Appendix B -
Hydrogeologic Conceptual Model Excerpts and Near AEM Profiles

GSP Area or Basin Name	AEM Profile (yes or no)	Comments
B1 - Sacramento Valley Hydrologic Area		
Anderson_PA	Yes	
Antelope_PA	Yes	
BIG VALLEY_5-004_PA	No	No AEM flight paths
BIG VALLEY_5-015_PA	Yes	
BOWMAN_PA	Yes	
Butte_PA	Yes	
COLUSA_PA	Yes	
CORNING_PA	Yes	
Enterprise_PA	Yes	
LosMolinos_PA	Yes	
North&SouthYuba_PA	Yes	
NorthAmerican_PA	Yes	
Red_Bluff_PA	Yes	See Los Molinos
Sierra_Valley_PA	Yes	
Solano_PA	Yes	
South_American_PA	Yes	
Sutter_PA	Yes	
Vina_PA	Yes	Already has AEM data for cross sections
Wyandotte_PA	Yes	See Butte
Yolo_PA	Yes	
B2 - San Joaquin Valley Hydrologic Area		
Chowchilla_PA	Yes	
Cosumnes_PA	Yes	
DM_Aliso_PA	No	New common chapter for wide DM subbasin included (Delta Mendota Subbasin Common Chapter_PA_NEW)
DM_Farmers_PA	Yes	
DM_Fresno_PA	Yes	
DM_NorthCentral_PA	Yes	
DM_SJREC_PA	Yes	
EastContraCosta_PA	Yes	
EasternSanJoaquin_PA	Yes	
Madera_GFWD_PA	Yes	
Madera_Joint_PA	Yes	See Chowchilla
Madera_Newstone_PA	Yes	
Madera_RootCreek_PA	Yes	See Madera_Newstone
Merced_PA	Yes	
Modesto_PA	Yes	

GSP Area or Basin Name	AEM Profile (yes or no)	Comments
B3 - Tulare Lake Hydrologic Area		
Castac_Lake_PA	No	No AEM flight paths
Kaweah_East_Kaweah_PA	Yes	See Greater Kaweah
Kaweah_GreaterKaweah_PA	Yes	
Kaweah_Mid_Kaweah_PA	Yes	See Greater Kaweah
Kern_BVGSA_PA	Yes	
Kern_HenryMiller_PA	Yes	
Kern_KGA_PA	Yes	
Kern_Olcese_PA	Yes	
Kern_SOKR_PA	Yes	
Kern-KRGSA	Yes	
Kings_James_PA	Yes	Part of Kings_Subbasin_PA
Kings_KingsRiverEast_PA	Yes	
Kings_McMullin_PA	Yes	Part of Kings_Subbasin_PA
Kings_NorthFork_PA	Yes	Part of Kings_Subbasin_PA
Kings_NorthKings_PA	Yes	Part of Kings_Subbasin_PA
Kings_SouthKings_PA	Yes	Part of Kings_Subbasin_PA
Pleasant_Valley5-002_PA	Yes	
Tulare_Lake_PA	Yes, but only portions	
Tule_Alpaugh_PA	Yes	
Tule_DEID_PA	Yes	
Tule_ETGSA_PA	Yes	See Tule_DEID
Tule_LTRID_PA	Yes	See Tule_DEID
Tule_Pixley_PA	Yes	See Tule_DEID
Tule_TCWD_PA	Yes	
Westside_PA	Yes	
White_Wolf_PA	Yes	

Appendix B1 - Sacramento Valley Hydrologic Region - GSP Hydrogeologic Conceptual Model Excerpts and Near AEM Profiles

Anderson Subbasin Groundwater Sustainability Plan

Draft

January 2022

Enterprise Anderson Groundwater Sustainability Agency generally moderate but may be quite high in regions dominated by gravels. Some wells in the alluvium have produced as much as 2,000 gpm, but many others produce only enough for domestic use.

3.1.5.3 Geologic Structures

Red Bluff Arch

A series of northeastward-trending anticlines and synclines located north of Red Bluff, the Red Bluff Arch, distinguishes the RAGB from the Sacramento Groundwater Basin. Data are insufficient to determine the groundwater and surface-water relationship in the vicinity of the Red Bluff Arch; however, the effect of the arch is hypothesized to force groundwater toward the surface to induce gaining streams (Pierce, 1983).

3.1.6 Local Hydrogeology

3.1.6.1 Lateral Basin Boundary

The RAGB is bounded by the foothills of the Cascade Range to the east, the Klamath Mountains to the north/northwest, the Coast Range to the west/southwest, and the Red Bluff Arch to the south (Pierce, 1983). Unlike the RAGB, much of the Anderson Subbasin is bounded by hydrologic features: the Sacramento River to the east and northeast and Cottonwood Creek to the south. Because some of the lateral subbasin boundaries are defined by surface streams, there is likely hydraulic communication between adjacent subbasins. That is, there may be subsurface flow into the Anderson Subbasin from adjacent subbasins and from the Anderson Subbasin into adjacent subbasins.

3.1.6.2 Definable Bottom of Basin

The base of fresh water defines the bottom of the basin. In the RAGB, this is the top of the Chico Formation (Figure 3-9). Although water-bearing formations exist below this depth, the saline nature of the groundwater and the depth to formation prevent the Chico Formation from being a viable aquifer. The top of the Chico Formation in the Anderson Subbasin ranges from a depth of less than 100 feet in the northwest to a depth of greater than 2,000 feet in the southeast (DWR, 1968).

3.1.6.3 Principal Aquifers and Aquitards

Much of the water supply in the Anderson Subbasin, and in the greater RAGB, is stored in surface reservoirs; and as a result, the communities in the region are less dependent on groundwater. This may contribute to the fact that groundwater elevations in the RAGB do not show evidence of continuous decline (as will be discussed further in subsequent sections). In the portions of the Anderson Subbasin near either Sacramento River, Clear Creek, or Cottonwood Creek, depths to groundwater are shallow, within 25 feet of land surface. However, depth to groundwater generally increases to the west, with increasing distance from the streams. In areas outside of large drainages, depths to groundwater can range from 150 to 250 feet below land surface. Shallow, alluvial deposits have moderate to high permeabilities in the subbasin, but deposits are not significant sources for groundwater use in the subbasin because of the limited lateral and vertical extents. The Red Bluff Formation is generally present above the regional water table; however, local perched zones may yield small quantities of water to domestic wells (DWR, 1968, Pierce, 1983). The principal water-bearing formations in the Anderson Subbasin, the Tuscan and Tehama Formations, together function as one large, leaky unconfined aquifer with increasing degrees of confinement with depth. Groundwater use of the principal aquifer is for urban, industrial, and agricultural purposes, and is described in greater detail in Chapter 2. Due to the reliability of surface water storage and the readily available groundwater supply within the Tuscan and Tehama aquifers, few resources have been dedicated to describing other aquifers within the RAGB. As shown on Figures 3-7 and

3-8, although laterally discontinuous fine-grained zones are present within the subbasin, there is no evidence of a regional aquitard.

3.1.6.4 Aquifer Properties

Aquifer systems function as a combination of subsurface reservoirs for storage of groundwater and conduits for the transmission of groundwater. The following sections describe the aquifer system properties in the Anderson Subbasin. The magnitude and distribution of hydrogeologic properties of the principal aquifers in the subbasin have not been well characterized or documented. The scarcity of available quantitative estimates of the aquifer properties of the subbasin's principal aquifers results in uncertainties that will be further refined during implementation of this GSP. This will be accomplished through evaluation of hydraulic data collected during development of the new monitoring well and through calibration of the numerical model being developed as part of this GSP.

Transmissivity and Hydraulic Conductivity

There are two general terms that are used to describe the capacity of an aquifer to transmit water: hydraulic conductivity and transmissivity. Hydraulic conductivity is defined as the coefficient of proportionality describing the rate at which a fluid can move through a porous medium and is dependent on the fluid density, fluid viscosity, and the intrinsic permeability. Transmissivity is defined as the capacity of an aquifer to transmit groundwater through a unit width of the aquifer under a unit hydraulic gradient. Transmissivity is equal to the product of the hydraulic conductivity (which is reported in units of feet per day [ft/day]) and saturated thickness, and is generally reported in units of gallons per day per foot or square feet per day (ft^2/day).

Numerous well completion logs filed with DWR include information that can be used to estimate the specific capacity of the associated well, which can then be used to approximate the transmissivity (CNRA, 2020). Additionally, specific capacity estimates are available from short-duration (45- to 176-minute) hydraulic testing performed at the end of development of 13 ACID groundwater monitoring wells (CH2M HILL, 2004). In general, estimated transmissivity values are lower in the west/southwestern portion of the Anderson Subbasin and increase to the east/northeast, where the thickness of unconsolidated deposits increases. Estimated transmissivities based on reported specific capacity values on well logs by well type are as follows for the Anderson Subbasin:

- Domestic Wells (80 logs): 6 to 9,000 ft^2/day with a geometric mean of 230 ft^2/day
- Public Wells (8 logs): 120 to 13,750 ft^2/day with a geometric mean of 2,400 ft^2/day
- Industrial and Irrigation Wells (11 logs): 600 to 35,000 ft^2/day with a geometric mean of 3,300 ft^2/day
- Monitoring Wells, Test Wells, and Unknown Well Type (15 logs): 80 to 22,000 ft^2/day with a geometric mean of 1,325 ft^2/day

Hydraulic conductivity was estimated from specific capacity data by dividing the estimated transmissivity by the well screen length, where available. Estimated hydraulic conductivity values for the Anderson Subbasin are as follows:

- Domestic Wells (57 logs): 0.2 to 500 ft/day with a geometric mean of 11 ft/day
- Public Wells (4 logs): 42 to 230 ft/day with a geometric mean of 87 ft/day
- Industrial and Irrigation Wells (9 logs): 5.5 to 113 ft/day with a geometric mean of 19 ft/day
- Monitoring Wells, Test Wells, and Unknown Well Type (14 logs): 2.5 to 735 ft/day with a geometric mean of 43 ft/day

Excluding lower-yield wells (those with reported pumping rates less than 50 gpm) and relatively shallow wells (those with depths less than 150 feet below ground surface [bgs]), transmissivity ranges from 150 to

35,000 ft^2/day (hydraulic conductivity of 2.5 to 230 ft/day) with a geometric mean of 1,700 ft^2/day (hydraulic conductivity of 20 ft/day).

In addition to estimating transmissivity based on specific capacity measurements, aquifer properties have been estimated through the process of numerical model calibration, which is a process of adjusting model inputs (such as transmissivity) to achieve a reasonable match to field observations of interest. The most recent version of the Redding Basin Finite Element Model (REDFEM) included transmissivity estimates of less than 1,000 ft^2/day (hydraulic conductivity of 5 ft/day) in the northern portion of the subbasin to more than 200,000 ft^2/day (hydraulic conductivity of 300 ft/day) in the southern portion of the subbasin (CH2M HILL, 2011). These values represent the estimated transmissivity for the entire thickness of unconsolidated materials of the principal aquifers overlying the Chico Formation (Figure 3-9) as opposed to aquifer thickness associated with a well screen (as is the case for specific capacity estimates). Estimates of transmissivity and hydraulic conductivity will be further refined in the numerical groundwater flow model development effort being performed to support this GSP.

Storativity

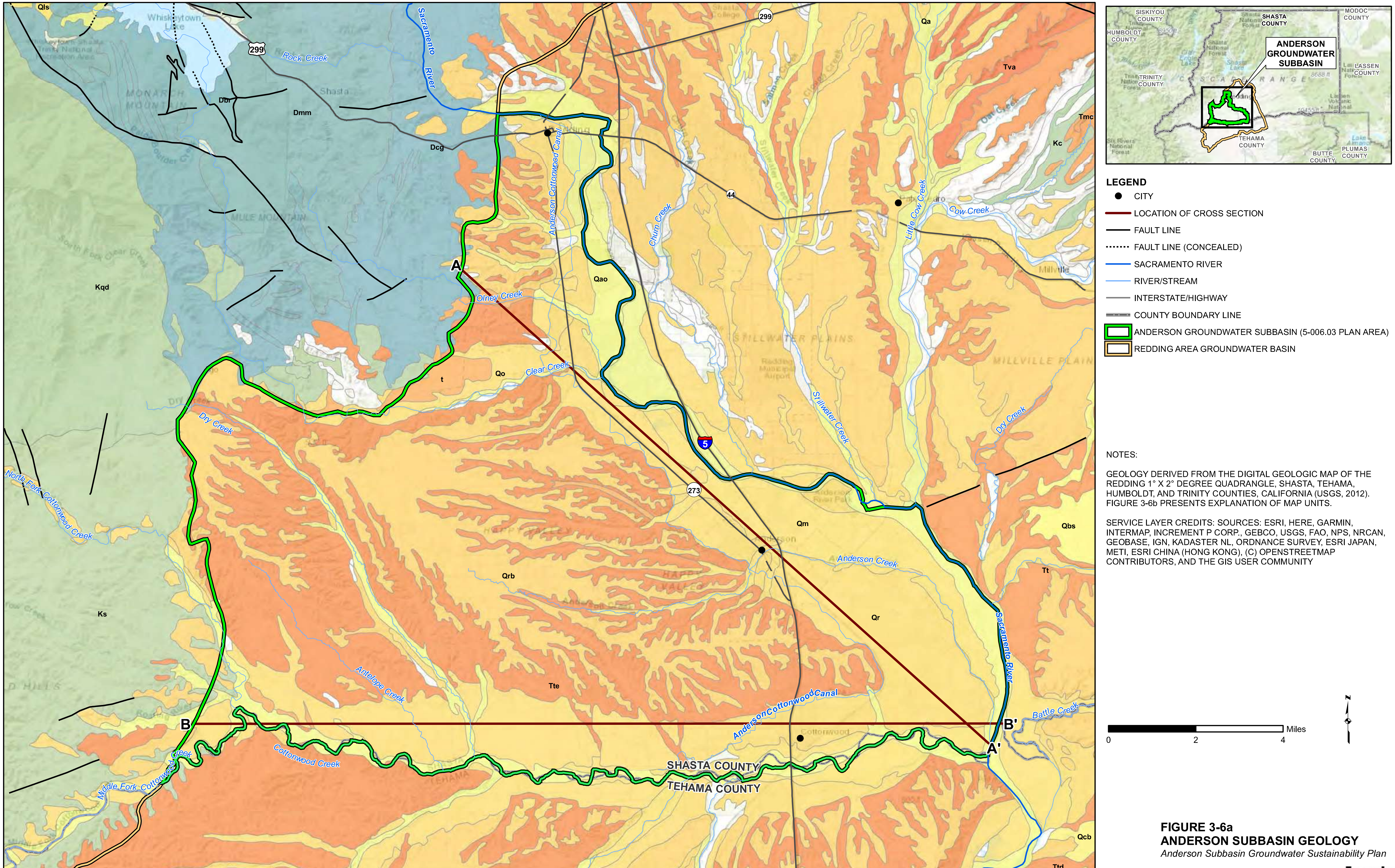
Storativity (or storage coefficient) is the volume of water released from (or taken into) storage in the aquifer system per unit area per unit change in head (i.e., groundwater elevation). In general, unconfined aquifer systems have relatively higher storativity values (typically known as specific yield), whereas confined aquifer systems have lower storativity values. Point estimates of aquifer storage from hydraulic testing within the Anderson Subbasin are currently unavailable. Values incorporated into REDFEM include a specific yield of 10 percent for shallow portions of the basin aquifer and a specific storage of 2×10^{-6} per foot for the deeper portions of the aquifer. Storativity values are computed by multiplying the specific storage value by the aquifer thickness. The assumed resulting storativity values for the deeper model layers in REDFEM range from 1×10^{-4} to 4×10^{-3} (CH2M HILL, 2011). Similar to transmissivity, storage properties will be further refined in the numerical groundwater flow model that is being developed as part of this GSP.

3.1.6.5 Natural Recharge Areas

Recharge to the principal aquifers (i.e., Tuscan and Tehama Formations) in the Anderson Subbasin and the shallower, overlying water-bearing units occurs through a combination of the following (DWR, 1968; Pierce, 1983):

- Groundwater recharge from precipitation
- Groundwater recharge from applied water
- Groundwater recharge from streams and irrigation canals
- Subsurface inflow from adjacent subbasins

Recharge to aquifer systems is influenced by a number of parameters including (but not limited to) the following: surface soil infiltration capacity; land use/vegetative cover; topography; lithology; and the frequency, intensity, duration, and volume of precipitation. Figure 3-10 presents the distribution of the Soil Agricultural Groundwater Banking Index (SAGBI) for the Anderson Subbasin. The SAGBI was developed by the University of California–Davis as part of a study of the potential to bank groundwater, while maintaining healthy crops as a drought management strategy (O'Geen et al., 2015). The SAGBI data presented on Figure 3-10 are based on the following factors: infiltration capacity of soils, the duration that the root zone would be anticipated to remain saturated, topography, potential for leaching of high-salinity soils to degrade groundwater quality, and the susceptibility of soils to compact and erode. As shown on Figure 3-10, the SAGBI indicates that much of the western (foothills of the Klamath Mountains and Coast Ranges) and central portions of the subbasin overlie areas with a moderately poor to very poor potential for groundwater recharge. Areas within and along stream channels, especially those of the Sacramento



LEGEND

- CITY
- LOCATION OF CROSS SECTION
- FAULT LINE
- FAULT LINE (CONCEALED)
- SACRAMENTO RIVER
- RIVER/STREAM
- INTERSTATE/HIGHWAY
- COUNTY BOUNDARY LINE
- ANDERSON GROUNDWATER SUBBASIN (5-006.03 PLAN AREA)
- REDDING AREA GROUNDWATER BASIN

NOTES:

GEOLOGY DERIVED FROM THE DIGITAL GEOLOGIC MAP OF THE REDDING 1° X 2° DEGREE QUADRANGLE, SHASTA, TEHAMA, HUMBOLDT, AND TRINITY COUNTIES, CALIFORNIA (USGS, 2012). FIGURE 3-6b PRESENTS EXPLANATION OF MAP UNITS.

SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY

Miles
0 2 4

FIGURE 3-6a
ANDERSON SUBBASIN GEOLOGY
Anderson Subbasin Groundwater Sustainability Plan

Jacobs

FIGURE 3-6a MAP UNIT EXPLANATION

SURFICIAL DEPOSITS

t	Man-made materials (Holocene)
Qa	Alluvium and colluvium (Holocene)
Qo	Overbank deposits (Holocene)
Qao	Alluvial and overbank deposits, undivided (Holocene)
Qls	Landslide deposits (Holocene)
Qm	Modesto formation of Davis and Hall (1959) (Pleistocene)
Qr	Riverbank Formation (Pleistocene)
Qrb	Red Bluff formation of Diller (1894) (Pleistocene)

VOLCANIC ROCKS

Qbs	Basalt of Shingletown Ridge (Pleistocene)
Qcb	Basalt of Coleman Forebay (Pleistocene)
Tva	Andesitic breccia (Pliocene)

SEDIMENTARY ROCKS

Tte	Tehama Formation (Pliocene)
Tt	Tuscan Formation, undivided (Pliocene)
Ttd	Fragmental Deposits
Tmc	Montgomery Creek Formation (Eocene)
Kc	Chico Formation (Upper Cretaceous)
Ks	Sedimentary Rocks (Lower Cretaceous)

EASTERN KLAMATH TERRANE

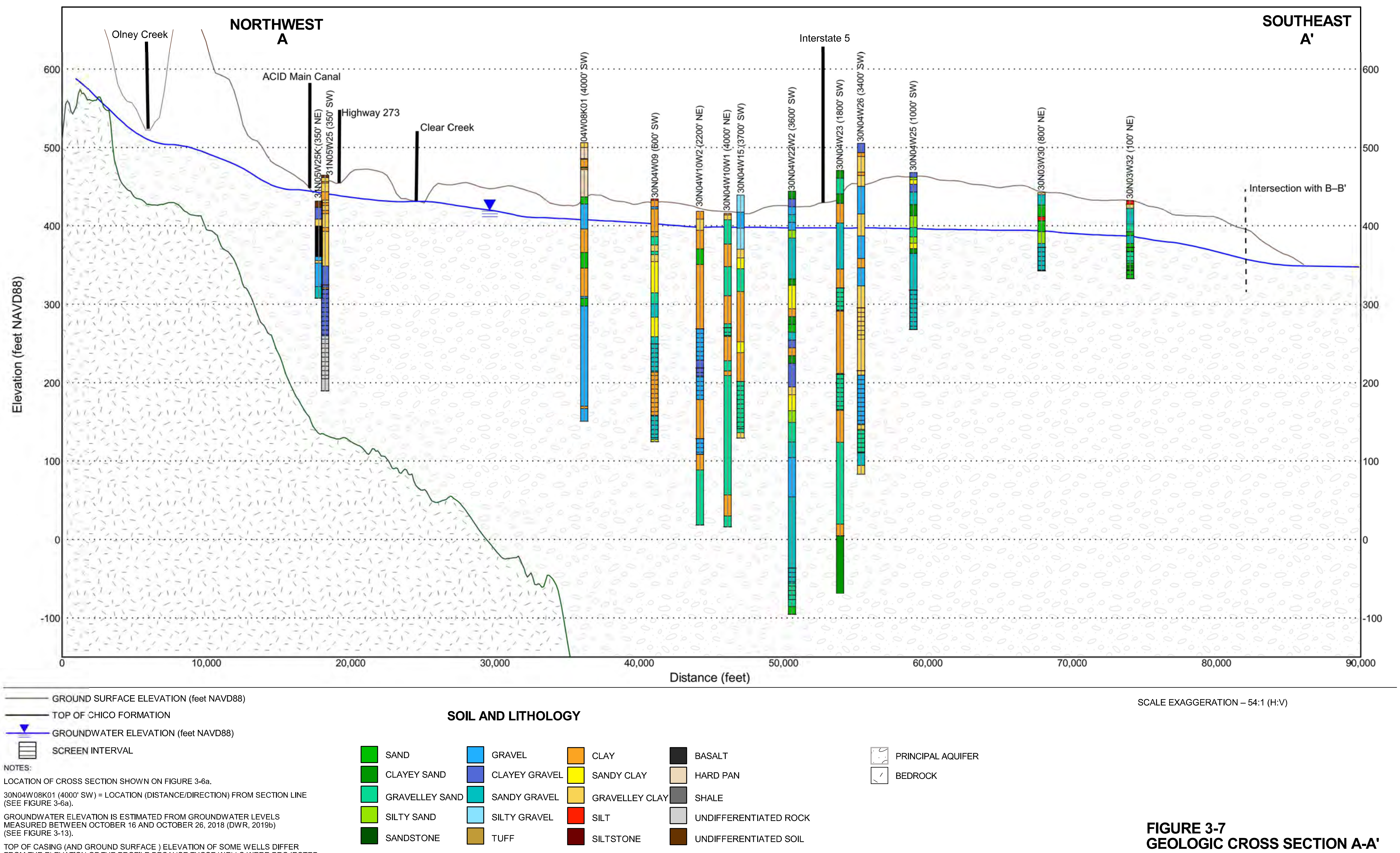
Dmm	Mule Mountain stock (Devonian)
Dbr	Balaklala Rhyolite (Devonian(?))
Dcg	Copley Greenstone (Devonian(?))

NOTES:

GEOLOGY DERIVED FROM THE DIGITAL GEOLOGIC MAP OF THE REDDING 1° X 2° DEGREE QUADRANGLE, SHASTA, TEHAMA, HUMBOLDT, AND TRINITY COUNTIES, CALIFORNIA (USGS, 2012).

MAP UNIT (Ttm) LABELED ON THE MAP IS OF UNKNOWN IDENTITY AND AGE; UNLABELED AREAS ARE OF UNKNOWN IDENTITY AND AGE. BOTH ARE UNFILLED ON THIS MAP.

FIGURE 3-6b
LIST OF MAP UNITS
Anderson Subbasin Groundwater Sustainability Plan



NOTES:

LOCATION OF CROSS SECTION SHOWN ON FIGURE 3-6a.

30N04W08K01 (4000' SW) = LOCATION (DISTANCE/DIRECTION) FROM SECTION LINE (SEE FIGURE 3-6a).

GROUNDWATER ELEVATION IS ESTIMATED FROM GROUNDWATER LEVELS MEASURED BETWEEN OCTOBER 16 AND OCTOBER 26, 2018 (DWR, 2019b) (SEE FIGURE 3-13).

TOP OF CASING (AND GROUND SURFACE) ELEVATION OF SOME WELLS DIFFER FROM THE ELEVATION OF THE PROFILE BECAUSE THOSE WELLS WERE PROJECTED ONTO THE PLANE OF THE CROSS SECTION FROM VARYING DISTANCES.

NAVD88 = NORTH AMERICAN VERTICAL DATUM OF 1988.

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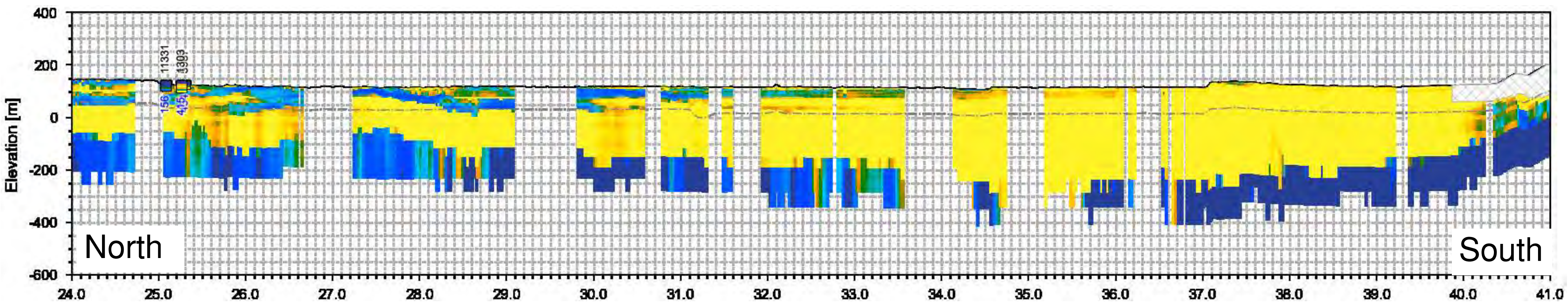
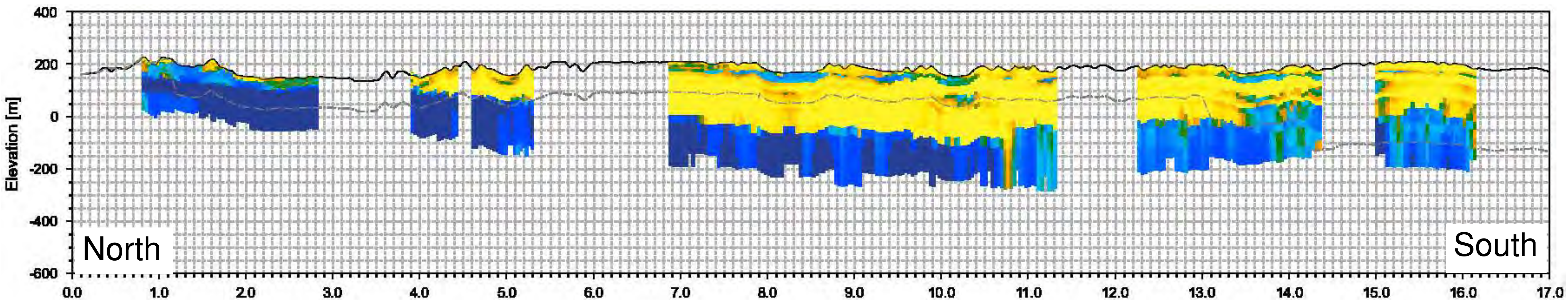
FIGURE 3-7
GEOLOGIC CROSS SECTION A-A'
Anderson Subbasin Groundwater Sustainability Plan

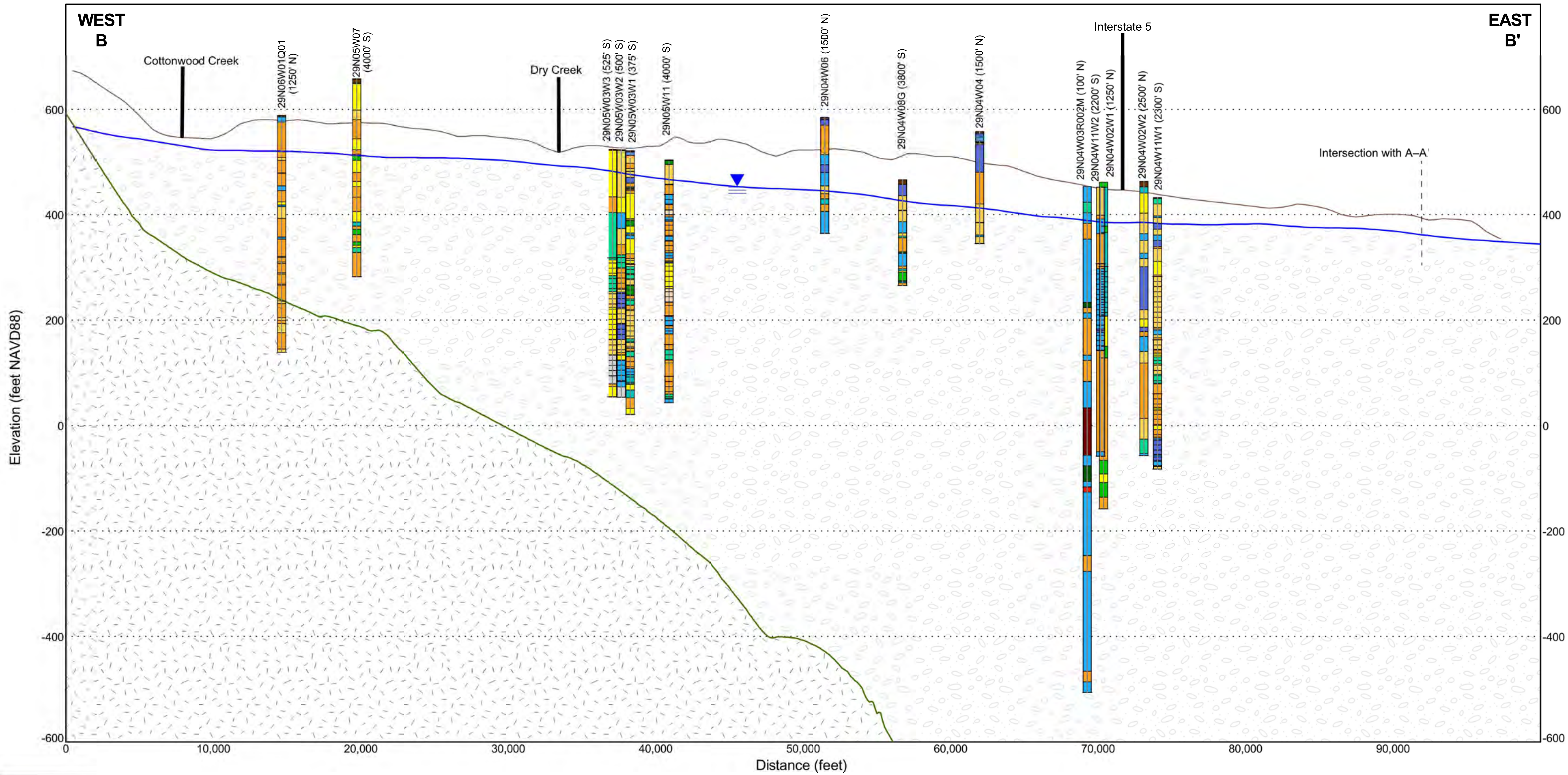
Jacobs

Nearest AEM Flight path to the East
A - A'



Nearest AEM Flight path to the West
A - A'





GROUND SURFACE ELEVATION (feet NAVD88)

TOP OF CHICO FORMATION (DASHED WHERE UNCERTAIN)

GROUNDWATER ELEVATION (feet NAVD88)

SCREEN INTERVAL

SOIL AND LITHOLOGY

SAND | GRAVEL | CLAY | BASALT
CLAYEY SAND | CLAYEY GRAVEL | SANDY CLAY | HARD PAN
GRAVELLEY SAND | SANDY GRAVEL | GRAVELLEY CLAY | SHALE
SILTY SAND | SILTY GRAVEL | SILT | UNDIFFERENTIATED ROCK
SANDSTONE | TUFF | SILTSTONE | UNDIFFERENTIATED SOIL

PRINCIPAL AQUIFER

BEDROCK

SCALE EXAGGERATION – 36:1 (H:V)

NOTES:

LOCATION OF CROSS SECTION SHOWN ON FIGURE 3-6a.

30N04W08K01 (4000' SW) = LOCATION (DISTANCE/DIRECTION) FROM SECTION LINE (SEE FIGURE 3-6a).

GROUNDWATER ELEVATION IS ESTIMATED FROM GROUNDWATER LEVELS MEASURED BETWEEN OCTOBER 16 AND OCTOBER 26, 2018 (DWR, 2019b) (SEE FIGURE 3-13).

TOP OF CASING (AND GROUND SURFACE) ELEVATION OF SOME WELLS DIFFER FROM THE ELEVATION OF THE PROFILE BECAUSE THOSE WELLS WERE PROJECTED ONTO THE PLANE OF THE CROSS SECTION FROM VARYING DISTANCES.

NAVD88 = NORTH AMERICAN VERTICAL DATUM OF 1988.

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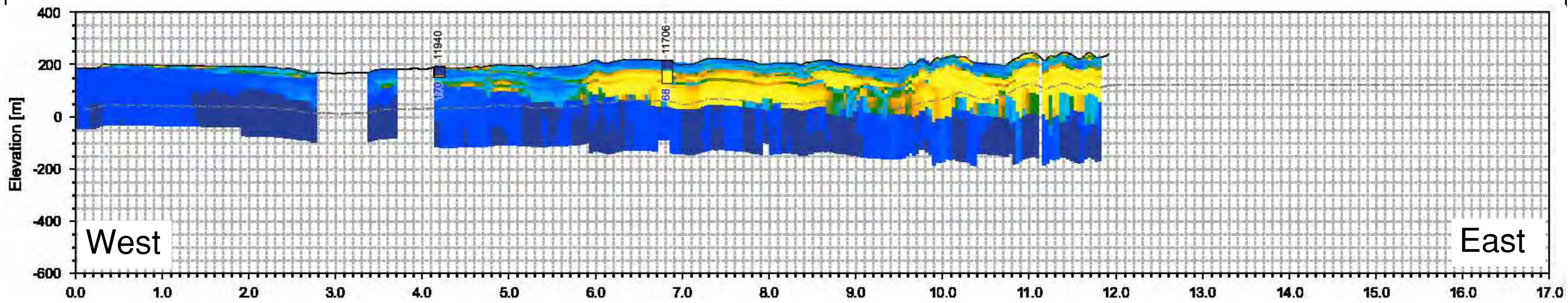
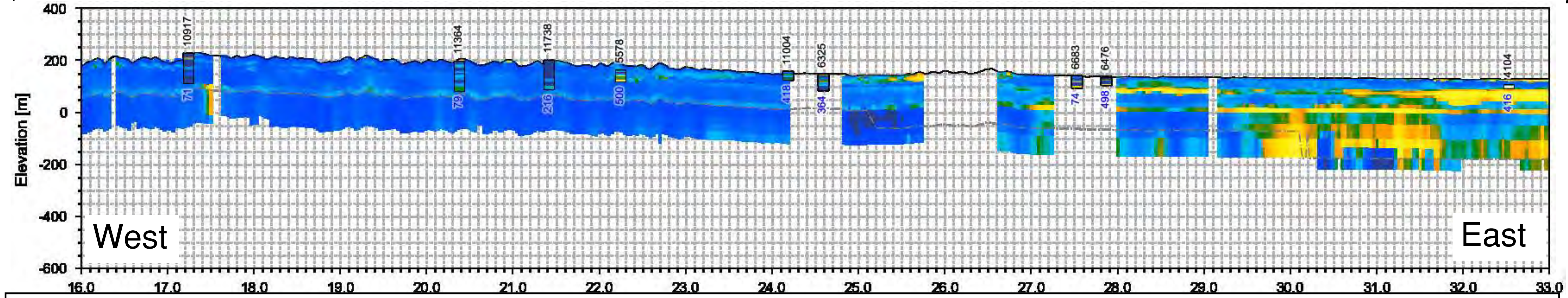
FIGURE 3-8
GEOLOGIC CROSS SECTION B-B'
Anderson Subbasin Groundwater Sustainability Plan

Jacobs

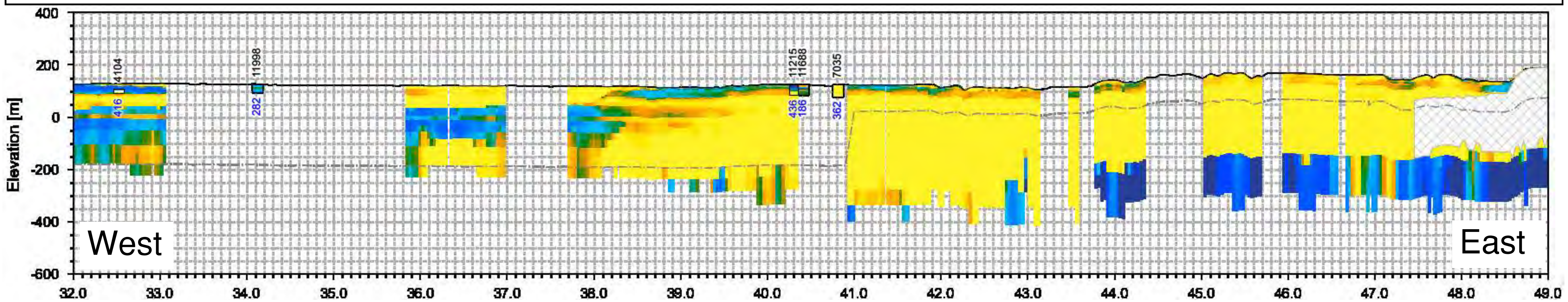
Nearest AEM Flight path to the North
B - B'



Nearest AEM Flight path to the South, West
B - B'



Nearest AEM Flight path to the South, East
B - B'



TEHAMA COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT

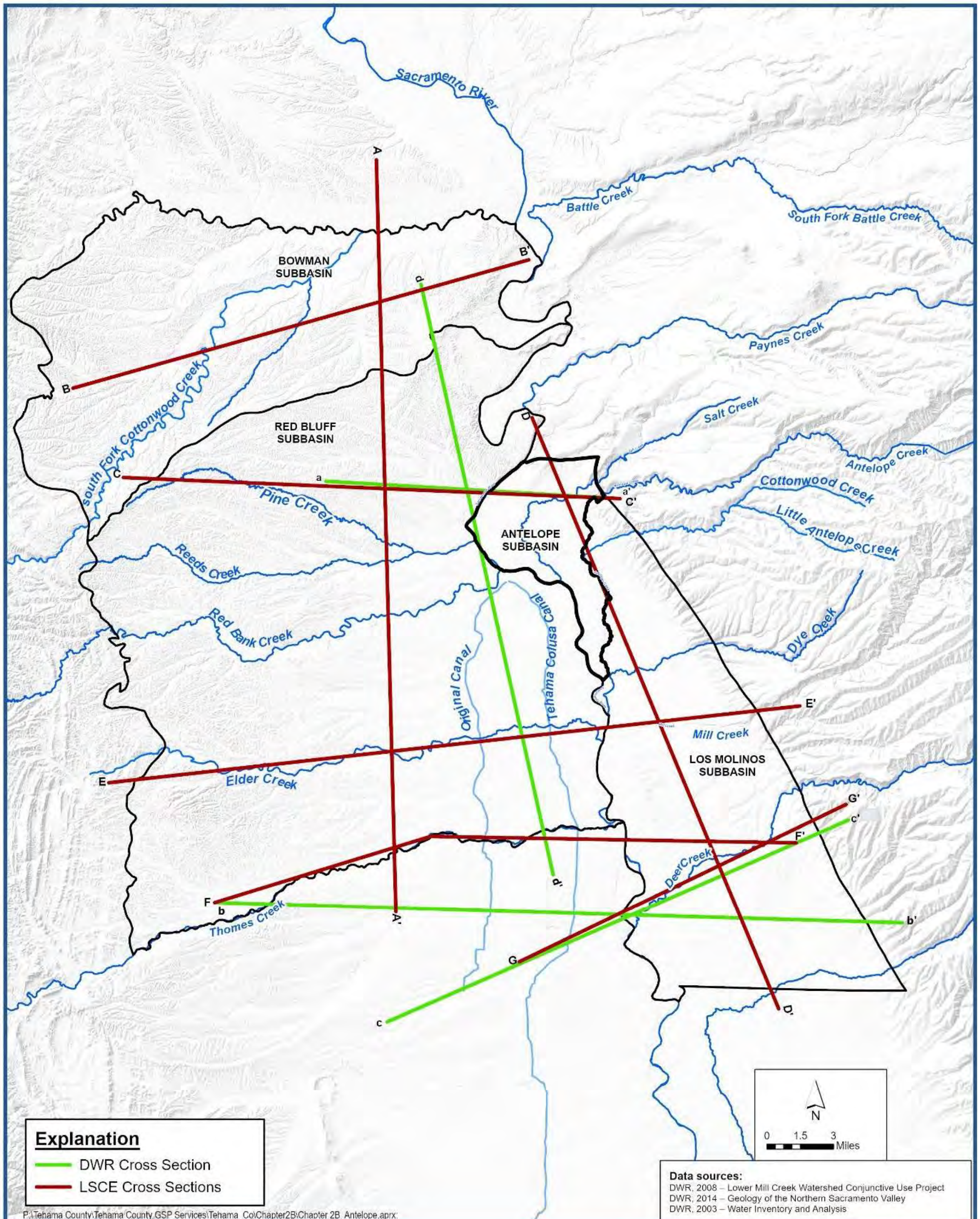
Groundwater Sustainability Plan

Antelope Subbasin

JANUARY 2022

PREPARED BY

Luhdorff & Scalmanini
Consulting Engineers



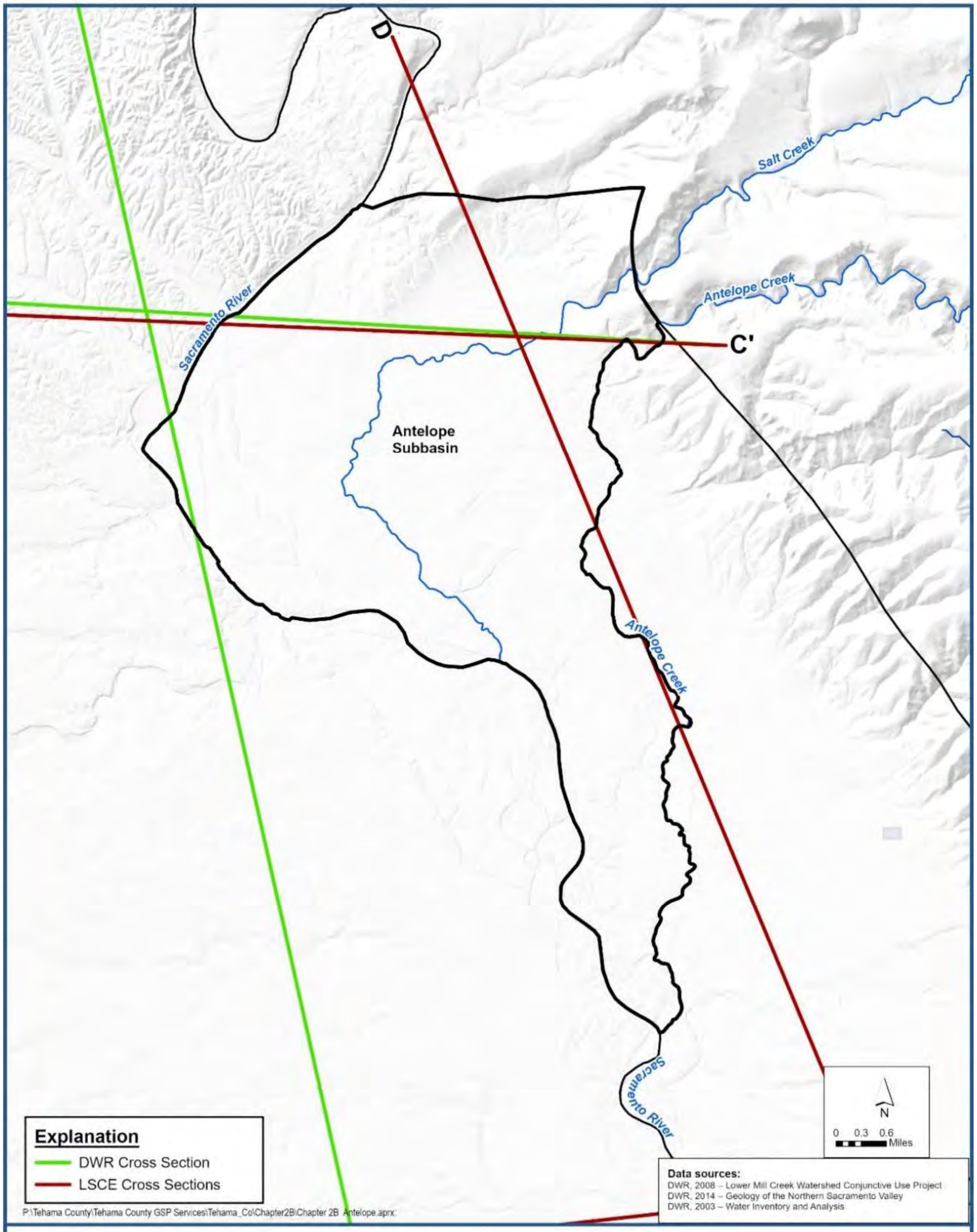
TEHAMA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT

LSCE Team

Map of Cross Section Locations

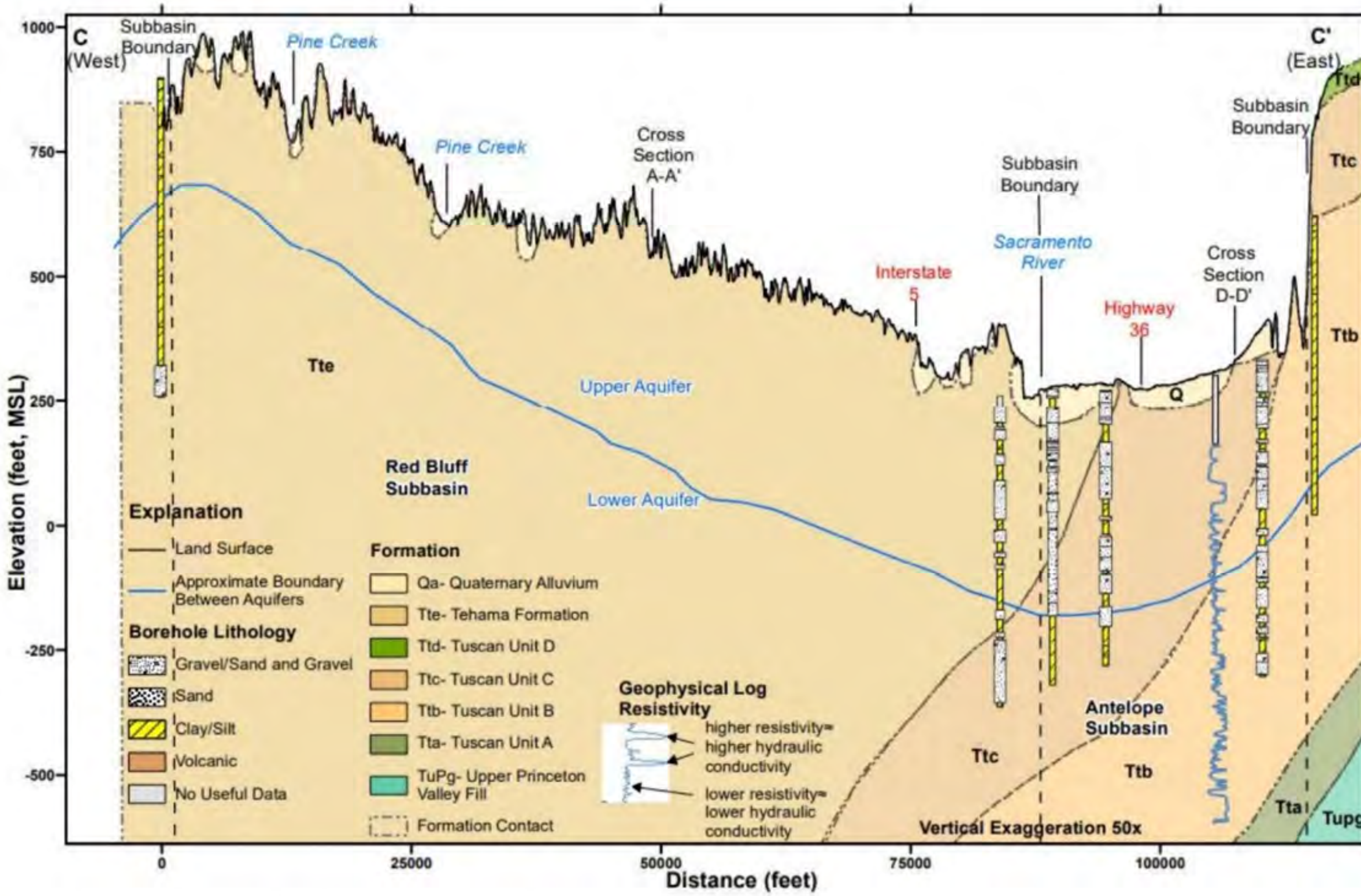
Groundwater Sustainability Plan
Antelope Subbasin

