses are scarce and, where present, are poorly sorted and have low permeability. Pebbles and cobbles of quartz and metamorphic rocks generally dominate the gravels (DWR, 1974; Olmstead and Davis, 1961). The combined thickness of the two units is probably less than 200 feet.

Due to the predominantly fine-grained character of these two formations, wells completed in them reportedly have low to moderate yields, usually less than 1,000 gallons per minute.

4.7.4 Mehrten Formation

The Mehrten Formation crops out along the southeastern Sacramento and Northern San Joaquin valleys and within the NASb. It is exposed only on the eastern side of the Subbasin near the City of Lincoln and south toward the City of Roseville and has been penetrated by wells as far west as the town of Nicolaus. The Mehrten Formation was deposited on an irregular eroded surface (unconformable) of marine sediments of the Valley Springs and Ione formations (Olmstead and Davis, 1961).

Depending on location, the Mehrten Formation is between 200 and 1,200 feet thick (DWR, 2003). It is thinnest in the eastern portion of the NASb and thickens towards the west. The thickness of the Mehrten Formation in the Sacramento Valley is about 200 feet where exposed and ranges between 400 and 500 feet in thickness in the subsurface (Page, 1986). Black sands are characteristic of the Mehrten Formation.

Two distinct units in the Mehrten Formation have been described in the Sacramento Valley—an upper unit composed of unconsolidated black sands interbedded with blue-to-brown clay, and a lower unit composed of hard, angular rock fragments in a fine grained matric (breccia), which is sometimes reported by well drillers as "lava" (DWR, 1978; Page, 1986). This breccia may act as a confining layer in the subsurface. The volcanic source material is from the Sierra Nevada.

Wells completed in the sand and gravel units have reported pumping capacities of over 3,000 gallons per minute.

4.8 Non-Water or Non-Fresh Water Bearing Formations

Non-water or non-fresh water bearing formations in the NASb include the Tertiary-age Ione and Valley Springs formations and the Paleocene to Eocene Central Valley Formation. These strata are underlain by crystalline igneous and metamorphic basement rock like those exposed in the foothills east of the Subbasin. The Ione and Valley Springs formations exist beneath the Mehrten Formation and are thought to be a transitional system that contains a mixture of saline and fresh groundwater.

4.8.1 Valley Springs Formation

The Valley Springs Formation is a sequence of mostly fluvial sediments that unconformably overlies the Ione Formation, and is composed of sandy clay, sand, rhyolitic ash, and siliceous gravel (Davis and Hall, 1959). Well-log information and outcrop exposure in the Sacramento Valley indicated that the Valley Springs Formation is estimated to be up to 200 feet thick (Piper and others, 1939; DWR, 1978). Fine ash and clay in the Valley Springs Formation limit the quantity of water produced by wells (Page and Balding, 1973). The Valley Springs Formation is exposed along Antelope Creek and in the community of Granite Bay.

4.8.2 Ione Formation

The Ione Formation was deposited on eroded surfaces (unconformably) of the Central Valley Formation and crystalline and metamorphic rocks near the eastern portion of the Subbasin. The formation is near the surface in most of the Placer County portion of the Subbasin generally east of Highway 65 and the foothills. The western extent of the Ione Formation is characterized by shallow marine deposition in the remnants of the inland sea, while the eastern extent of the formation is characterized by non-marine deltaic deposition (Redwine, 1984; Springhorn, 2008). It is exposed in the clay pit area near the city of Lincoln. The thickness of the formation varies because the top is eroded. The formation is about 200 to 300 feet thick in the vicinity of the city of Roseville, 500 to 600 feet thick in the vicinity of the city of Lincoln and thickens to about 1,000 feet at the western margin of Placer County. There are also small exposures in the Granite Bay area.

Clean sands of the Ione Formation are partially and erratically flushed by fresh waters in the area between the foothills and Highway 65. However, there is very little movement of groundwater in this formation, and due to low yields and poor water quality, it is not considered an economical source of groundwater for irrigation. Owing to the degree of consolidation and clay content, the Ione Formation yields a limited quantity of water to wells (DWR, 1978; Page, 1986).

4.8.3 Central Valley Formation

Overlapping the granite and metamorphic crystalline bedrock are the Upper Cretaceous marine sedimentary rocks that compose the Central Valley Formation. The strata form a wedge thickening generally westward beneath the Subbasin. Water contained in these sediments is generally saline and of very low yield to wells. The total thickness of the Central Valley Formation near the eastern portion of the Subbasin where it overlaps on the bedrock is only a few hundred feet thick, but it increases to several thousand feet thick near the western boundary of the Subbasin.

The Central Valley Formation and other marine formations contain economic quantities of natural gases. Several small gas fields are located primarily along the western border of the Subbasin, near the Willows Fault. Drilling and operation of natural gas wells are highly regulated by the California Geologic Energy Management Division (commonly known as “CalGEM”), formerly known as Division of Oil, Gas, and Geothermal Resources, which was formed in 1913. However, exploration holes and abandoned wells drilled prior to 1913 and not properly sealed could affect freshwater quality. At this time, no water quality problems in the Subbasin can be directly attributed to these holes or wells. **Figure 4-6** shows the locations of the natural gas wells in the Subbasin, illustrating potential areas where old exploration holes may have been improperly abandoned but could provide vertical conduits for brackish water to intrude the freshwater aquifers.