Figure 2-21



Map of Cross Section Locations **Figure 2-21B**

Groundwater Sustainability Plan
Antelope Subbasin



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TEHAMA COUNTY

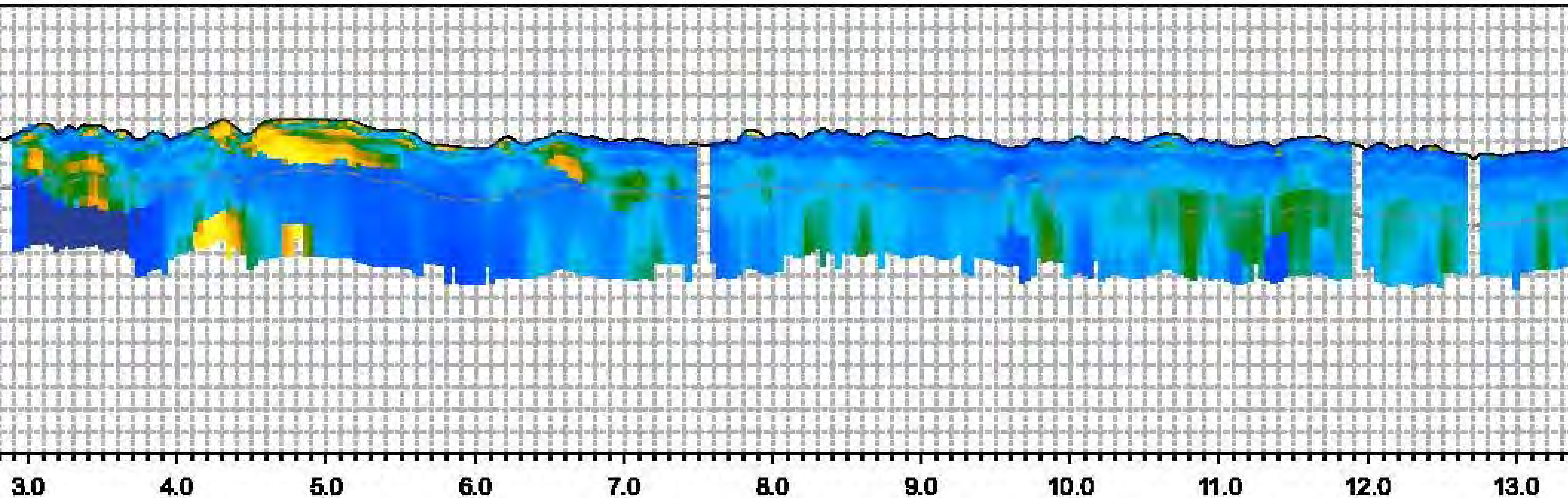
LSCE Team

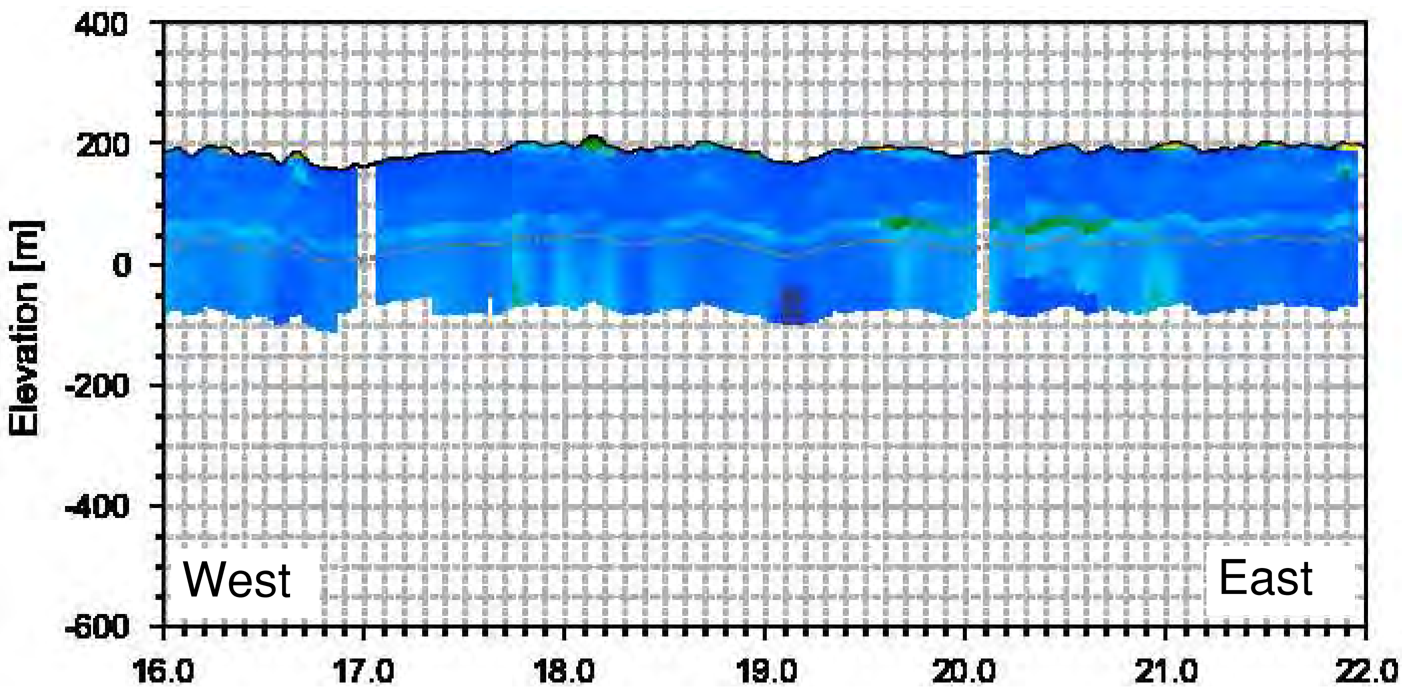
Cross Section C-C'

Groundwater Sustainability Plan
Antelope Subbasin

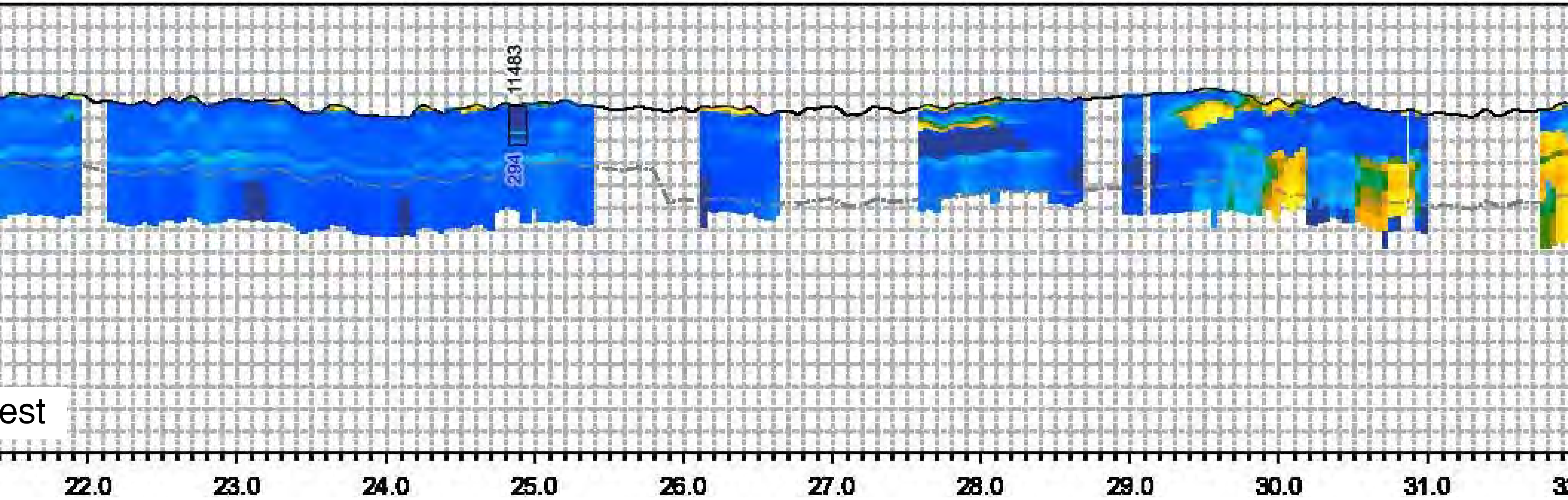
Figure 2-22

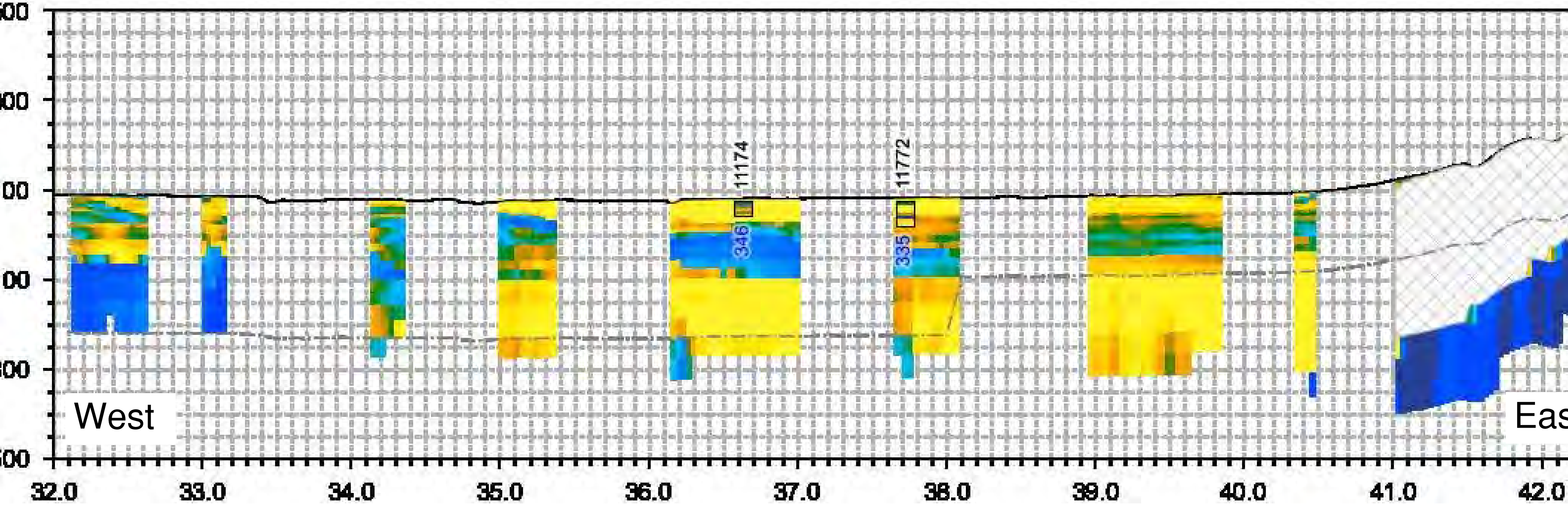
C - C' Nearest AEM Log



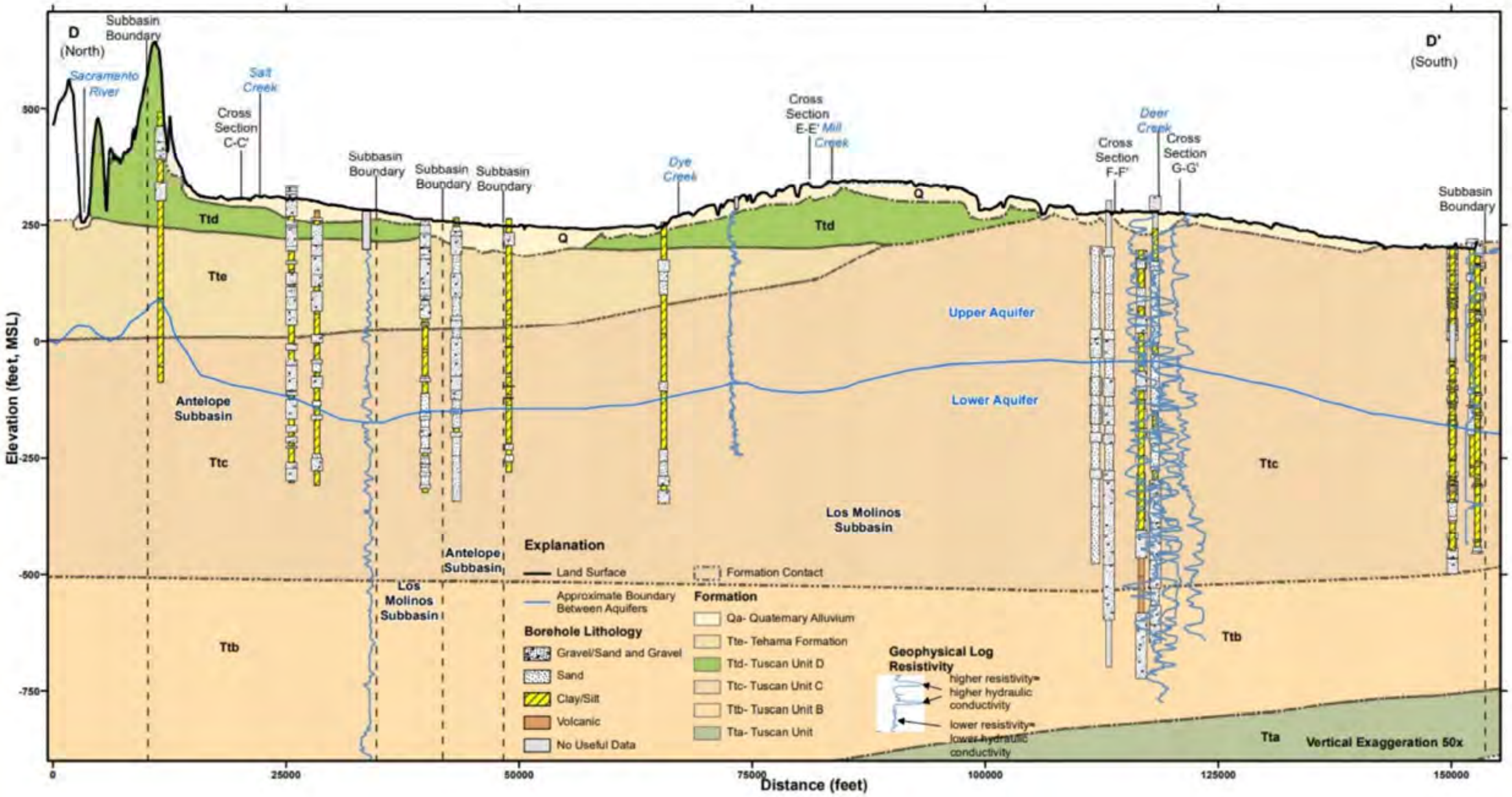


C - C' Nearest AEM Log





This AEM log is NOT continuous with the previous AEM log.



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

TEHAMA COUNTY

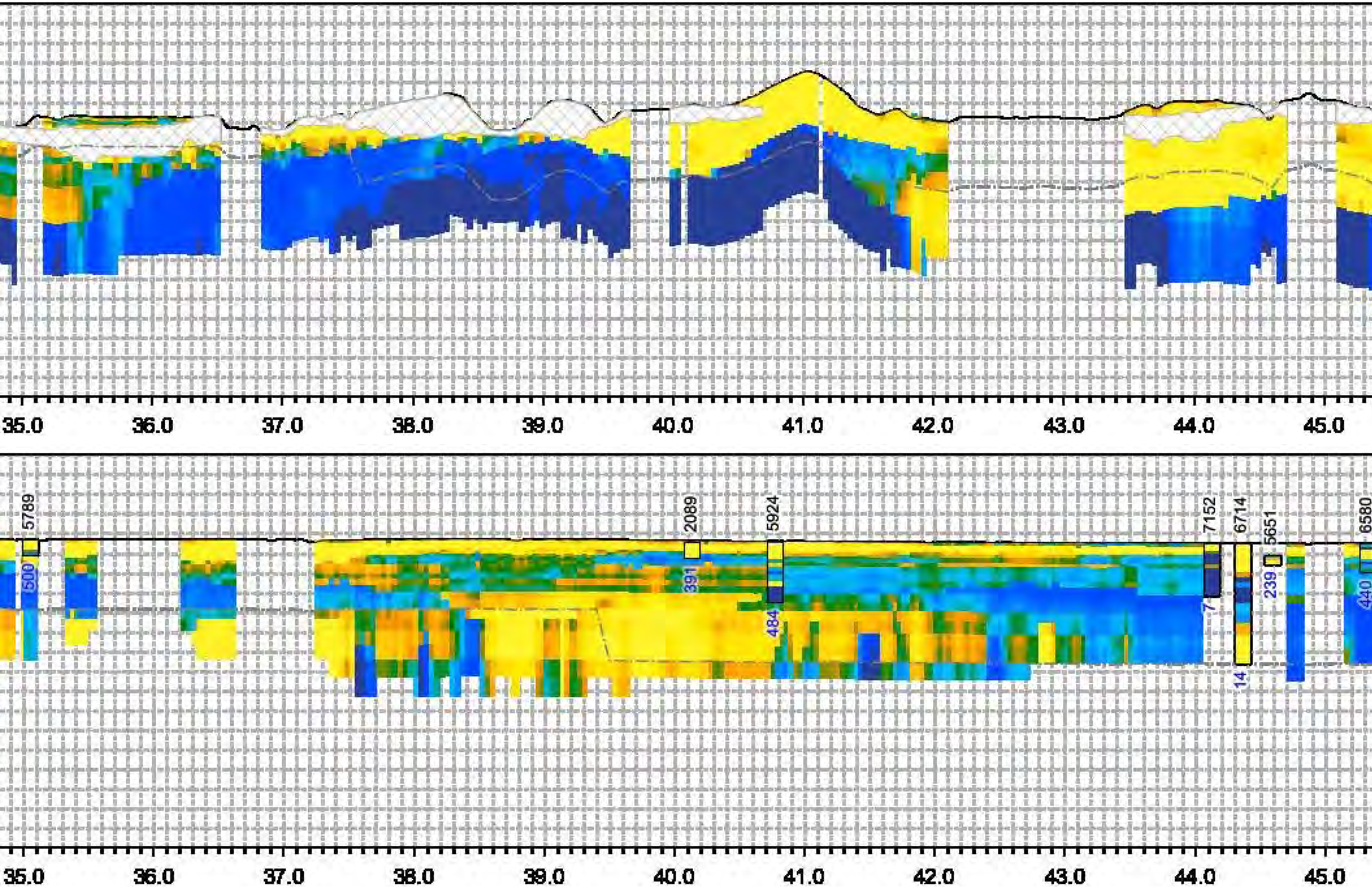
LSCE Team

Cross Section D-D'

Figure 2-23

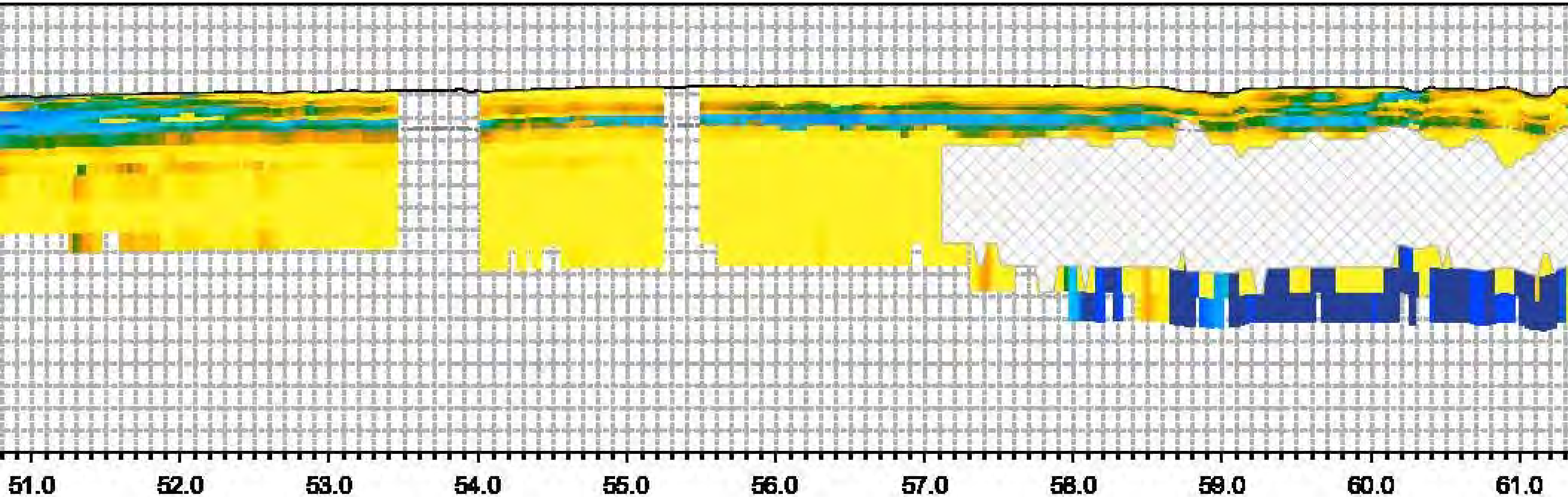
Groundwater Sustainability Plan
Antelope Subbasin

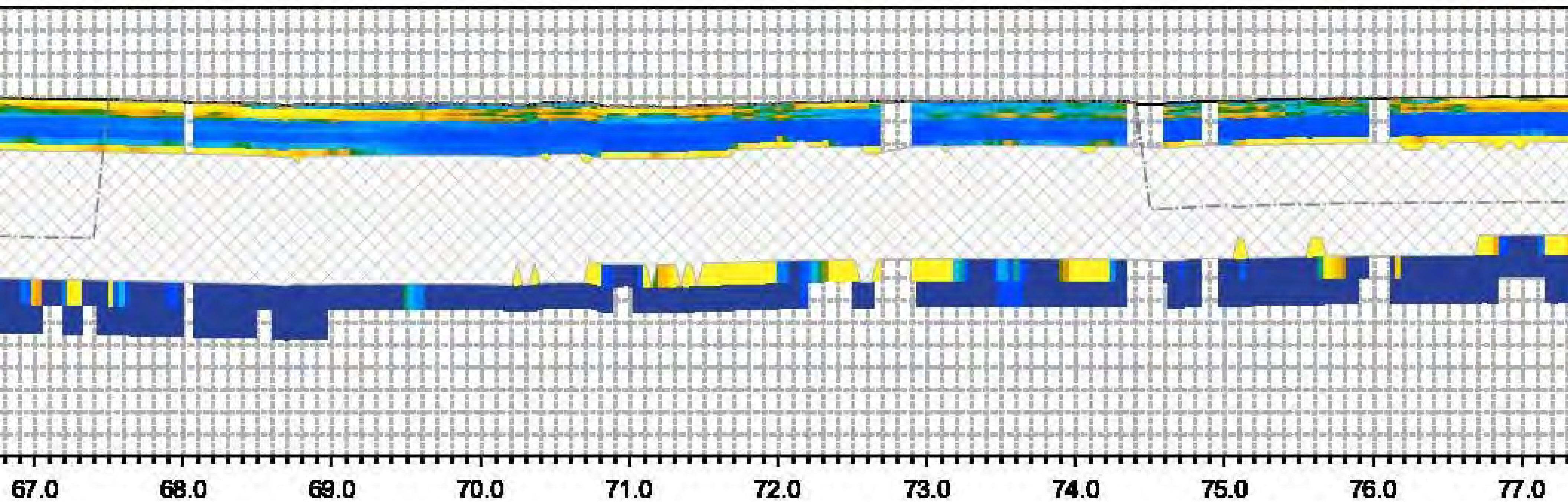
D - D' Nearest AEM Log

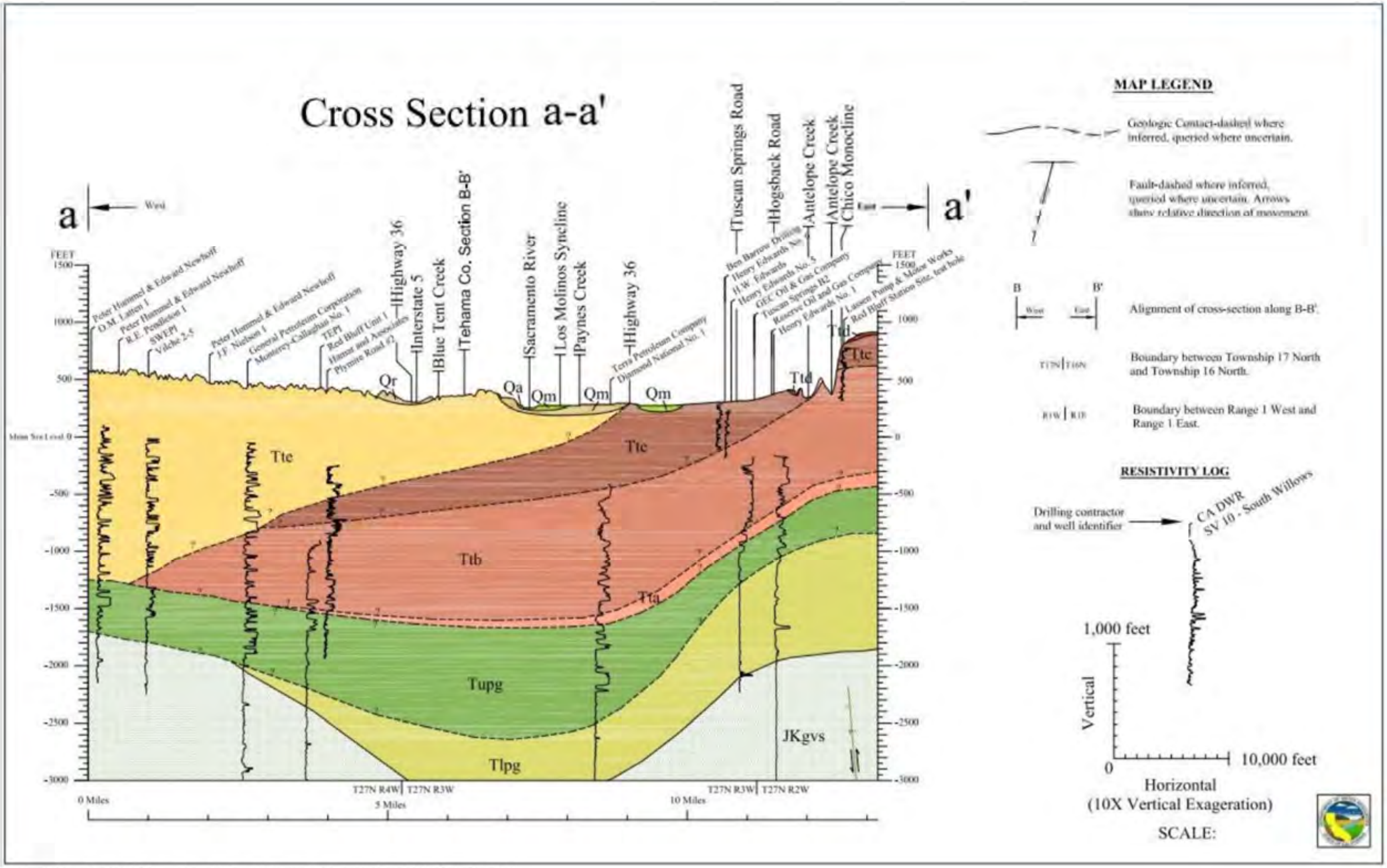


This AEM log is NOT continuous with the previous AEM log.

D - D' Nearest AEM Log







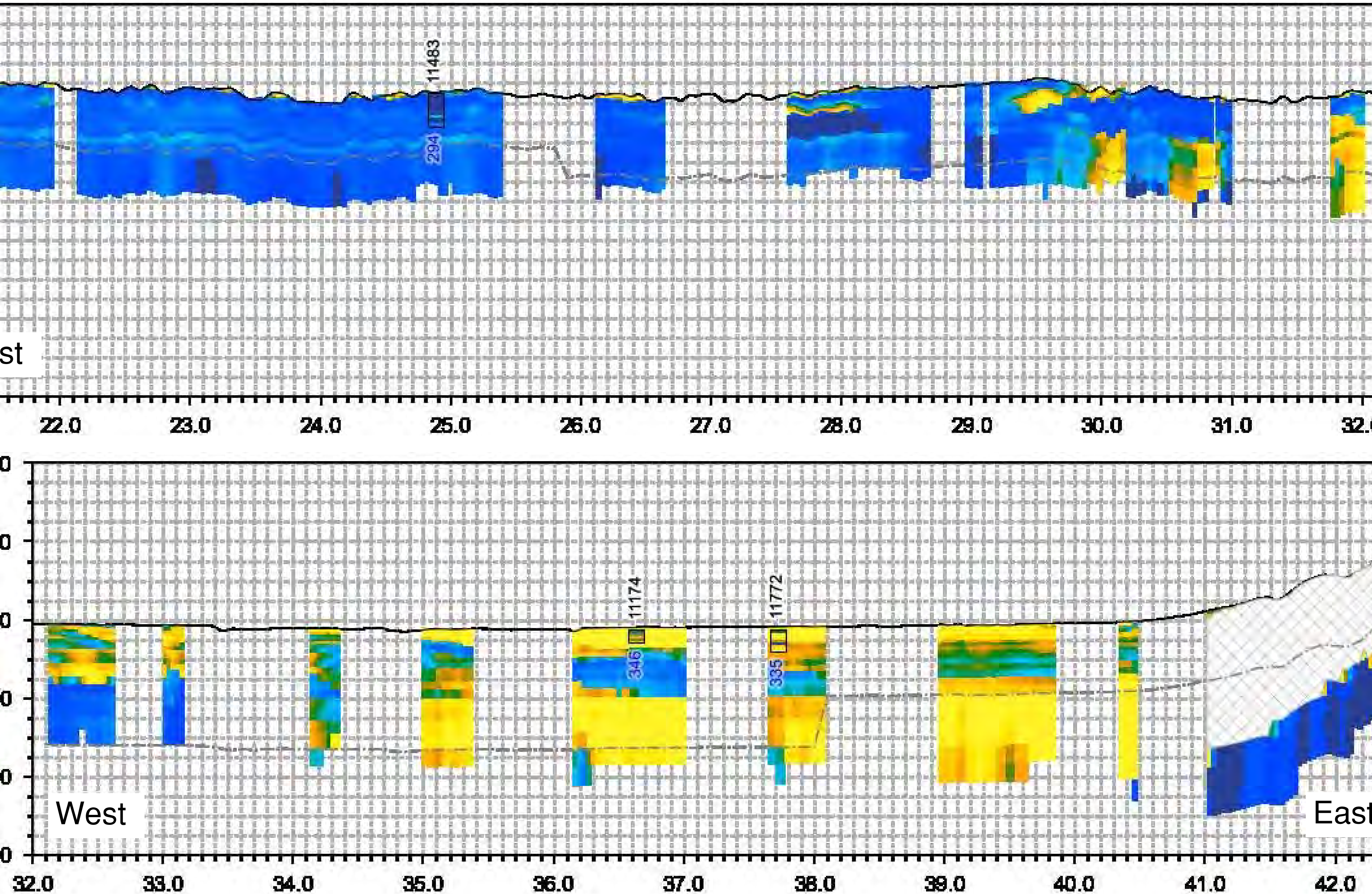
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B_Antelope.aprx Figure 2-11 DWRcrossSectionA_A

Cross Section a-a'

Figure 2-24

Groundwater Sustainability Plan
Antelope Subbasin

a - a' Nearest AEM Log



This AEM log is NOT continuous with the previous AEM log.

2.2.1.5 Identification/Differentiation of Principal Aquifers

Two principal aquifer units are defined in the Subbasin: Upper Aquifer and Lower Aquifer. The two-aquifer designation is based on an examination of time-series groundwater elevation hydrographs, electric resistivity data from geophysical logs, lithologic logs, well construction details, and review of previous studies in the Subbasin. The northern Sacramento Valley depositional environment is dominated by fluvial and alluvial deposition after the Eocene marine depositional environment transitioned to a subaerial one. The Pliocene depositional environment is similar to the current depositional conditions, with eastern depositional streams sourced from the Cascade Range and western depositional streams sourced from the Coast Ranges draining onto a central floodplain. This depositional environment resulted in a complex and varied series of water bearing sedimentary deposits and the Tuscan / Tehama Formations that collectively form a two-aquifer system in the Subbasin and beyond. Within singular water bearing formations there are areas where confined or unconfined conditions can be dominant. Generally, confined aquifer conditions are encountered at depth and unconfined conditions are seen in the shallower porous media. The complexity of the geologic materials and the formations makes it difficult to define a singular widespread aquitard or distinctive change in geologic materials separating an upper and lower aquifer. To delineate between areas with a higher likelihood of confined conditions, well construction data throughout the Subbasin were examined. Most of the wells in the Subbasin are screened or completed above 400 feet below ground surface (ft bgs). The bottom of numerical model layer 5 best corresponds with this depth. The bottom of model layer 5 is used as the delineation between the Upper and the Lower Aquifer. This model layer boundary also generally corresponds to fine grained lithology from available well completion reports (**Figure 2-22**; **Figure 2-23**). Lastly, the degree of heterogeneity and anisotropy (directional preferable flow) is likely significant, but not easy to define based on current information.

Upper Aquifer

The Upper Aquifer is defined as the water bearing material from ground surface to the bottom of model layer 5 (approximately 350-450 ft bgs in the Subbasin). The Upper Aquifer has unconfined to semi-confined water conditions. Water bearing geologic units in the Upper Aquifer include the Quaternary formations and the upper portions of the Tehama and Tuscan Formations. Wells screened in the Upper Aquifer are largely for domestic purposes. The depth to the bottom of the Upper Aquifer is approximately 350-450 ft bgs (**Figure 2-22 and Figure 2-23**). The storage capacity of the Antelope Subbasin Upper Aquifer is estimated to be approximately 270,000 acre-feet to a depth of 200 feet (DWR, 2004).

Site-specific Aquifer properties obtained from aquifer tests were not readily available for the Subbasin, however, aquifer tests were conducted in surrounding subbasins. Hydraulic conductivity (rate at which water moves through an aquifer), transmissivity (hydraulic conductivity multiplied by aquifer thickness), and storage coefficients (ability of the aquifer to store water, commonly expressed as specific yield for water table/unconfined aquifers and storativity for confined aquitards) have been estimated near the Subbasin.

In the Los Molinos Subbasin, to the south, estimated transmissivity of the upper portion of the Tuscan Formation (70-530 ft bgs) is approximately 14,000 square feet per day (ft^2/day) to approximately 55,000 ft^2/day (DWR, 2003). This depth interval covers a portion of the Lower Aquifer but is mostly within the Upper Aquifer. In the neighboring Red Bluff Subbasin, the Tehama Formation has an average transmissivity of approximately 4,000 ft^2/day, an average storativity of 0.00089, and an average hydraulic conductivity of 120 ft/day based on a 1989 constant discharge aquifer test at the Rancho Tehama Reserve (McManus, 1993; DWR, 2003).

Lower Aquifer

The Lower Aquifer is defined as the freshwater bearing geologic units throughout the Subbasin from the bottom of model layer 5 at approximately 350-450 ft bgs, to the bottom of the Subbasin. The aquifer has confined to semi-confined conditions. Water bearing geologic units include the lower portions of the Tehama and Tuscan Formations. Wells screened in the Lower Aquifer are largely for non-domestic purposes.

The lack of wells screened in the Lower Aquifer in the Subbasin creates a data gap for hydraulic properties. Hydraulic conductivity has not been directly measured in the Subbasin; however, the lower Tuscan Formation (Units A and B) has a hydraulic conductivity estimate (via an aquifer test south of Deer Creek and North of Little Chico Creek) of 41-88 ft/day (Brown and Caldwell, 2013). Transmissivity of the lower parts of the Tuscan Formation (340-920 ft bgs) ranges from 5,415 ft^2/day to 49,986 ft^2/day south in the Los Molinos Subbasin (DWR, 2003). Storativity in the Los Molinos Subbasin is estimated to be 0.0025 and hydraulic conductivity is estimated to be 40 ft/day to 60 ft/day (Harrison, 1989; Ely, 1994; DWR, 2003). The Tehama Formation has an average transmissivity of 4,341 ft^2/day, an average storativity of 0.00089, and an average hydraulic conductivity of 120 ft/day based on a 1989 constant discharge aquifer test at the Rancho Tehama Reserve in the Red Bluff Subbasin (McManus, 1993; DWR, 2003).

2.2.1.6 Definable Bottom of Basin

The base of the post-Eocene continental deposits is defined as the bottom of the basin. The post-Eocene deposits are the deepest locations where fresh water may exist. Contours of the base of post-Eocene deposits (**Figure 2-16)** are on the base of the Upper Princeton Valley Fill in the majority of the Subbasin. The Upper Princeton Valley Fill is a transitional formation from marine to terrestrial deposition. Interstitial fresh and brackish water is contained in the Upper Princeton Valley Fill and fresh water can intersect with the formation in places (USGS, 1974; TFCWCD, 2012). Fresh water is defined as having a maximum EC of 3,000 µmhos/cm (Berkstresser, 1973). The base of fresh water is the shallowest in the north at elevations of near -800 to -1,200 ft msl and deepest in the west at elevations deeper than -2,000 ft msl (**Figure 2-15;** Berkstresser, 1973). The elevation of the base of fresh water, as depicted by the equal elevation contour lines, is interrupted in the northeast where the Chico Monocline possibly affects the depth to fresh water (**Figure 2-15**). Fresh water depth based on electrical conductivity is corroborated by studies by DWR (2014).

Big Valley Groundwater Sustainability Plan

Adopted December 15, 2021

No. 5-004 Big Valley Groundwater Basin

Prepared by:

LASSEN COUNTY CALIFORNIA

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GEI Consultants

UC CE

and provide subsurface recharge to the BVGB. These recharge areas suggested by DWR are shown in red shading on **Figure 4-5** and correlate with Pliocene to Pleistocene[23] basalts (Tpbv and Qpbv). These units are mapped by DWR (1963) outside the Basin to the northwest and southeast, as well as along the crests of Barber and Ryan Ridges to the northeast of Big Valley.[24] GeothermEx (1975) generally concurs with this mapping, except for the areas along Barber and Ryan Ridges, which they map as a much older unit (Miocene), corroborated by a radiometric age date measured at 13.8 million years. This distinction is important because an older unit is more likely to underlie the Basin sediments and is less likely to be hydraulically connected to the BVGB. At the northwestern end of Barber Ridge, GeothermEx mapped the oldest unit in the BVGB area (Tm) of andesitic composition. This unit contains the site of the Shaw Pit quarry.

4.4 Principal Aquifer

4.4.1 Formation Names

The Pliocene-Pleistocene[23] age Bieber Formation (TQb) is the main formation of aquifer material defined within BVGB, and DWR (1963) estimates that it ranges in thickness from a thin veneer to over 1,000 feet. It meets the ground surface around the perimeter of the Basin, especially on the southeast side (DWR 1963). The formation was deposited in a lacustrine (lake) environment and is comprised of unconsolidated to semi-consolidated layers of interbedded clay, silt, sand, gravel, and diatomite[25]. Layers of black sand and white sand (pumiceous) were identified as highly permeable but discontinuous and mostly thin. GeothermEx (1975) did not embrace the DWR name and identified this formation as an assemblage of tuffaceous, diatomaceous lacustrine, and fluvial sediments (Ttsu, Ttsl). Both investigations identified the formation in the same overall location based on a comparison of the two geologic maps, but the GeothermEx map provides more detail and resolution than the DWR map. For the purposes of the GSP, the name Bieber Formation will be used.

Recent Holocene[26] deposits (labeled with Q) were mapped within the center of the Basin and along drainage courses from the upland areas and are identified by DWR (1963) as alluvial fans (Qf), intermediate alluvium (Qal) and Basin deposits (Qb). The composition of these unconsolidated deposits varies from irregular layers of gravel, sand and silt with clay to poorly sorted silt and sand with minor clay and gravel (Qal) to interbedded silt, clay and "organic muck" (Qb). The latter two deposits occur in poorly drained, low-lying areas where alkali[27] could accumulate. The thickness of these sediments is estimated to be less than 150 feet. GeothermEx (1975) identified these deposits as older valley fill (Qol), lake and swamp deposits (Ql), fan deposits (Qf) and undifferentiated alluvium (Qal). All these recent deposits are aquifer material[28] and are part of the Big Valley principal aquifer. There is discrepancy

[23] 5.3 million years to 12 thousand years ago.
[24] The GSAs specifically requested a basin boundary modification to include these upland recharge areas within the Basin boundary. The request was denied by DWR as not being sufficiently substantiated. (*See* **Appendix 1A**)
[25] Diatomite is a fine-grained sedimentary rock made primarily of silica, and is formed from the deposition of diatoms, which are microscopic creatures with shells made from silica.
[26] Recent geologic period from 12 thousand years old to present.
[27] Alkali means relatively high in alkali and alkali earth metals (primarily sodium, potassium, calcium, and magnesium) and generally results in a high pH (greater than 7 or 8).
[28] Meaning they contain porous material with recoverable water.

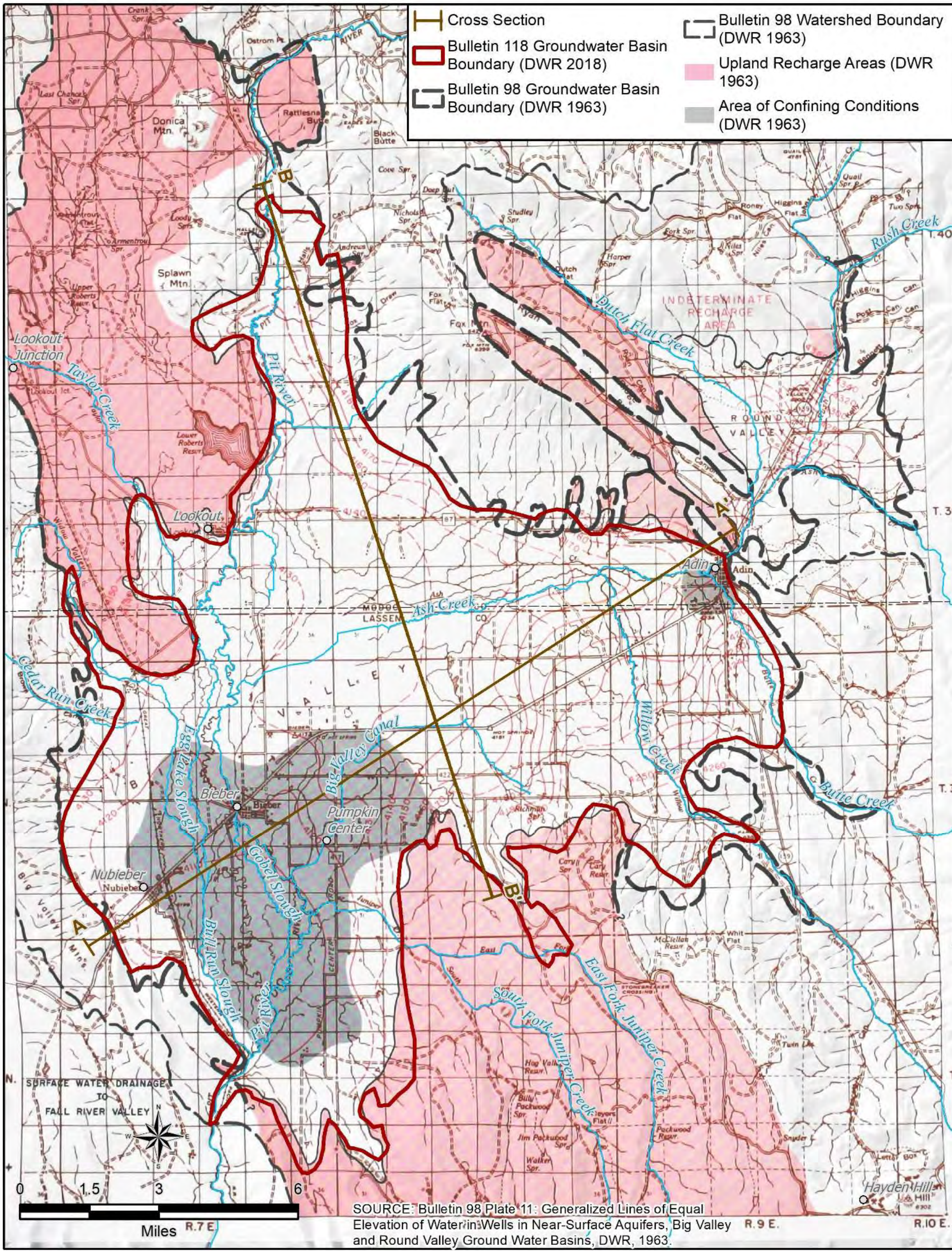


Figure 4-5 DWR 1963 Upland Recharge Areas and Areas of Confining Conditions

between the two maps in the northeastern portion of the Basin, where GeothermEx extends the alluvial sediments much further upslope toward Barber Ridge and Fox Mountain as discussed in Section 4.3 – Local Geology.

The principal aquifer consists of the Bieber Formation (TQb and recent deposits (Qal, Qg, Qb)). While DWR (1963) delineates an "area of confining conditions" in the southwest area of the Basin on **Figure 4-5**, the data to support the confinement and the definition of a broad-scale, well-defined aquitard[29] is not currently available.

As described herein, aquifer conditions vary greatly throughout the Basin. However, clearly defined, widespread distinct aquifer units have not been identified, and with the data currently available all the water bearing units in the Basin are defined as a single principal aquifer for this GSP.

4.4.2 Geologic Profiles

Figure 4-6 and **Figure 4-7** show cross-sections across Big Valley. The locations of the cross-sections are shown on **Figure 4-3**, **Figure 4-4** and **Figure 4-5**. The locations of these sections were drawn to be similar to those drawn by DWR (1963) and GeothermEx (1975) and characterize the aquifers in two directions (southwest-northeast and northwest-southeast). The sections show the lithology of numerous wells across the Basin. Very little geological correlation could be made across each section which is likely to be related to the concurrent block faulting and volcanic and alluvial depositional input from various highland areas flowing radially into Big Valley. These complex structural and depositional variables result in great stratigraphic variation over short distances. The pertinent information from cross-sections presented by DWR (1963) and GeothermEx (1975) are shown on the sections.

4.4.3 Definable Bottom

The SGMA and DWR GSP regulations do not provide clear guidance for what constitutes a "definable bottom" of a basin. However, DWR (2016a) Bulletin 118 Interim Update describe the "physical bottom" as where the porous sediments contact the underlying bedrock and the "effective bottom" as the depth below which water could be unusable because it is brackish or saline.

The "physical bottom" of BVGB is difficult to define because few borings have been drilled deeper than 1200 feet and the compositions of the alluvial and bedrock formations are similar (derived from active volcanism), with contacts that are gradational. Also, some of the lavas most likely flowed into Big Valley forming lava lenses that are now interlayered with permeable aquifer sediments. Moreover, the base of the aquifer system is likely variable across BVGB due to the concurrent volcanism and horst/graben faulting of the bedrock.