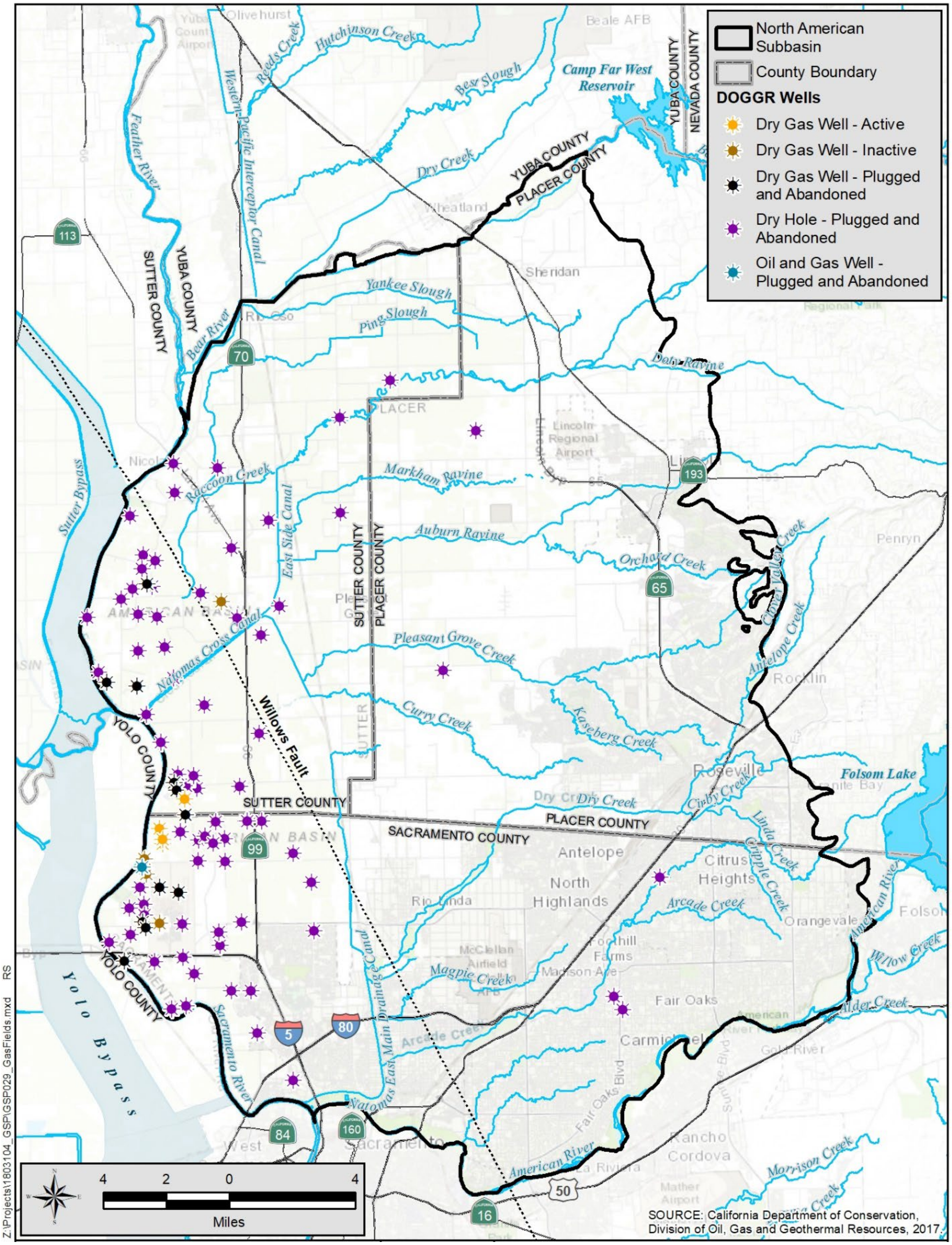


Figure 4-6. Natural Gas Wells

4.8.4 Basement Rocks

All of the formations and sediments mentioned above are underlain by igneous and metamorphic rocks, potentially similar to those exposed in the Coast Ranges and in the Sierra Nevada. Along the eastern margin of the Subbasin where the Ione and Central Valley formations are present at shallow depths, generally north of the city of Lincoln, domestic and agricultural well owners have constructed wells into the basement rocks, due to the low yielding and poor-quality water in the marine sediments, to obtain fresh water.

4.9 Regional Geologic Sections

Three geologic sections were created for this Groundwater Sustainability Plan (GSP) using previous sections developed by DWR (1997) and are straight lines through the Subbasin as shown on **Figure 4-7**. The coarse-grained sediments (sands and gravels) that are aquifers were deposited as stream or river channels that meandered through the Subbasin in a sinusoidal (snake like) pattern and therefore a straight profile may not show their full extent or their inter-connectedness. **Figure 4-8** illustrates these channel deposits and how they wander and may be stacked upon each other (DWR, 1974).

Geologic sections of the Subbasin exist from multiple sources, but historical sections did not cross the entire Subbasin. The longest and most detailed sections were prepared by DWR (1997). The DWR sections were used as a starting point and modified to extend across the entire Subbasin for this GSP effort. Lithologic information from well logs was normalized and digitized to generally conform with the Unified Soil Classification System. Lithology and well screens from dedicated groundwater monitoring wells, constructed after the DWR sections were created, were also added to the geologic sections for this GSP effort. The profiles are presented to illustrate the subsurface relationships and distribution of the formations and coarse-grained sediments that constitute principal aquifers. The profile locations are shown on **Figure 4-7**. **Figures 4-9, 4-10, and 4-11** illustrate the subsurface with sediment types, saturated sediments, and the base of fresh water. These figures were created from the well driller's reports attached in **Appendix D**.

The profiles show the general contact between the Mehrten Formation and younger formations. The profiles also show different dips of the aquifers respecting the unconformities previously documented.