The deepest lithologic information in the Basin is derived from two test borings by DWR to depths of 1843 and 1231 feet and from two geothermal test wells near Bieber to depths of 2125 and 7000 feet. The 7000-foot well is east of Bieber, but only has lithologic descriptions to a depth of 4100 feet, including descriptions of aquifer-type materials (sands) throughout. The other three deep lithologies give similar indication of aquifer material to their total depth.

[29] Layer of low permeability that prevents significant flow, except at very slow rates.

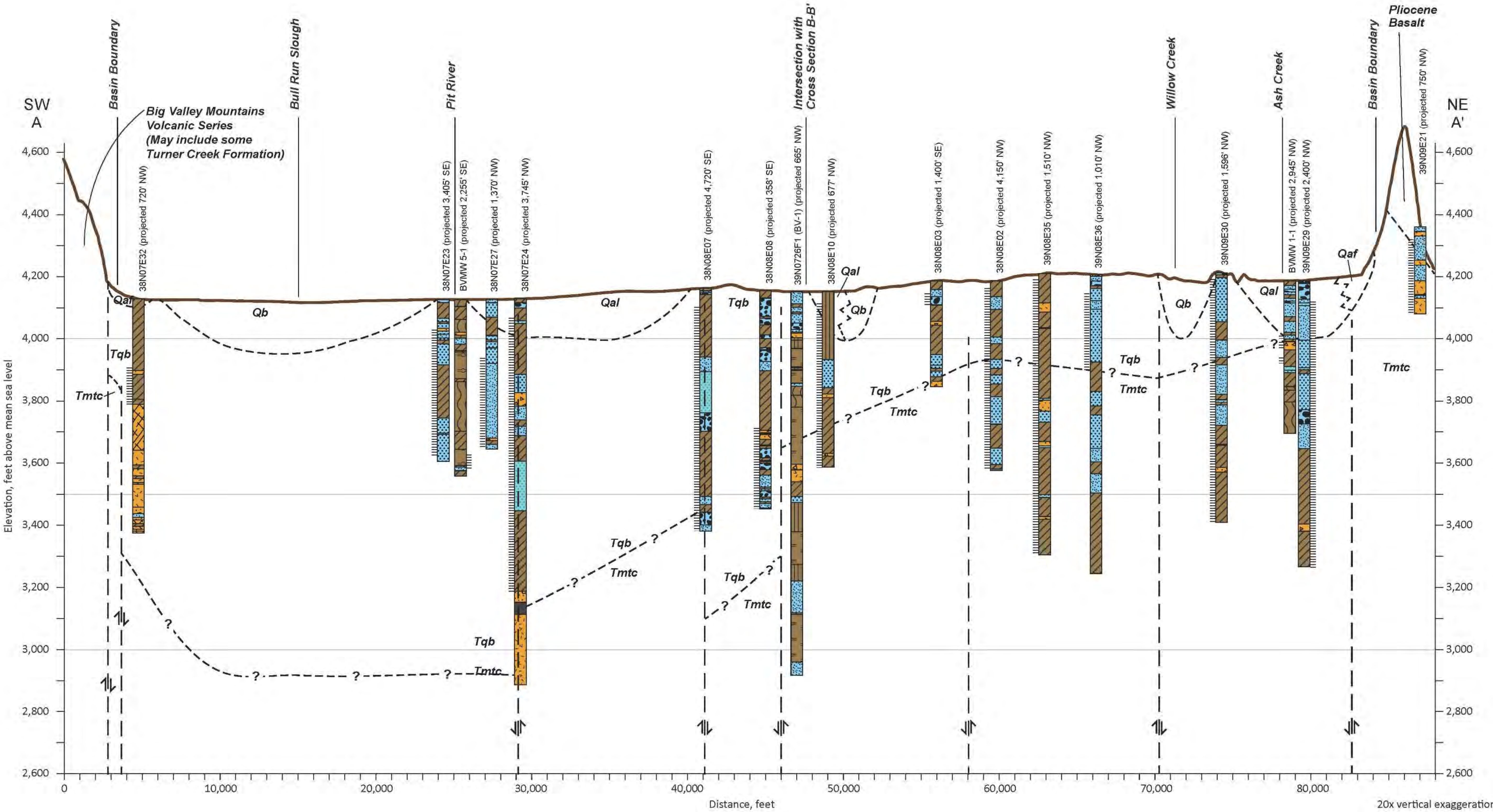
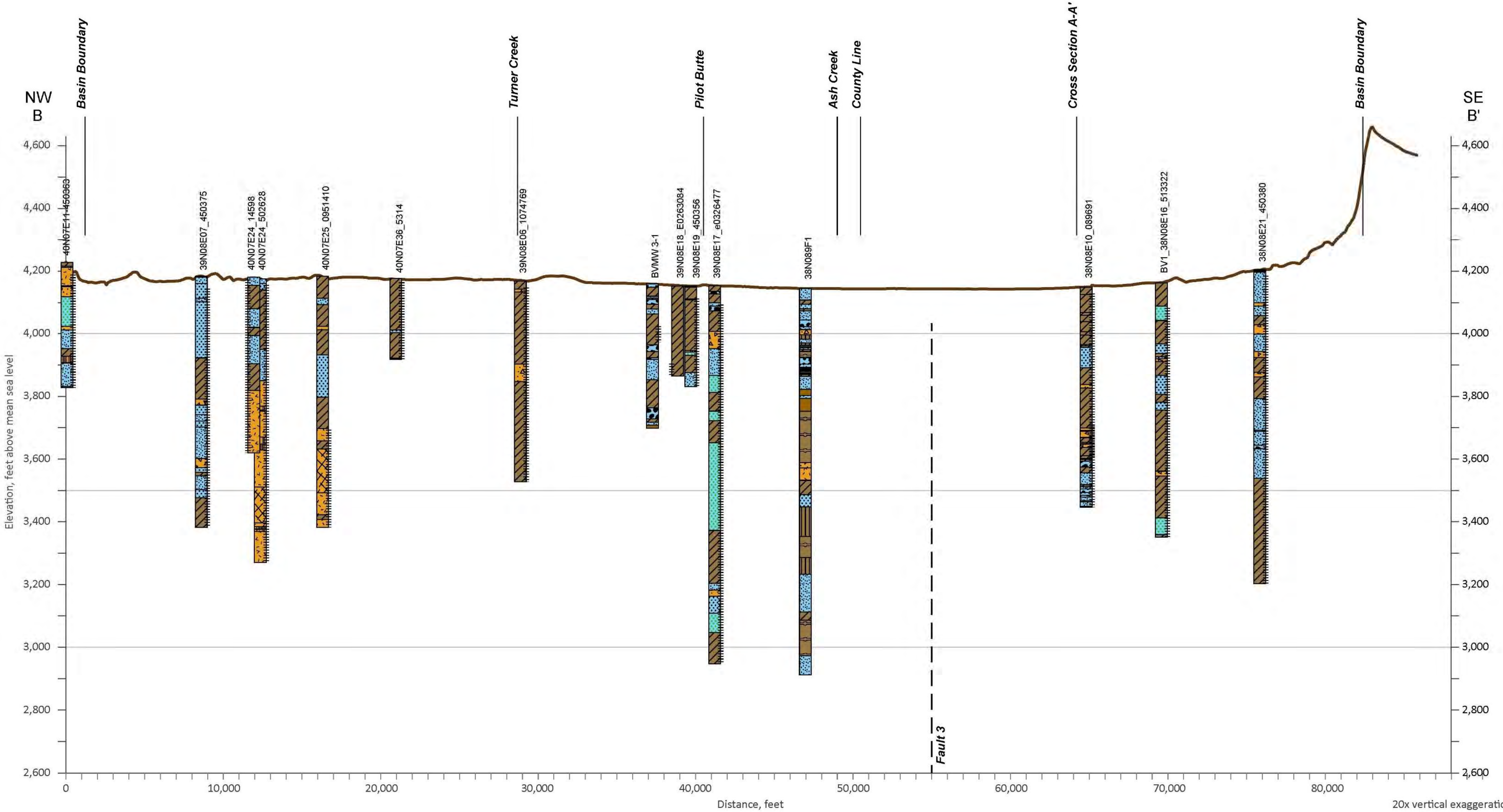


Figure 4-6 Geologic Cross Section A-A'



1370 **Figure 4-7 Geologic Cross Section B-B'**

The two geothermal wells also had temperature logs and some water quality. Water temperatures increased to over 100°F at depths of about 2000 to 3000 feet. One of them located near the Bieber School had water quality samples collected from the 1665- to 2000-foot interval and indicated water quality higher in total dissolved solids (632 milligrams per liter) than is present in shallower portions of the Basin.

The information from these two wells indicated that temperature and water quality concerns increase with depth, but a clear delineation of where water becomes unusable cannot be determined with the data available. With limited scientific evidence to clearly define a physical or effective bottom of the aquifer, an approach to define a practical bottom is being used to satisfy the GSP Regulations which require the aquifer bottom to be defined (§ 354.14(a)(1)), as described below.

The approach for defining the practical bottom is to ensure that all known water wells are included within the aquifer. DWR's well log inventory shows that over 600 wells have been installed in the BVGB. Although DWR's well log inventory does not completely and precisely assess the total number or status of the wells (e.g. abandoned), it is the only readily-available data. The well inventory has been identified as a data gap within this GSP. Wells in this inventory with known depths are summarized in **Table 4-1**. The only borings drilled deeper than 1,200 feet are the two DWR test borings and two geothermal wells discussed previously.

Table 4-1 Well Depths in DWR Inventory

<table>
<tr><th>Depth Interval (ft bgs)</th><th colspan="2">Deepest Well per Section[a]</th><th>Count of All Wells</th></tr>
<tr><td>< 200</td><td>10%</td><td></td><td>41%</td></tr>
<tr><td>200 – 400</td><td>16%</td><td rowspan="2">43%</td><td>25%</td></tr>
<tr><td>400 – 600</td><td>27%</td><td>17%</td></tr>
<tr><td>600 – 800</td><td>28%</td><td rowspan="2">42%</td><td>12%</td></tr>
<tr><td>800 – 1000</td><td>14%</td><td>4%</td></tr>
<tr><td>1000 – 1200</td><td>4%</td><td></td><td>1%</td></tr>
<tr><td>> 1200[b]</td><td>1%</td><td></td><td>< 1%</td></tr>
</table>

Notes:
[a] Section is a 1 mile by 1 mile square. There are 134 sections in the BVGB
[b] Test borings: BV-1 and BV-2 were drilled deeper than 1200 feet

For this GSP, the "practical bottom" of the aquifer is set at 1200 feet but may extend to 4,100 or deeper. This delineation of 1200 feet is consistent with DWR's approach, established over 50 years ago, which declared a practical bottom of 1000 feet. A depth of 1200 feet encompasses the levels where groundwater can be accessed and monitored for beneficial use but does not preclude drilling and pumping from greater depths.

Big Valley Groundwater Sustainability Agency

GROUNDWATER SUSTAINABILITY PLAN
for Big Valley Basin (5-015)

January 2022

Alluvium (Qal)

The surface distribution of younger alluvium is restricted to the streams flowing into Big Valley. The younger alluvium generally extends to depths of 40- to 90-feet and consists of alternating layers of gravel, sand, silt, and clay (DWR 2003). In the mountains to the south, scattered older alluvial deposits occur as remnants of older channel deposits and are typically disrupted by faulting.

2.2.1.6 Groundwater Producing Formations

Characterization of the aquifers in the Basin were conducted by Soil Mechanics and Foundation Engineers Inc. (SMFE 1967), DWR (2003), and Lake County (2003). Based on driller's logs, SMFE (1967) and Lake County (2003) developed five and seven geologic cross sections, respectively, to depict subsurface geologic conditions in the Basin.

SMFE (1967) designated four hydrogeologic units: young alluvium and lakebed (i.e., lacustrine) deposits in the lowland area; older, high level alluvial deposits in the upland area; "volcanic ash" and fracture zones in the Clear Lake Volcanics and the Franciscan Formation. Lake County (2003) identified four aquifers. The Quaternary floodplain and basin deposit system (Ql, Qal) contains an upper aquifer (A1) and a lower aquifer (A2). The Kelseyville Formation (Qk) also contains two aquifers: the upper aquifer (A3) and underlying "volcanic ash" aquifer, where the upper aquifer (A3) is similar in characteristics to the A2 aquifer.

Based on these prior studies, there appears to be three groundwater producing aquifer deposits and the underlying fractured bedrock water-bearing formation in the Basin:

- **Quaternary Alluvium (Qal) and Lake Deposits (Ql)** – includes recent stream channel, overbank and alluvial fan deposits, and lake deposits.
- **Kelseyville Formation (Qk)** – excludes the Kelsey Tuff Member, the Kelseyville Formation was mapped as Quaternary terrace deposits in SMFE (1967) and DWR (2003).
- **"Volcanic Ash" Aquifer (Qk)** – Rymer (1981) and Hearn et al. (1988) termed as Kelsey Tuff Member and included in the Kelseyville Formation.
- **Fractured Bedrock** – fracture zones in both the lower (JKl) and upper (JKu) Franciscan Formation and Clear Lake volcanic rocks (Qpy, Qda, Qpd, Qro and Qob), though generally limited, may store and transmit water locally.

Quaternary Alluvium (Qal) and Lake Deposits (Ql)

This section summarizes the hydrogeologic characteristic of the Quaternary alluvium (Qal) and lake deposits (Ql). Sediments contained in this hydrogeologic unit range in character from lacustrine silt and clay to alluvial and fluvial sand and gravel. A near surface fine grained layer is present over most of the lowland area north of the Big Valley fault. At a depth of about 70 feet bgs, one or a series of "blue clay" layers are present (SMFE 1967). To the east of Kelsey Creek, a similar clay layer is present at a depth of about 130 feet bgs. SMFE (1967) postulated that this is the same layer offset by displacement along a branch of the Big Valley fault.

Coarse grained materials were deposited along river channels of ancestral Kelsey and Adobe Creeks, over floodplain and in river delta areas at depths of 20 to 70 feet bgs. In general, these coarse-grained deposits give way to finer grained sediments to the north, toward Clear Lake. Less continuous zones of coarse-grained deposits are present between depths of 50 and 200 ft bgs, which is the depth interval that most of the water wells in the Basin were perforated. Lake County (2003) defined the A1 aquifer as ranging in thickness from 10 to 126 feet and occupies much of the northern portion of the Basin. The A2 aquifer underlies the A1 aquifer and is composed of fluvial deposits of gravel, sand, and silty clay. The thickness of the A2 aquifer ranges from 14 to 140 feet (Lake County 2003).

The general flow direction of groundwater in the Quaternary alluvium and lake deposits is northward toward Clear Lake. SMFE (1967) reported that this groundwater movement occurs principally in the upper 70 feet above the persistent “blue clay” layer and suggests groundwater circulation in the deep aquifers is probably limited.

Kelseyville Formation (Qk)

While the Quaternary alluvium and lake deposits are distributed in the northern portion of the Basin; the Kelseyville Formation occupies the southern portion of the Basin (**Figure 2-8**). These two hydrogeologic units are separated by the Big Valley Fault, which uplifted the Kelseyville Formation in the south (Lake County 2006a).

Excluding the Kelsey Tuff Member, Lake County (2003) designated the water bearing portion of the Kelseyville Formation as the A3 aquifer. The A3 aquifer contains similar deposits as the A1 and A2 aquifers and is comprised of fluvial gravel, sand, and silt deposits. The thickness of the A3 aquifer ranges from five to 160 feet.

Volcanic Ash Aquifer (Qk)

Logged by drillers as “volcanic cinders,” “volcanic ash,” or “volcanic gravel” and referred by SMFE (1967) as “volcanic-ash aquifer” and “aquifer ash,” the Kelsey Tuff member of the Kelseyville Formation (Rymer, 1981) was identified by Lake County (2003) as the “volcanic ash” aquifer. The aquifer, where present, ranges from one to eight feet in thickness. A few wells completed in this aquifer reported a yield over 1,000 gallons per minute. Given the relatively small aquifer thickness, Well Completion Reports for wells completed in the volcanic ash aquifer do not indicate how long pumping at this elevated pumping rate can be sustained.

The horizontal extent of the “volcanic ash” was delineated by SMFE (1967), Rymer (1981) and Lake County (2003) and a compilation is depicted in **Figure 2-9**. Bounded by the Big Valley Fault to the north and northeast, the “volcanic ash” aquifer defines a band approximately 3 miles wide that extends diagonally across the valley. SMFE (1967) reported that the “volcanic ash” aquifer is offset by the Adobe Creek fault system and the “volcanic ash” aquifer is tilted down to the northeast in the area west of the Adobe Creek fault. Lake County (2003) estimated the lateral distribution of the “volcanic ash” aquifer included in the Kelseyville Formation amounts to about 15 square miles.

Figure 2-9 indicates that the “volcanic ash” aquifer occurs throughout most of the Basin. To the south, the “volcanic ash” aquifer is exposed in Kelsey Creek and along Highway 29. The “volcanic ash” aquifer is overlain by 50 to 150 feet of Quaternary alluvium west of Adobe Creek Fault. North of the Big Valley fault, Rymer (1981) reported that in one well the “Volcanic ash” aquifer is overlain by over 500 feet of Quaternary alluvium. However, in most instances, driller's logs that reported encountering volcanic ash, volcanic cinders, or volcanic gravel, indicated depths of less than 200 ft bgs.

The presence of the "volcanic ash" aquifer to the north of the Big Valley Fault is certain, even to the north at depth below the sediments of Clear Lake (Hearn et al.,1988). However, its lateral and vertical extent in this area is unknown. The greater depth of the "volcanic ash" aquifer north of the Big Valley fault and the generally much shallower depth of wells drilled in the Big Valley Basin minimizes the development of groundwater supplies from this aquifer in this area. Except in areas where the "volcanic ash" crops out, groundwater contained in the "volcanic ash" aquifer is encountered under artesian conditions. Based on measured water levels in wells which were perforated in the "volcanic ash" aquifer only, SMFE (1967) estimated pressure heads of up to 100 to 150 feet. In areas where water level measurements from wells completed in both the "volcanic ash" aquifer and the overlying alluvial aquifer, only slight water level differences were observed (SMFE 1967), which suggests that the "volcanic ash" aquifer may be in hydraulic communication with the alluvial aquifer.

Under natural conditions, the "volcanic ash" aquifer is recharged by infiltration of precipitation in hilly areas to the south where it outcrops. Surface water also recharges the "volcanic ash" aquifer along upstream river channels where it is in hydraulic communication with streambed alluvial deposits. The "volcanic ash" aquifer may also be recharged from the fractured bedrock aquifer to the south. Recharge from slightly permeable, fine-grained sediments in the central and northern areas of the Big Valley Basin to the 'volcanic ash" aquifer occurs to a much lesser extent.

Regionally, groundwater in the "volcanic ash" aquifer flows from the south (highland area) to the north (SMFE 1967; Lake County 2003). This regional flow regime is interrupted by intra aquifer flow or modified by thinning, warping, or faulting of the aquifer. SMFE (1967) reported that the Adobe Creek fault down dropped the "volcanic ash" aquifer approximately 180 feet on the northwest side of the fault. Due to the minimal thickness of the "volcanic ash" aquifer, even relatively minor fault displacement would completely offset the aquifer and break hydraulic continuity across the fault (SMFE 1967). However, groundwater level contours presented by SMFE (1967) and Lake County (2003) in the Adobe Creek fault area are continuous on either side of the Adobe Creek fault and suggest that the "volcanic ash" aquifer is not displaced by the Adobe Creek fault. It is estimated that approximately 31,500 AF of water is stored in the "volcanic ash" aquifer (SMFE 1967). The "volcanic ash" aquifer is the only source of groundwater in the upland areas.

Fractured Bedrock

Compared to the Quaternary alluvial and lake deposits and Kelseyville Formation, fractured areas in the Franciscan Formation and Clear Lake volcanic rocks are of less hydrogeologic significance. Precipitation infiltrates into the subsurface in outcrop areas via fractures or after a brief surface flow. This water either discharges to temporary springs or seeps out to lower reaches of creeks or as underflow that recharges the other hydrogeologic units in the Basin.

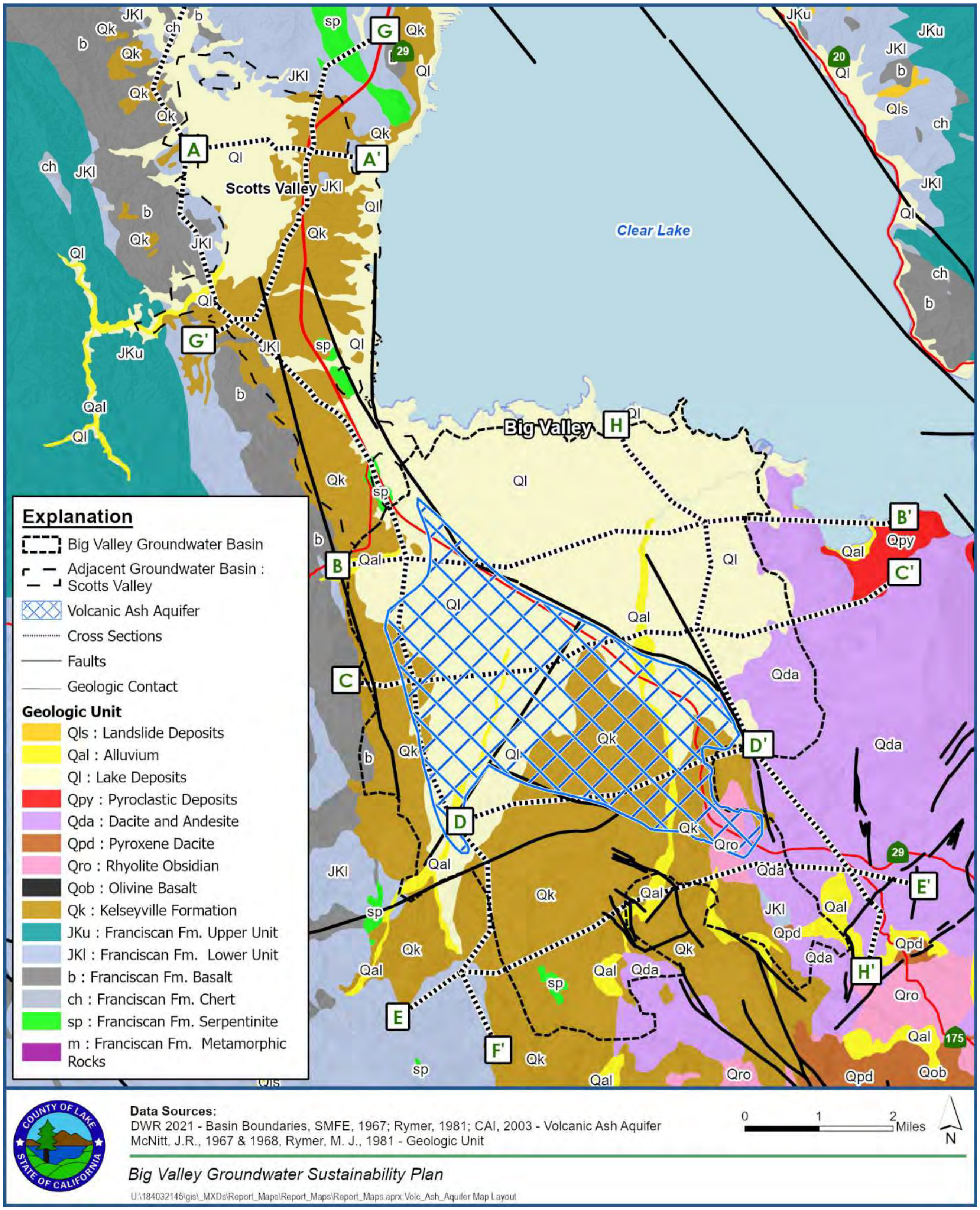


Figure 2-9. Spatial Distribution of the "Volcanic Ash" Aquifer

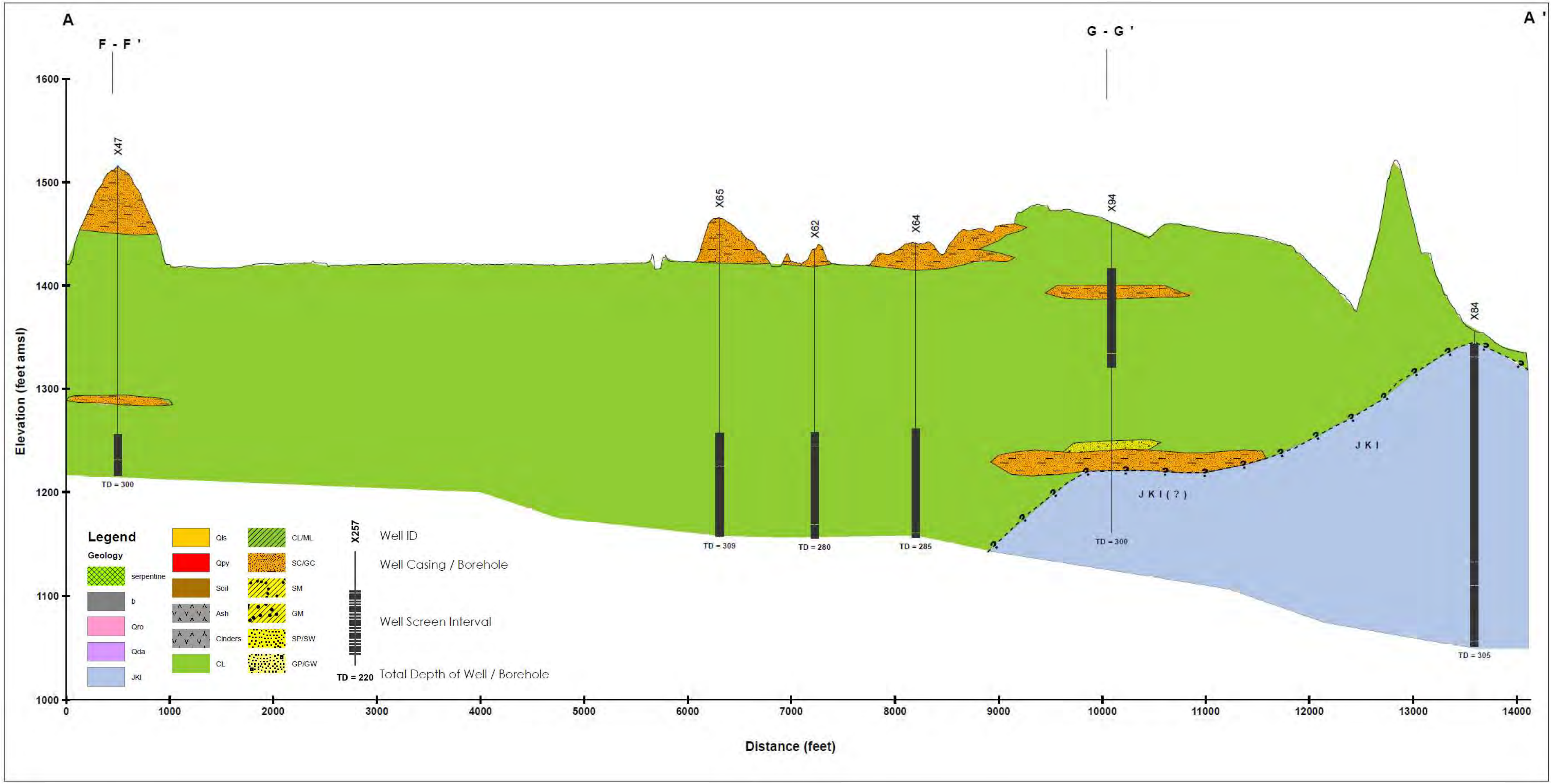


Figure 2-10. Cross Section A – A'

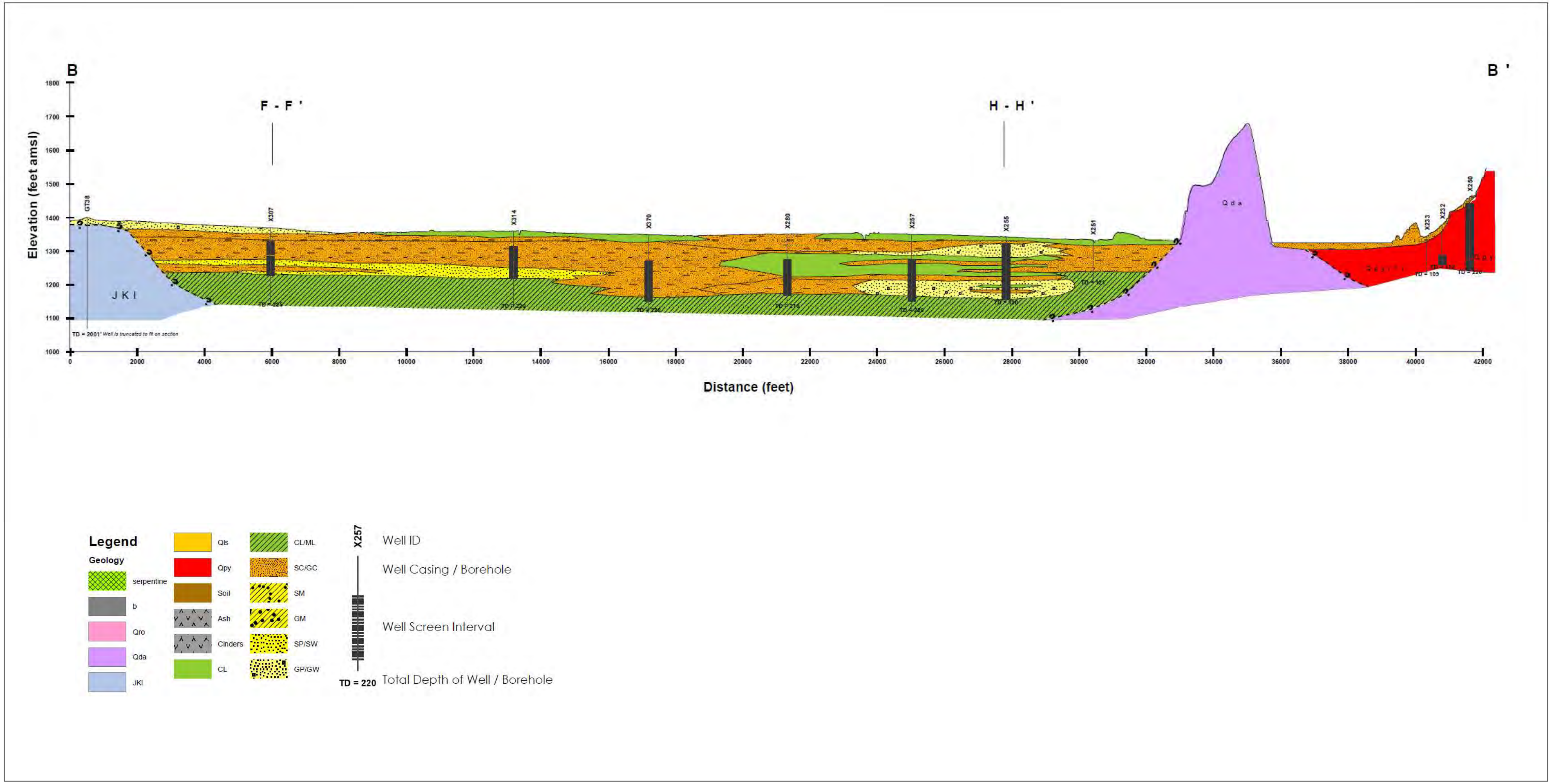
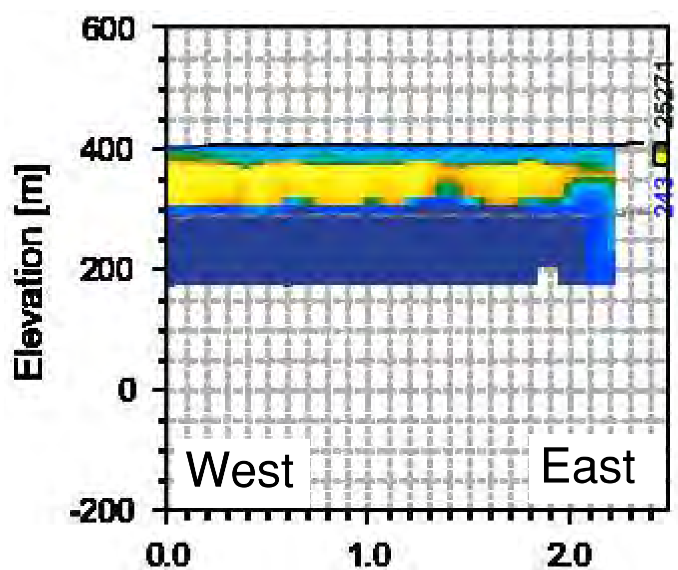


Figure 2-11. Cross Section B – B'

B - B' Nearest AEM Log



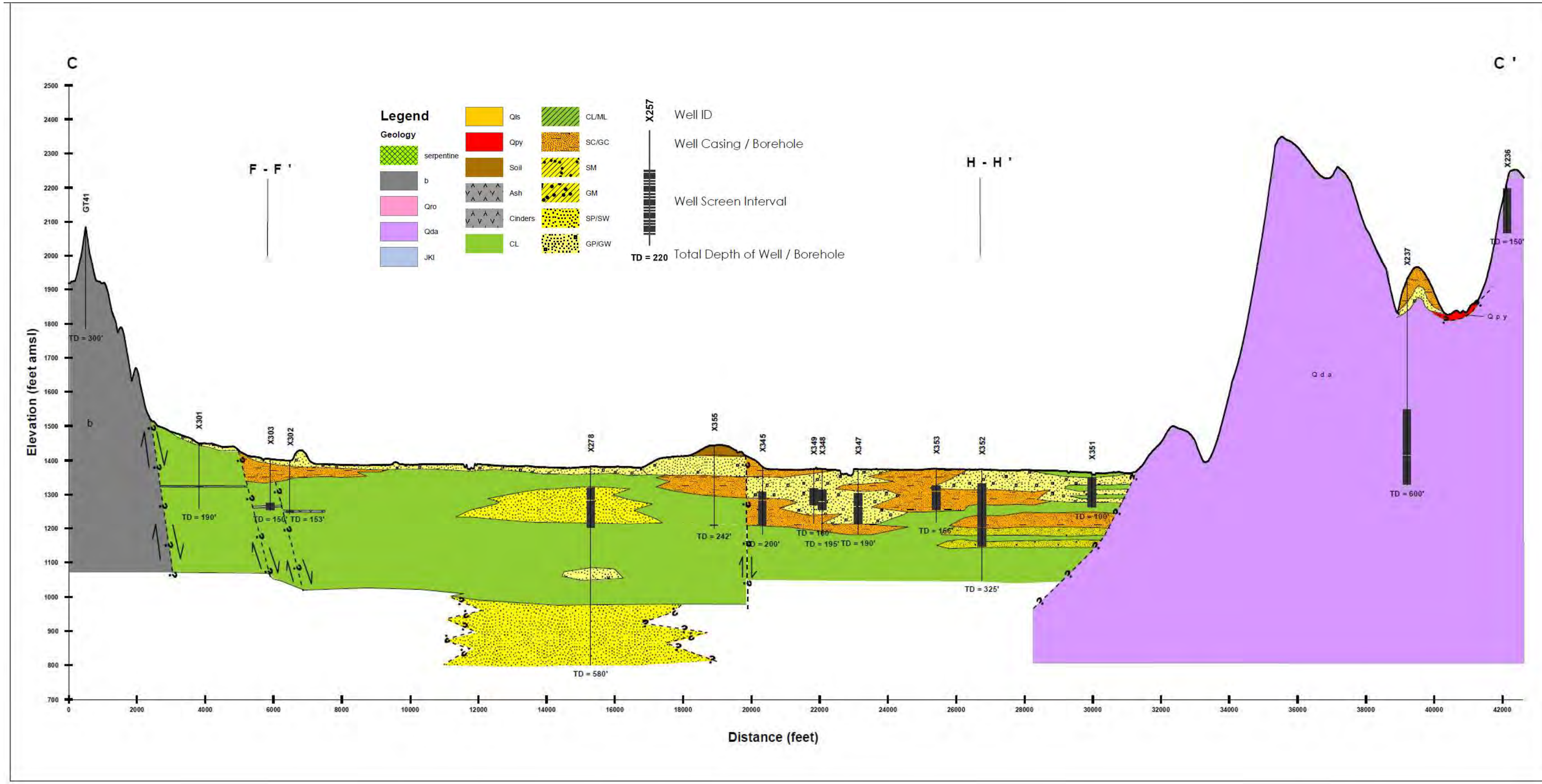


Figure 2-12. Cross Section C – C'

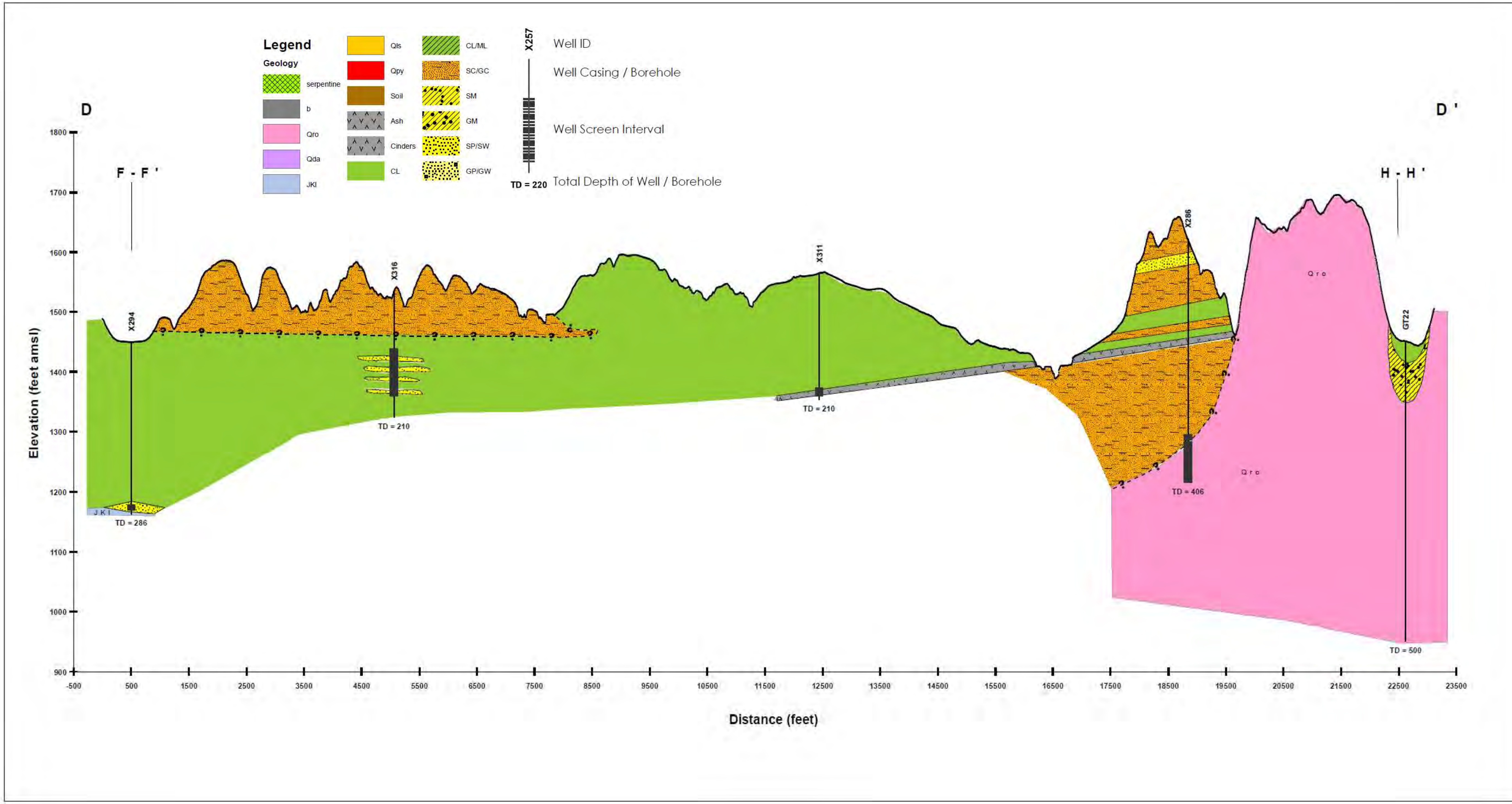
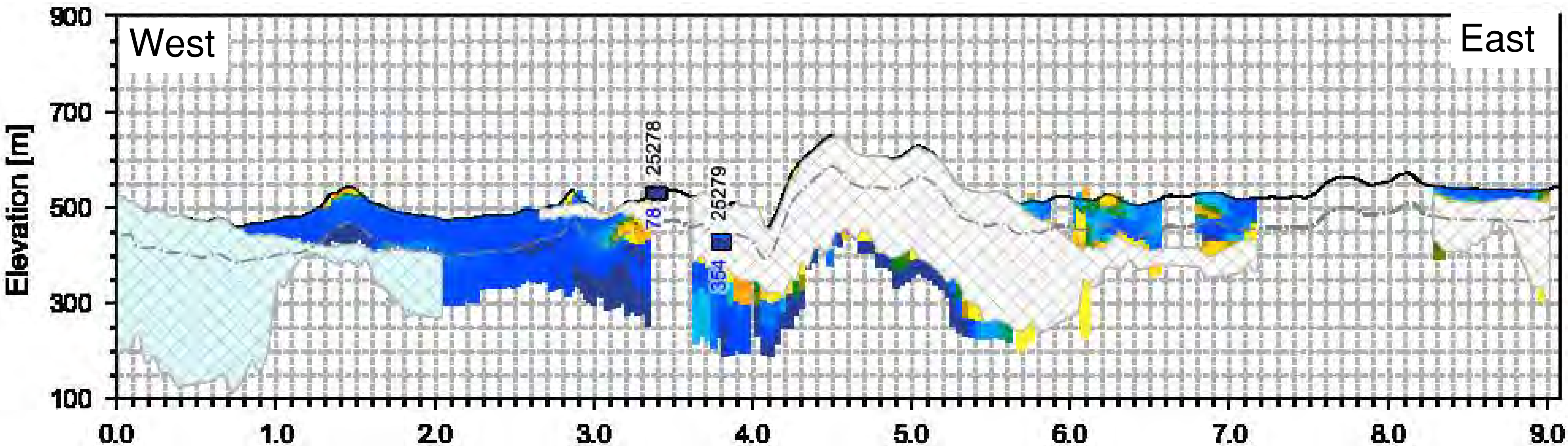


Figure 2-13. Cross Section D – D'

D - D', E - E' Nearest AEM Log



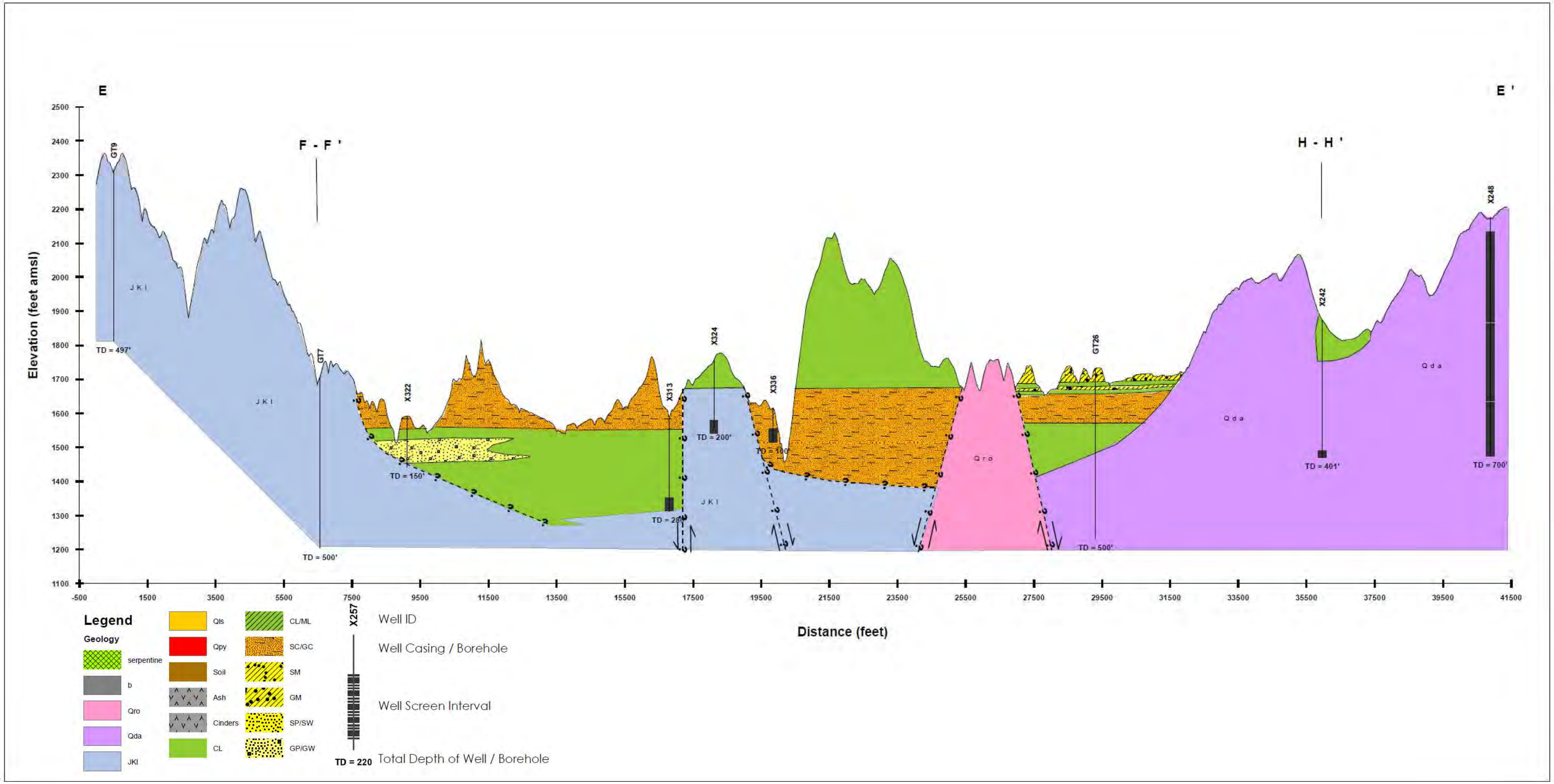


Figure 2-14. Cross Section E – E'

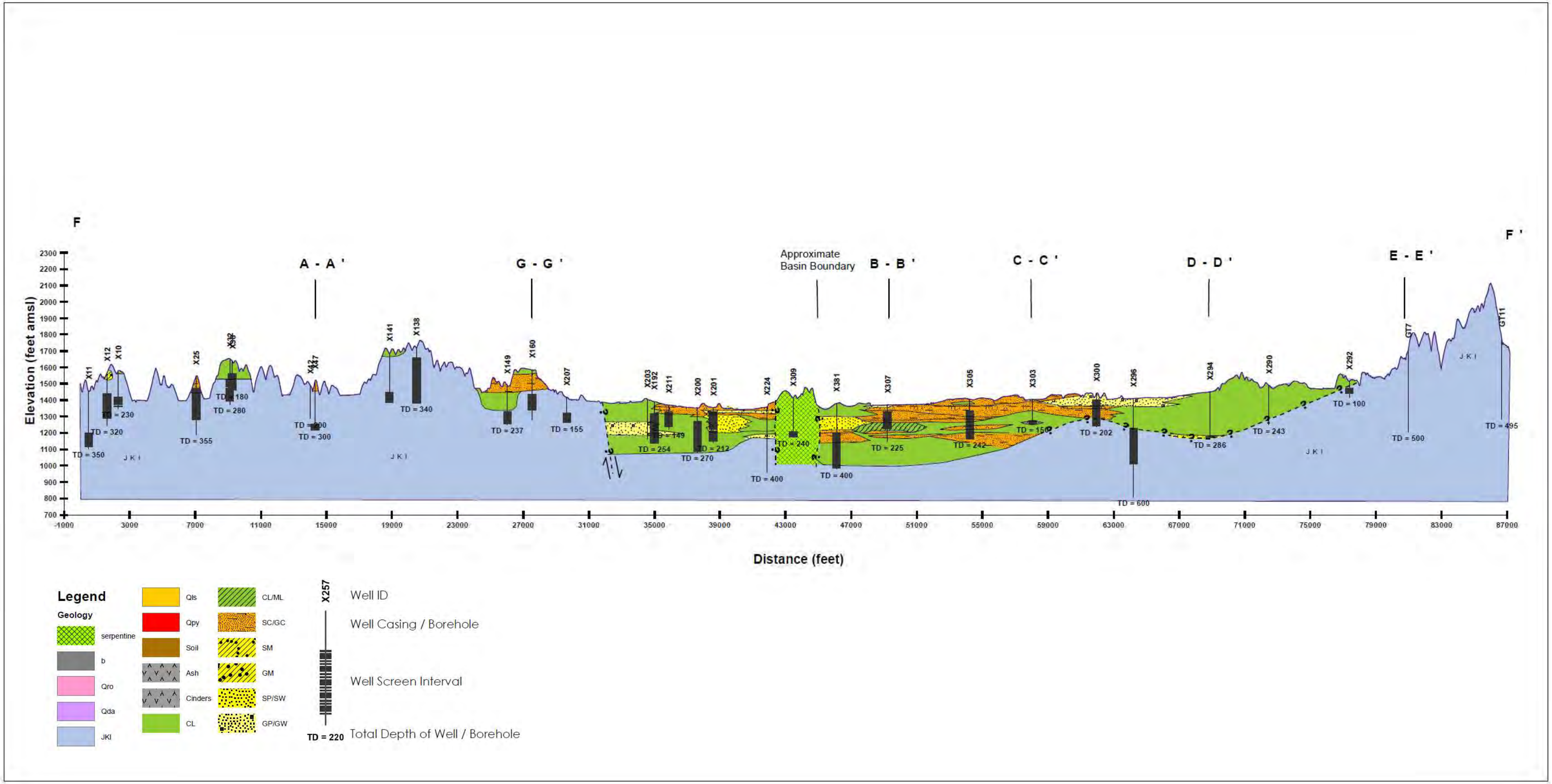
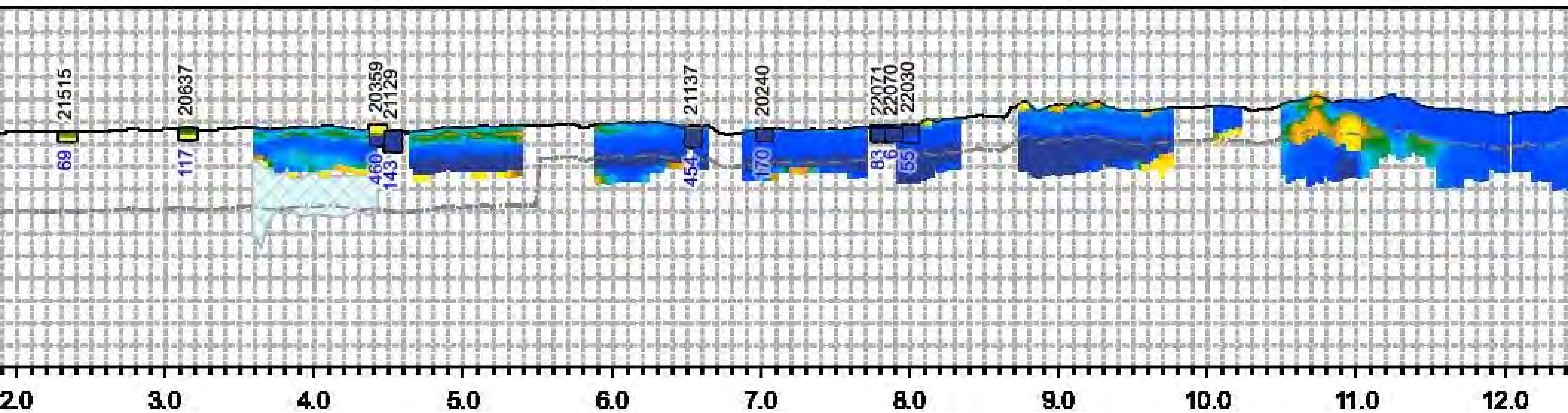


Figure 2-15. Cross Section F – F

F - F' Nearest AEM Log, South



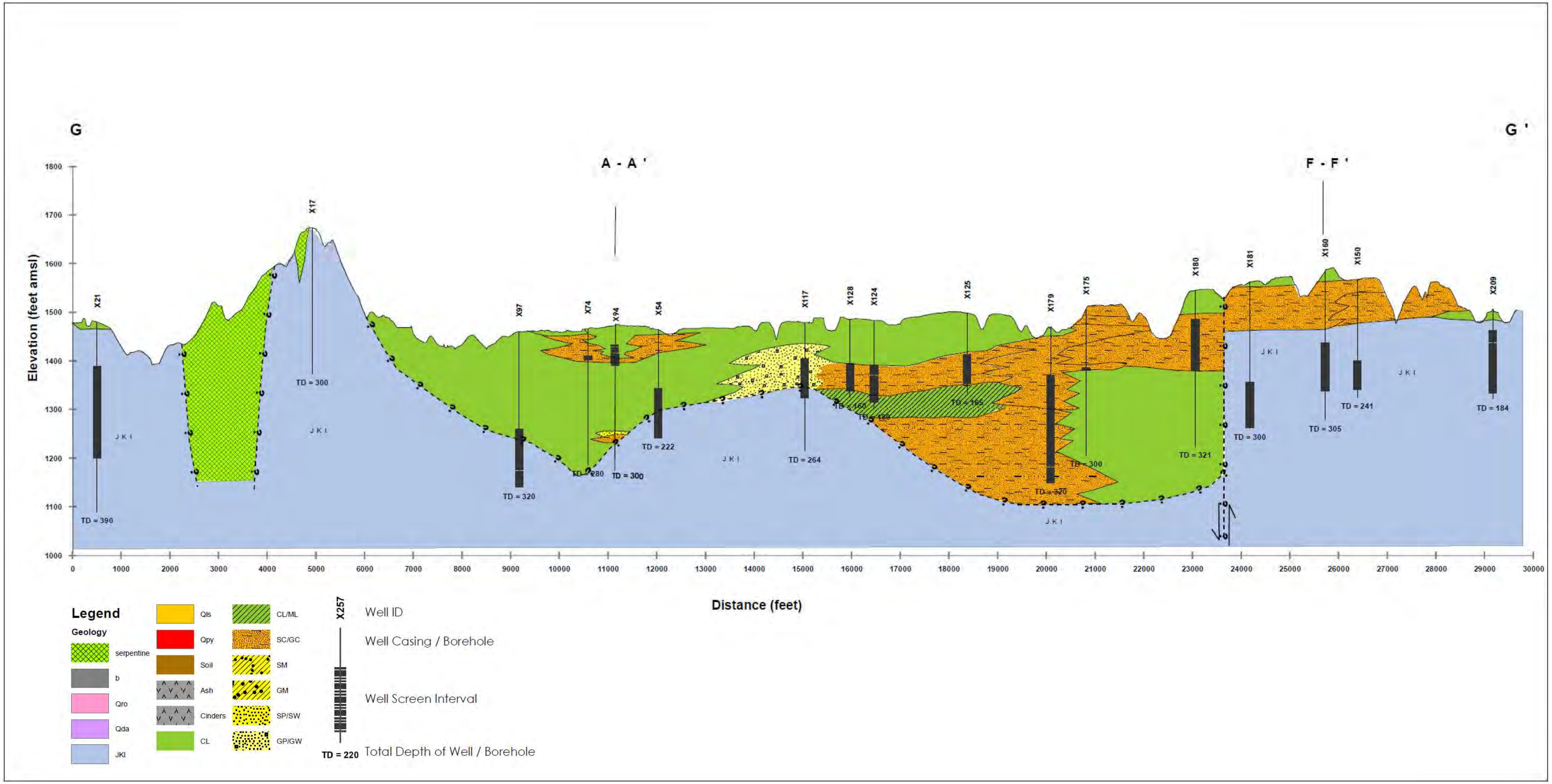


Figure 2-16. Cross Section G – G'

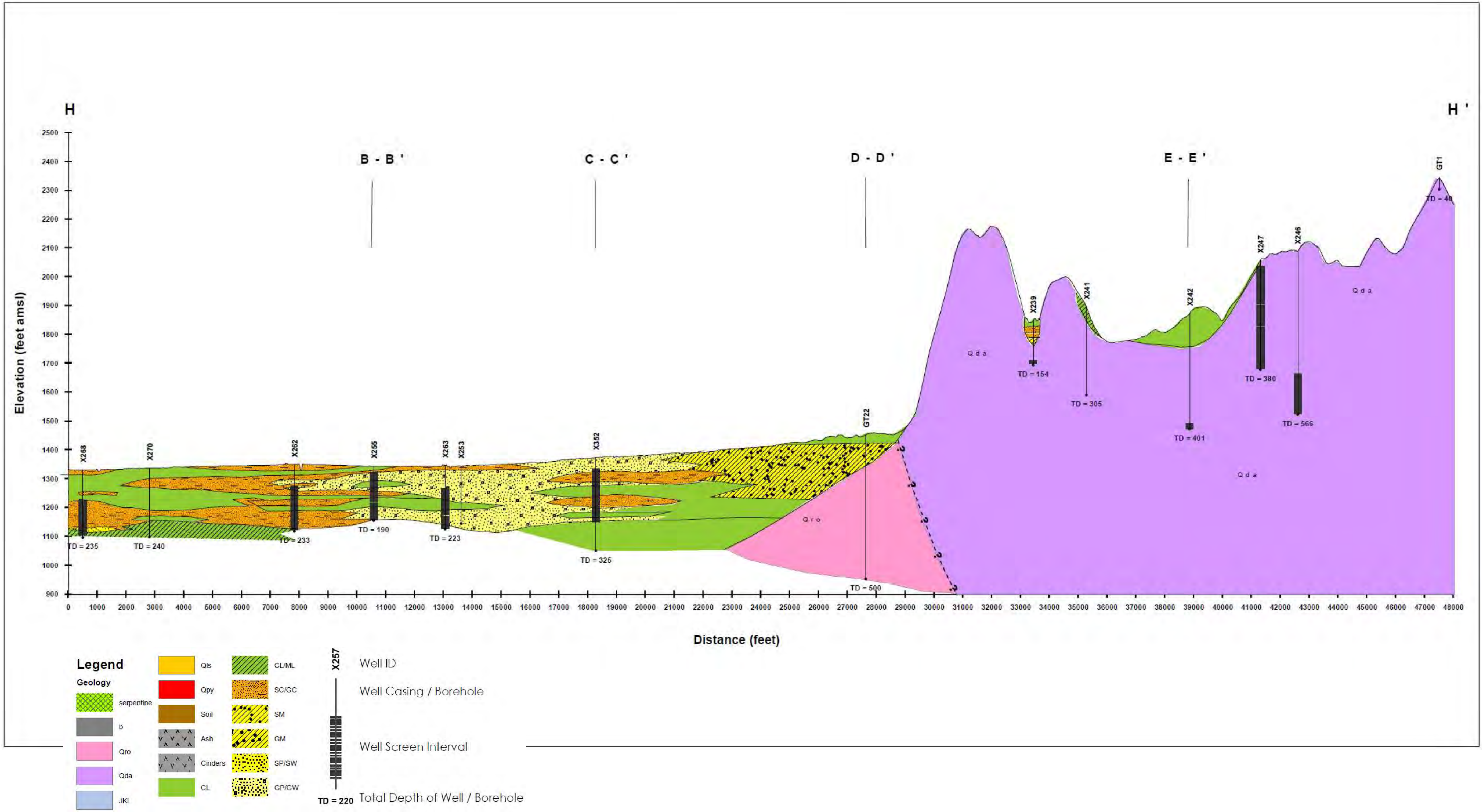
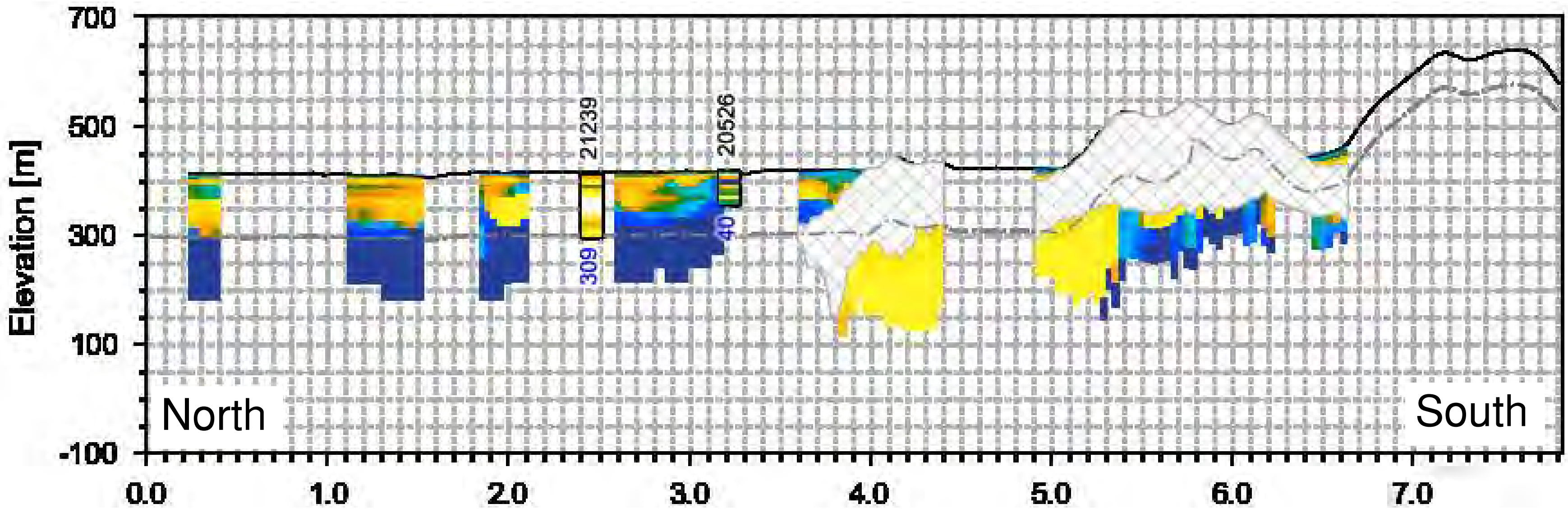


Figure 2-17. Cross Section H – H'

H - H' Nearest AEM Log



TEHAMA COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT

Groundwater Sustainability Plan

Bowman Subbasin

JANUARY 2022

PREPARED BY

Luhdorff & Scalmanini
Consulting Engineers

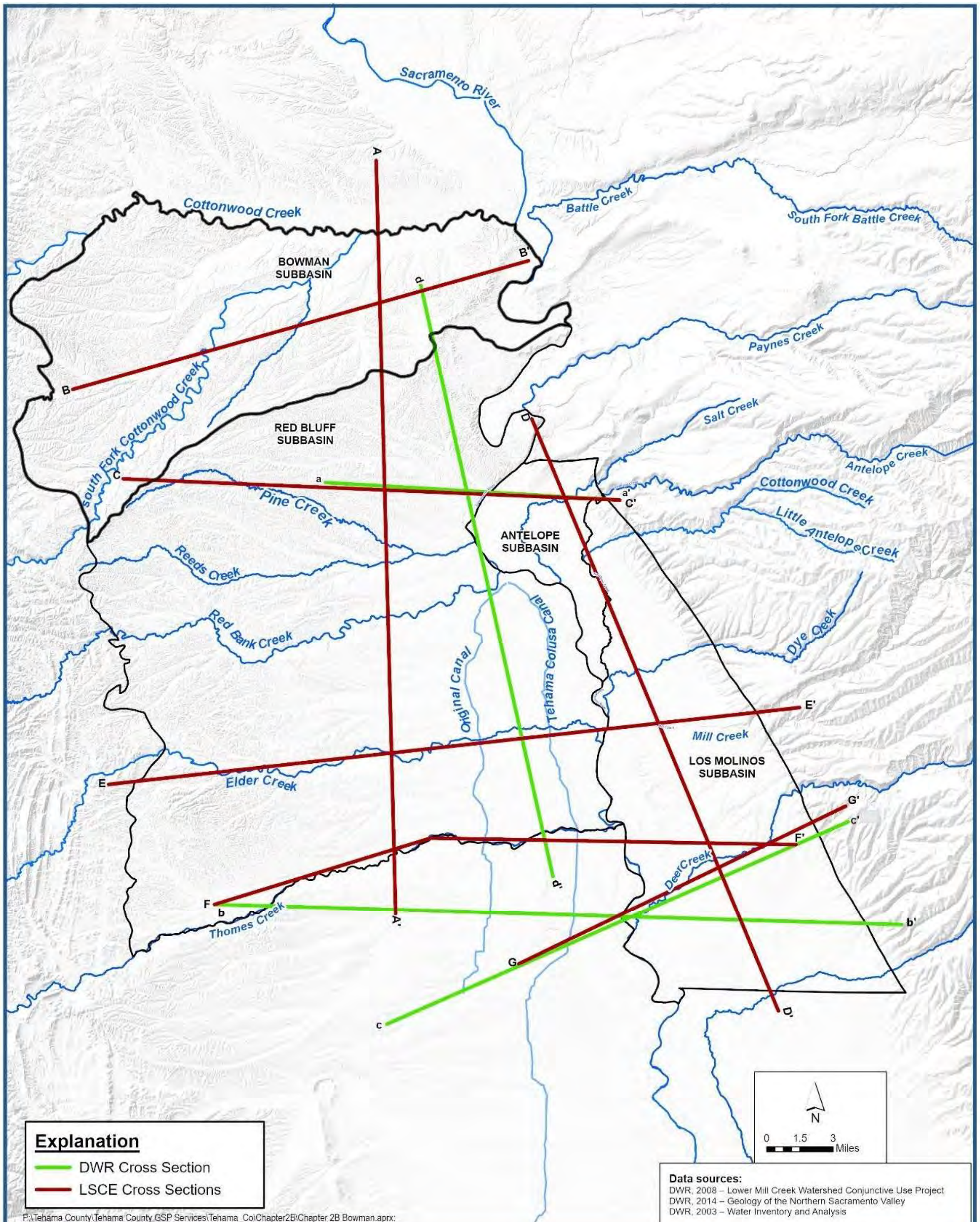
TEHAMA COUNTY

LSCE Team

Geologic Map with Faults

Groundwater Sustainability Plan
Bowman Subbasin

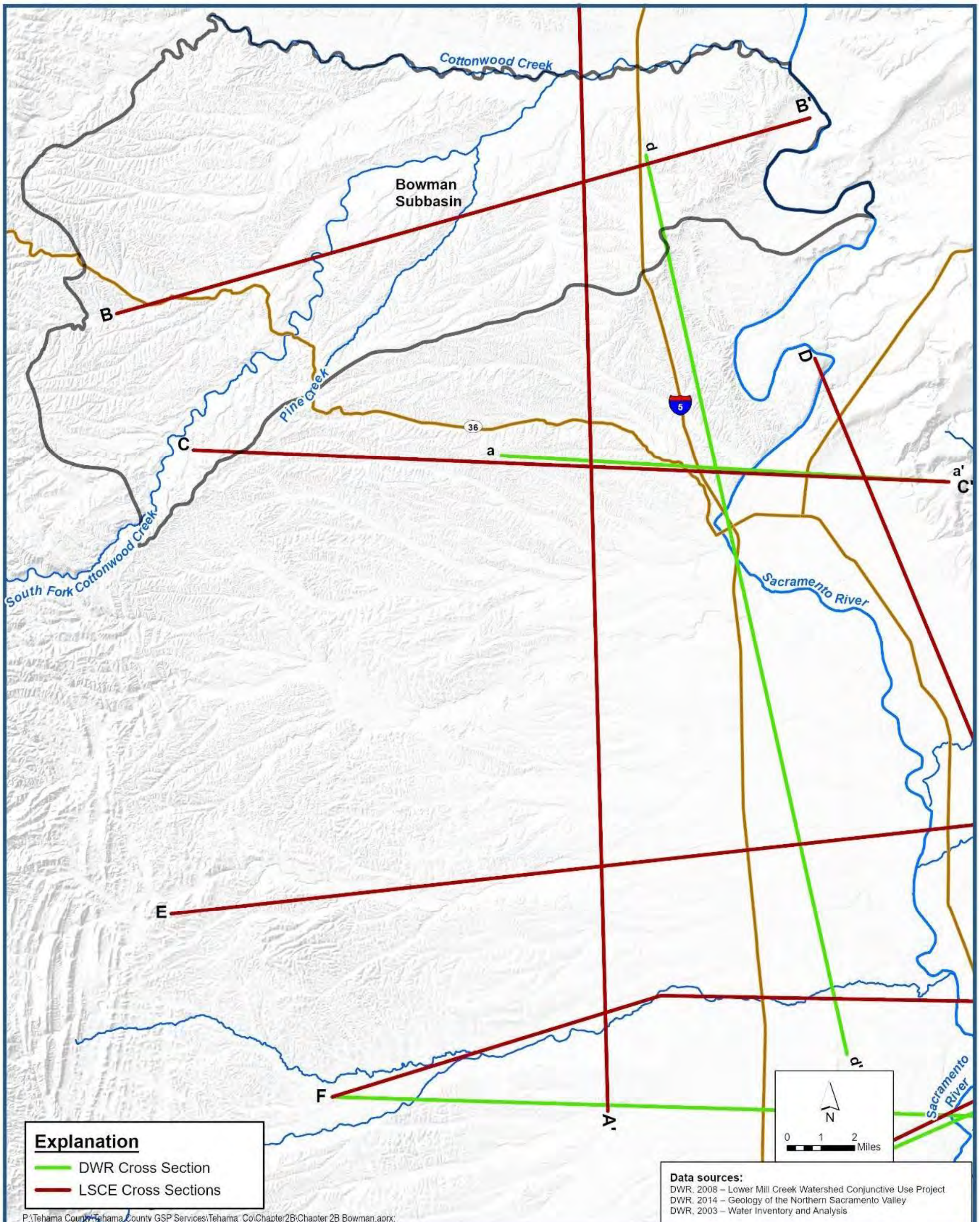
Figure 2-21B



Map of Cross Section Locations

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-22



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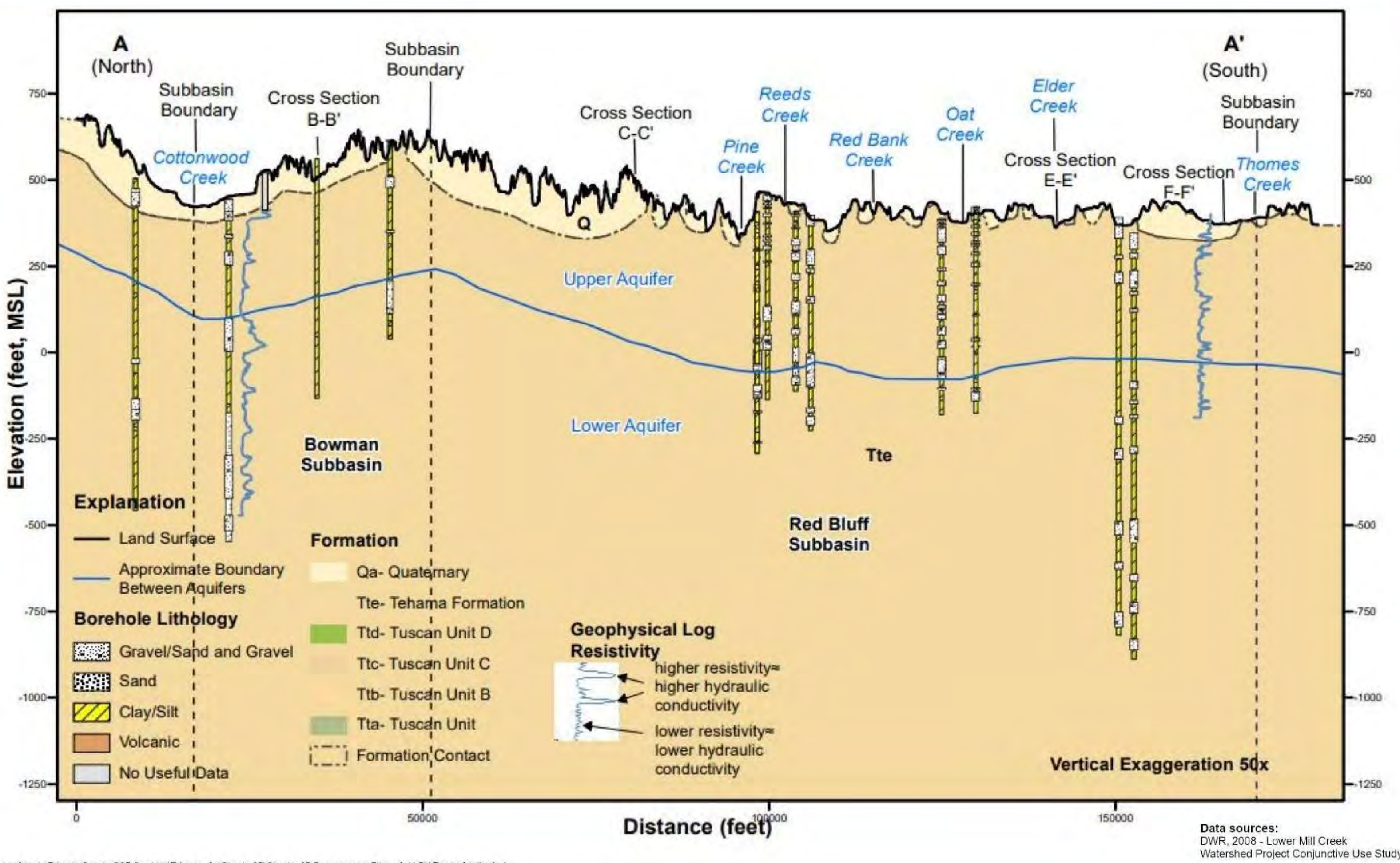
Map of Cross Section Locations

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-22B



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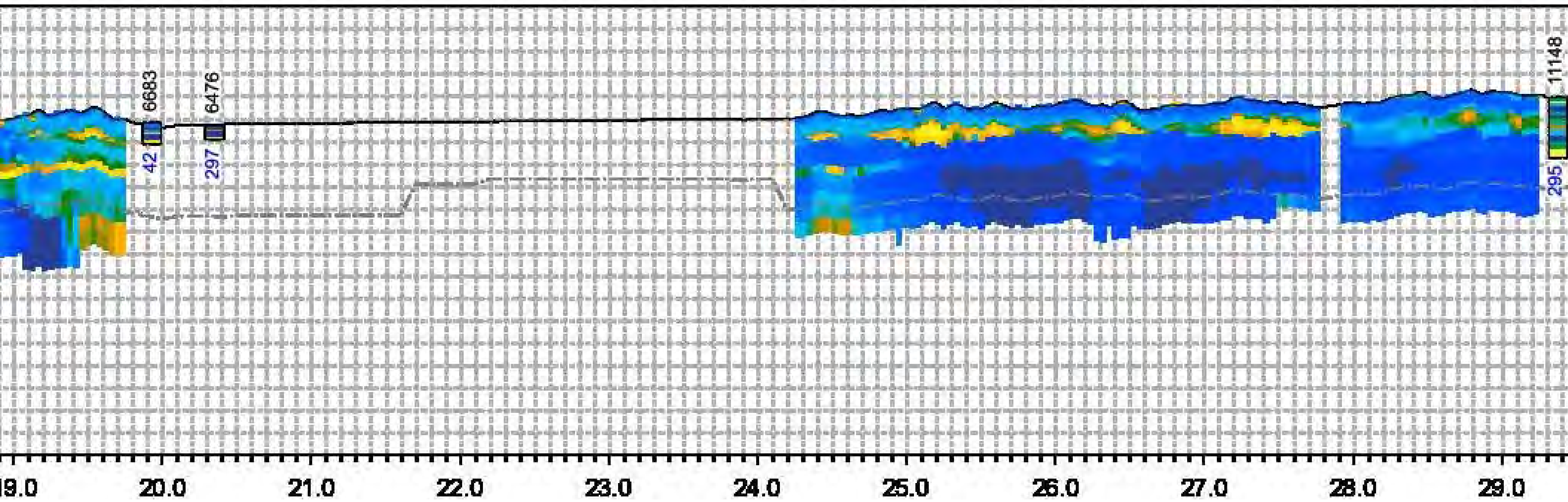
Cross Section A-A'

Groundwater Sustainability Plan
Bowman Subbasin

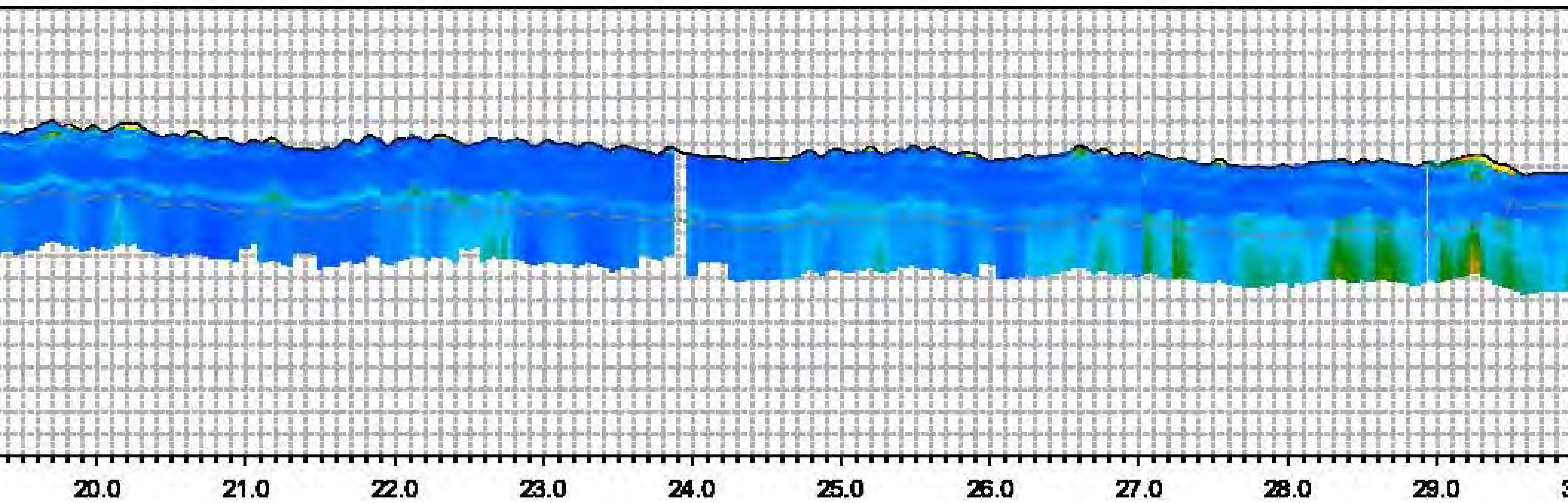
Figure 2-23

A - A' Nearest AEM Log



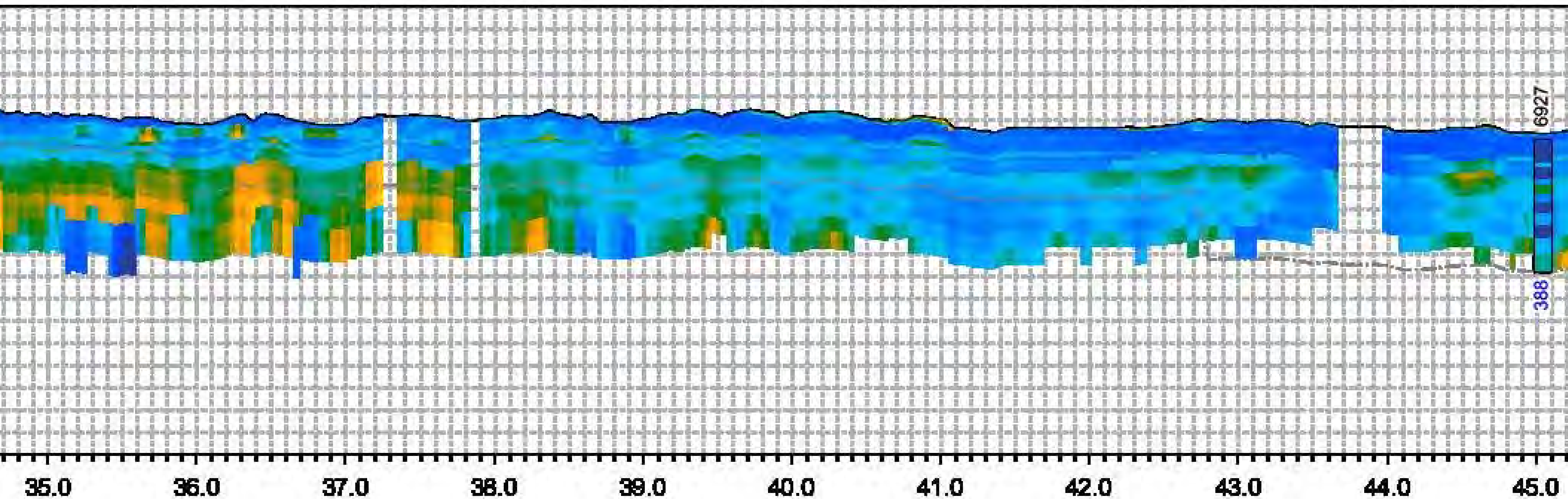
A-A' Nearest AEM logs are NOT continuous.

A - A' Nearest AEM Log

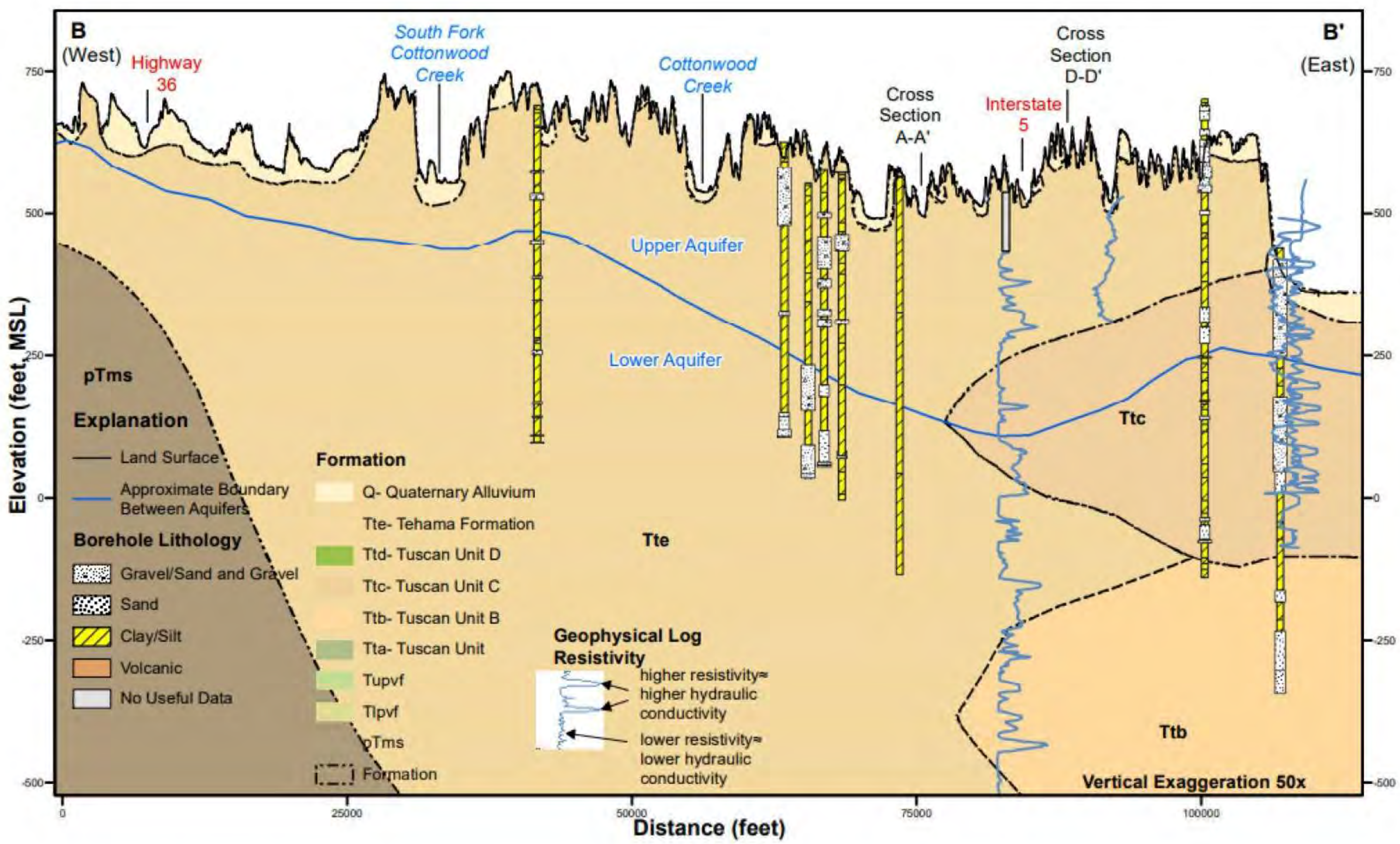


A-A' Nearest AEM logs are NOT continuous.

A - A' Nearest AEM Log



A-A' Nearest AEM logs are NOT continuous.



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

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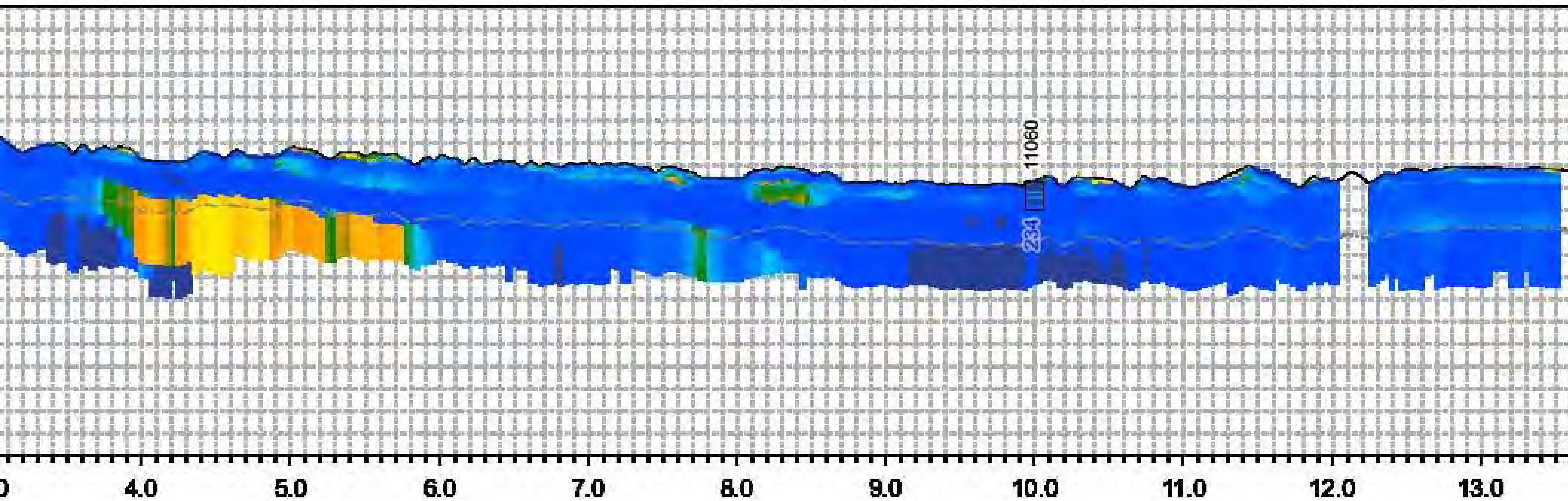
Cross Section B-B'

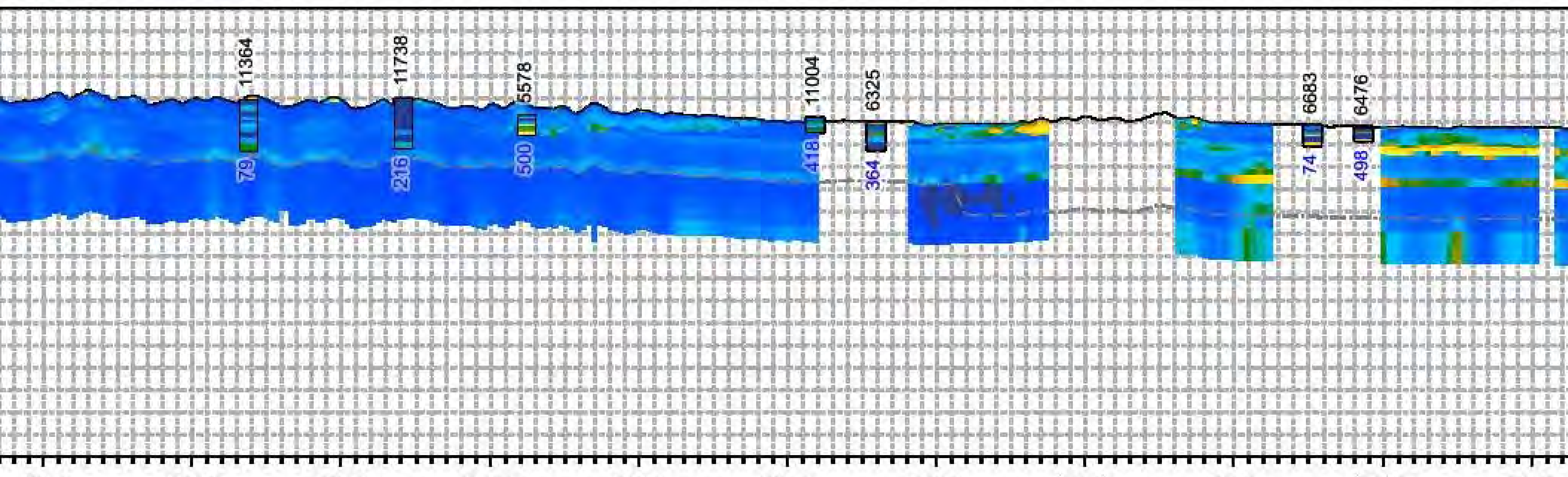
Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-24

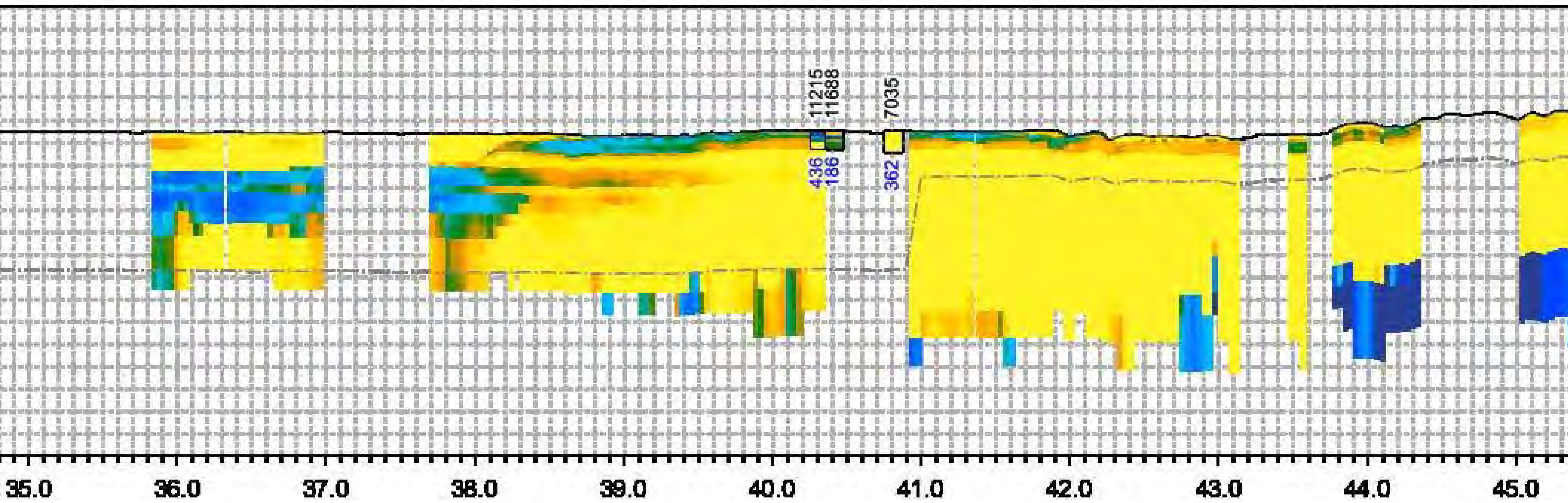
B - B' Nearest AEM Log

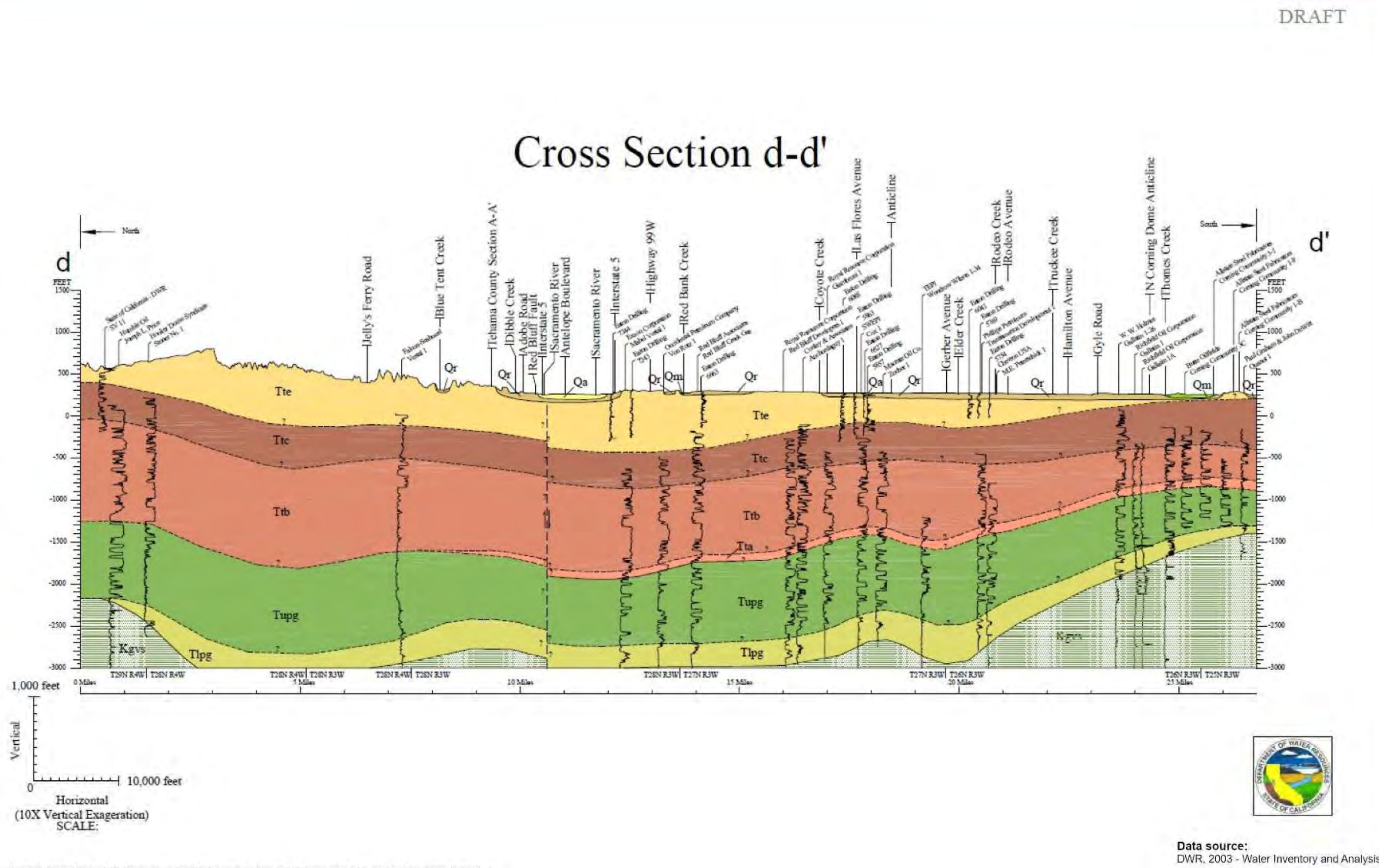


B - B' Nearest AEM Log



B - B' Nearest AEM Log





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

TEHAMA COUNTY

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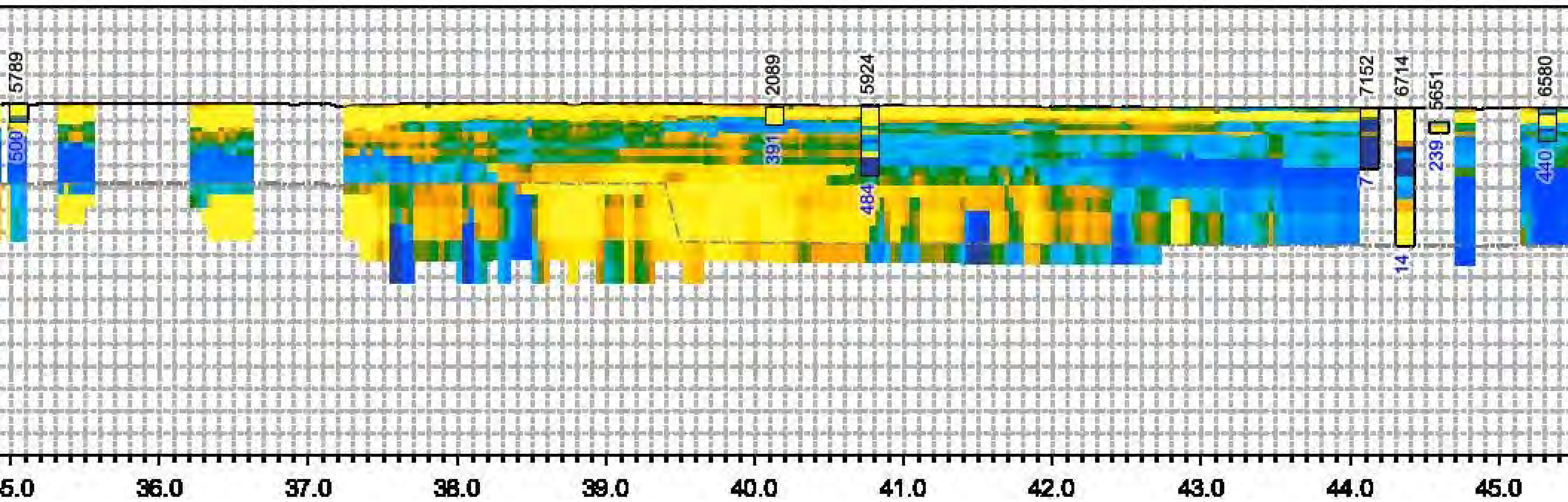
Cross Section d-d'