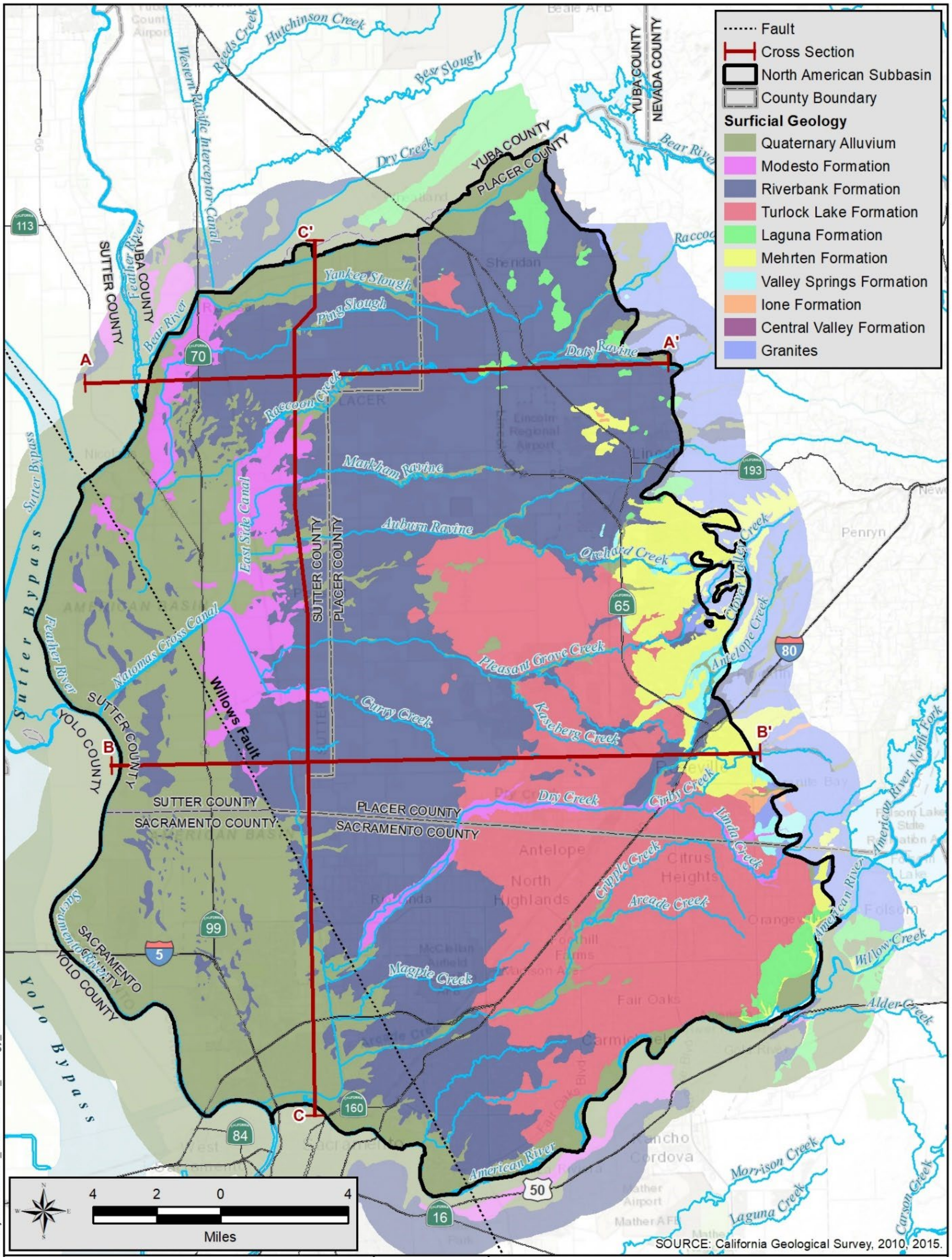


Figure 4-7. Geologic Section Locations

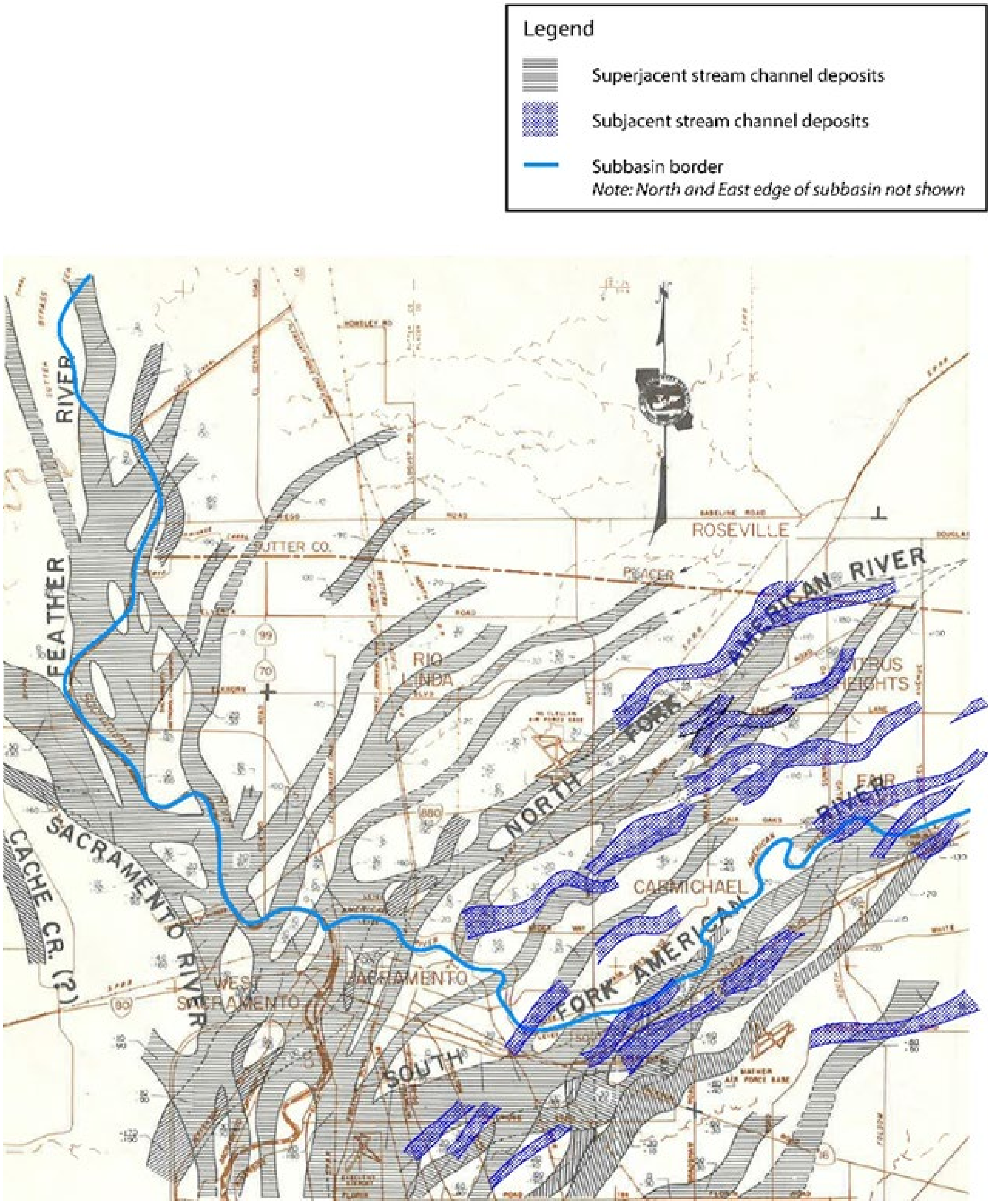


Figure 4-8. Stream Channel Deposits

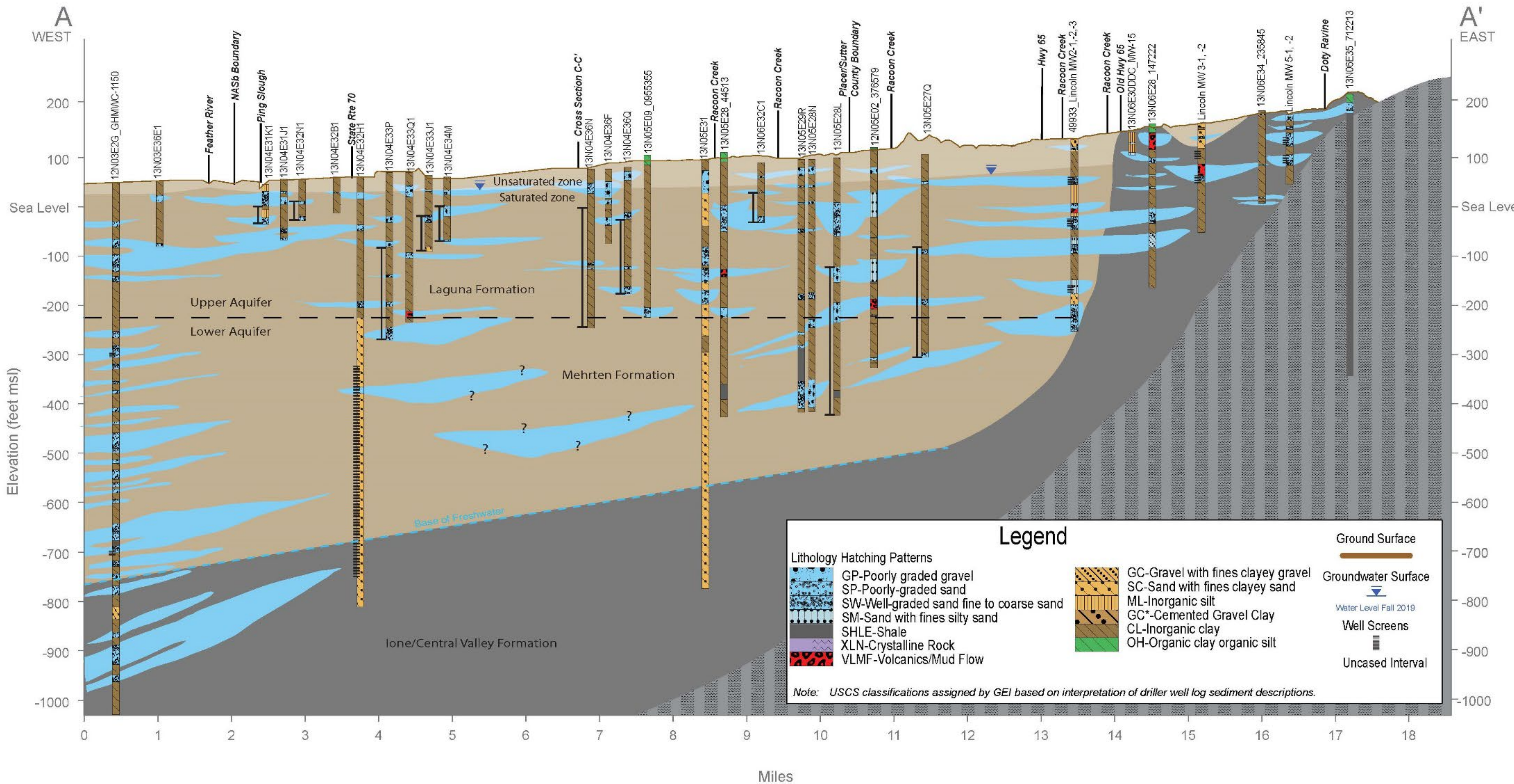
4.9.1 Section A-A'

Figure 4-9 shows Geologic Section A-A', a regional east-west profile through the northern portion of the Subbasin. Section A-A' generally runs parallel to the direction of groundwater flow.