Groundwater Sustainability Plan
Bowman Subbasin

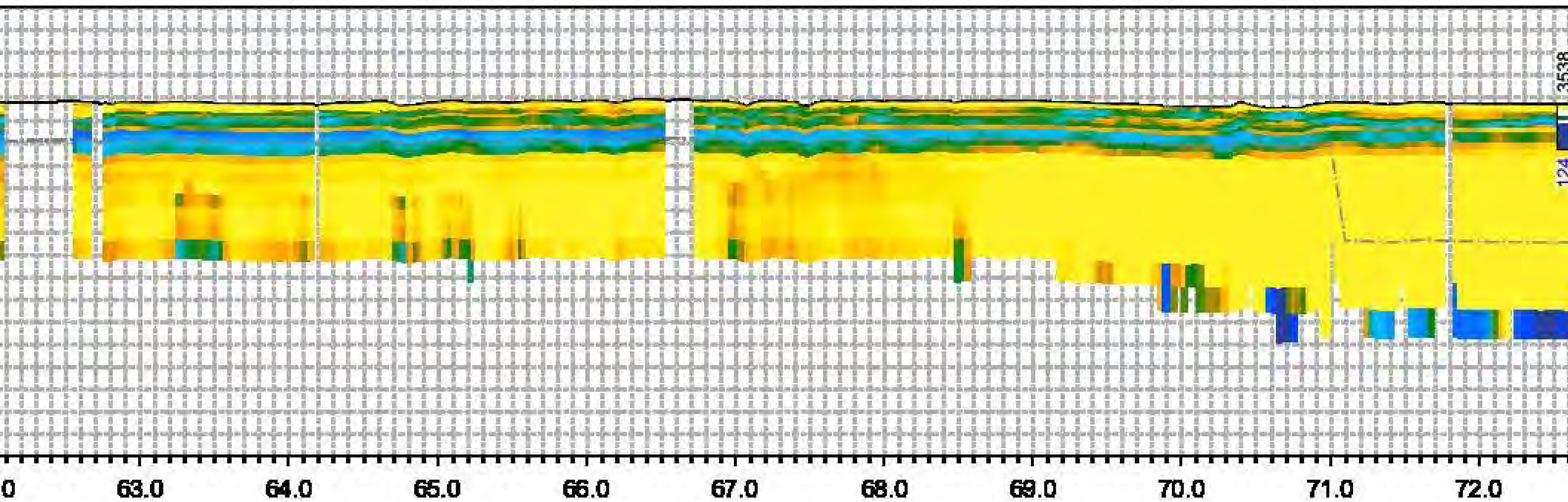
Figure 2-25A

D - D' Nearest AEM Log North

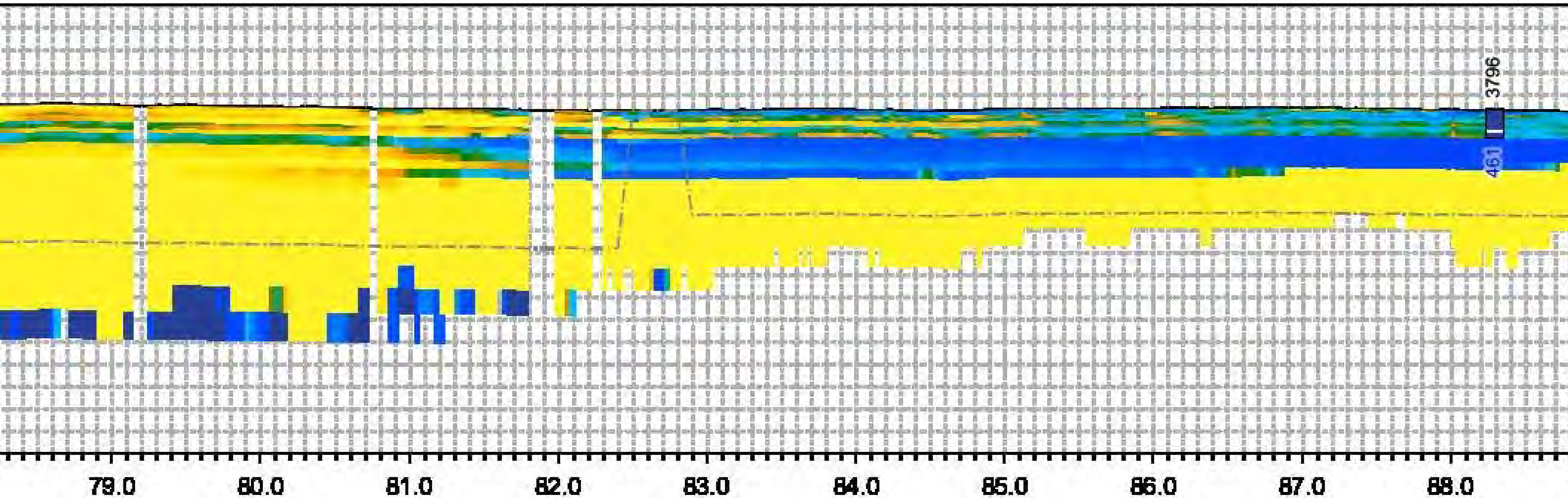


D-D' Nearest AEM log North is NOT continuous with following log.

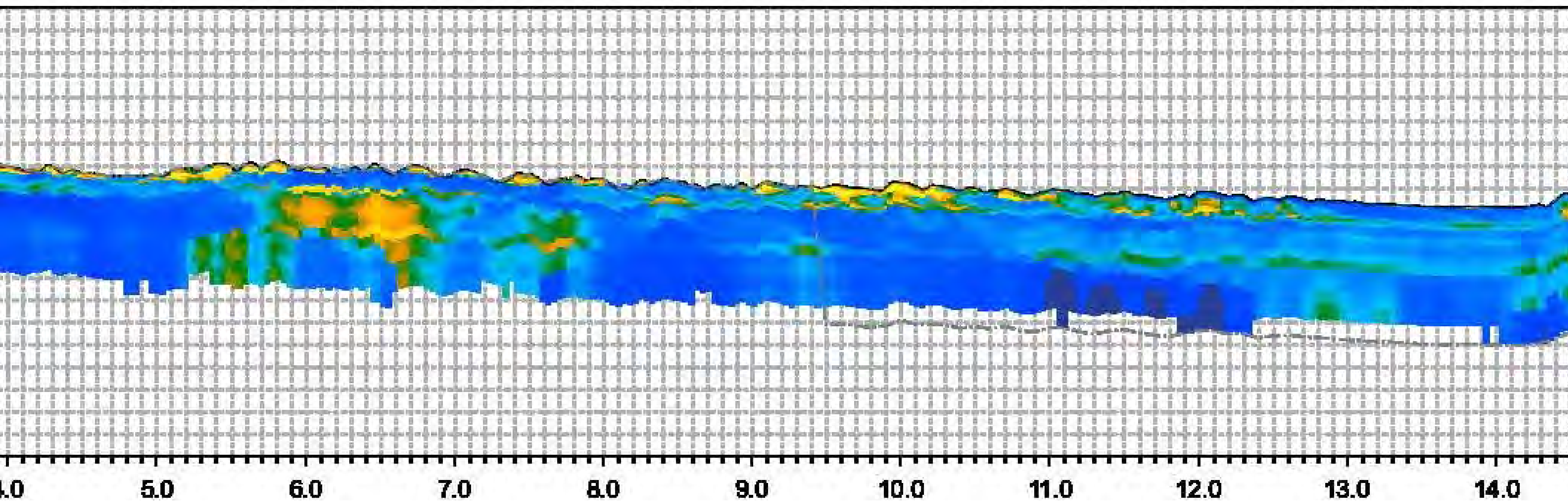
D - D' Nearest AEM Log



D - D' Nearest AEM Log



F - F' Nearest AEM Log



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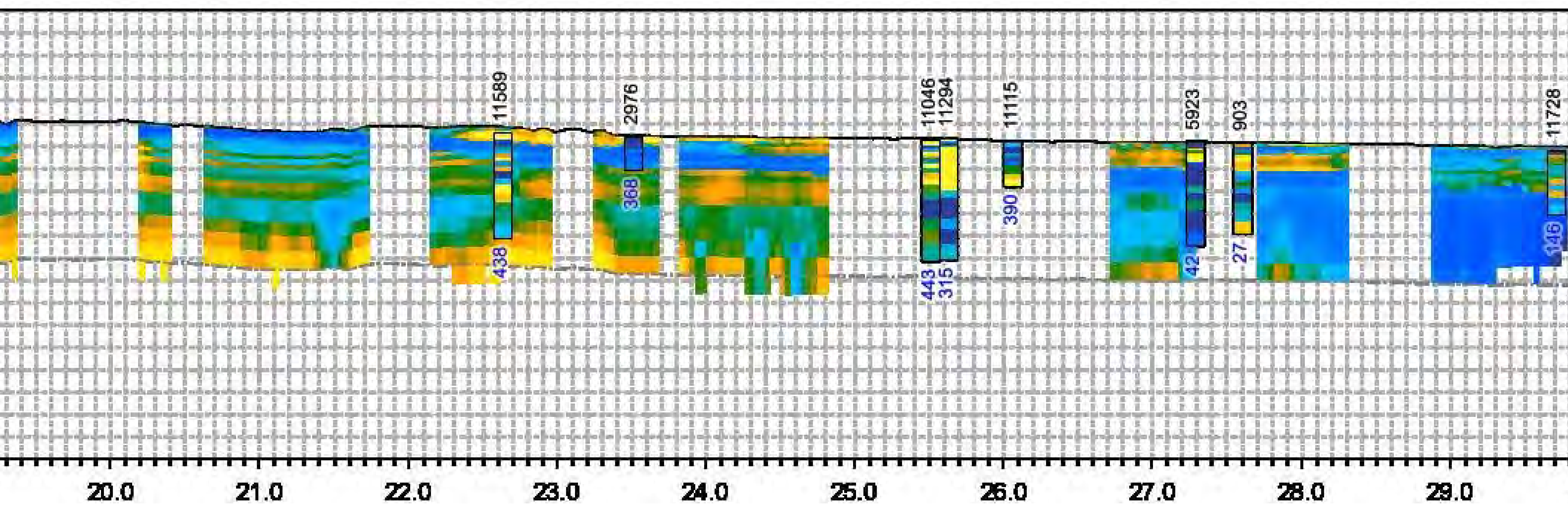
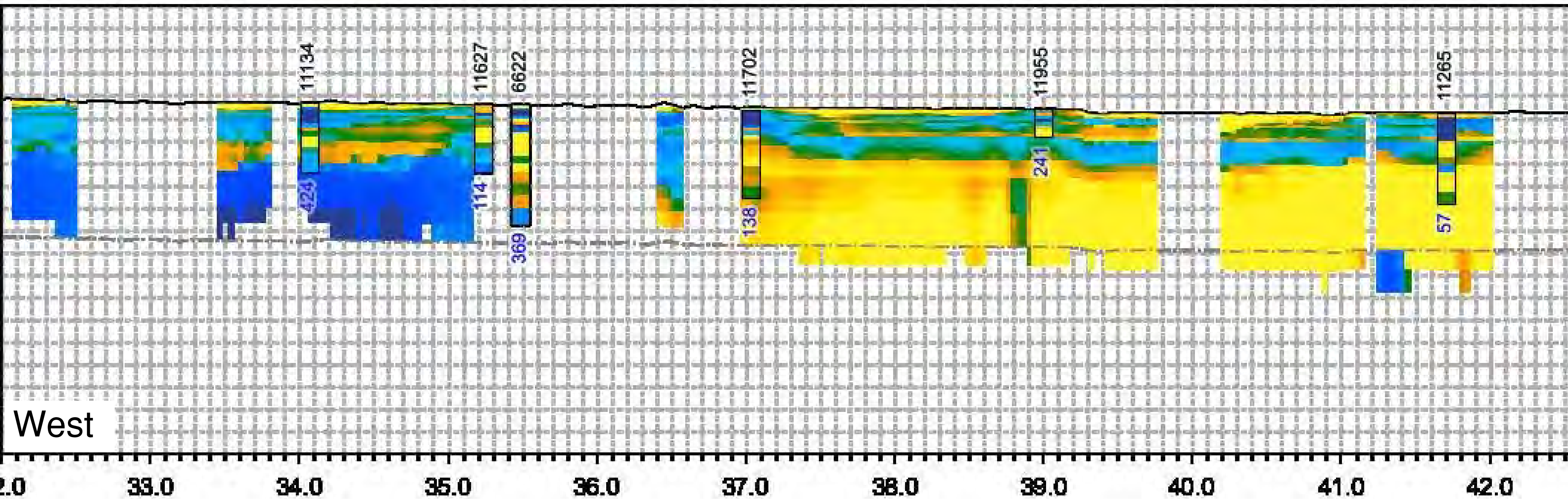
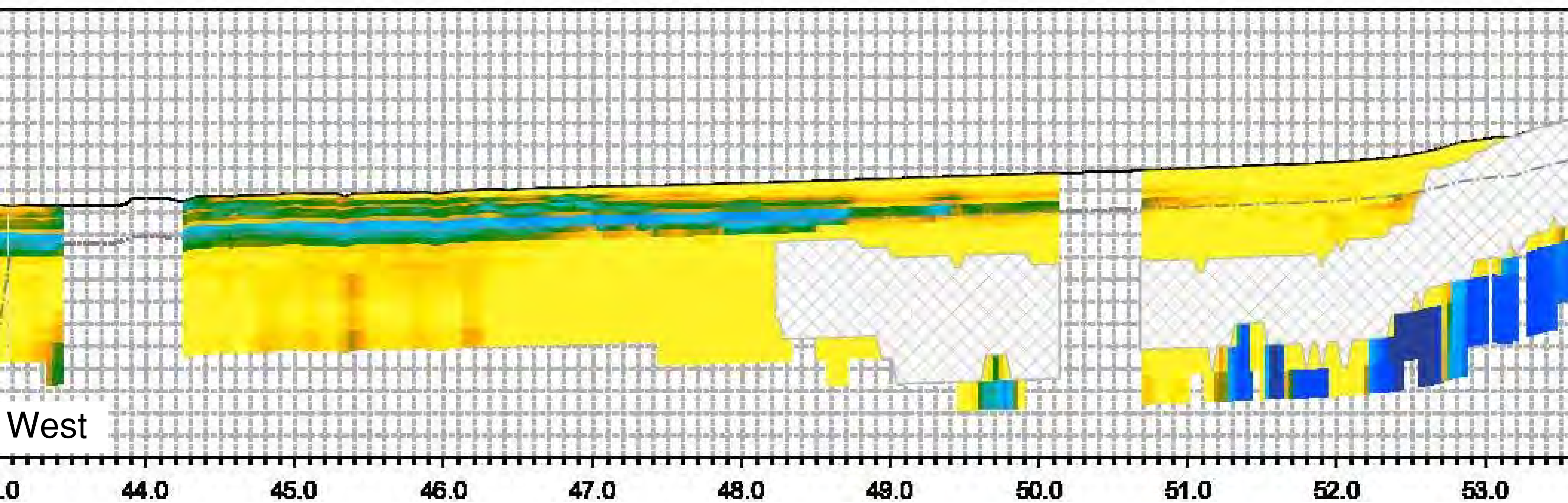


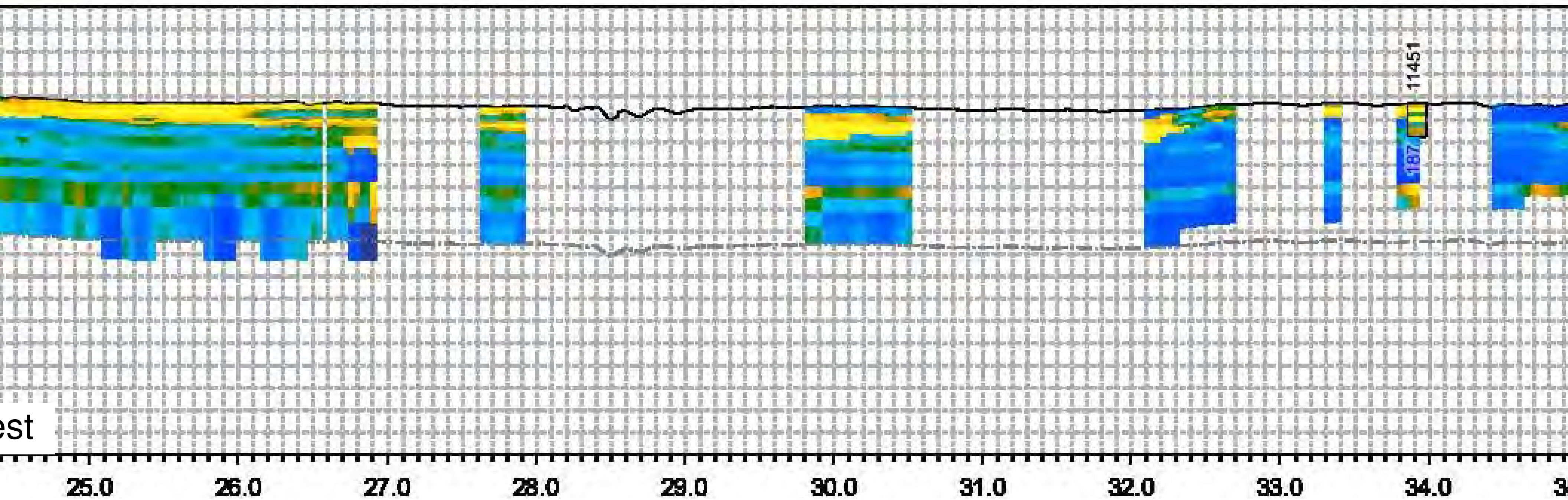
F - F' Nearest AEM Log



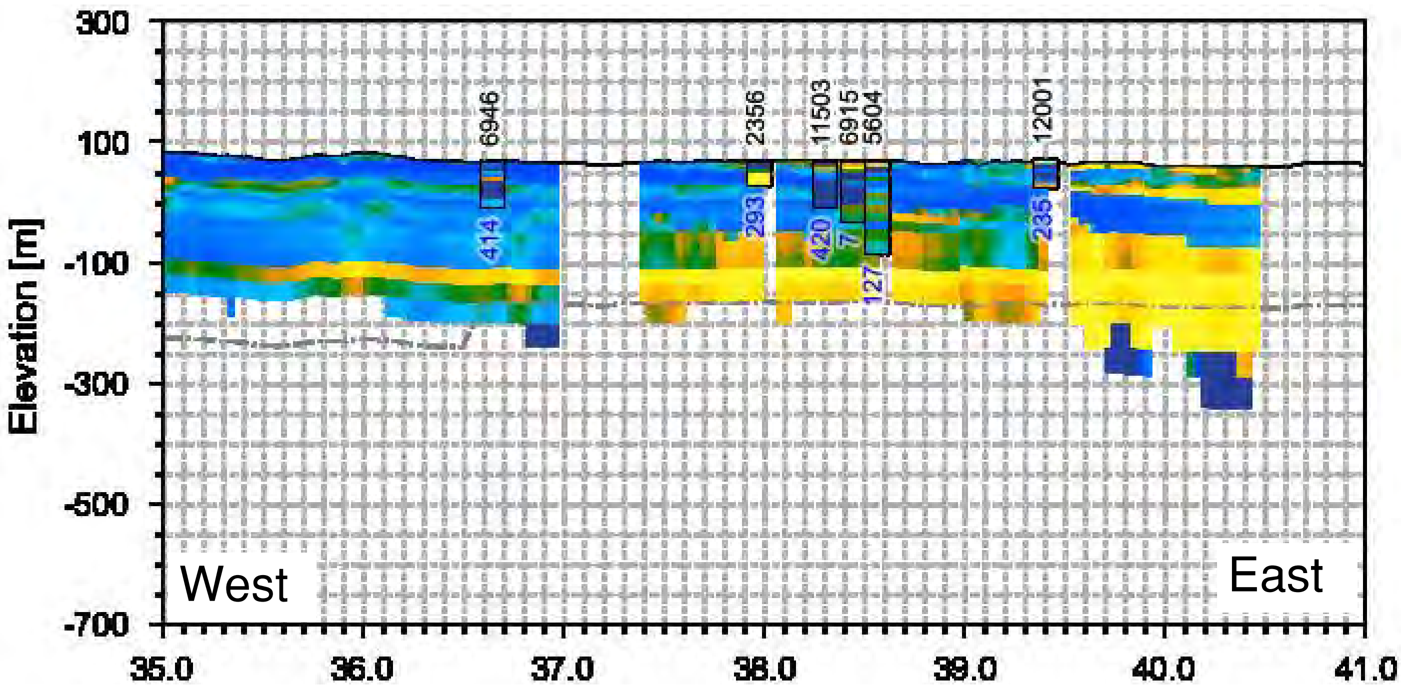
F - F' Nearest AEM Log



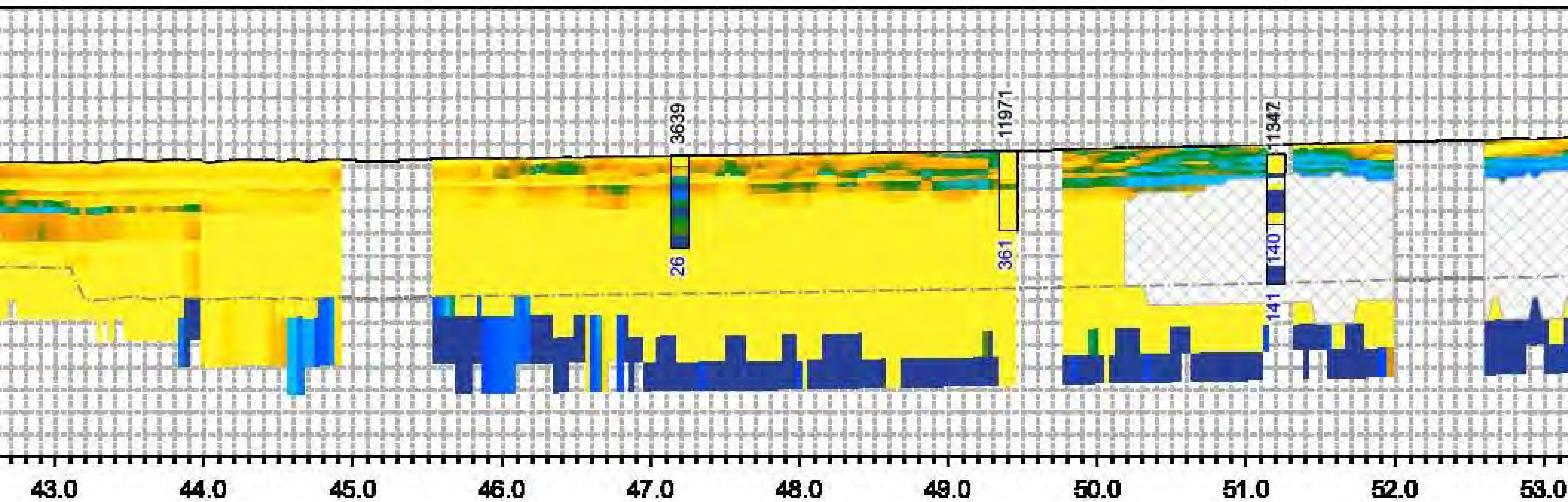
G - G' Nearest AEM Log



G - G' Nearest AEM Log



G - G' Nearest AEM Log



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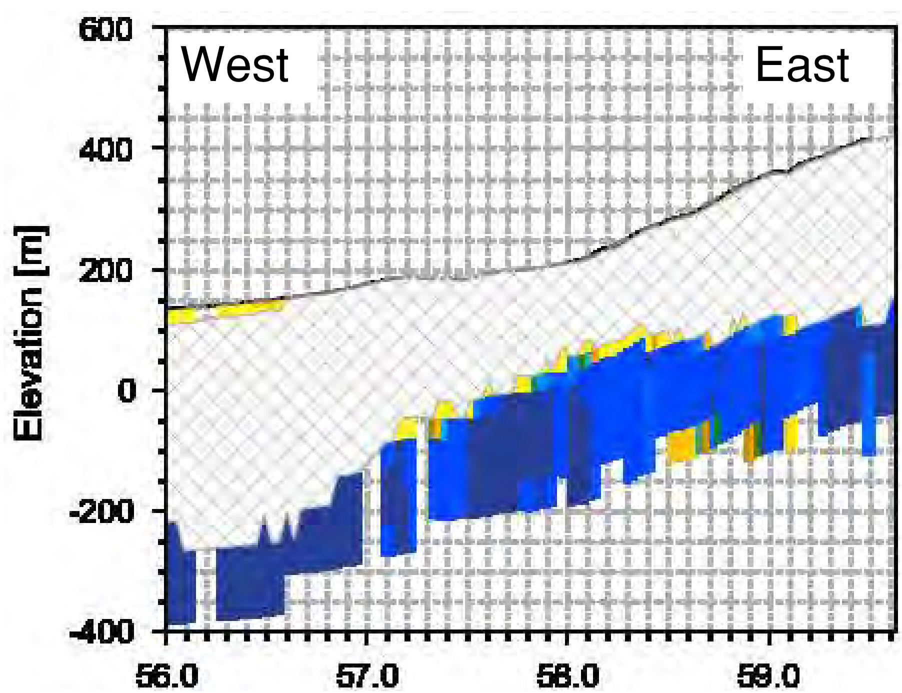


DESCRIPTION OF MAP UNITS

Qa	**Alluvium** (Holocene)-Includes surficial alluvium and stream channel deposits of unweathered gravel, sand and silt, maximum thickness 80 ft. *(adapted from Helley & Harwood, 1985)*.
Qb	**Basin Deposits** (Holocene)-Fine-grained silt and clay derived from adjacent mountain ranges, maximum thickness up to 200 ft. *(adapted from Helley & Harwood, 1985)*.
Qm	**Modesto Formation**, undifferentiated (Pleistocene)-Alluvial fan and terrace deposits consisting of unconsolidated weathered and unweathered gravel, sand, silt and clay; maximum thickness approximately 200 ft. *(adapted from Helley & Harwood , 1985).*
Qr	**Riverbank Formation**, undifferentiated (Pleistocene)-Alluvial fan and terrace deposits consisting of unconsolidated to semi-consolidated gravel, sand and silt; maximum thickness approximately 200 ft. *(adapted from Helley & Harwood, 1985).*
Tte	**Tehama Formation** (Plio-Pleistocene)-Includes Red Bluff Formation on west side. Pale green, gray and tan sandstone and siltstone with lenses of pebble and cobble conglomerate; maximum thickness 2,000 ft. *(adapted from Helley & Harwood, 1985).*
Ttd	**Tuscan Unit D** (Plio-Pleistocene)-Fragmental flow deposits characterized by monolithic masses containing gray hornblende and basaltic andesites and black pumice, maximum thickness 160 ft. *(adapted from Helley & Harwood, 1985).*
Ttc	**Tuscan Unit C** (Plio-Pleistocene)-Includes Red Bluff Formation on east side. Volcanic lahars with some interbedded volcanic conglomerate and sandstone, and reworked sediments; maximum thickness 600 ft. *(adapted from Helley & Harwood, 1985, DWR Bulletin 118-7, 2001, draft report).*
Ttb	**Tuscan Unit B** (Pliocene)-Layered, interbedded lahars, volcanic conglomerate, volcanic sandstone and siltstone; maximum thickness 600 ft. *(adapted from Helley and Harwood, 1985; DWR Bulletin 118-7, 2001, draft report).*
Tta	**Tuscan Unit A** (Pliocene)-Interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone containing metamorphic rock fragments; maximum thickness 400 ft. *(adapted from Helley & Harwood, 1985; DWR Bulletin 118-7 (in progress), 2001).*
Tl	**Lovejoy Basalt** (Miocene)-Black, dense, hard microcrystalline basalt; maximum thickness 65 ft. *(adapted from Helley & Harwood, 1985).*
Tupg	**Upper Princeton Valley Fill** (Late Oligocene to Early Miocene)-Non-marine sediments composed of sandstone with interbeds of mudstone and occasional conglomerate and conglomerate sandstone; maximum thickness 1,400 ft. *(adapted from Redwine, 1972)*.
Ti	**Ione Formation** (Eocene)-Marine to non-marine deltaic sediments, light colored, commonly white conglomerate, sandstone and siltstone, which is soft and easily eroded; max. thickness 650 ft. *(adapted from DWR Bulletin 118-6, 1978; Creely, 1965).*
Tlpg	**Lower Princeton Submarine Valley Fill** (Eocene)-includes Capay Formation. Marine sandstone, conglomerate and interbedded silty shale, maximum thickness 2,400 ft. (*adapted from Redwine, 1972*)
JKgvs	**Great Valley Sequence** (Late Jurassic to Upper Cretaceous)-Marine clastic sedimentary rock consisting of siltstone, shale, sandstone and conglomerate; maximum thickness 15,000 ft.
JKf	**Franciscan Formation** (Jurassic to Cretaceous)-Dominated by greenish-grey greywackes with lesser amounts of dark shale, limestone and radiolarian chert, maximum thickness up to 25,000 ft. *(adapted from strand, 1962 and Norris & Webb, 1990).*

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

TEHAMA COUNTY

LSCE Team

DWR Cross Section Legend

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-25B

2.2.1.5 Identification/Differentiation of Principal Aquifers

Two principal aquifer units are defined in the Subbasin: Upper Aquifer and Lower Aquifer. The two-aquifer designation is based on an examination of time-series groundwater elevation hydrographs, electric resistivity data from geophysical logs, lithologic logs, well construction details, and review of previous studies in the Subbasin. The northern Sacramento Valley depositional environment is dominated by fluvial and alluvial deposition after the Eocene marine depositional environment transitioned to a subaerial one. The Pliocene depositional environment is similar to the current depositional conditions, with eastern depositional streams sourced from the Cascade Range and western depositional streams sourced from the Coast Ranges draining onto a central floodplain. This depositional environment resulted in a complex and varied series of water bearing sedimentary deposits and the Tuscan/Tehama Formations that collectively form a two-aquifer system in the Subbasin and beyond. Within singular water bearing formations there are areas where confined or unconfined conditions can be dominant. Generally, confined aquifer conditions are encountered at depth and unconfined conditions are seen in the shallower porous media. The complexity of the geologic materials and similarly among the formations makes it difficult to define a singular widespread aquitard or distinctive change in geologic materials separating an upper and lower aquifer. To delineate between areas with a higher likelihood of confined conditions, well construction data throughout the Subbasin were examined. Most of the wells in the Subbasin are screened or completed above 400 feet below ground surface (ft bgs). The bottom of numerical model layer 5 best corresponds with this depth. The bottom of model layer 5 is used as the delineation between the Upper and the Lower Aquifer (**Figure 2-23 and Figure 2-24**). Lastly, the degree of heterogeneity and anisotropy (directional preferable flow) is likely significant, but not easy to define based on current information.

Upper Aquifer

The Upper Aquifer is defined as the water bearing material from ground surface to the bottom of model layer 5 (approximately 350-450 ft bgs in the majority of the Subbasin). The aquifer has unconfined to semi-confined water conditions. Water bearing geologic units in the Upper Aquifer include the Quaternary formations and the upper portions of the Tehama and Tuscan Formations. Wells screened in the Upper Aquifer are largely for domestic purposes. The depth to the bottom of the Upper Aquifer is approximately 350-450 ft bgs (**Figure 2-23 and Figure 2-24**).

Site-specific aquifer properties obtained from aquifer tests are available for localized areas of the Subbasin. In addition, aquifer tests were conducted in surrounding subbasins. Hydraulic conductivity (rate at which water moves through an aquifer), transmissivity (hydraulic conductivity multiplied by aquifer thickness), and storage coefficients (ability of the aquifer to store water, commonly expressed as specific yield for water table/unconfined aquifers and storativity for confined aquitards) have been estimated at the Holiday Ranch Site south of Cottonwood and in neighboring subbasins. Aquifer tests were conducted in a well screened from 140 ft bgs to 520 ft bgs at the Holiday Ranch Site near Cottonwood (Lawrence and Associates, 2007). Transmissivity at the Holiday Ranch Site is 90,000 ft^2/d and hydraulic conductivity is 450 to 500 ft/d with a storage coefficient of 0.00025 (Lawrence and Associates, 2007). As the test well spans both the Upper Aquifer and Lower Aquifer horizons the aquifer parameter values represent a combination of both aquifers.

The Tehama Formation has an average transmissivity of approximately 4,000 ft^2/d, an average storativity of 0.00089, and an average hydraulic conductivity of 120 feet per day (ft/d) based on a 1989 constant discharge aquifer test at the Rancho Tehama Reserve in the Red Bluff Subbasin (McManus, 1993; DWR, 2003). In the Vina Subbasin to the southeast, the transmissivity of the upper portion of the Tuscan Formation (70-530 ft bgs) is estimated to be approximately 14,000 square feet per day (ft^2/d) to approximately 55,000 ft^2/d (DWR, 2003).

Lower Aquifer

The Lower Aquifer is defined as the freshwater bearing geologic units throughout the Subbasin from the bottom of model layer 5 at approximately 350-450 ft bgs, to the bottom of the Subbasin. The aquifer has confined to semi-confined conditions. Water bearing geologic units include the lower portions of the Tehama and Tuscan Formations. Lack of a continuous confining layer in the Subbasin creates challenges for defining the top of the Lower Aquifer.

The lack of wells screened in the Lower Aquifer in the Subbasin creates a data gap for hydraulic properties. Hydraulic properties of the Tehama Formation have been characterized in the Subbasin but are not specific to the Lower Aquifer. In a well screened from 200-500 ft bgs, average transmissivity is 90,000 ft^2/d, hydraulic conductivity is 450-500 ft/d, and the storage coefficient is 0.00025 at the Holiday Ranch Site near Cottonwood in the Subbasin (Lawrence and Associates, 2007). As the test well spans both the Upper Aquifer and Lower Aquifer horizons the aquifer parameter values represent a combination of both aquifers.

The Tehama Formation has an average transmissivity of 4,000 ft^2/d, an average storativity of 0.00089, and an average hydraulic conductivity of 120 feet per day (ft/d) based on a 1989 constant discharge aquifer test at the Rancho Tehama Reserve in the Red Bluff Subbasin (McManus, 1993; DWR, 2003). The Tuscan Formation has not been directly characterized in the Subbasin; however, the lower Tuscan Formation (Units A and B) has a hydraulic conductivity estimate (via an aquifer test south of Deer Creek and North of Little Chico Creek) of 41-88 ft/d (Brown and Caldwell, 2013). Transmissivity of the lower parts of the Tuscan Formation (340-920 ft bgs) ranges from 5,415 ft^2/d to 49,986 ft^2/d in the Los Molinos Subbasin (DWR, 2003). Storativity in the Los Molinos Subbasin is estimated to be 0.0025 and hydraulic conductivity is estimated to be 40 ft/d to 60 ft/d (Harrison, 1989; Ely, 1994; DWR, 2003).

2.2.1.6 Definable Bottom of Basin

The base of the post-Eocene continental deposits is defined as the bottom of the basin. The post-Eocene deposits are the deepest locations where fresh water may exist. Contours of the base of post-Eocene deposits (**Figure 2-17)** are on the base of the upper Princeton Valley Fill in the majority of the Subbasin. The upper Princeton Valley fill is a transitional formation from marine to terrestrial deposition. Interstitial fresh and brackish water is contained in the upper Princeton Valley Fill and fresh water can intersect with the formation in places (USGS, 1974; Tehama County FCWCD, 2012). Fresh water is defined as having a maximum electrical conductivity (EC) of 3,000 micromhos per centimeter (µmhos/cm) (Berkstresser, 1973). The base of fresh water is the shallowest in the west at elevations above -400 ft mean sea level (msl) and deepest in the east at elevations deeper than -1,200 ft, msl (**Figure 2-16;** Berkstresser, 1973). Fresh water depth based on electrical conductivity is corroborated by studies by DWR (2014).

2.2.1.7 Surface Water Features and Areas of Recharge

The primary surface water features in the Subbasin are the Sacramento River, Cottonwood Creek (including the South Fork), Little Dry Creek, Hooker Creek, Patterson Creek, and Pine Creek (**Figure 2-32**). The Sacramento River and Cottonwood Creek flow throughout the year (perennial), but the remaining streams flow seasonally. The Sacramento River flows southward along the eastern boundary of the Subbasin. The other streams flow northward draining the Subbasin and feeding Cottonwood Creek. Cottonwood Creek flows eastward where it enters the Sacramento River at the eastern boundary. Several small seasonal ponds (surface area less than 10 acres) occur along streams, but there are no natural lakes or reservoirs within the Subbasin.

BUTTE SUBBASIN

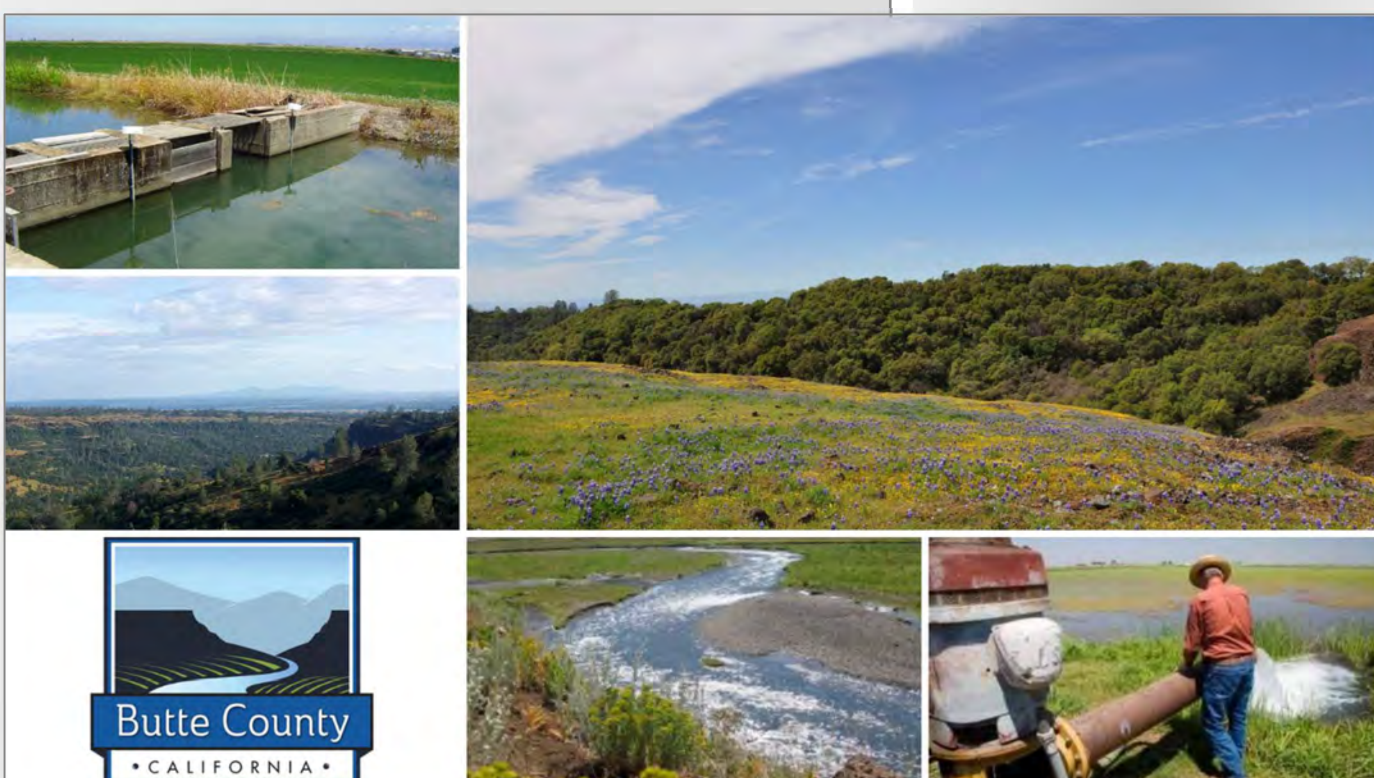
Sustainable Groundwater Management Act (SGMA)

Groundwater Sustainability Plan (GSP)

January 2022

Prepared by

Davids Engineering, Inc
Woodard & Curran, Inc.
GEI Consultants, Inc.



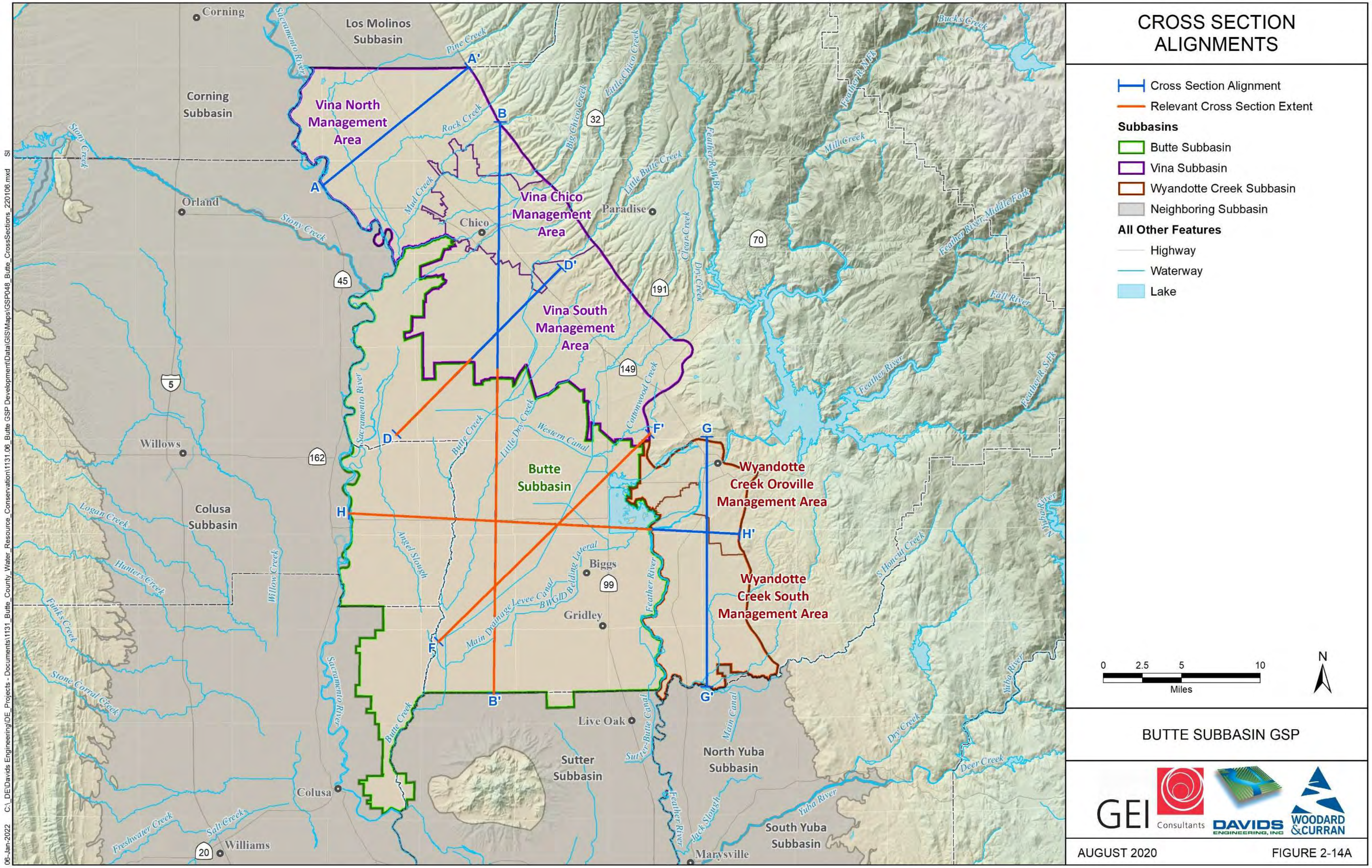


Figure 2-14A. Alignment and Extent of Geologic Cross-Sections.

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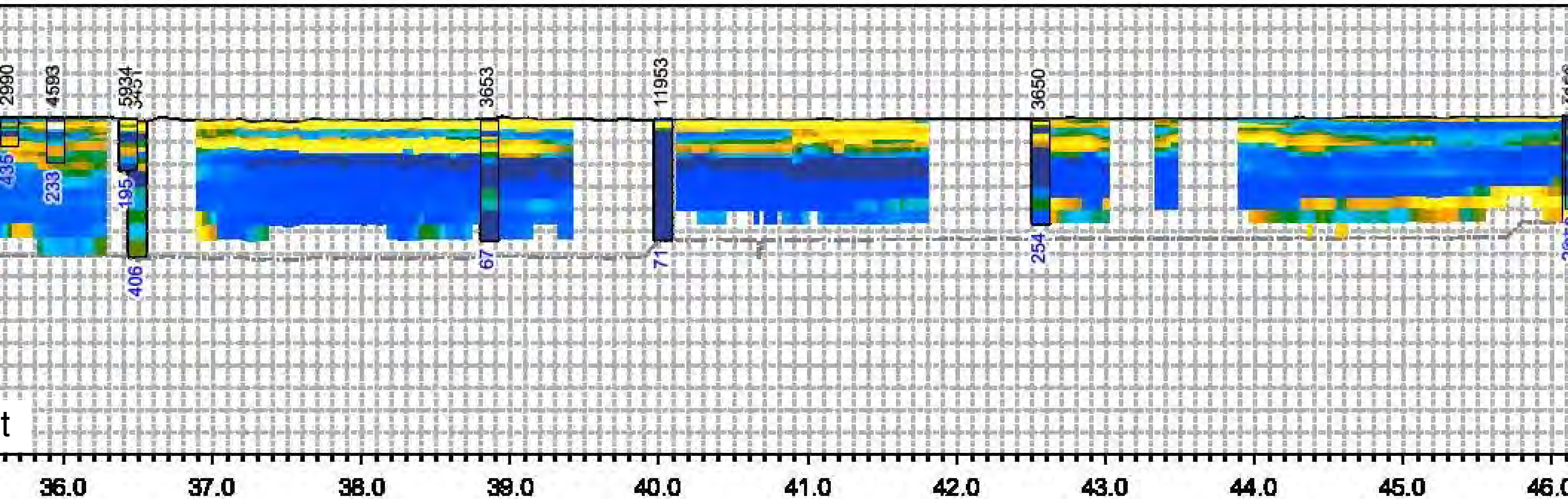
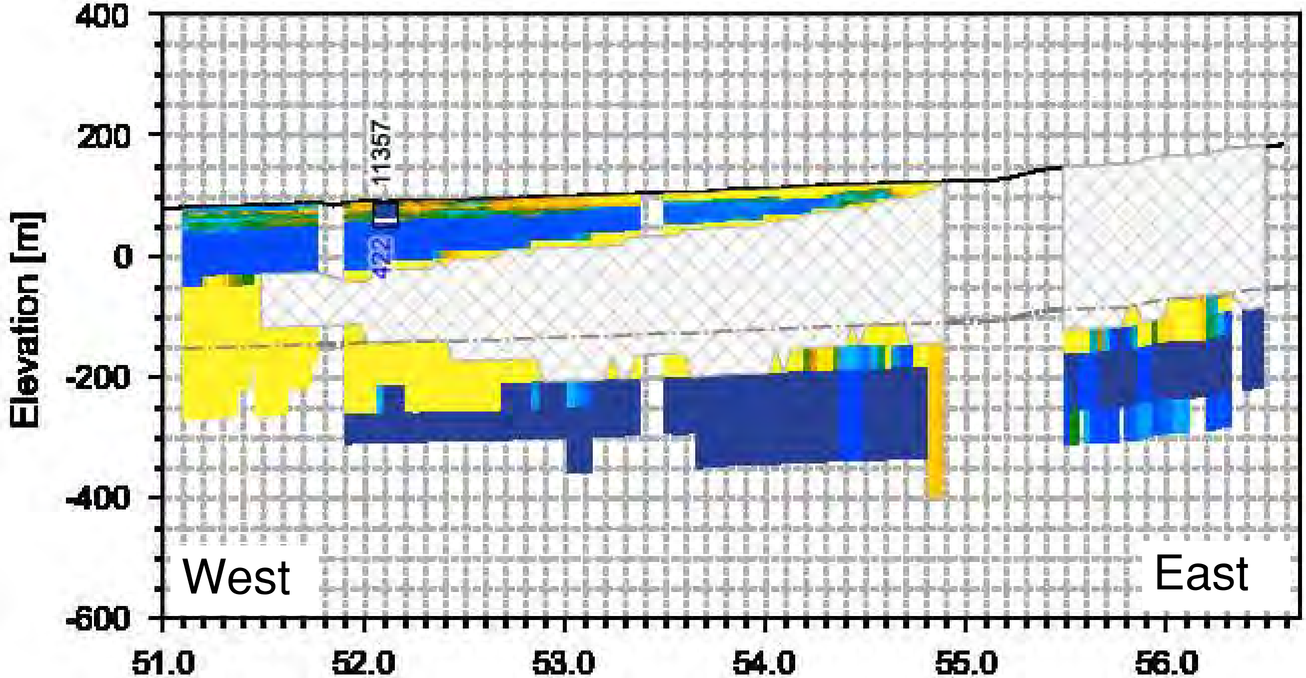
A - A' Nearest AEM Log





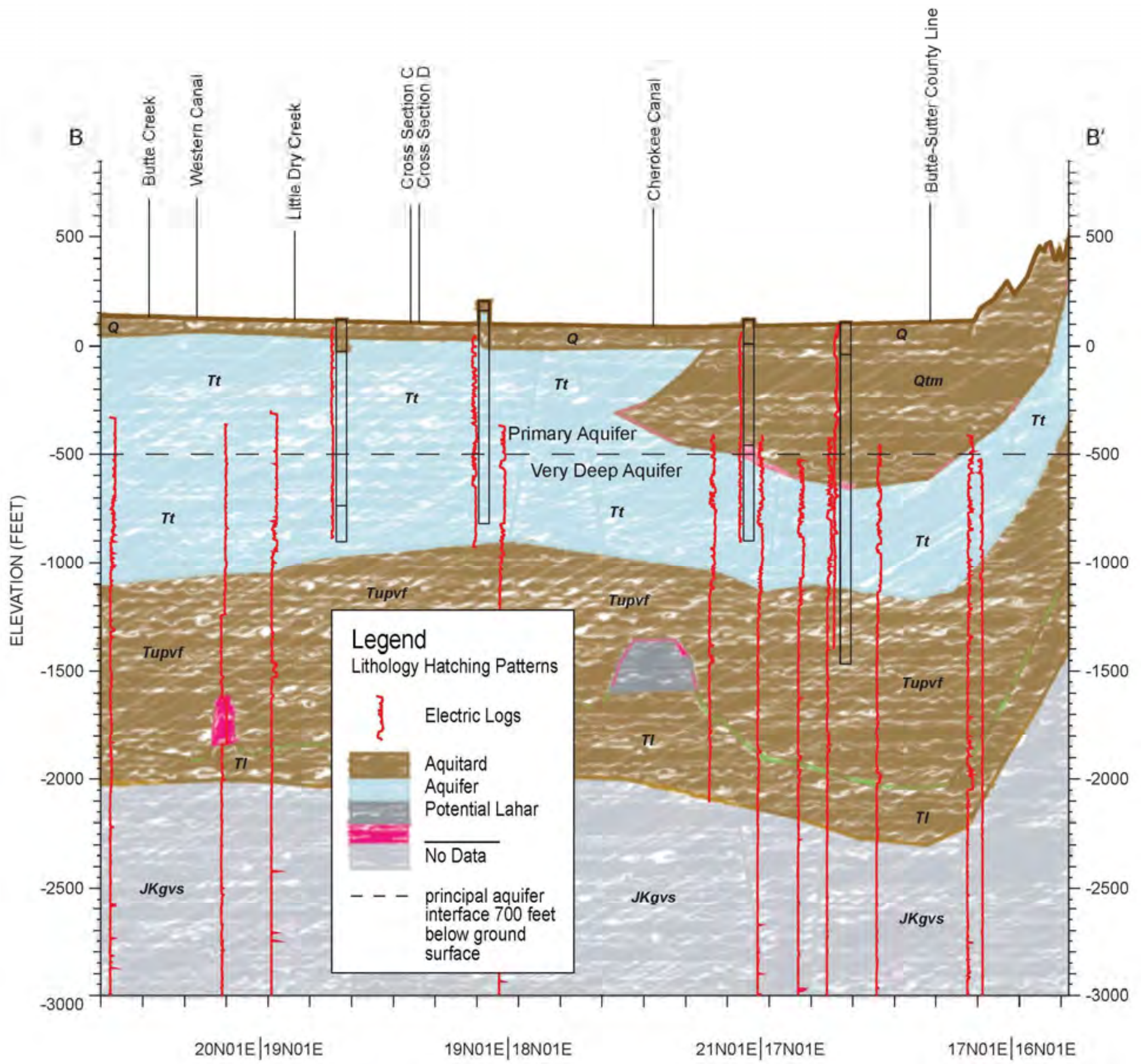
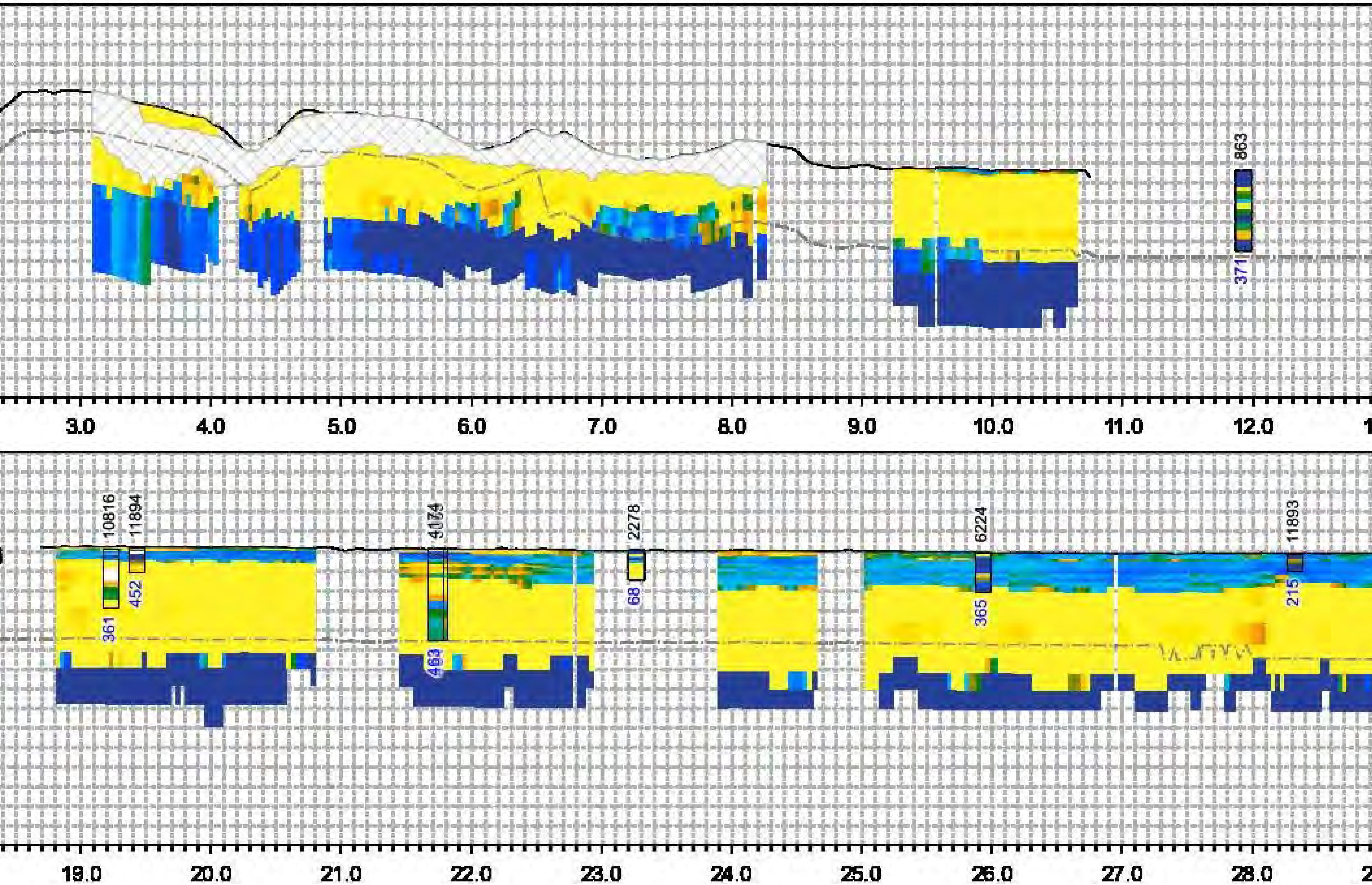
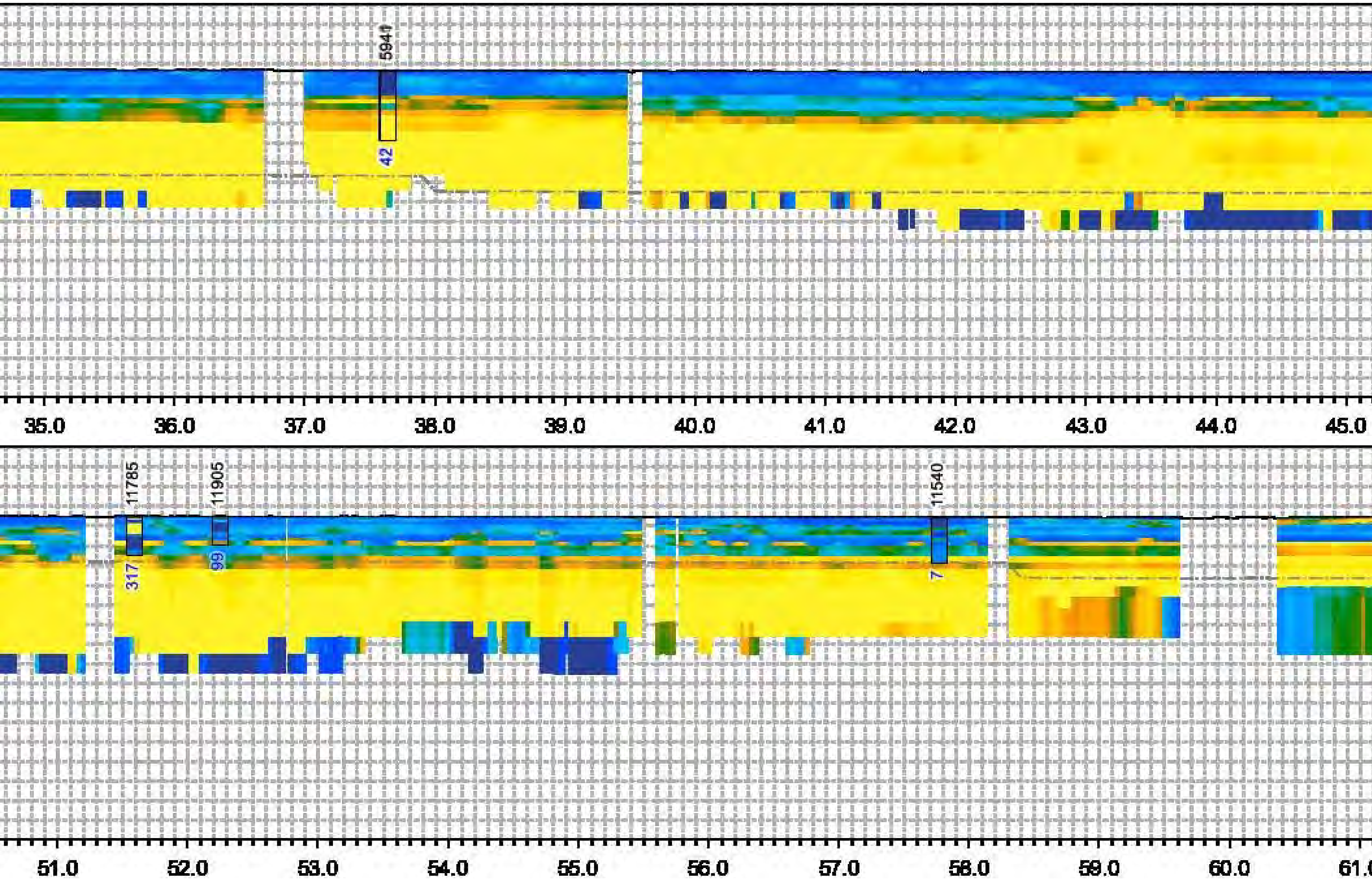


Figure 2-14B. North-South Geologic Cross Section B-B'

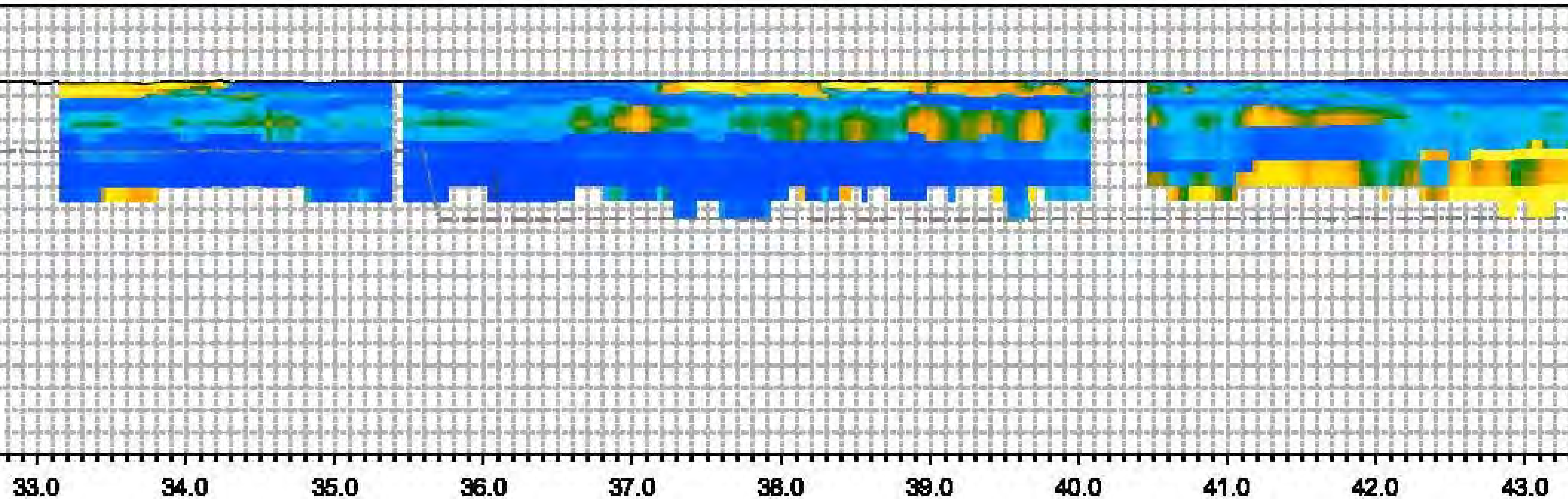
B - B' Nearest AEM Log

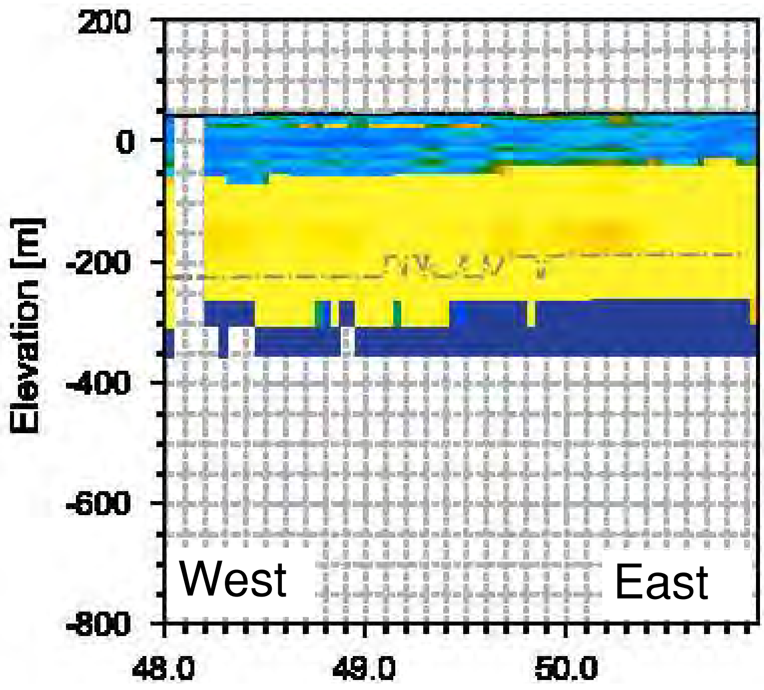


B - B' Nearest AEM Log

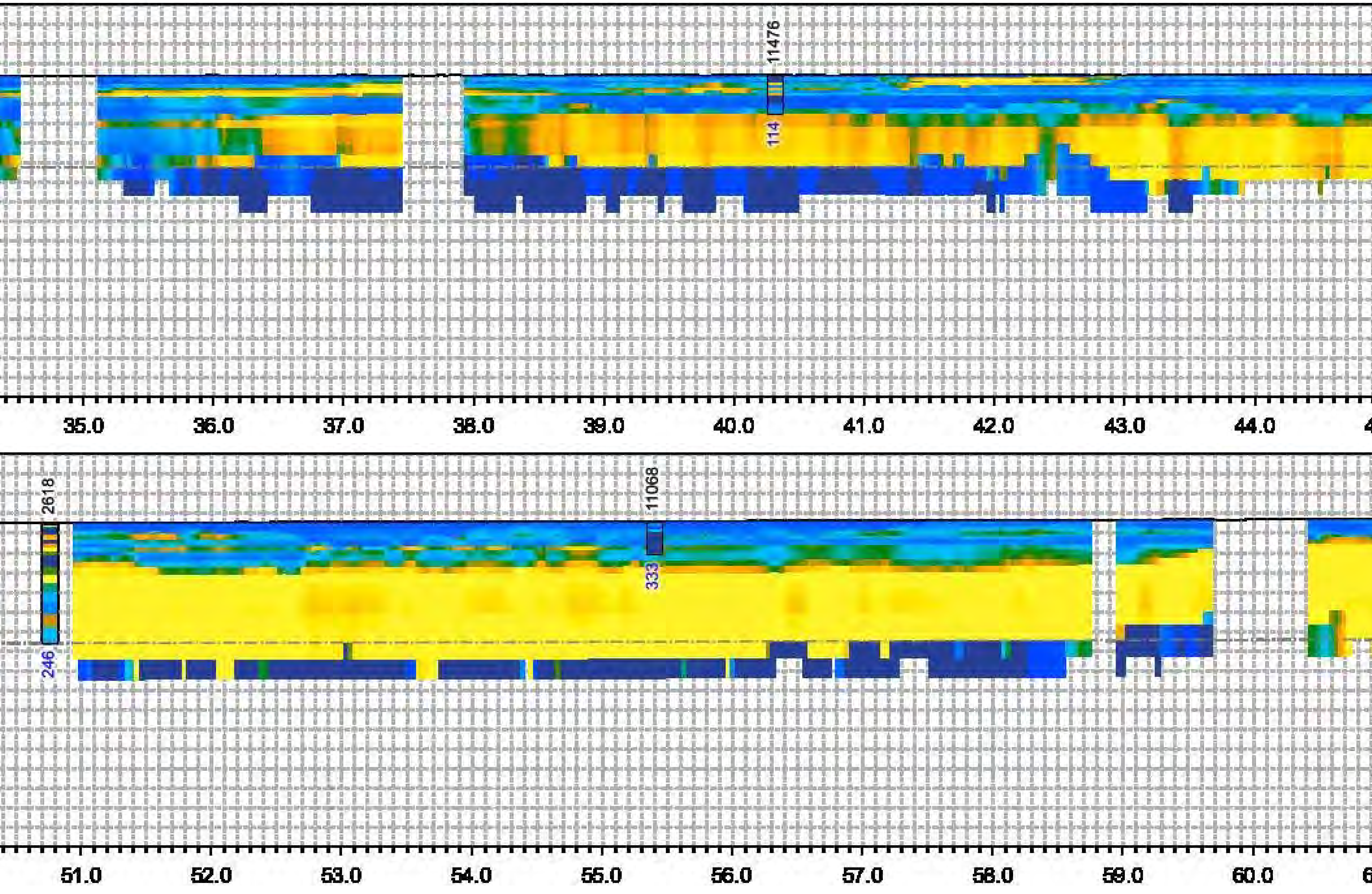


D - D' Nearest AEM Log





F - F' Nearest AEM Log



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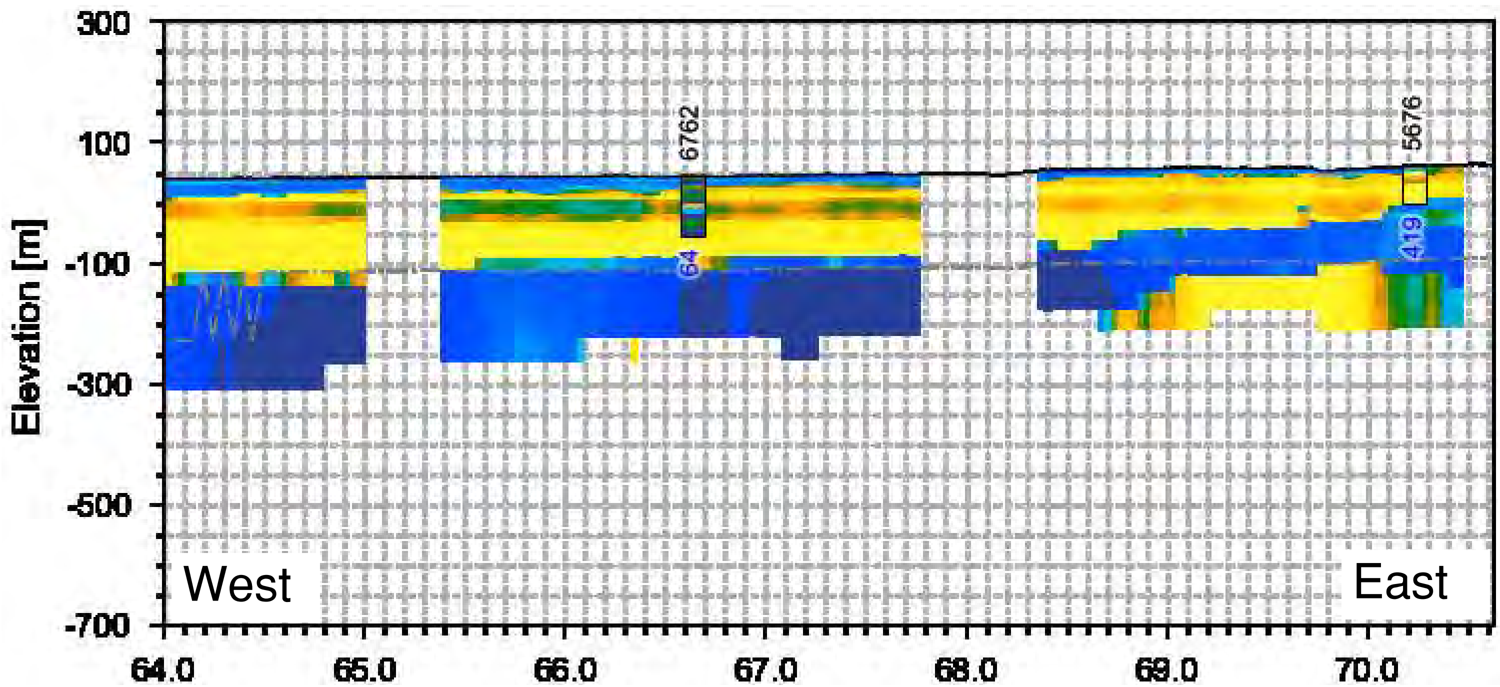


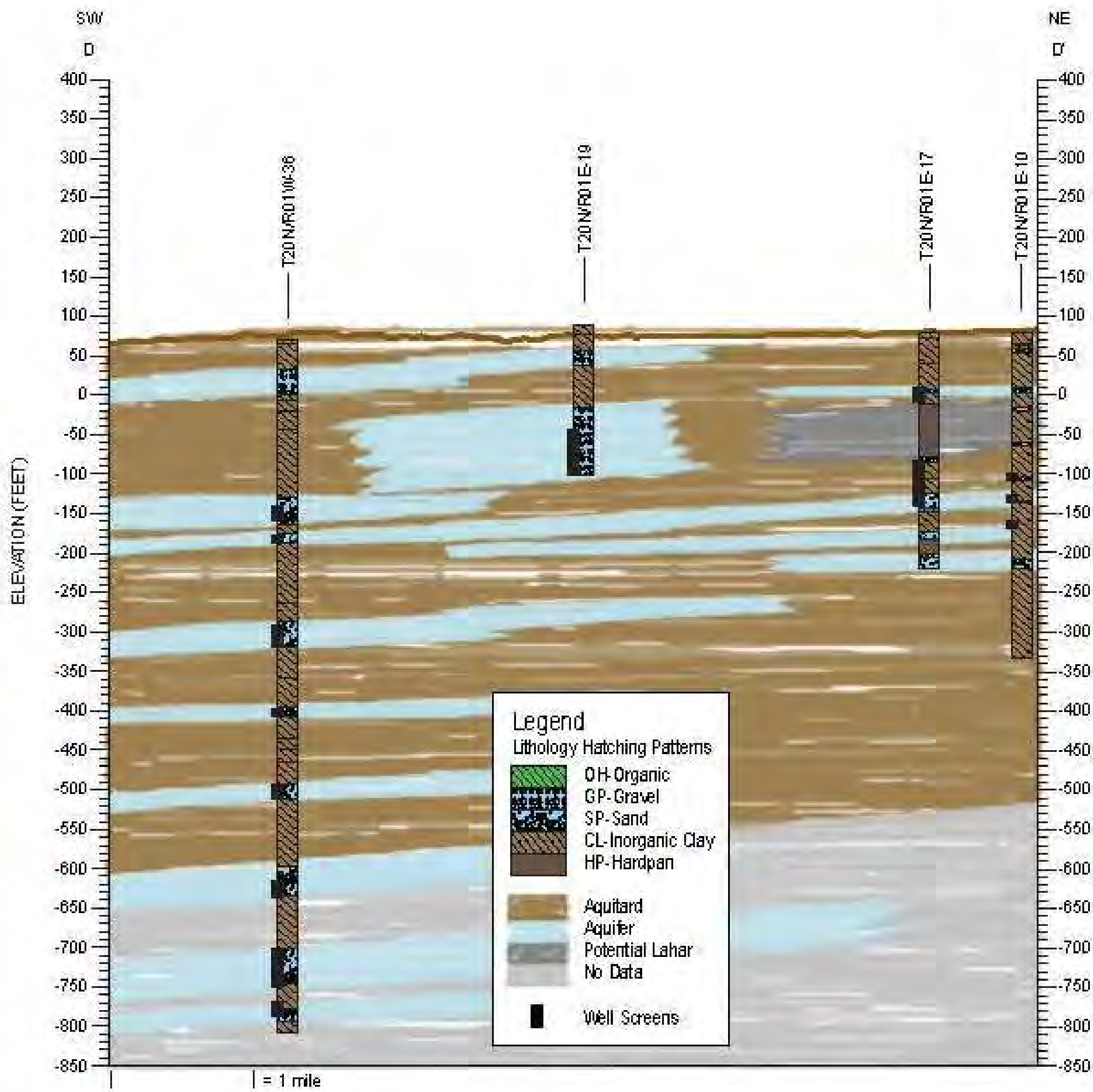


Figure 2-14C. Northeast-Southwest Diagonal Geologic Cross Section D-D'

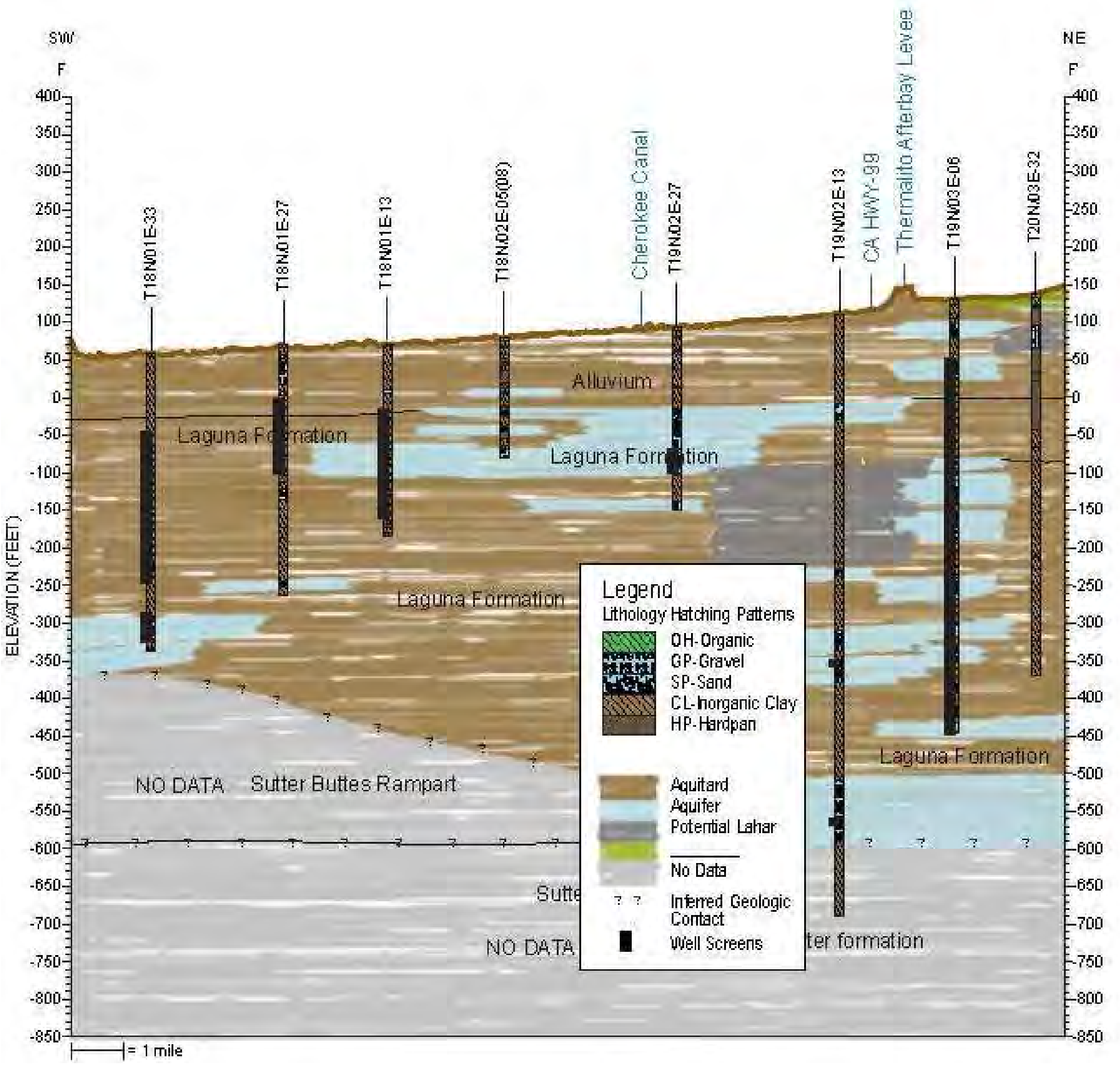


Figure 2-14D. Northeast-Southwest Geologic Cross Section F-F'

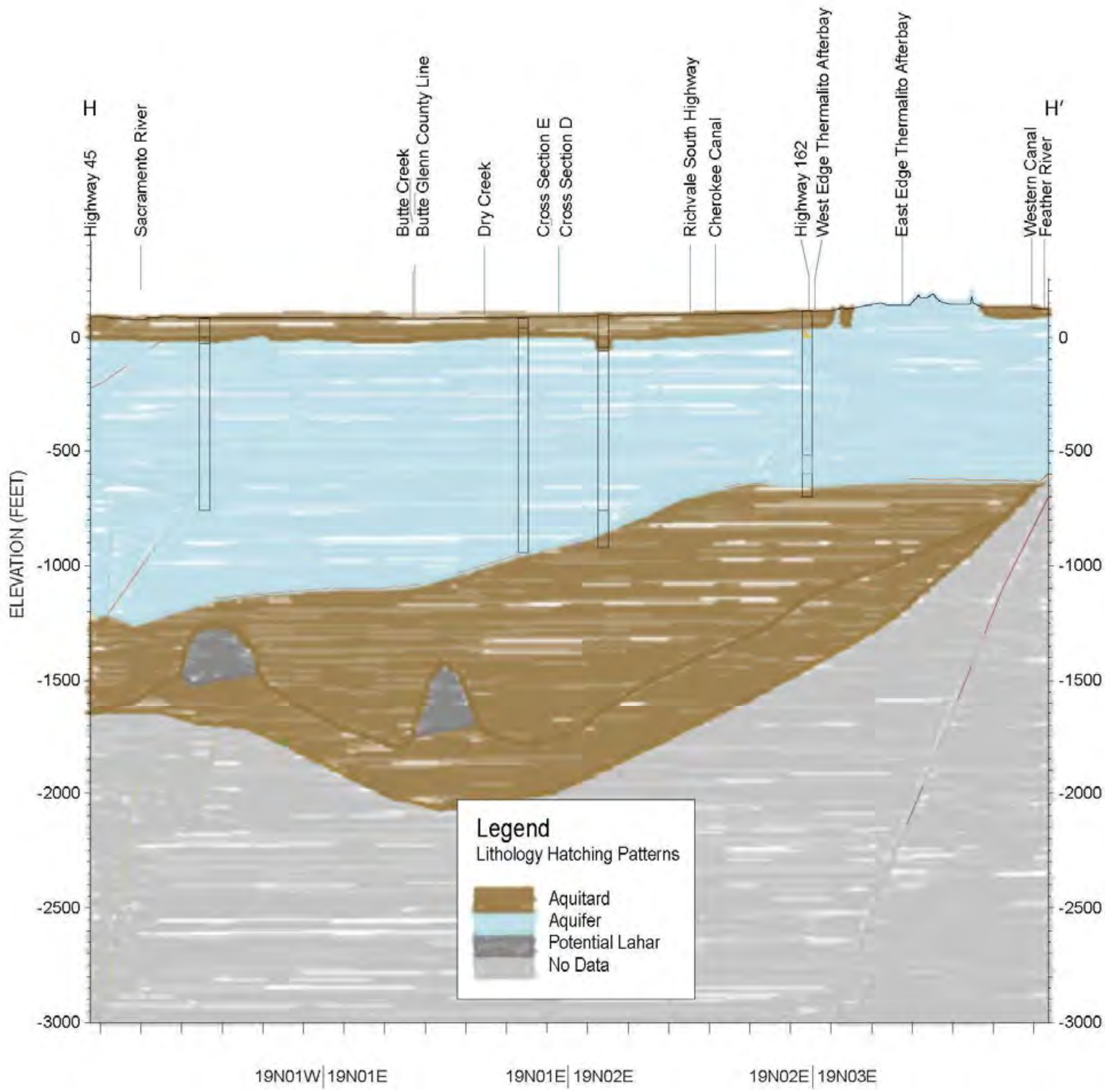
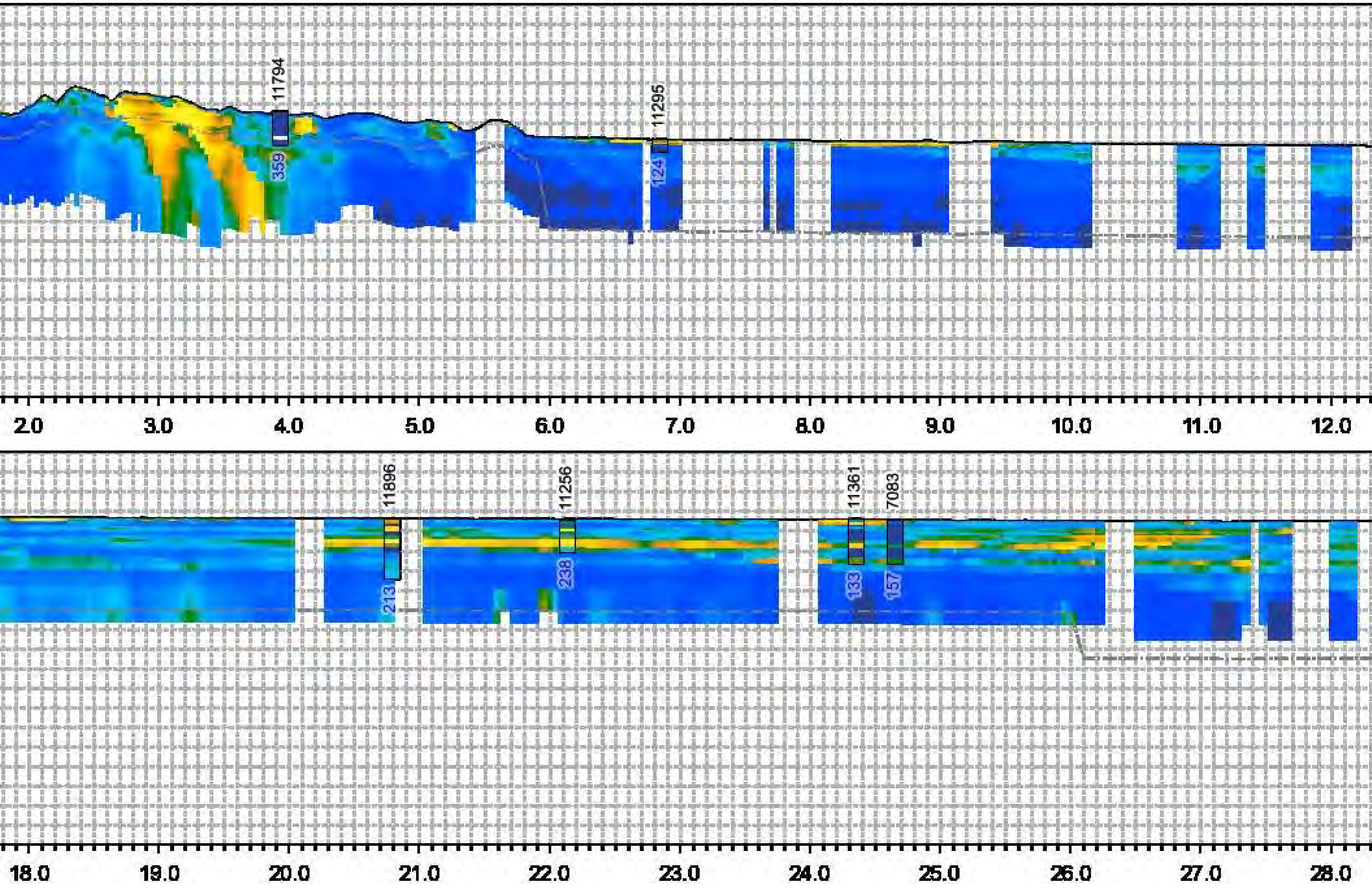


Figure 2-14E. East-West Geologic Cross-Section H-H'

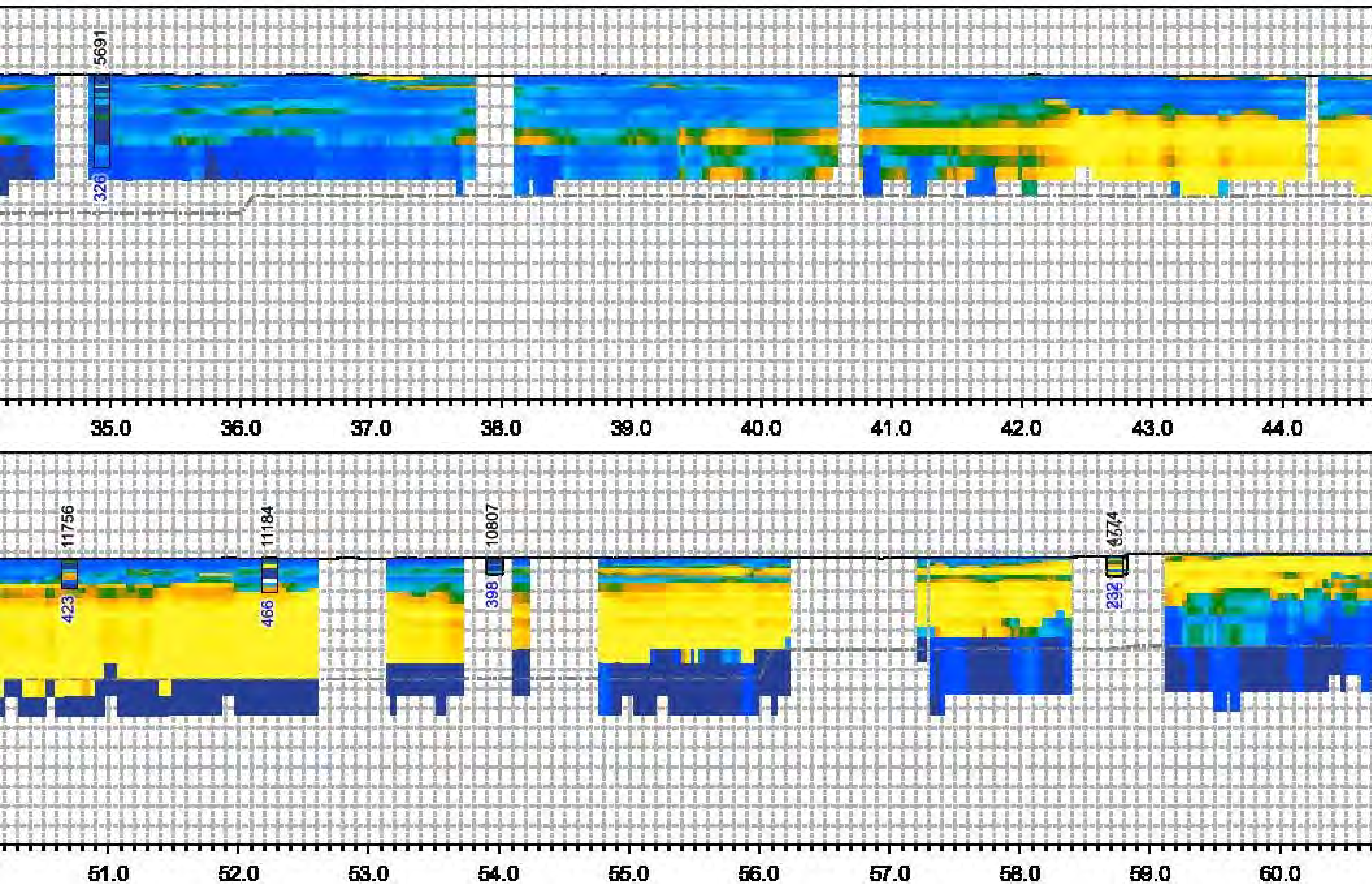
2.2.1.7 *Key Geologic Features*

Barriers to groundwater flow in the Northern Sacramento Valley region include geologic structures such as the Red Bluff Arch, the Corning domes, the Sutter Buttes, and the buried Colusa Dome. In the northern part of the valley, the Red Bluff Arch acts as a groundwater divide separating the Sacramento Valley groundwater basin from the Redding groundwater basin. South of Corning, the surface expression of the Corning domes influences the flow patterns of Stony Creek and Thomes Creek. Stony Creek flows southeast of the domes, with regional flow to

H - H' Nearest AEM Log



H - H' Nearest AEM Log



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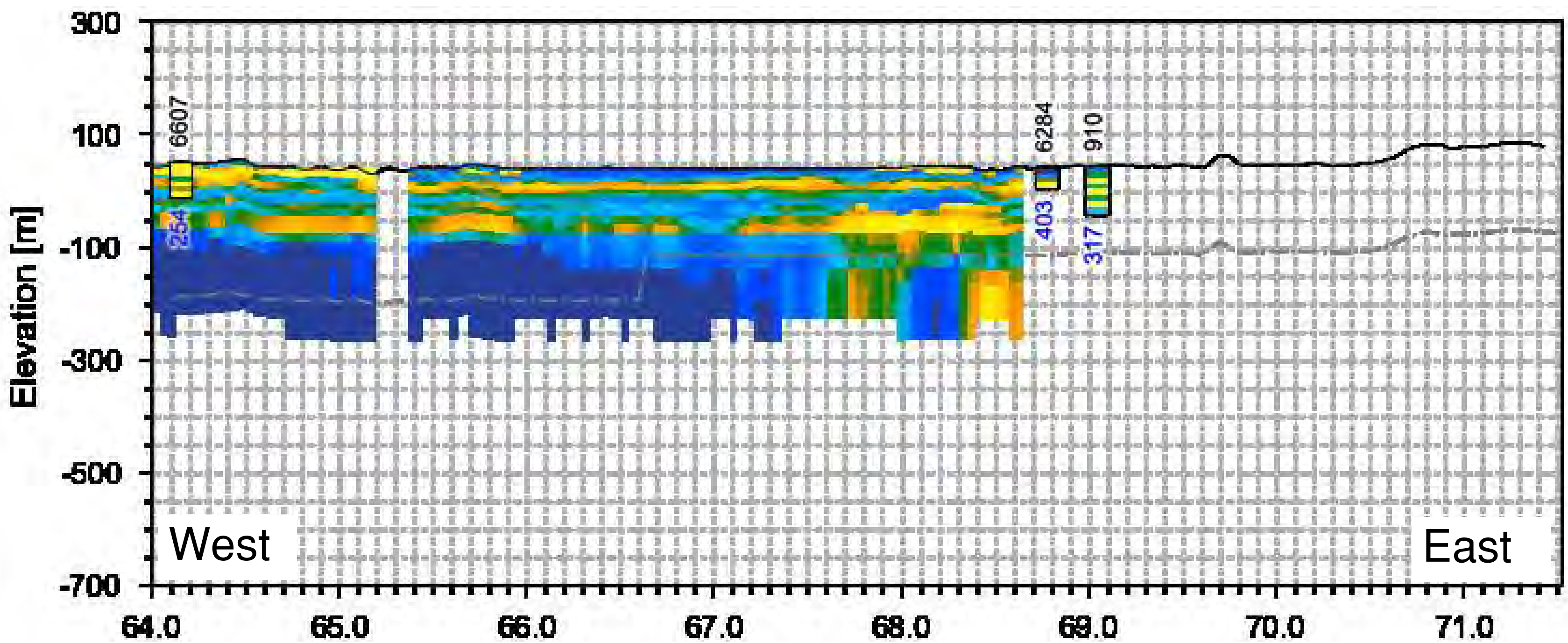

2.2.1.7.3 Sutter Buttes

The Sutter Buttes are the eroded remnants of a single volcano that erupted during the early Pleistocene, less than 2 million years ago (Hausback and Nilsen 1999) and provide the only significant topographic relief on the Sacramento Valley floor. This small-scale volcanic mountain range intruded the valley sediments during the early Pleistocene (1.2 million years before present) epoch. The intrusion buckled the valley sediments upward, forming a barrier to groundwater flow. The Sutter Buttes block the general north-to-south trend of groundwater migration, forcing groundwater to the surface. The upward movement results in a shallow groundwater table and the formation of wetlands along the west side of the Sutter Buttes.