Section A-A' shows that the eastern area generally has clays and silts (shown in brown color), low permeability sediments near surface, and permeable sediments (sands and gravels shown in light blue) throughout the depth profile. Continuous layers of sand and gravels are not identified likely due the sinusoidal nature of the river channels associated with these types of sediments.

In the western portion of the Subbasin, fine-grained sediments are more prevalent and, supported by groundwater levels and water quality information, suggest that the shallow aquifer is unconfined and separate from the deeper semi-confined to confined aquifers in the Mehrten Formation.

Cross sections A-A' and B-B' show the general shape of the groundwater gradient at the northern end of the Subbasin where water levels are highest in the east and decrease to the west. The Ione Formation, or the base of fresh water, is at or near surface in the eastern portions of the Subbasin and has multiple permeable sediment layers that could contribute brackish water to the fresh-water-bearing aquifers in the Laguna and Mehrten formations. The top of the Ione Formation and the base of fresh water is relatively shallow in this portion of the Subbasin.



Source: DWR, 1995. Modified by GEI 2019. Berkstresser, 1973.

Figure 4-9. Geologic Section A-A'

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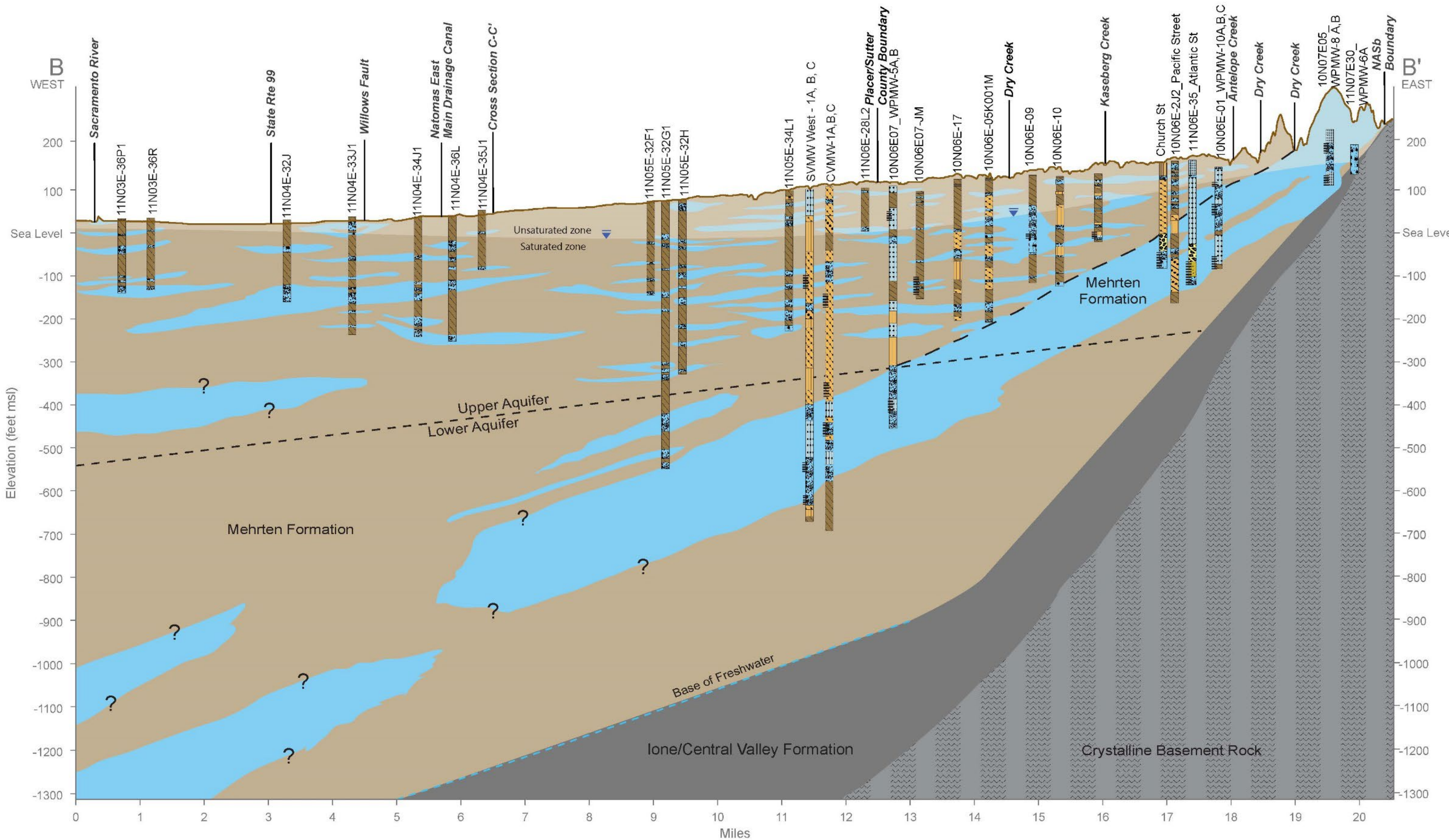
4.9.1 Section B-B'

Figure 4-10 shows Geologic Section B-B', an east-west profile located near the Sacramento, Placer, and Sutter County lines. Section B-B' generally runs parallel to the direction of groundwater flow.

Section B-B' shows the layering of Laguna, Mehrten, and Ione formations. The Mehrten Formation and its permeable sand and gravel are exposed at ground surface in the eastern portion of the Subbasin, near the city of Roseville, and can be traced to the west indicating this area can allow surface water to recharge the aquifers to the west. Toward the west, the Mehrten Formation thickens and deepens.

Section B-B' shows the groundwater levels across the central area of the Subbasin. Water levels are highest in the east, where recharge from the Sierra Nevada originates. To the west, water levels are depressed at the center of the Subbasin and are shallower further to the west. The base of fresh water is much deeper in this area than to the north as is shown on Section A-A'.



Source: DWR, 1995. Modified by GEI 2019. Berkstresser, 1973.