2.2.1.7.4 Effects on Groundwater Flow

These structures cause a deviation in the typical regional direction of groundwater flow which is generally toward the Sacramento River from the northeast to the southwest and from the northwest to the southeast. However, in the area of the Gray Lodge Wildlife Refuge north of the Sutter Buttes, groundwater flow converges toward the Butte Sink. Groundwater from the central portion of the Butte Subbasin flows southwestward, while groundwater from the Sacramento River flows southeastward and eastward. The converging groundwater flow in this area is structurally controlled due to the intrusion of the Sutter Buttes to the east and the buried Colusa Dome to the west (DWR 2005).

2.2.1.8 Principal Aquifers and Aquitards

DWR defines "principal aquifers" under SGMA as the "aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems" (Cal. Code of Regs., title 23, § 351(aa)). Through an examination of hydrographs and lithology logs from multi-completion monitoring wells, two principal aquifers are defined in the Butte Subbasin: 1) Primary Aquifer and 2) Very Deep Aquifer.

The following observations from monitoring wells with continuous data in the Butte Subbasin support the definition of two principal aquifers:

- For the purposes of these observations the zones are defined as follows below ground surface: Very Shallow is 0-100 feet. Shallow is 100-200 feet. Intermediate is 200-600 feet. Deep is 600-700 feet. Very Deep is greater than 700 feet.
- Generally, the shallow, intermediate and deep zones of the aquifer systems in the Butte Subbasin show similar patterns of variability in groundwater levels (within and between years).
- However, the shallow and intermediate zones appear to be more heavily affected by groundwater pumping than other zones (evidenced by greater variability in water levels during the irrigation season).

- A vertical gradient exists in most multi-completion wells in the Butte Subbasin as shown by hydrographs depicting different groundwater levels in different zones of the aquifer system. In some cases, the direction of the vertical gradient (upward or downward) changes seasonally or over time from year to year.
- Monitoring wells across the Subbasin with screened intervals 700 feet below ground surface or deeper have shared characteristics and patterns in their observed water levels. This led to identification of the "Very Deep" zone.
- Although the Very Deep zone shows similar patterns in the timing of groundwater level variability from year to year compared to shallower zones, groundwater levels also show some distinct characteristics. Groundwater levels change more gradually over time (hydrographs appear "smoother" with less extremes) and water levels are higher than in shallower zones. The latter indicates an upward vertical gradient from a pressurized aquifer system in the Very Deep Zone.
- Vertical gradients suggest these different zones of the aquifer system are semi-confined and aquifer materials at various depths likely have different hydrogeologic properties. In addition, pumping activity concentrated in different zones likely also contributes to the differences in groundwater levels and gradients between zones.
- Lithology descriptions from a number of the monitoring wells show thick intervals of clay or fine-grained material (50-200 feet thick) separating screened intervals in multi-completion wells.
- Despite these thick fine-grained layers, trends and patterns in water levels within and between years show a hydraulic connection between the shallow and deepest zones of the aquifer system.

Groundwater levels shown in the hydrograph of multi-completion monitoring well 18N01W02E001-003 located near Butte City are presented in **Figure 2-15** below and reflect many of the observations outlined above.

Additional analysis of well logs is needed to identify the primary geologic formations making up the aquifer materials of these two principal aquifers.

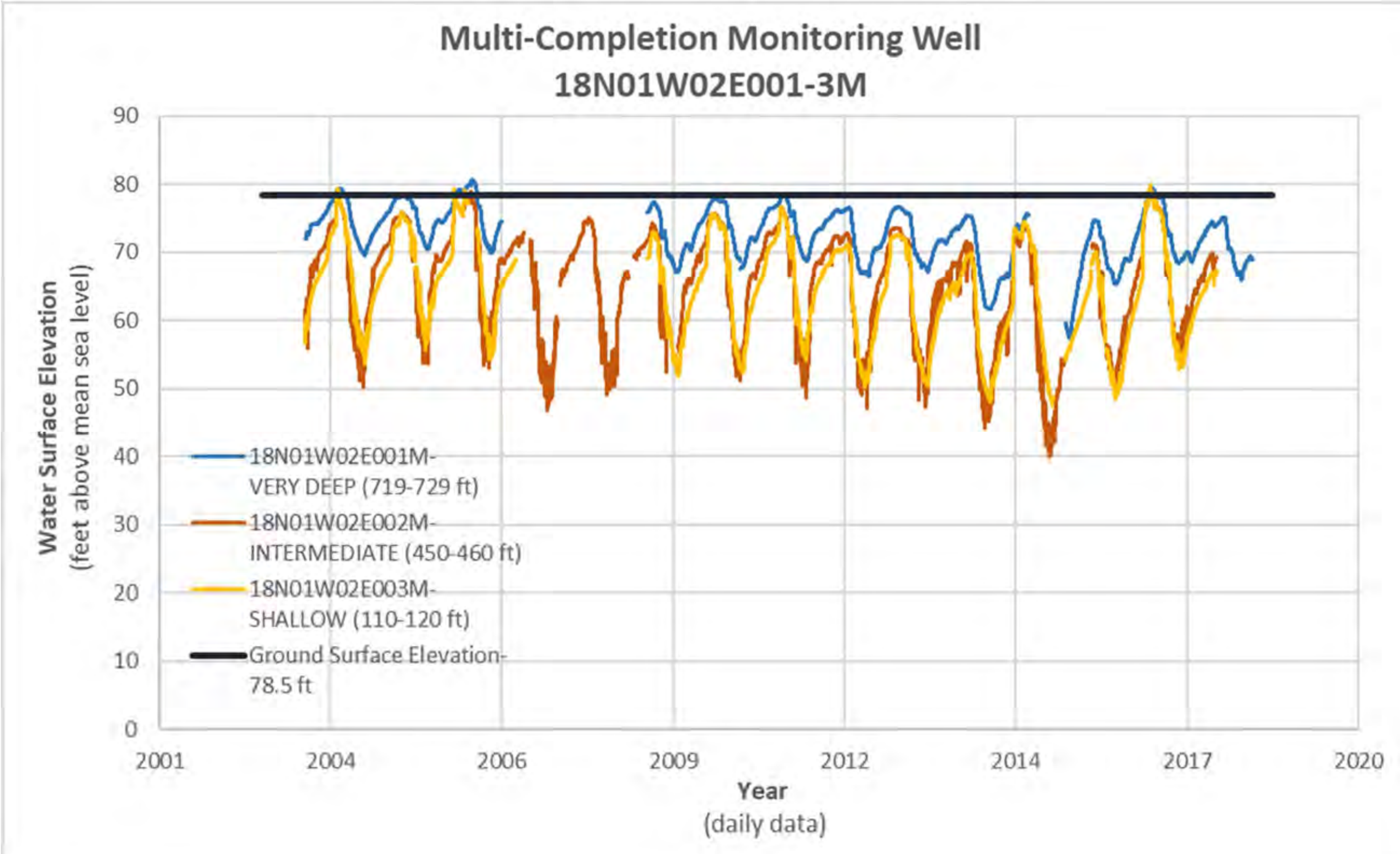

Figure 2-15. Groundwater Levels in Multi-completion Well near Butte City.

2.2.1.8.1 Primary Uses

Water produced from the Primary Aquifer is used to meet irrigation, domestic, and municipal water demand. Domestic supply is largely used to meet rural residential demands. Domestic wells are shallow with the vast majority being less than 100 feet deep. Municipal supply is largely used to meet demand from towns such as Biggs and Gridley.

The Very Deep Aquifer is only accessed by a limited number of wells.

2.2.1.8.2 Storage Coefficient

Specific Yield, or storativity, quantifies the ability of the aquifer to hold or store water. Estimates of specific yield for areas in the Butte Subbasin range from 5.9 to 7.7 percent (DWR 2005; DWR 2004a; DWR 2004b).

2.2.1.8.3 Transmissivity

Transmissivity (T) quantifies the ability of water to move through aquifer materials. The aquifer hydraulic conductivity (K) quantifies the rate of groundwater flow and is related to the transmissivity and aquifer thickness (b) by the following formula: $T = K \times b$. Limited hydraulic conductivity data is available for the subbasin.

2.2.1.8.4 Water Quality

Calcium-magnesium bicarbonate and magnesium-calcium bicarbonate waters are the predominant groundwater water types in the Subbasin. Magnesium bicarbonate waters occur locally near Biggs-Gridley, south and east to the Feather River. Total dissolved solids range from 122 to 570 mg/L, averaging 235 mg/L (DWR 2004a). Sodium bicarbonate type waters occur at the southern tip of the subbasin west of the Sutter Buttes. Water quality impairments include localized high concentrations of manganese, iron, magnesium, total dissolved solids, conductivity, ASAR, and calcium occurring within the Subbasin (DWR 2004a; DWR 2004b).

In the vicinity of the Colusa Dome and Willows Fault, the base of fresh water rises to close to 400 feet below ground surface (DWR unpublished data). This mound of saline water is explored and documented by Curtin 1971, suggesting that connate marine water moves upward along fault zones. Areas of high chloride water are thought to be from Cretaceous marine sedimentary rocks brought closer to the surface by faulting associated with the formation of the Sutter Buttes (Hull 1984). A study of groundwater quality in the Sacramento Valley also sampled a well in this area and observed elevated levels of salinity and other constituents such as total dissolved solids, chloride, and boron (USGS 2008).

The Butte Basin is defined as the flood basin between the Sacramento and Feather Rivers from Chico in the north to Yuba City in the South. Groundwater in the Butte Basin has a somewhat higher average dissolved-solids concentration compared to the eastern margins of the valley, possibly reflecting longer subsurface residence times or a change in sediment lithology. High

Colusa Groundwater Authority &
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Colusa Subbasin Groundwater Sustainability Plan

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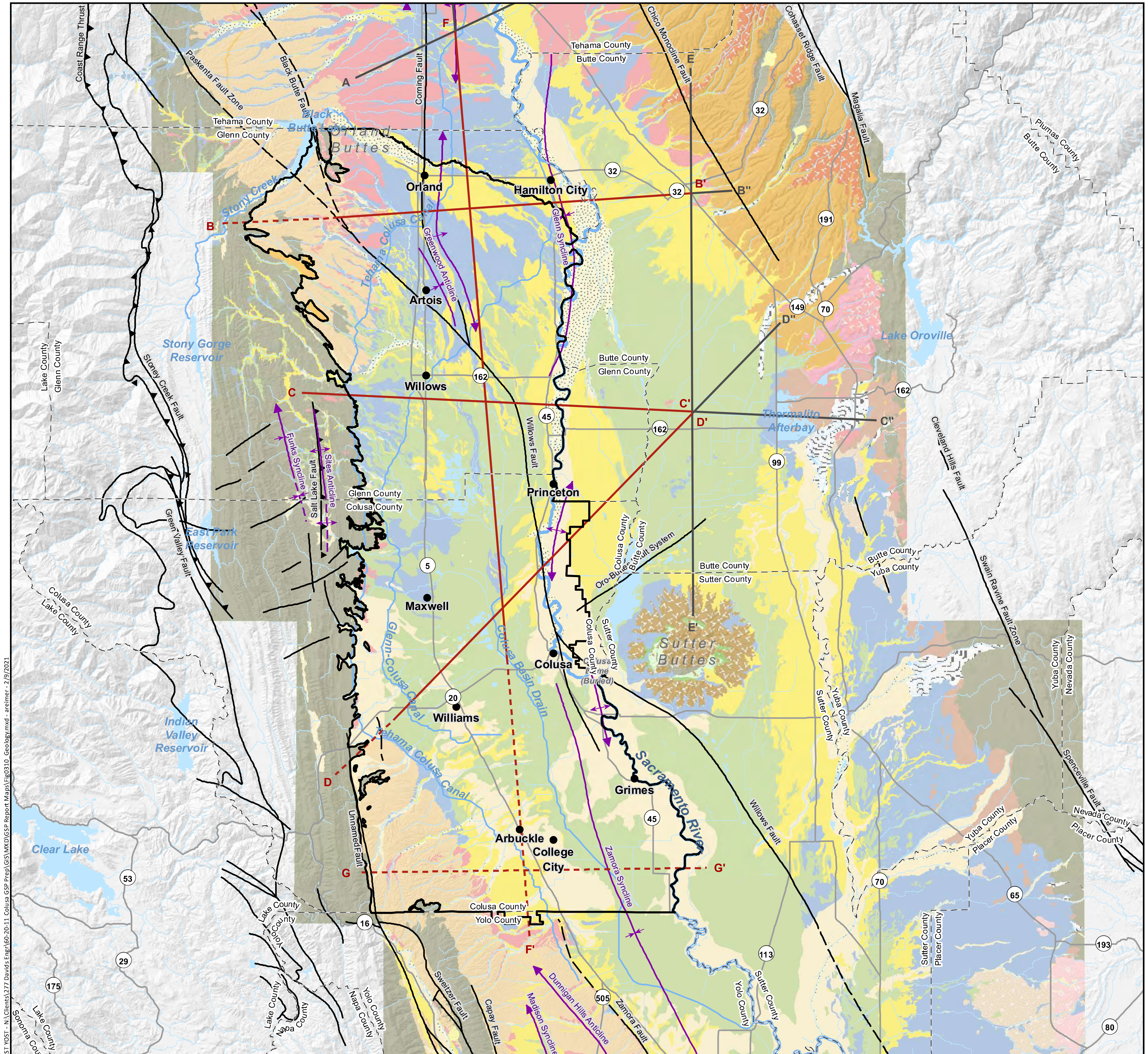
COLUSA SUBBASIN



Northern Sacramento Valley Geology Cross Section Used for the Hydrogeologic Conceptual Model

Section Extension or New Cross Section

Northern Sacramento Valley Geology Cross Section Not Used for the Hydrogeologic Conceptual Model

Study Area

Geologic Structures

- Anticline
- Syncline
- Plunging Anticline
- Plunging Syncline
- Doubly Plunging Anticline
- Double Plunging Syncline
- Fault
- Thrust Fault

Geologic Units

- Stream Channel Deposits (Holocene)
- Alluvial Deposits (Holocene)
- Basin Deposits (Holocene)
- Landslides (Quaternary)
- Modesto Formation (Pleistocene)
- Riverbank Formation (Pleistocene)
- Red Bluff Formation (Pleistocene)
- Turlock Lake Formation (Pleistocene)
- Volcanic Rocks and Lacustrine Deposits of Sutter Buttes (Pleistocene - Pliocene)
- Basaltic Rocks (Pleistocene - Pliocene)
- Tehama Formation (Pliocene)
- Nomlaki Tuff Member (Pliocene)
- Putah Tuff Member (Pliocene)
- Tuscan Formation (Pliocene)
- Laguna Formation (Pliocene)
- Sutter Formation of Williams and Curtis (1977) (Pliocene - Oligocene)
- Channel Deposits (Pliocene - Miocene)
- Mehrten Formation (Pliocene - Miocene)
- Lovejoy Basalt (Miocene)
- Ione Formation (Eocene)
- Sedimentary Rocks in Sutter Buttes Area (Eocene)
- Metamorphic, Igneous, and Sedimentary Rocks (pre-Paleogene)
- Tailings

Source:

1. California Department of Water Resources, 2014, Geology of the Northern Sacramento Valley: prepared by the California Department of Water Resoures Northern Region Office, Groundwater and Geologic Investigations Section, updated September 2014.
2. Helley, E.J. and Harwood, D.S., 1985, Geologic Map of the Late Cenozoic Deposits of the Sacramento Valley and Northern Sierran Foothills, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1790, scale 1:62,500, GIS geodatabase.
3. Jennings, C.W. and Strand, R.G., 1960, Geologic Map of California, Olaf P. Jenkins Edition, Ukiah Sheet: Department of Natural Resources Division of Mines and Geology, third printing 1992, scale 1:250,000.
4. Koenig, J.B., 1963, Geologic Map of California, Olaf P. Jenkins Edition, Santa Rosa Sheet: California Department of Natural Resources Division of Mines and Geology, scale 1:250,000.
5. Springhorn, S.T., 2008, Stratigraphic Analysis and Hydrogeologic Characterization of Cenozoic Strata in the Sacramento Valley near the Sutter Buttes: Master of Science Dissertation, California State University, Chico, 2008.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

Notes:

1. The Helley and Harwood mapping is used where available and is supplemented or revised using geologic mapping from the California Department of Natural Resources Division of Mines and Geology documents and information provided in the Springhorn dissertation (2008)
2. Geologic structures are dashed where approximated.

Figure 3-10

Geologic Map

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin Groundwater Sustainability Plan

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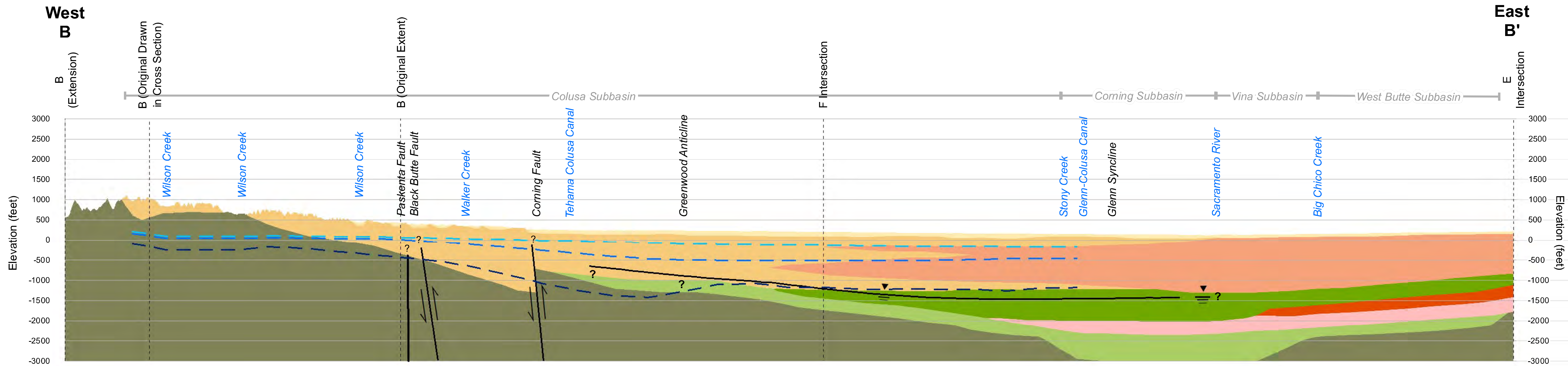
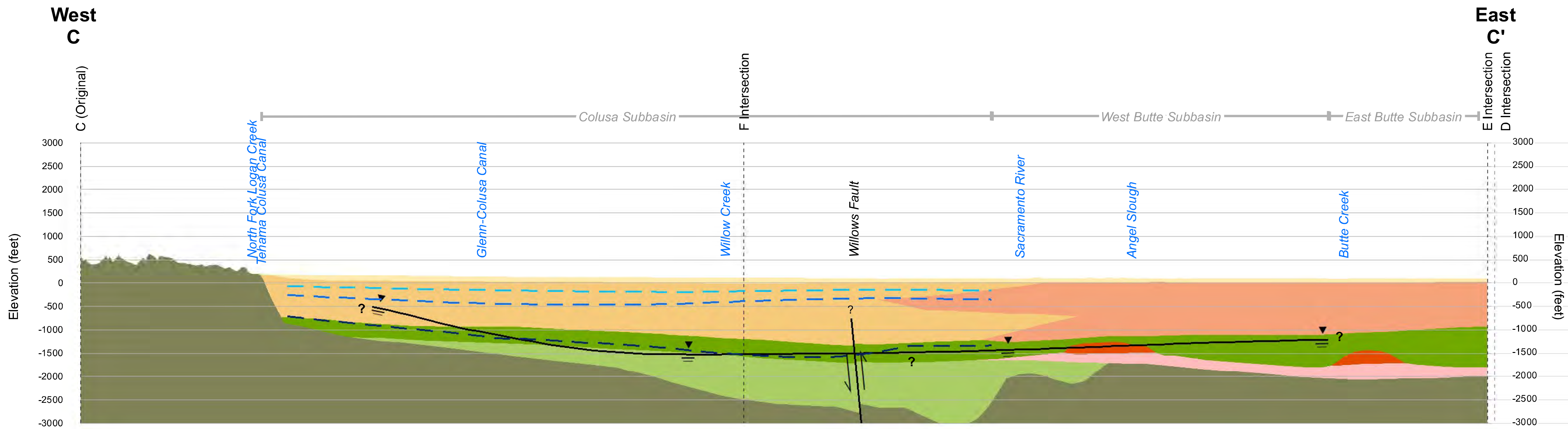
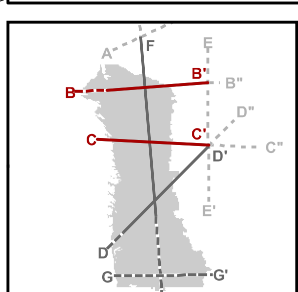


Cross Section B-B'



Cross Section C-C'



Inset Map Symbology

- Selected NSV Geology Cross Section Used for HCM
- Selected Section Extension or New Cross Section
- NSV Geology Cross Section Used for HCM
- Section Extension or New Cross Section
- NSV Geology Cross Section Not Used for HCM
- Colusa Subbasin

Cross Section Symbology

- Fault
- Base of Fresh Water (~2,000 mg/L TDS)
- Base of Model Layer 1 and Modeled Unconfined Aquifer
- Base of Model Layer 2 and Modeled Confined Aquifer Pumping
- Base of Model Layer 3 and Modeled Base of Fresh Water (~3,000 mg/L TDS)

Geologic Units

- Alluvium
- Tehama Formation
- Tuscan Formation
- Upper Princeton Valley Fill
- Lovejoy Basalt
- Ione Formation
- Lower Princeton Valley FIll
- Cretaceous Rocks (pre-Paleogene)

Notes:

1. Elevations are in North American Vertical Datum of 1988, feet (NAVD 88).
2. Cross sections shown are digitized versions of the cross sections included in the Department of Water Resources (DWR) Geology of the Northern Sacramento Valley, California report (DWR, 2014). Existing cross sections were extended and new cross sections were added, as needed, to provide coverage for the entire Colusa Groundwater Subbasin.
3. Cross sections B, C, and D were not digitized beyond their intersection with section E.
4. Base of fresh water was digitized from Olmsted and Davis (1961) and is not shown beyond the extent of the original base of freshwater contouring. Base of fresh water was defined by Olmsted and Davis as approximately 2,000 mg/L of total dissolved solids (TDS).
5. The preliminary approximation of the base of the groundwater subbasins within the study area is based on geologic formation boundaries.

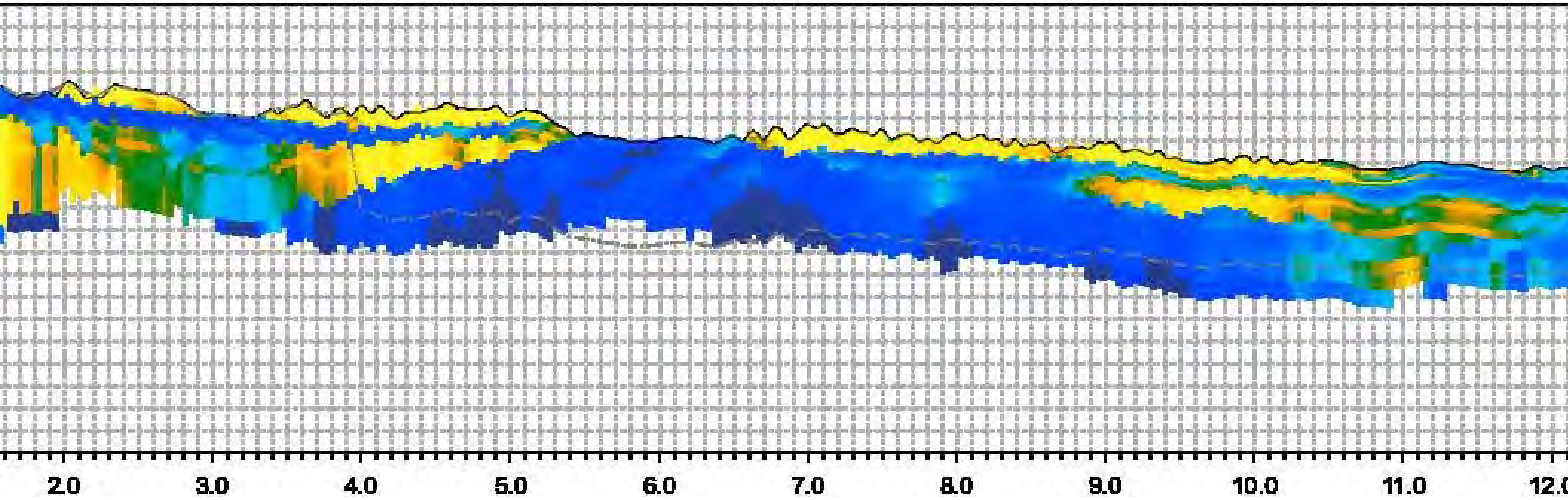
0 1.25 2.5
Scale in Miles
Vertical Exaggeration: 5.28

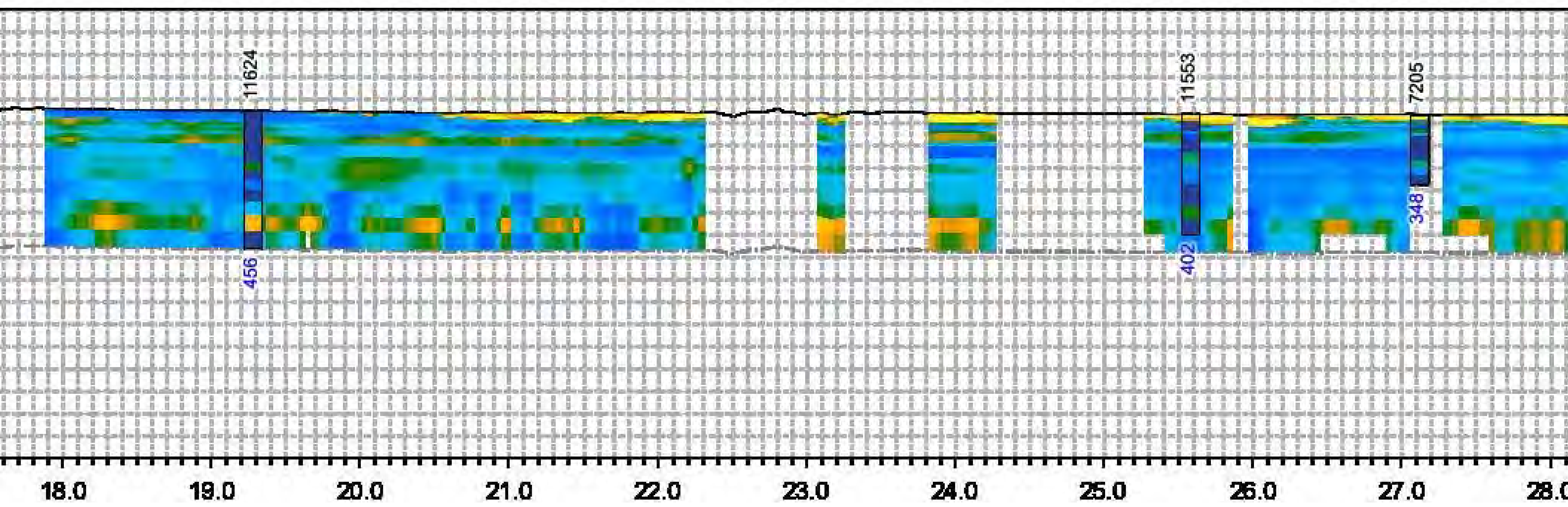
Figure 3-11

Cross Sections B-B' and C-C'

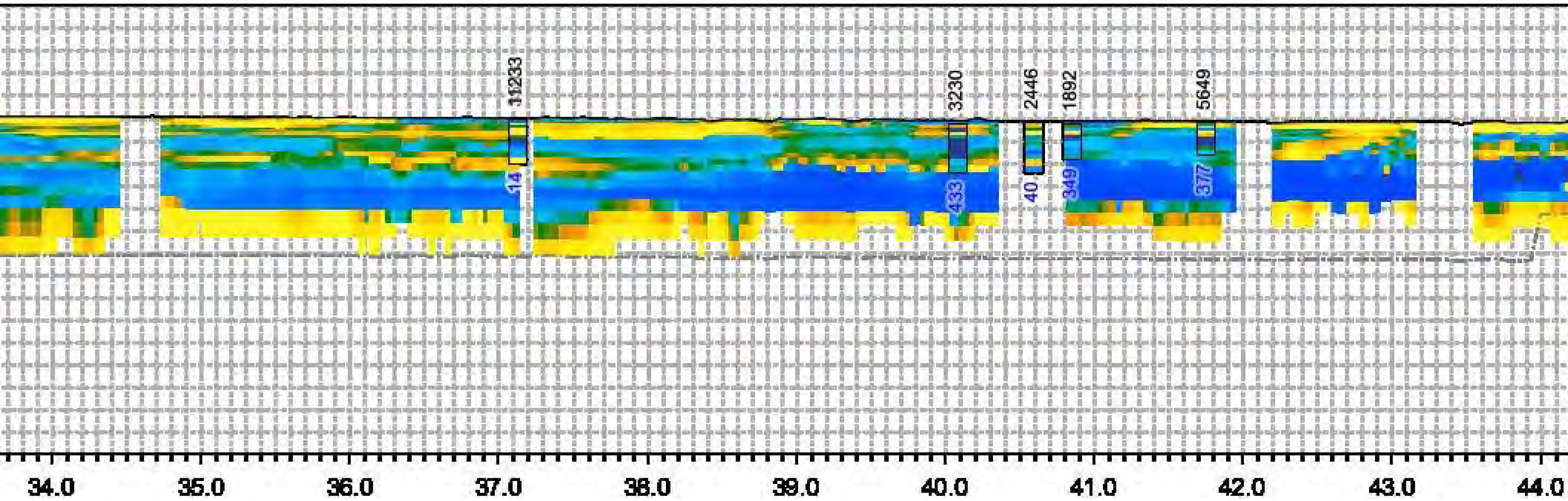
Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan

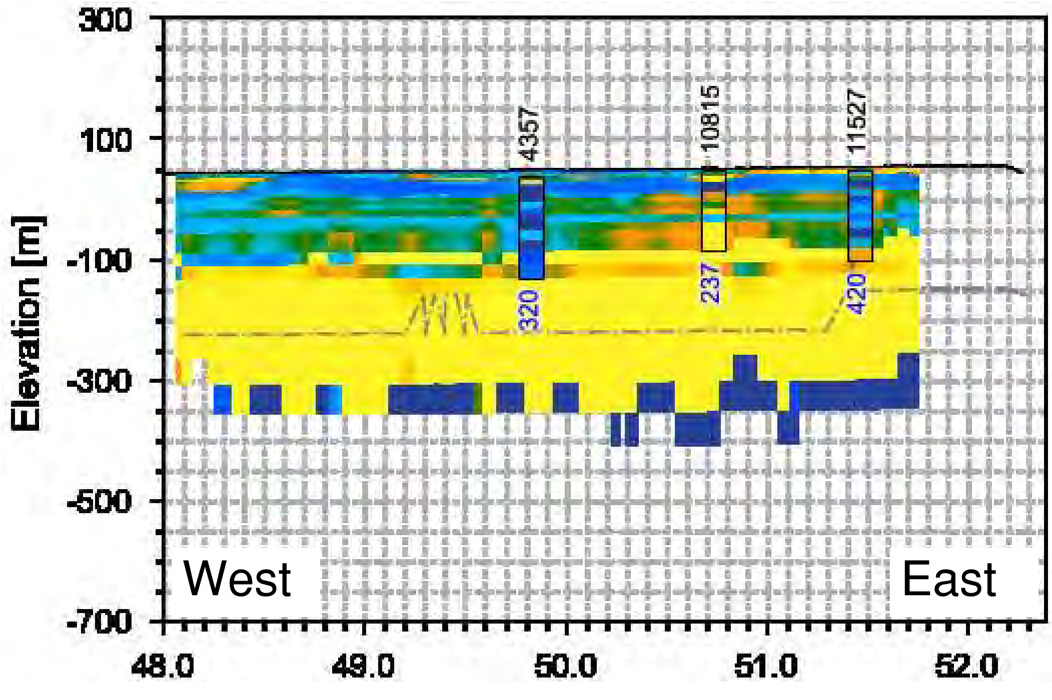
B - B' Nearest AEM Log



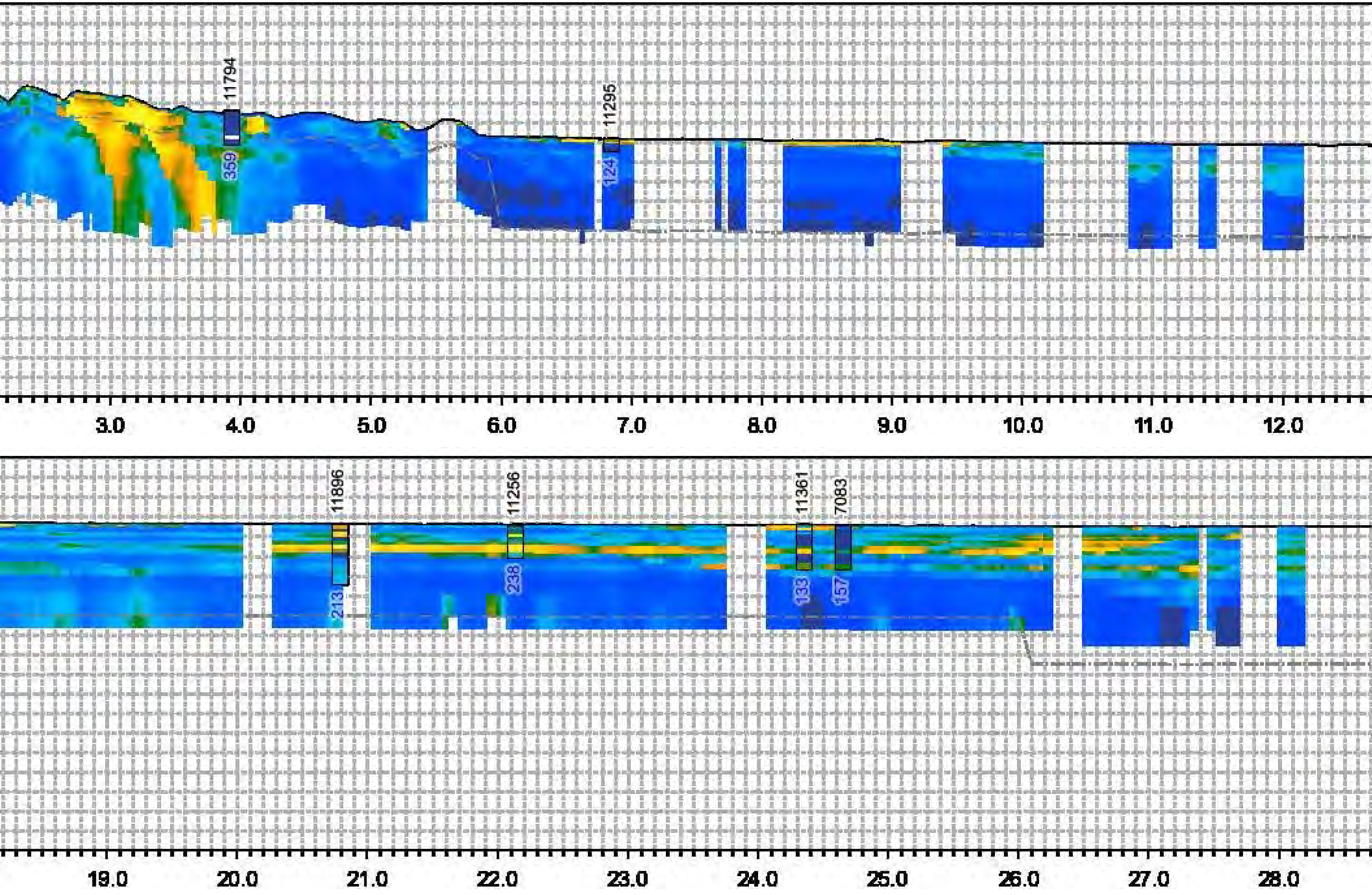


B - B' Nearest AEM Log

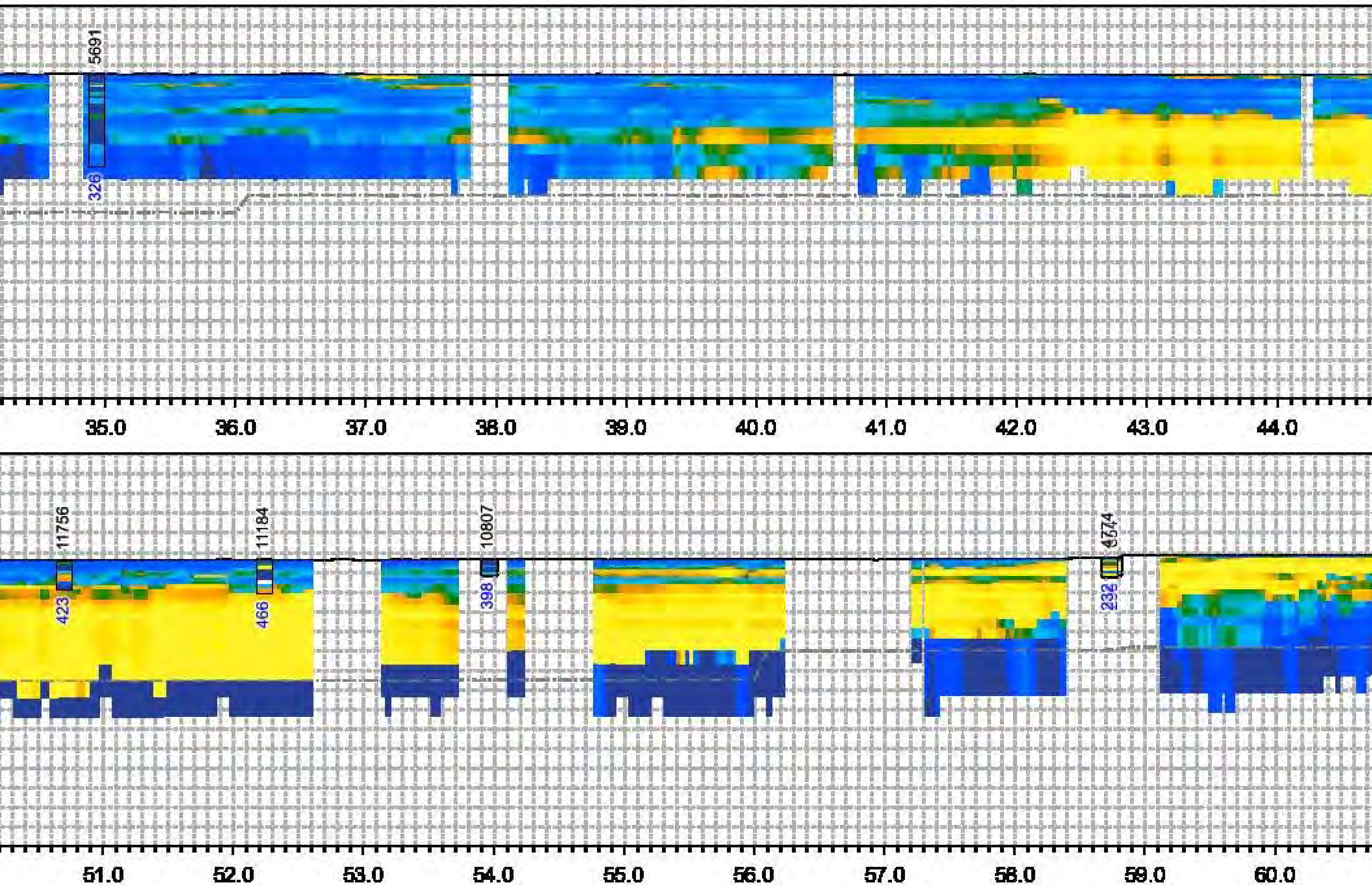




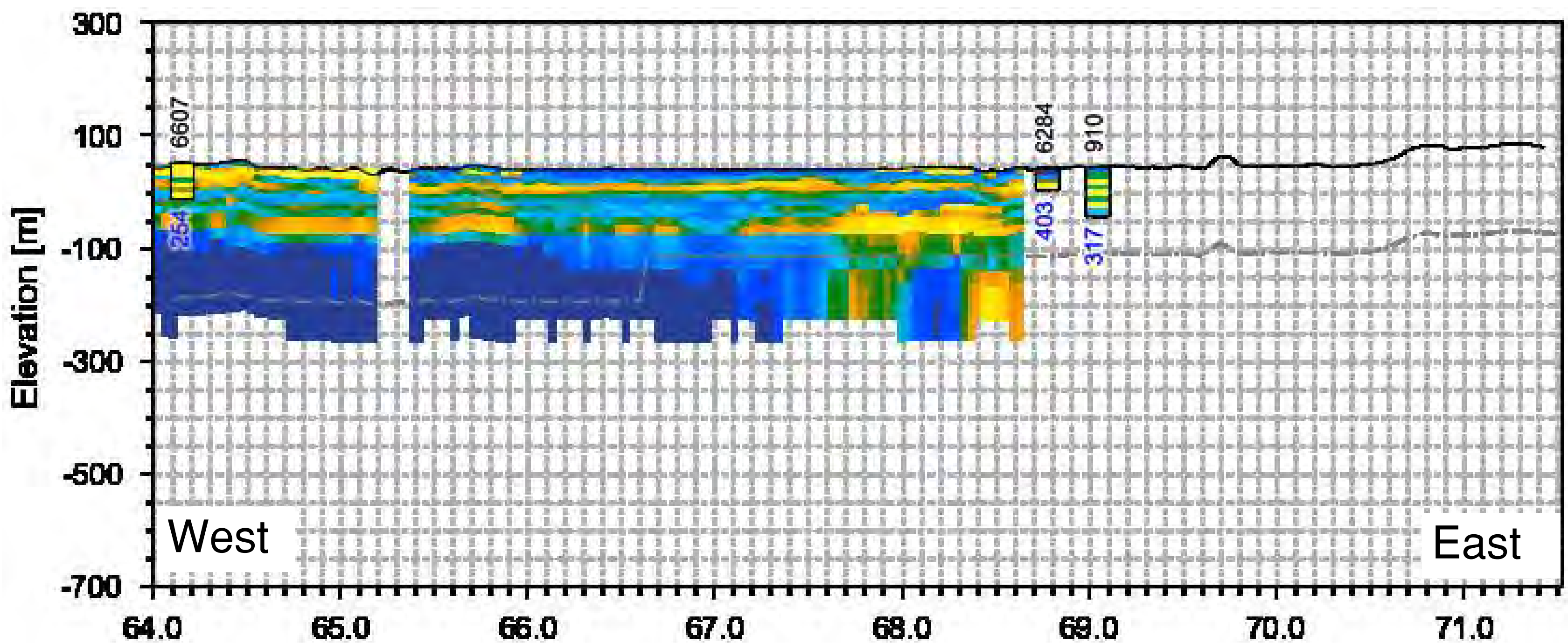
C - C' Nearest AEM Log

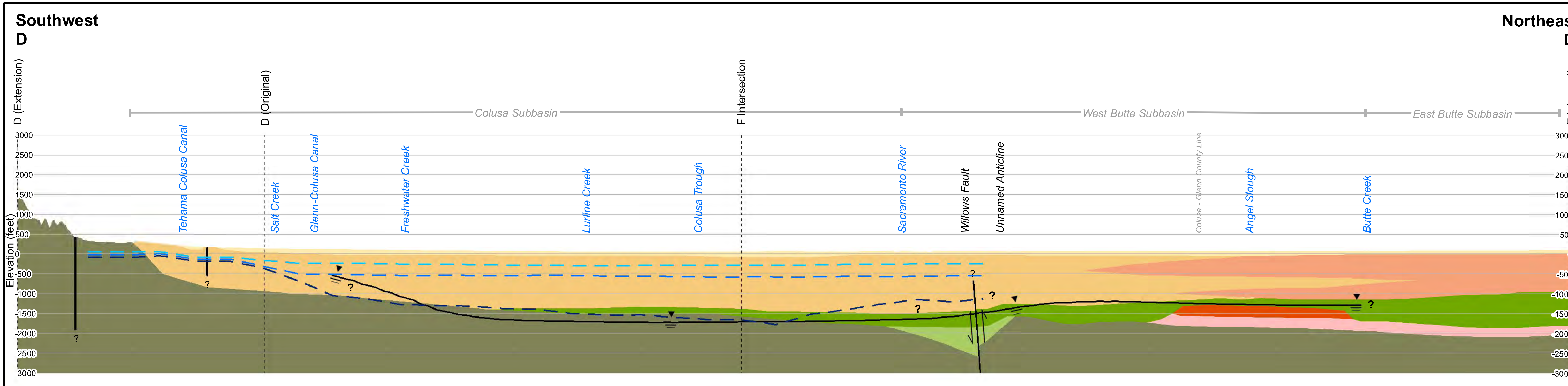


C - C' Nearest AEM Log

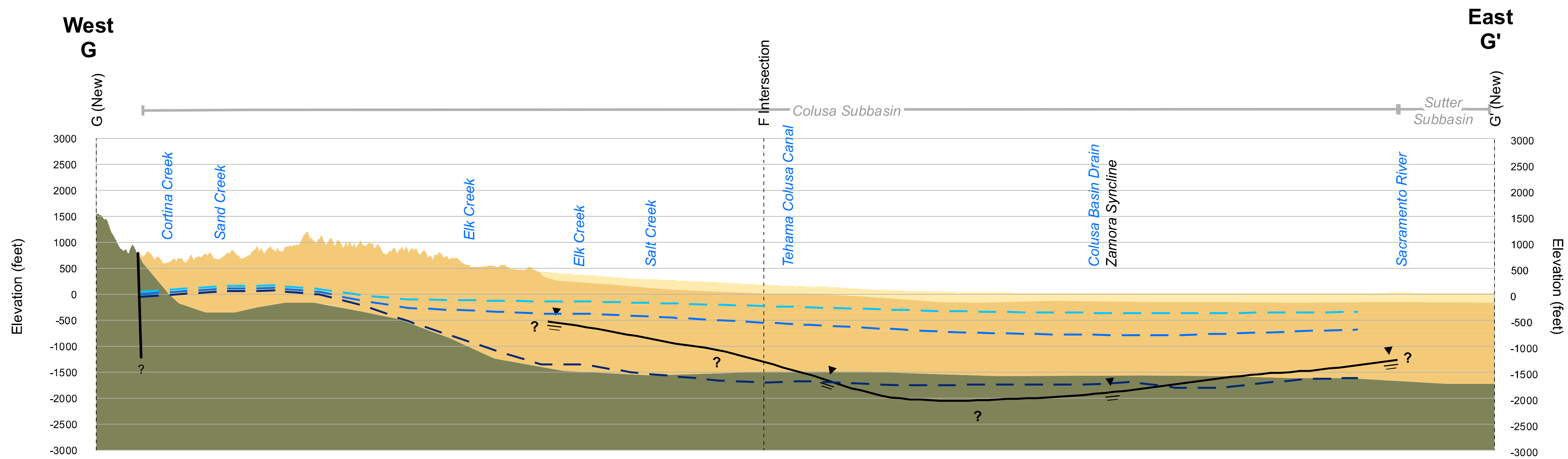


C - C' Nearest AEM Log

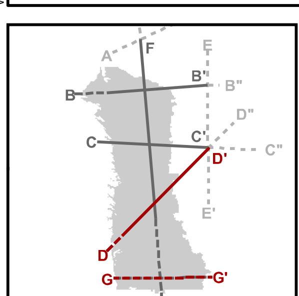




Cross Section D-D'



Cross Section G-G'



Inset Map Symbology

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- NSV Geology Cross Section Used for HCM
- Section Extension or New Cross Section
- NSV Geology Cross Section Not Used for HCM
- Colusa Subbasin

Cross Section Symbology

- Fault
- Base of Fresh Water (~2,000 mg/L TDS)
- Bottom of Model Layer 1 and Modeled Base of Unconfined Aquifer
- Bottom of Model Layer 2 and Modeled Base of Confined Aquifer Pumping
- Bottom of Model Layer 3 and Modeled Base of Fresh Water (~3,000 mg/L TDS)

Geologic Units

- Alluvium
- Tehama Formation
- Tuscan Formation
- Upper Princeton Valley Fill
- Lovejoy Basalt
- Ione Formation
- Lower Princeton Valley FIll
- Cretaceous Rocks (pre-Paleogene)

Notes:

1. Elevations are in North American Vertical Datum of 1988, feet (NAVD 88).
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5. The preliminary approximation of the base of the groundwater subbasins within the study area is based on geologic formation boundaries.