Figure 4-10. Geologic Section B-B'

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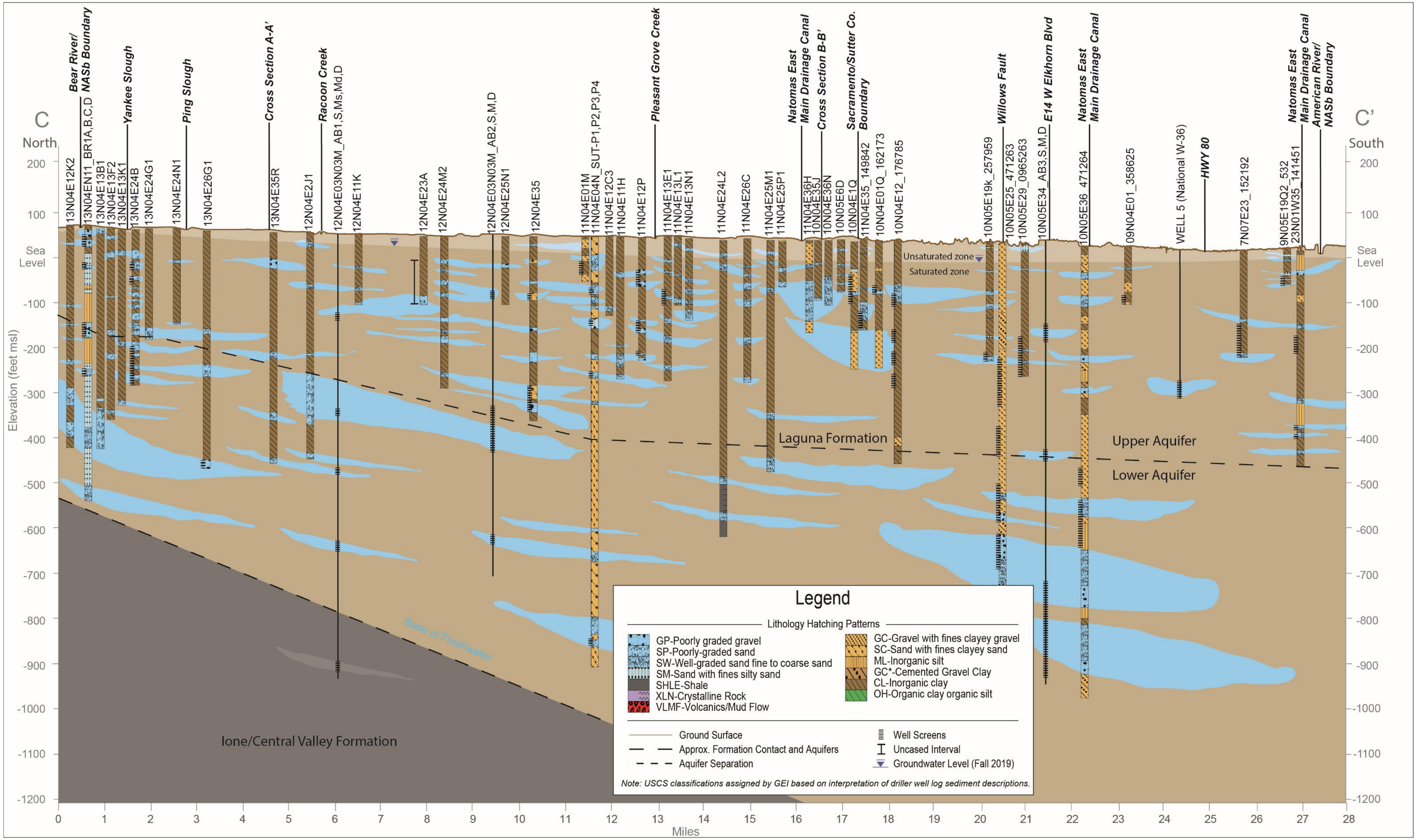
4.9.1 Section C-C'

Figure 4-11 shows Geologic Section C-C', a north-south profile that extends the length of the Subbasin. Section C-C' is generally perpendicular to the direction of the deposition of the sediments (bedding dip).

Fine-grained sediments appear to be more prevalent in the northern portion of the Subbasin, while more interconnected aquifers exist along the southern portions of the section. The base of fresh water is shallower in the northern portions of the Subbasin and dips steeply to the south before projecting below the depth profile.



Source: DWR, 1995. Modified by GEI 2019. Berkstresser, 1973.

Figure 4-11. Geologic Section C-C'

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4.9.2 Geotechnical Investigations Sections

In addition to these regional geologic sections, geotechnical investigations (to depths of up to 140 feet) have been performed along portions of the American, Bear, Feather, and Sacramento River levees. These studies provided subsurface information to design levee improvements to reduce seeps that could de-stabilize the levees during flood events. Profiles (geologic sections) were developed as part of these investigations. The investigations show sediment types where groundwater and surface water interactions occur, and where the Sacramento River (bathymetric elevations) has cut partially or entirely through coarse-grained sediments that are part of the shallow aquifer. They also show where man-made slurry walls were constructed that have reduced or eliminated this connectedness and where they are planned to be built. **Figure 4-12** shows the areas where slurry walls have been constructed. **Appendix E** provides these geologic profiles along the rivers. The sections do not contain a breakout of the geologic formations but, in general, dependent upon the location, would include Alluvium, Flood Basin Deposits, and Modesto and Riverbank formations.

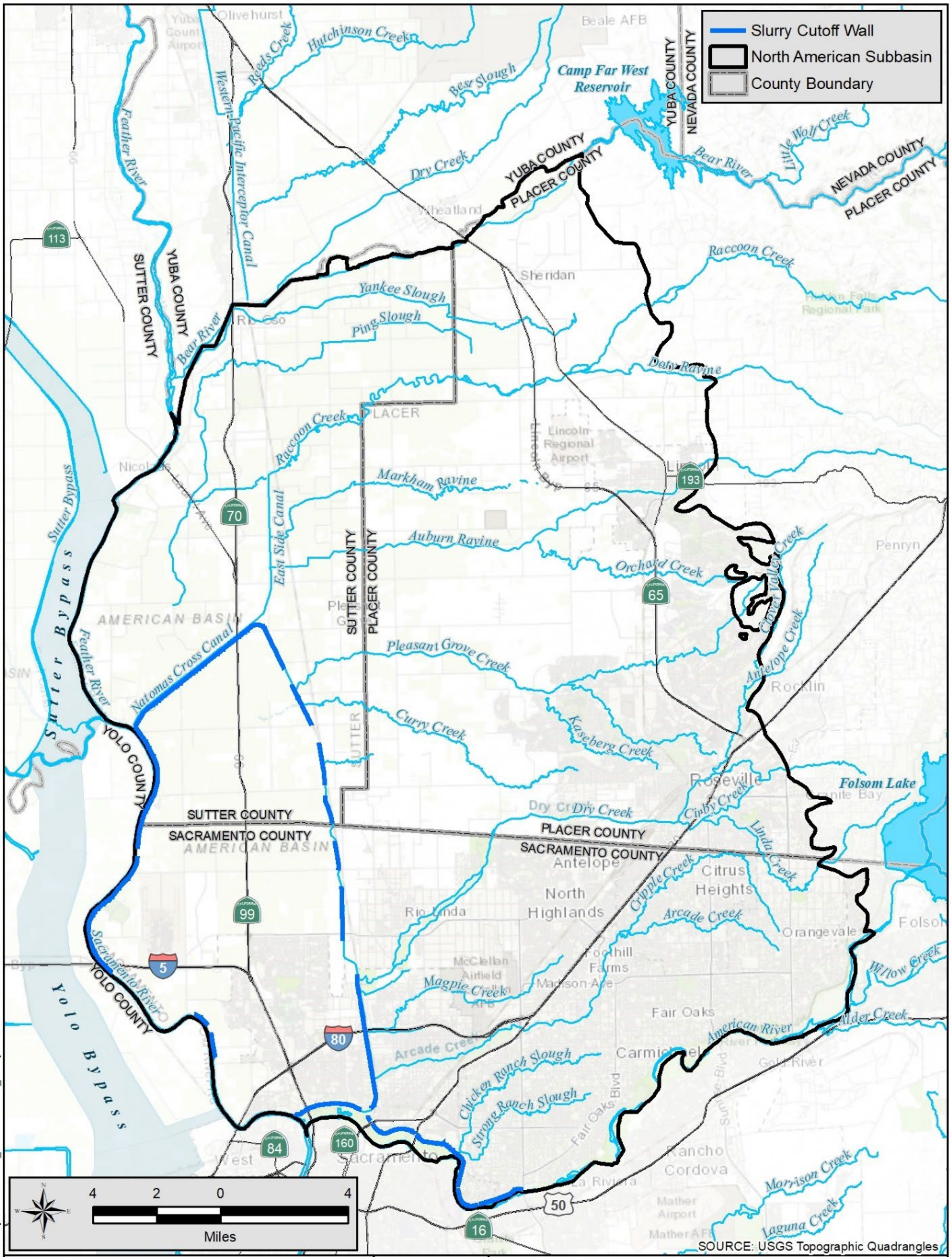

Figure 4-12. Detailed Geologic Sections - Slurry Cut Off Walls

4.10 General Water Quality

Most of the groundwater in the Subbasin can be grouped into two general types based on which minerals[1] are present at highest concentrations. If no one anion or cation are predominant, multiple names may be listed. Water Type 1 is a magnesium-calcium bicarbonate and is present in the shallowest aquifer zones sampled with one exception. Water Type 2 is a sodium bicarbonate water and is typically found at the intermediate depths (up to about 850 feet). Type 1 resembles Type 2 except that the percentage of cations changes (sodium is becoming more dominant). **Figure 4-13** shows the distribution of the water types in the Subbasin. The relative percentages of anions are similar for both water types. This may support the idea of cation exchange as a major factor in the evolution of chemistry of the groundwater (DWR, 1997).

Monitoring wells have been installed to provide information on discrete changes in water chemistry with depth. Although the data are limited, there appears to be a trend in the water chemistry with depth (DWR, 1997) changing from calcium-dominated water to magnesium and from bicarbonate to sodium with depth.

In the deepest monitored zone (well AB-1 deep, located in South Sutter Water District's corporate yard), the chemistry changes significantly and is characterized as sodium chloride water. The chemistry of well AB-1 deep (screened below the base of fresh water) is considered to be water that was deposited at the time of deposition of the sediments (connate water) in the Sacramento Valley. This well has groundwater with an electrical conductivity of about 1,800 micromohs per centimeter and is considered to be brackish water. Because of the regional southwestern dip of formations in the area these waters are closer to ground surface in the eastern portions of the Subbasin. Sodium chloride water is known to occur near the Bear River and Highway 65 where the Ione Formation is near the ground surface (**Figure 4-13**). Water quality evaluations in the eastern portions of the Subbasin, north of the city of Lincoln, have not been able to distinguish any significant effects of connate water discharging to freshwater (GEI, 2019).

There are multiple wells with chloride as the predominant anion, which suggests there may be mixing of connate water with fresh water (DWR, 1997). **Figure 4-14** shows the types of water in some of the monitoring wells in the Subbasin. Sodium chloride water may also be present due to evaporation of water as seen in some localized areas.

[1] cations which are calcium, magnesium, and sodium; and anions which are bicarbonate, sulfate, and chloride

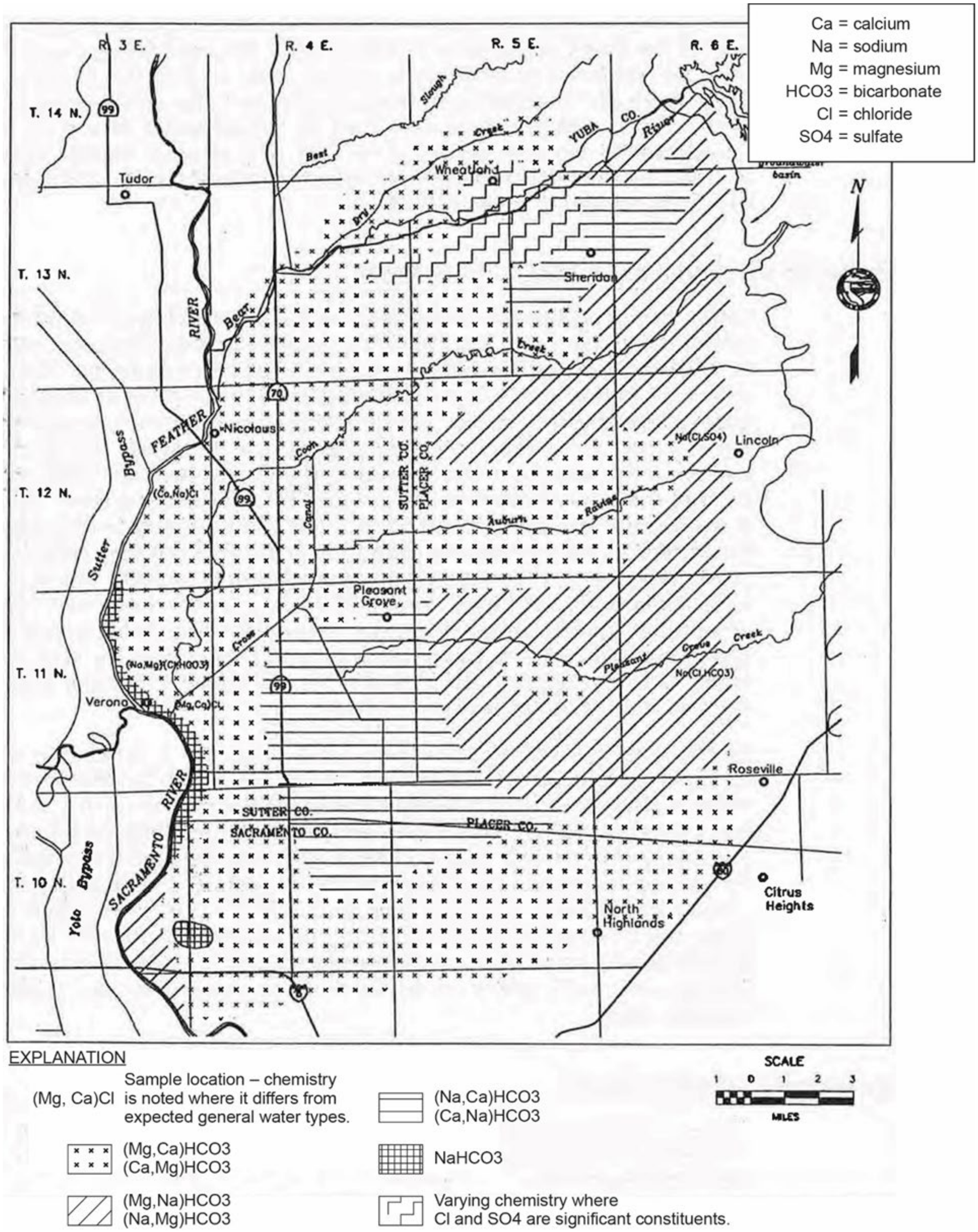

Figure 4-13. General Water Quality Types and Distribution

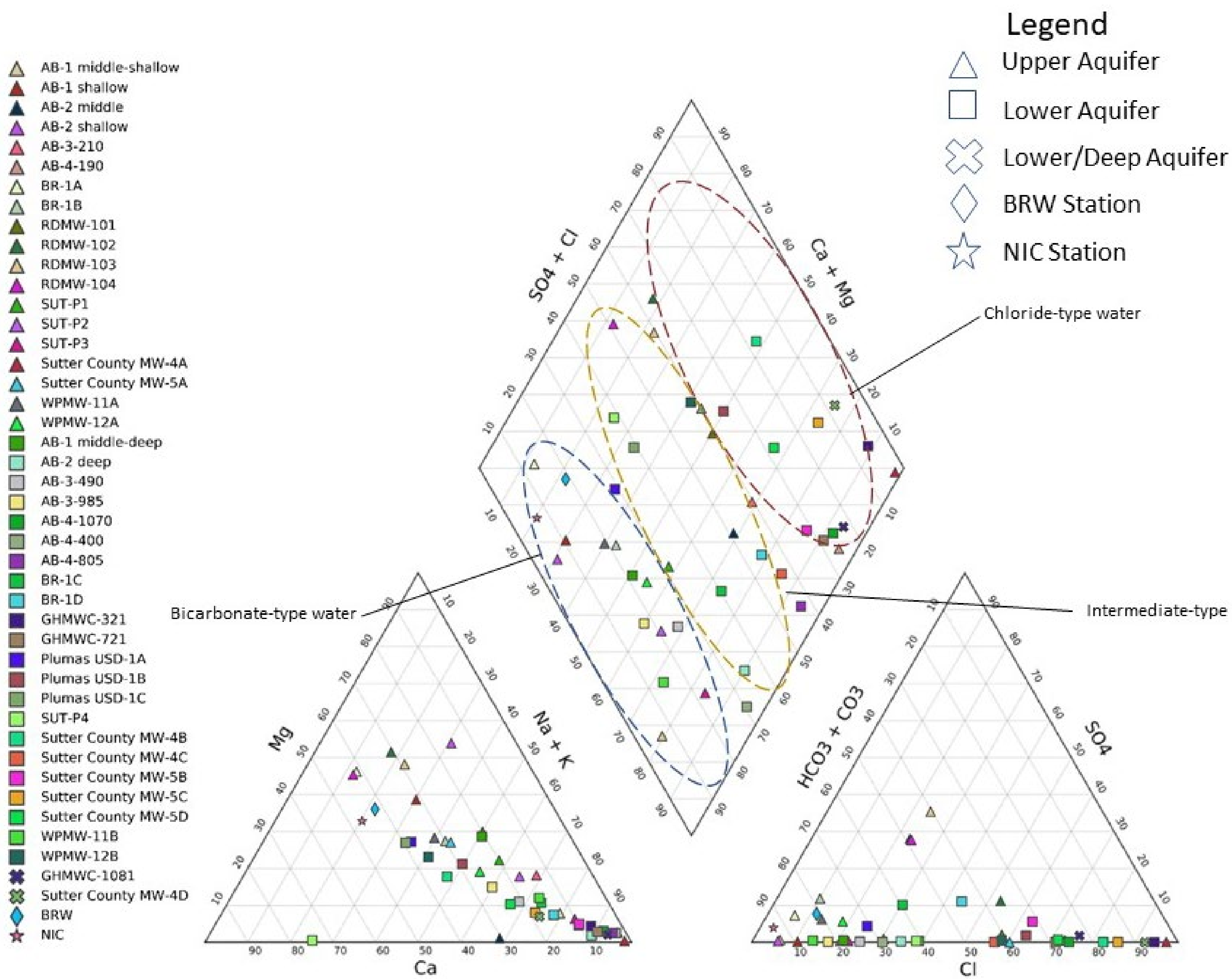

Figure 4-14. General Water Quality Types

4.11 Principal Aquifers

All sediments, to some extent, contain groundwater in the pores between particles. Near ground surface sediment pores are filled with mostly air but have some moisture. This moisture will gradually migrate down to the groundwater surface where the sediment pores will be entirely filled with water. At times there are low permeability sediment layers with a limited horizontal extent, where the moisture accumulates and fully fills the sediment pores, but the underlying sediments and pores are not filled with water. These occurrences are called Davis a water and do not constitute a principal aquifer. At the edges of these low permeability sediments, the water may then resume its vertical path to the groundwater surface. Aquifers are those coarse-grained sediment layers whose pores are completely filled with water and can be managed.

The aquifers underlying NASb are composed of cobbles, gravel, and sand, which are interspersed with deposits of silt and clay. Those interspersed layers are deposited in stream channels, alluvial fans, or floodplains by rivers draining the Sierra Nevada and the upper Sacramento Valley. DWR's Bulletin 118-3 describes the aquifers as "…a number of now-buried stream channel deposits. These deposits, which are composed of permeable sand and gravel, are enclosed by less permeable silt and clay. This has resulted in a network of meandering tabular aquifers." A graphic interpretation of the location of those ancestral channels is shown on **Figure 4-8** (DWR, 1974) for portions of the NASb. This complex system of intertwined and interbedded, fine and coarse-grained sediments interconnects shallow and deeper aquifers (DWR, 1997).

The geologic units described above were grouped and separated into two aquifers, an upper and lower aquifer system, by DWR in its evaluation of a proposed conjunctive use program in the NASb in the mid-1990s (DWR, 1997). The upper aquifer was defined as the upper 200 to 300 feet of the aquifer system. The lower aquifer was defined as extending from about 200 to 300 feet below ground surface to the base of fresh water. "The division between the two aquifers is inexact, due to the difficulty in accurately determining the formation contacts." The aquifer systems were, in part, defined by differences in groundwater levels. Since this was over 20 years ago, the geologic and groundwater information was re-evaluated to assess whether the aquifers should be divided into one or two principal aquifers. **Table 4-1** provides a summary of criteria used to determine if there is enough evidence to define two principal aquifers for the purposes of this GSP. Details of this analysis are provided in **Appendix F**. In addition to the hydrogeologic evidence a comparison of adjacent subbasin definitions of principal aquifers was made.

Table 4-1. Criteria Evaluated for Two Principal Aquifers

Criteria	Two Principal Aquifers?			Comments / Evidence
	Yes	No	Maybe	
Depth and Extent of Confining Bed		X		No regionally extensive clay layer defined.
Groundwater Level Difference				
• *Vertical Head Difference*			X	Up to 20 feet difference in western portion suggesting semi-confined to confined conditions but similar in eastern portion, suggesting unconfined.
• *Response to Stress Difference*		X		Similar trends in both aquifers but slight lag time in Lower aquifer.
• *Groundwater Contour Difference*			X	Similar groundwater flow directions. Lower aquifer not showing influence from rivers.
Aquifer Hydraulic Characteristics	-	-	-	No high-quality, multi-well aquifer tests available.
Water Quality Difference		X		Nothing distinct within NASb, Yuba, or Sutter subbasins.
Adjacent Subbasins Approach				
• *Yuba*		X		GSP submitted
• *South American*		X		Alternative Submittal
• *Yolo*	-	-	-	Unknown
• *Sutter*	X			Alternative Submittal

There is not enough evidence to define multiple principal aquifers in the NASb; therefore, for this GSP, only one principal aquifer is present in the Subbasin. This definition corresponds with adjacent subbasins both north and south of the NASb.

4.12 Groundwater Recharge and Discharge Areas

Groundwater recharge occurs throughout the Subbasin in varying amounts based on the SAGBI hydrologic classification for soils, *refer to* **Figure 4-4**. The soil's ability to allow water to migrate to the aquifers is significantly reduced if the soils have been covered by impermeable surfaces such as roads and houses. In some cases, although the soils may be classified as being more permeable, recharge may be limited due to underlying low permeability sediments (clays), especially along the rivers and creeks.

4.12.1 Recharge Areas Inside of the Subbasin

Recharge areas in the Subbasin have been defined based on the soils' hydrologic classifications along with a variety of techniques including water quality, isotopes, well logs indicating coarse-grained sediments are present near ground surface, and crop types. Overall, no geologic sediments are impermeable, so some recharge occurs in all areas that are not covered by impermeable surfaces such as asphalt or concrete. This is particularly important in agricultural areas where even though there are low permeability soils, in excess of a hundred thousand acres of land that have applied or ponded water throughout the growing season that aggregate to a large volume of recharge.

Investigations conducted along the river levees provide detailed profiles that allow for assessment of where coarse-grained sediments are present and where they are connected to the rivers (*see* **Appendix E**). **Figure 4-15** shows the combination of these studies, referenced sources, and recharge areas, including reaches of the rivers and some creeks. **Figure 4-15** also shows a rather broad potential recharge area, between the eastern edge of the Subbasin and a dashed line approximating the western edge where water could infiltrate from ground surface through coarse-grained soils and sediments directly into the underlying aquifers. Generally, the rate of movement is ten times higher when water moves horizontally along aquifer beds rather than percolating vertically through the sediments. As shown, this is a broad band parallel to the eastern side of the Subbasin.

4.12.2 Recharge Areas Outside of the Subbasin

Aquifers in the NASb extend beyond the Subbasin boundary and into adjacent subbasins. Dependent upon the groundwater gradients, groundwater may flow into or leave the Subbasin. Therefore, recharge to the NASb may occur from adjacent subbasins or even beyond these subbasins. The recharge areas in adjacent subbasins will be identified in their respective GSPs, once completed.

4.12.3 Groundwater Discharge Areas

Groundwater discharge occurs along some of the creeks, canals, and rivers. The conditions may change seasonally from recharge to discharge conditions. **Figure 4-15** shows these potential areas, which are typically along the rivers as they represent topographic lows where the groundwater surface may intersect the ground surface.

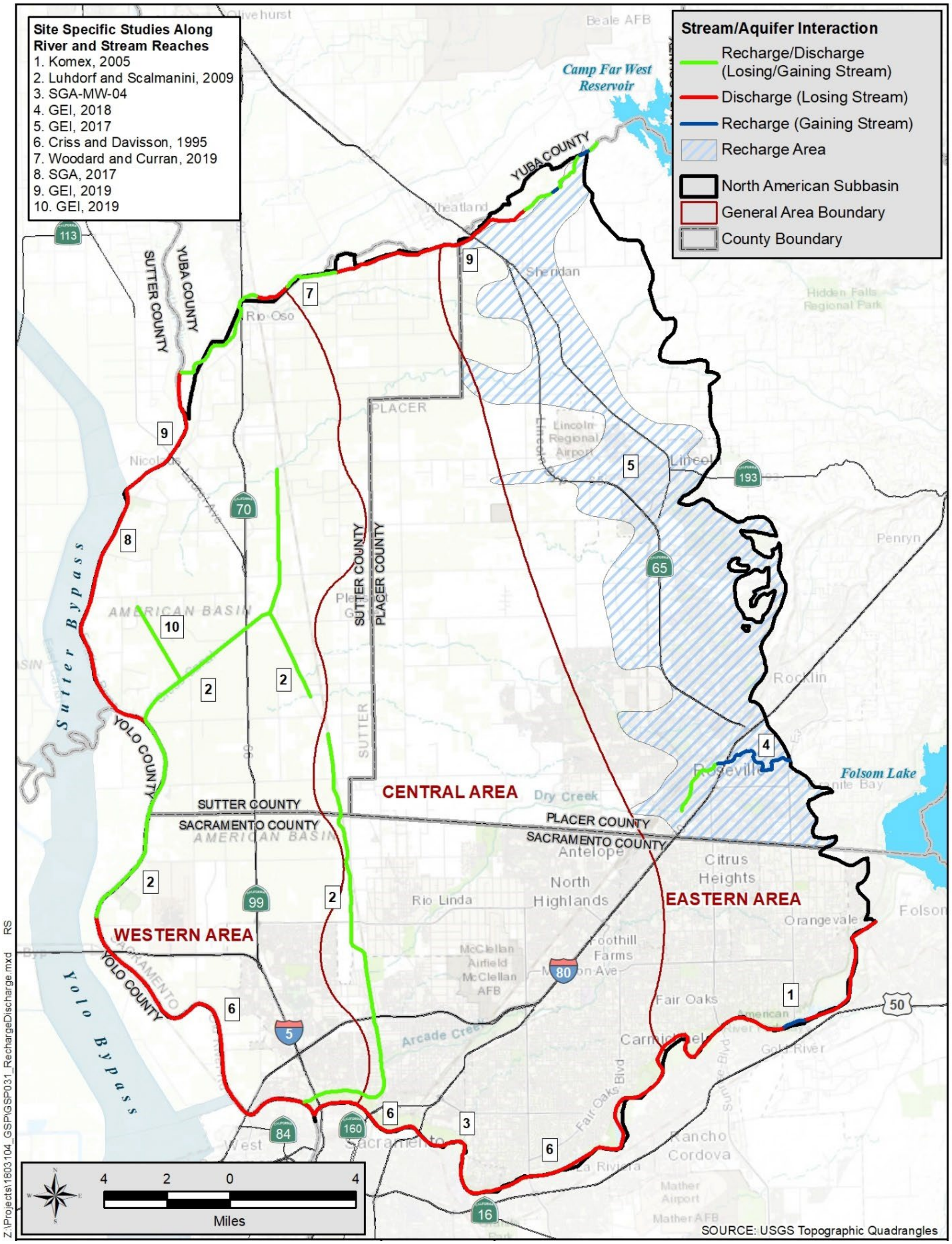

Figure 4-15. Recharge and Discharge Areas

4.13 Imported Water Supplies

For purposes of this GSP, imported water is defined as water that is brought in from areas outside of the Subbasin or its watershed. Diversions are defined as water that is diverted from rivers or tributaries within and adjacent to the Subbasin. For example, even though water in the Sacramento River may have originated from as far away as Lake Shasta, water diverted from the river is not considered to be imported because the river is adjacent to the Subbasin. The Subbasin does not have imported water other than water imported from the Yuba watershed into the Nevada Irrigation District and Placer County Water Agency service areas.

4.14 Data Gaps

The hydrogeologic conditions in the NASb have been investigated and documented since 1912 and continue through the present. Most of the recent improvements to data gathering have been construction of new monitoring wells to replace voluntary wells to improve the quality of groundwater levels. At this time, there are no data gaps that would affect the ability to sustainably manage the Subbasin within the next 5 years.