0 1.25 2.5

Scale in Miles

Vertical Exaggeration: 5.28

Figure 3-12

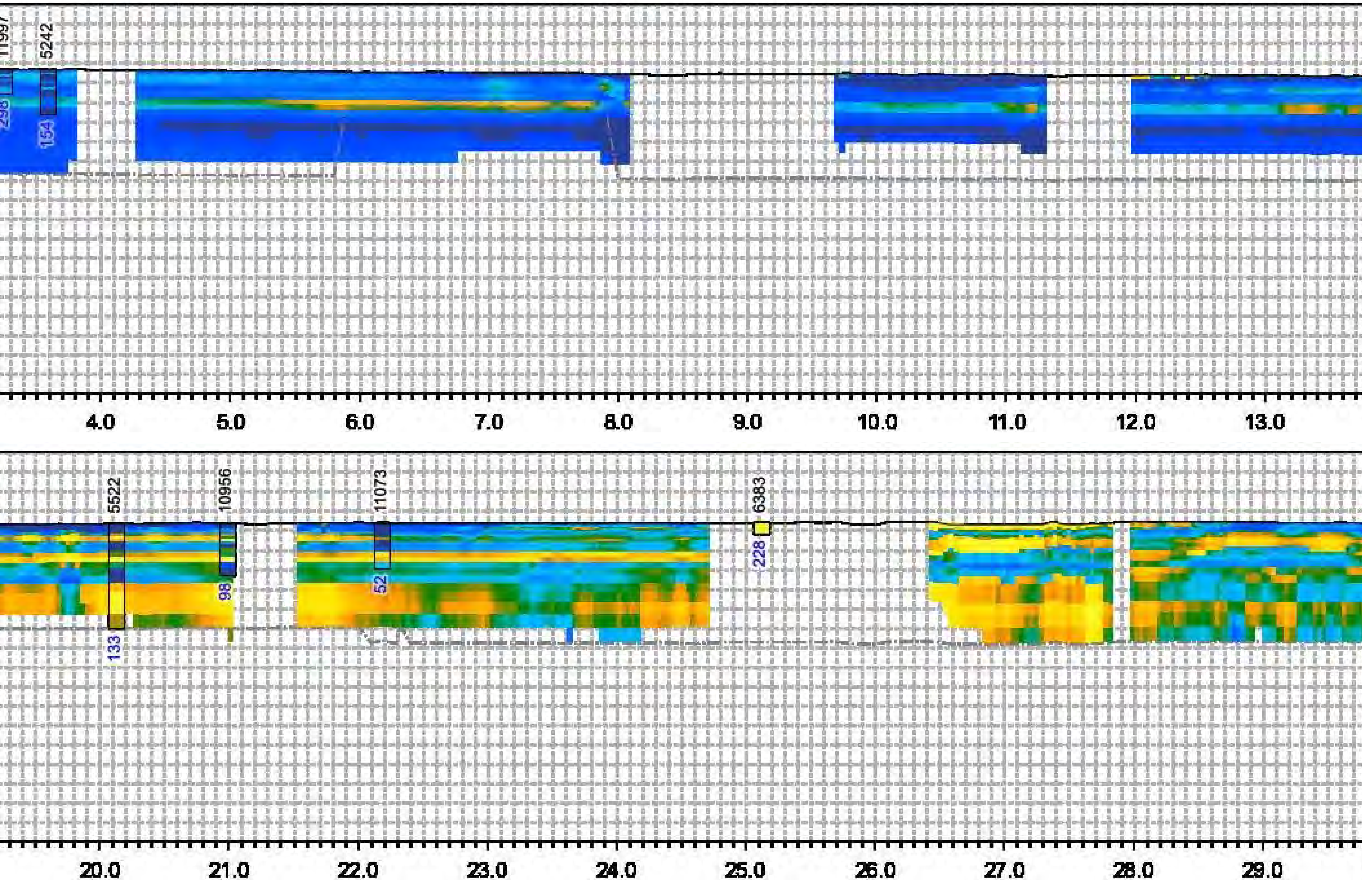
Cross Sections D-D' and G-G'

Colusa Groundwater Authority and Glenn Groundwater Authority

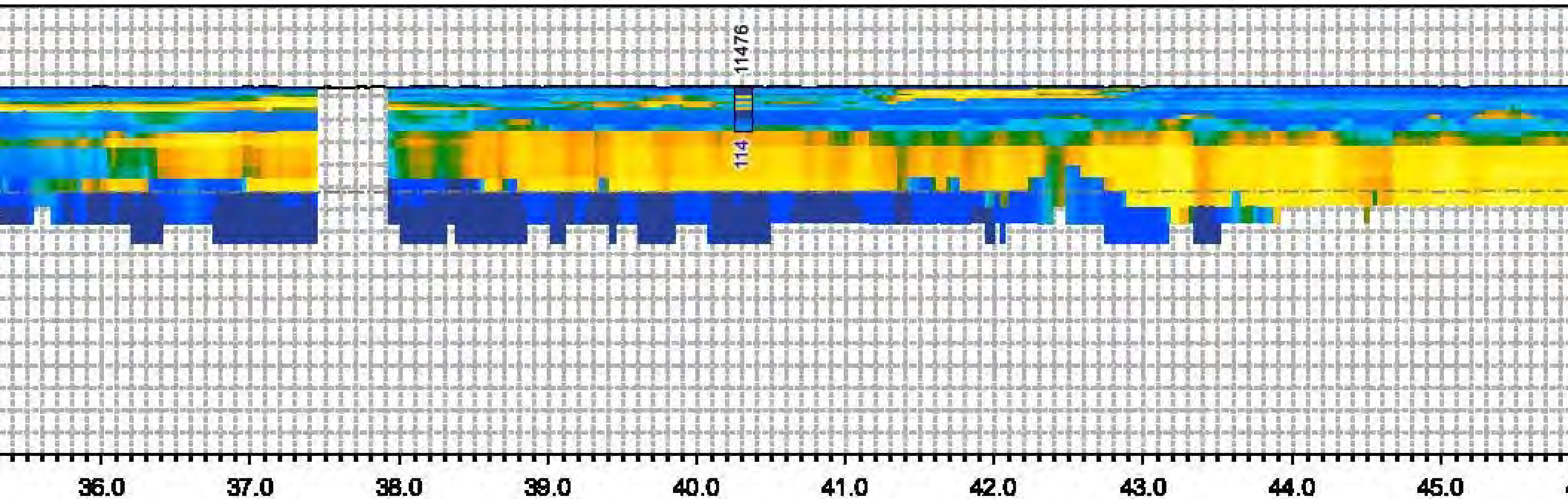
Colusa Subbasin

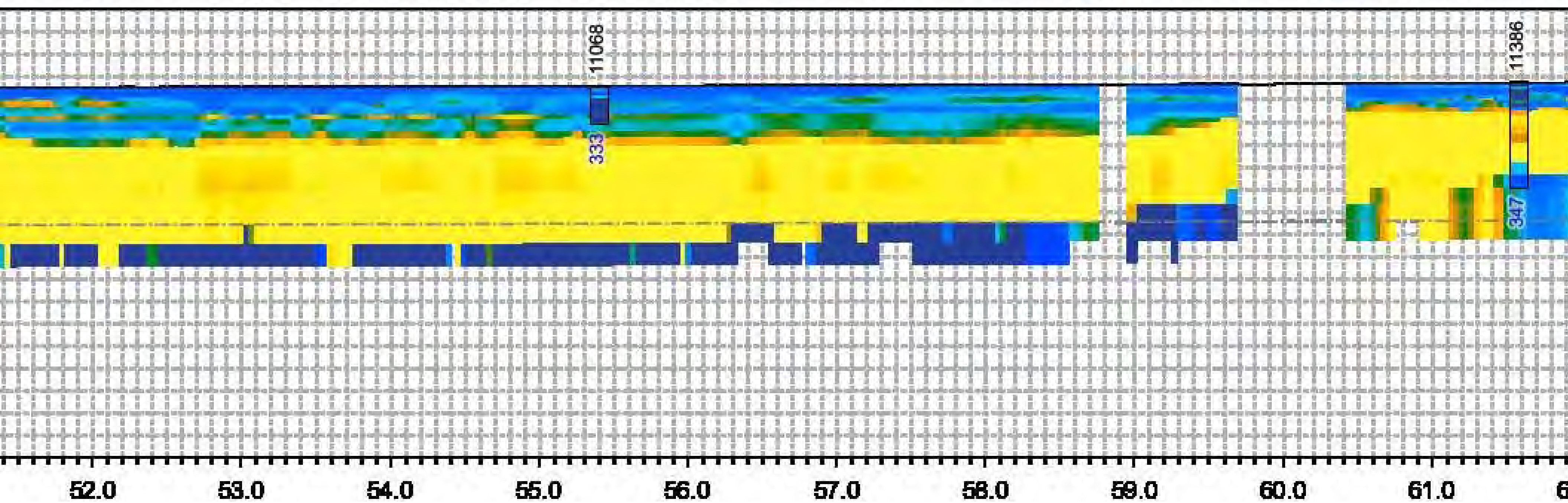
Groundwater Sustainability Plan

D - D' Nearest AEM Log

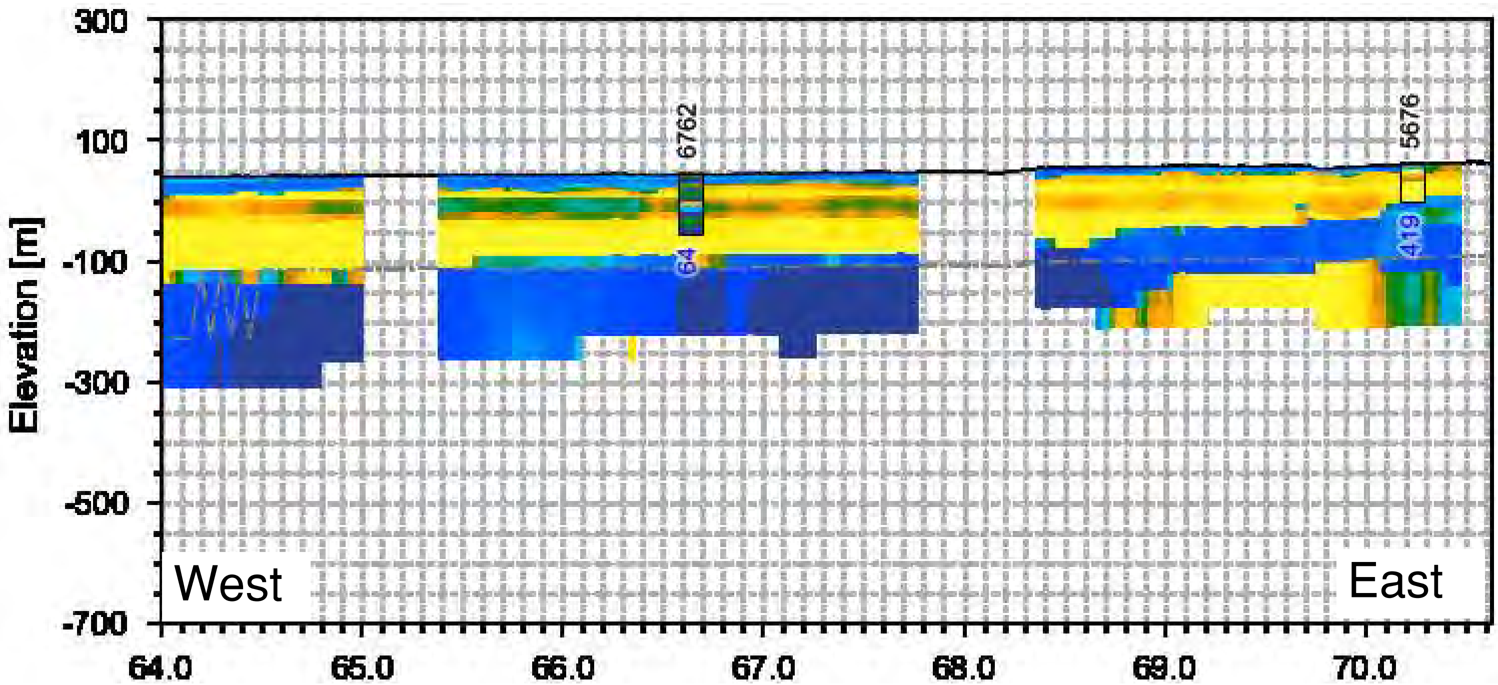


D - D' Nearest AEM Log

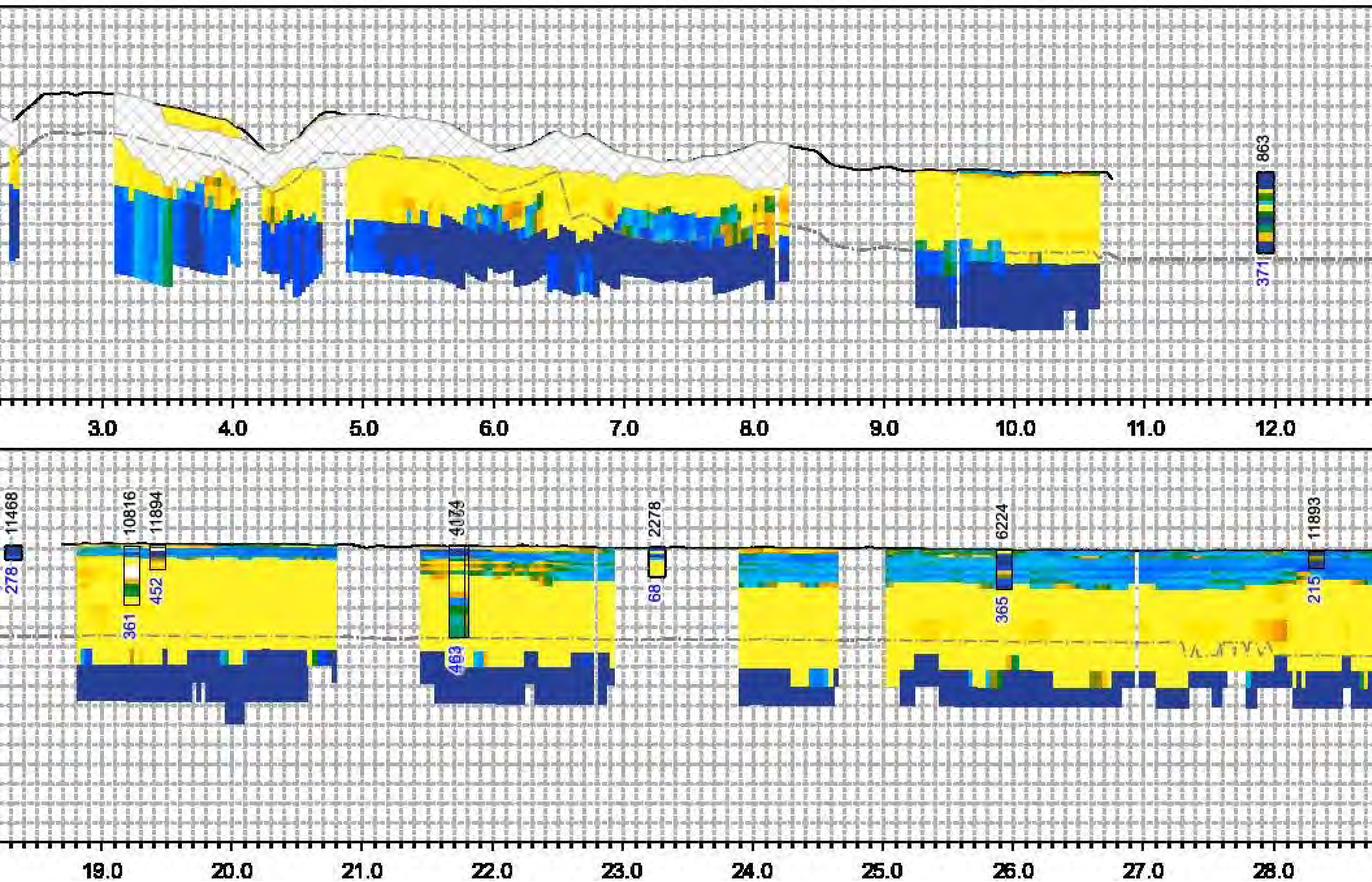




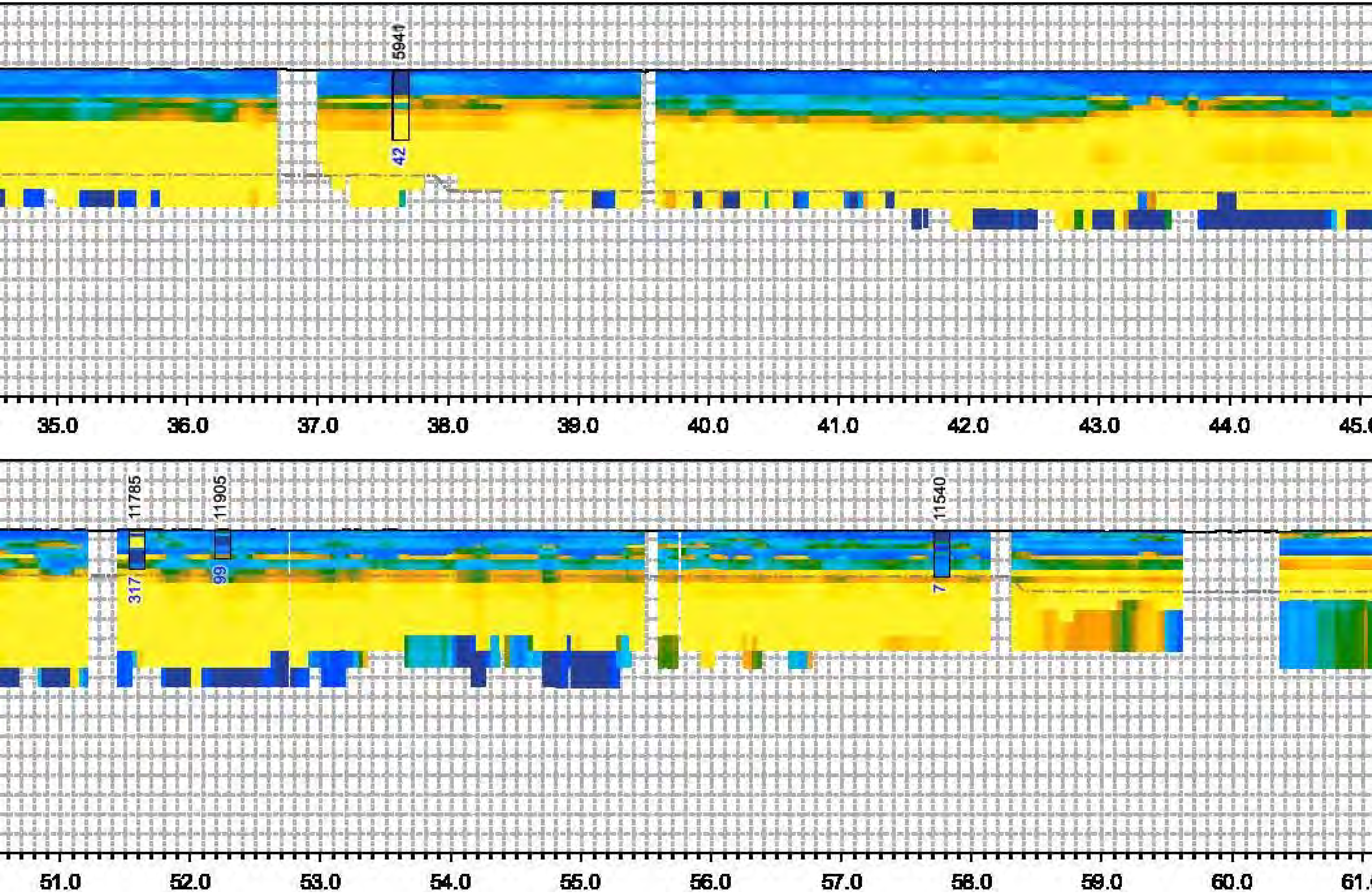
D - D' Nearest AEM Log



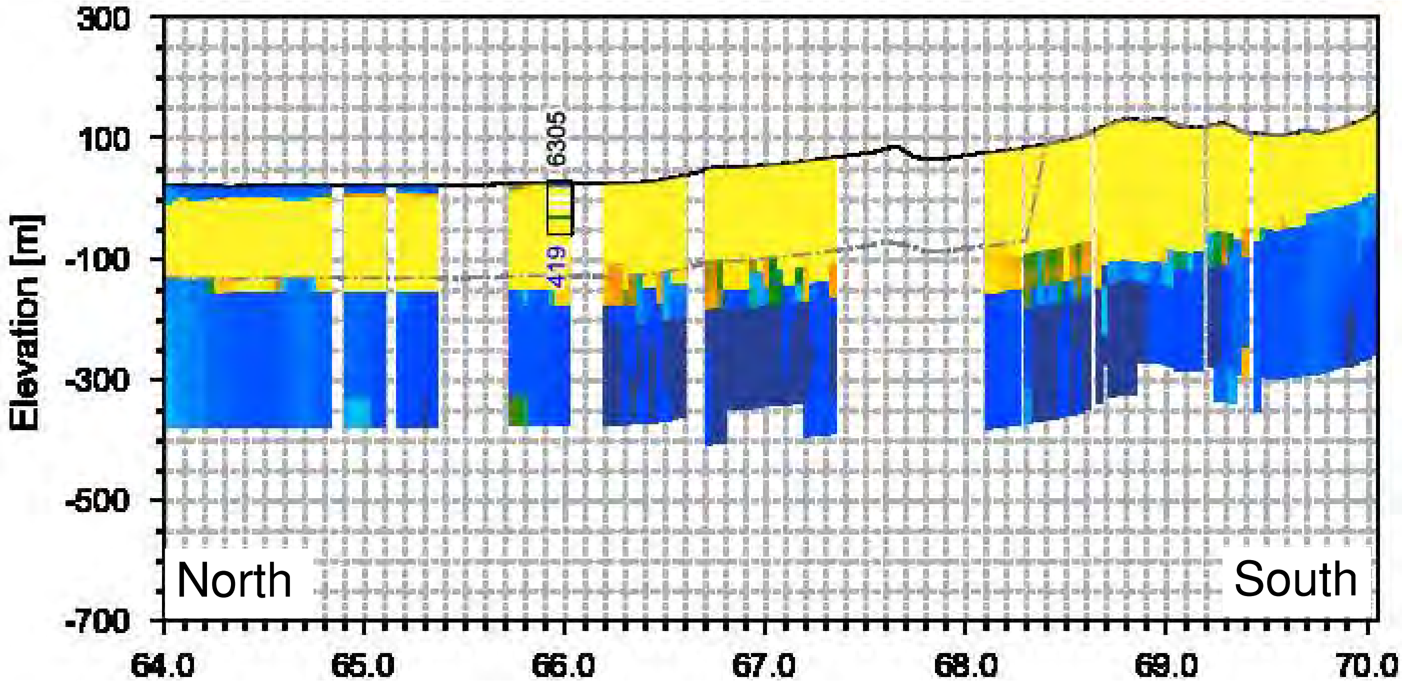
E - E' Nearest AEM Log

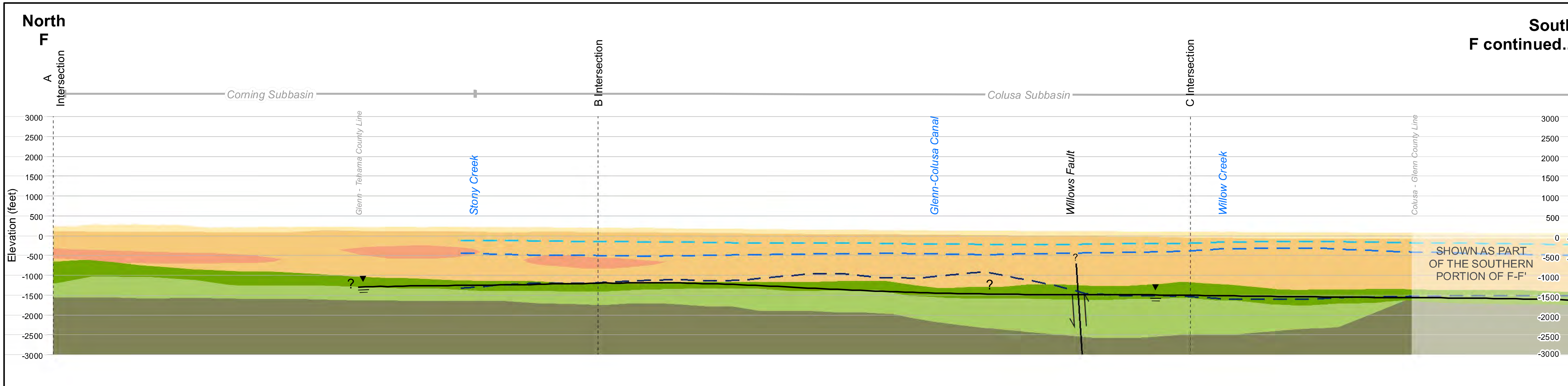


E - E' Nearest AEM Log

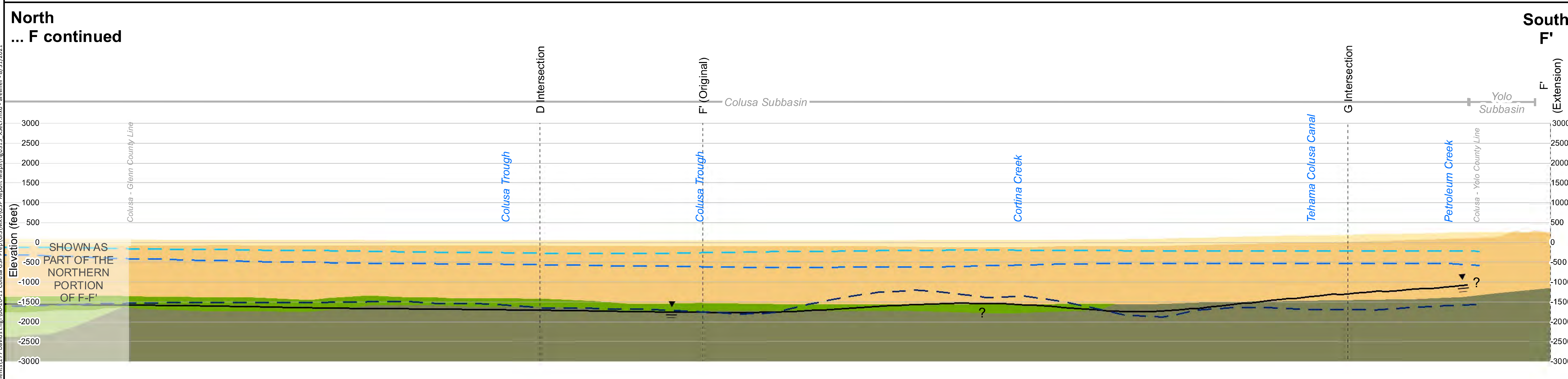


E - E' Nearest AEM Log

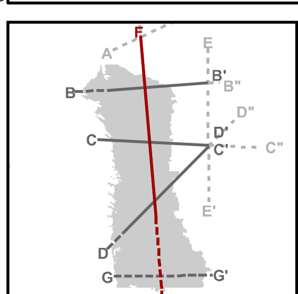




Cross Section F-F' Northern Portion



Cross Section F-F' Southern Portion



Inset Map Symbology

- Selected NSV Geology Cross Section Used for HCM
- Selected Section Extension or New Cross Section
- NSV Geology Cross Section Used for HCM
- Section Extension or New Cross Section
- NSV Geology Cross Section Not Used for HCM
- Colusa Subbasin

Cross Section Symbology

- Fault
- Base of Fresh Water (~2,000 mg/L TDS)
- Bottom of Model Layer 1 and Modeled Base of Unconfined Aquifer
- Bottom of Model Layer 2 and Modeled Base of Confined Aquifer Pumping
- Bottom of Model Layer 3 and Modeled Base of Fresh Water (~3,000 mg/L TDS)

Geologic Units

- Alluvium
- Tehama Formation
- Tuscan Formation
- Upper Princeton Valley Fill
- Lovejoy Basalt
- Ione Formation
- Lower Princeton Valley FIll
- Great Valley Sequence

Notes:

1. Elevations are in North American Vertical Datum of 1988, feet (NAVD 88).
2. Cross sections shown are digitized versions of the cross sections included in the Department of Water Resources (DWR) Geology of the Northern Sacramento Valley, California report (DWR, 2014). Existing cross sections were extended and new cross sections were added, as needed, to provide coverage for the entire Colusa Groundwater Subbasin.
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5. The preliminary approximation of the base of the groundwater subbasins within the study area is based on geologic formation boundaries.

0 1.25 2.5

Scale in Miles

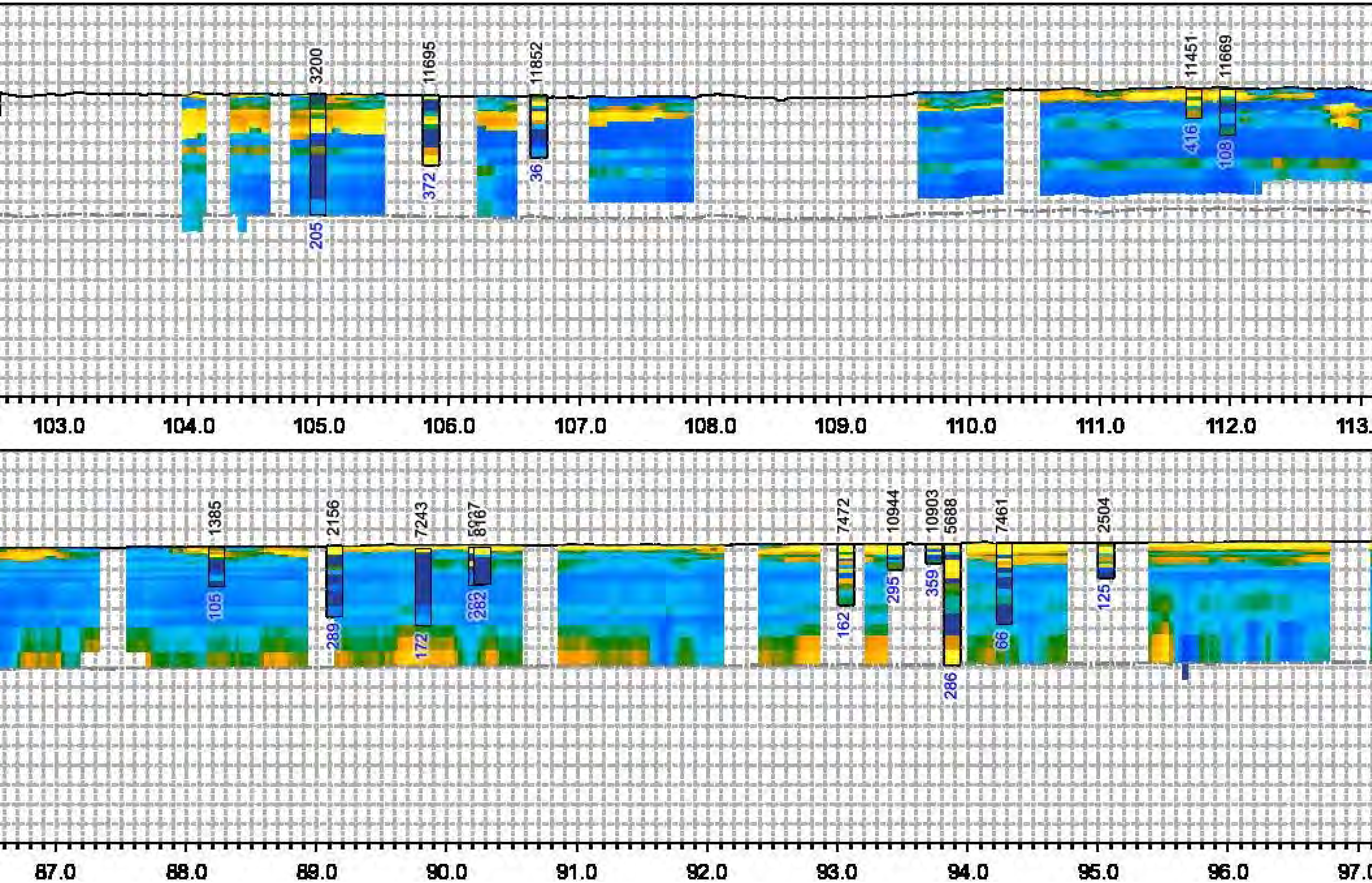
Vertical Exaggeration: 5.28

Figure 3-13

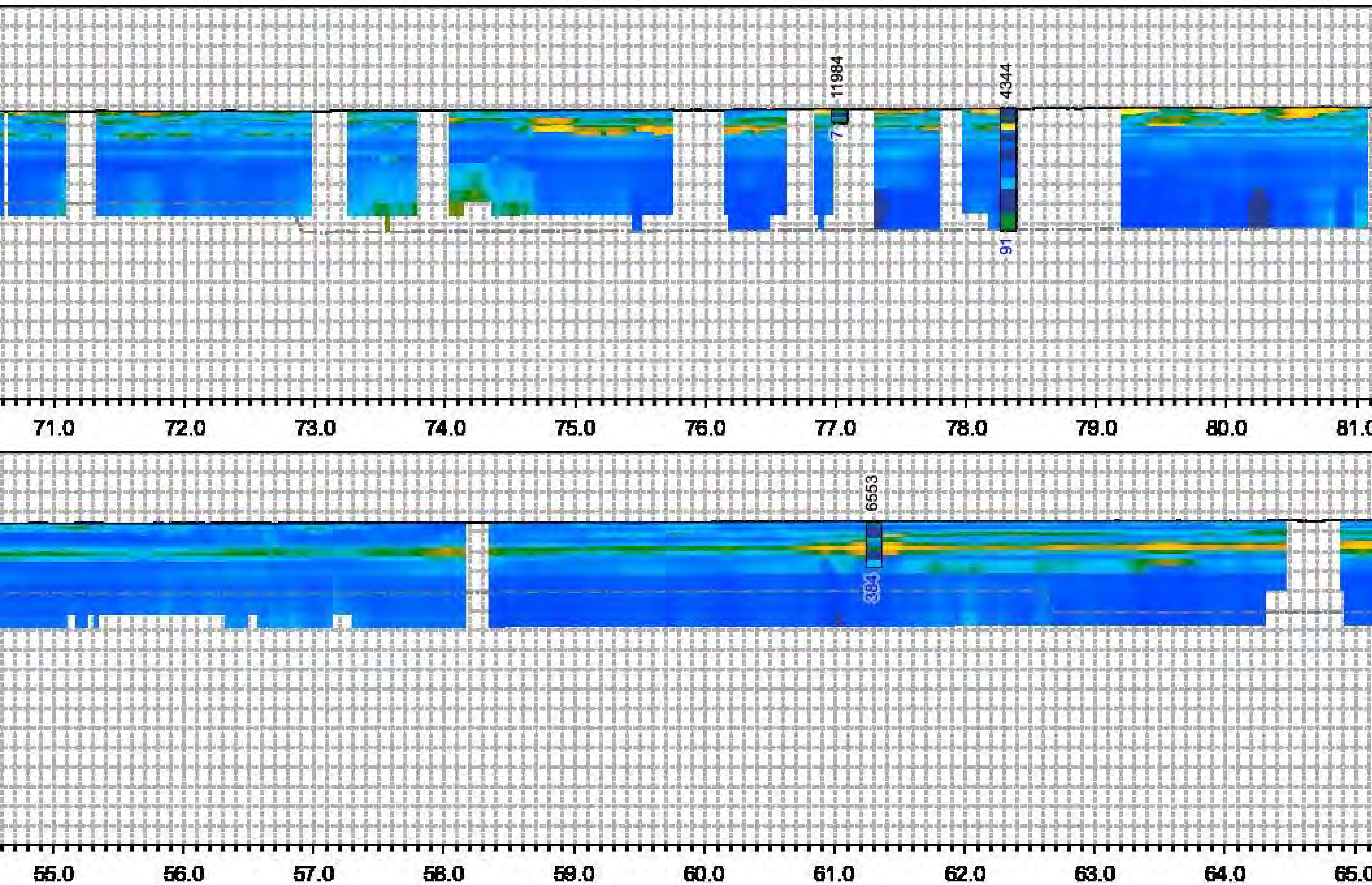
Cross Section
F-F'

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan

F - F' Nearest AEM Log



F - F' Nearest AEM Log



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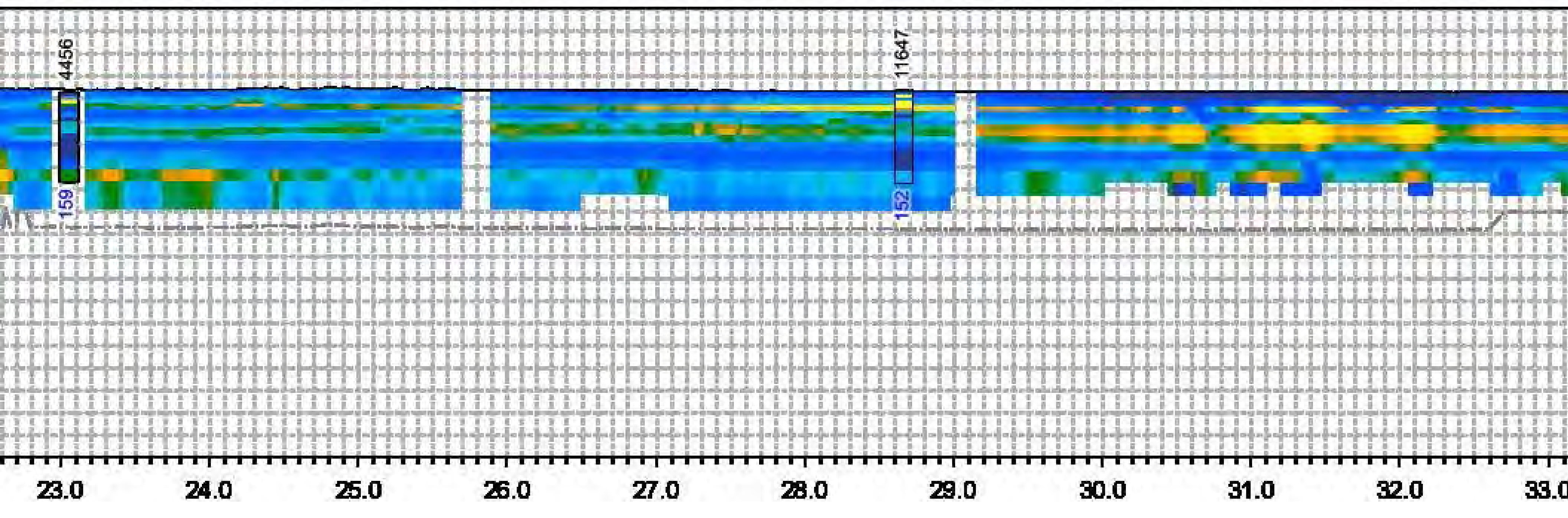
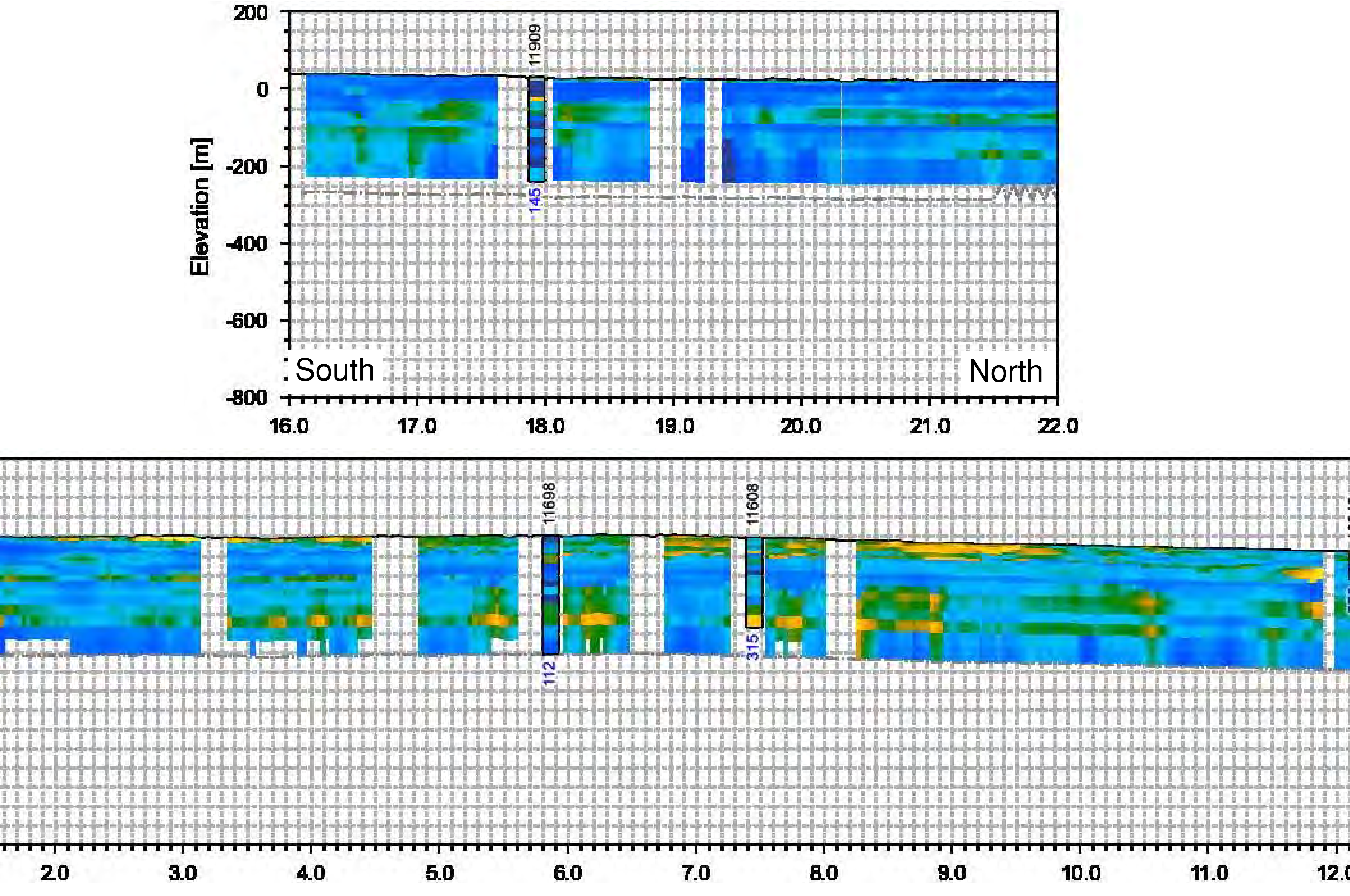
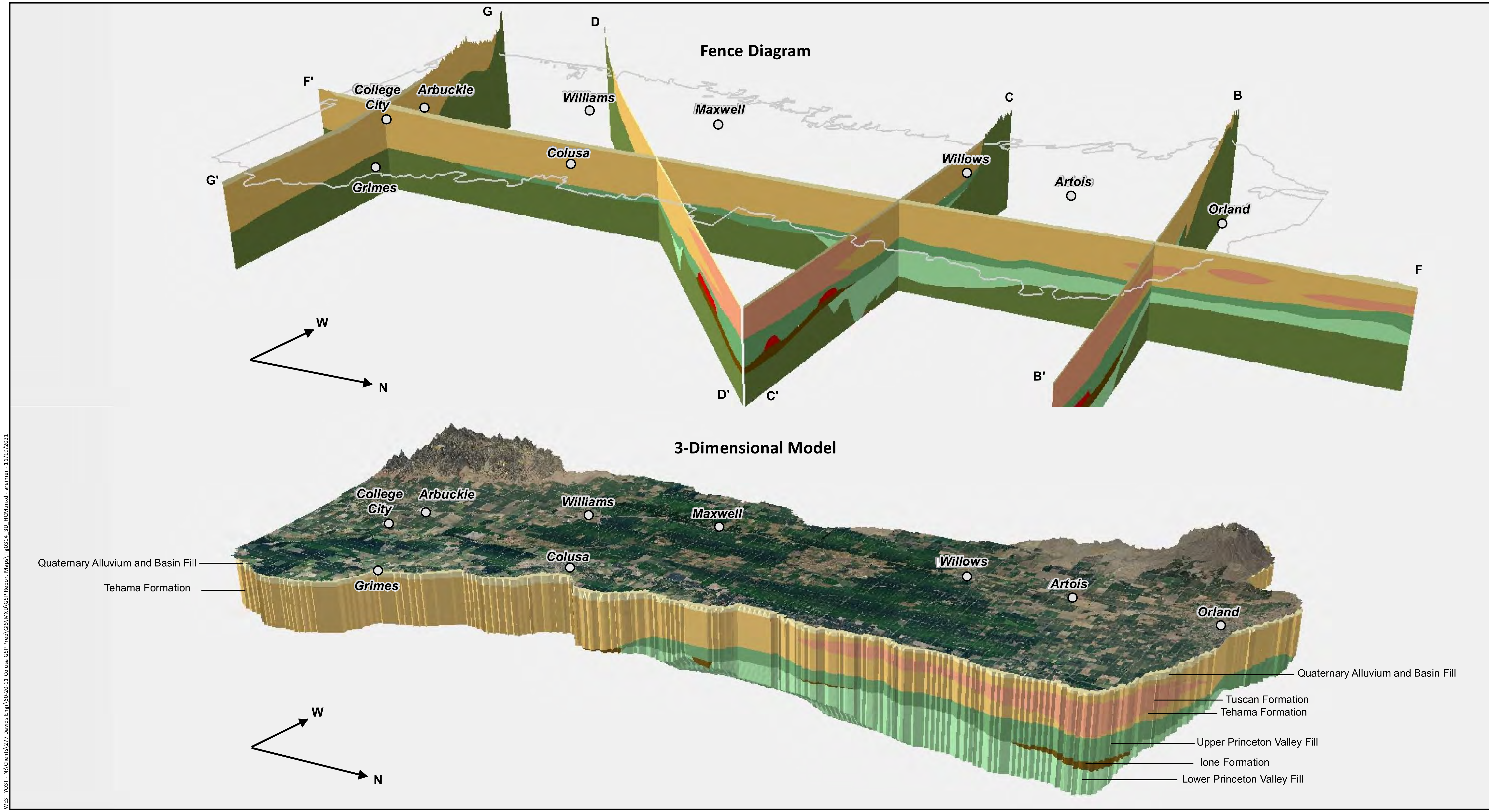


F - F' Nearest AEM Log





Datums: North American Datum of 1983, California State Plane Zone II, feet. North American Vertical Datum of 1988, feet.

Notes:
1. Vertical exaggeration is 10x.
2. Elevations are in North American Vertical Datum of 1988, feet (NAVD 88).
3. The fence diagram and 3-dimensional (3D) model are based on the cross sections included in the California Department of Water Resources (DWR) Geology of the Northern Sacramento Valley, California report (DWR, 2014) and have been updated and expanded upon based on available well completion reports to represent the water-bearing formations.
4. The 3D model excludes the Lovejoy Basalt.

Hydrogeologic Formation

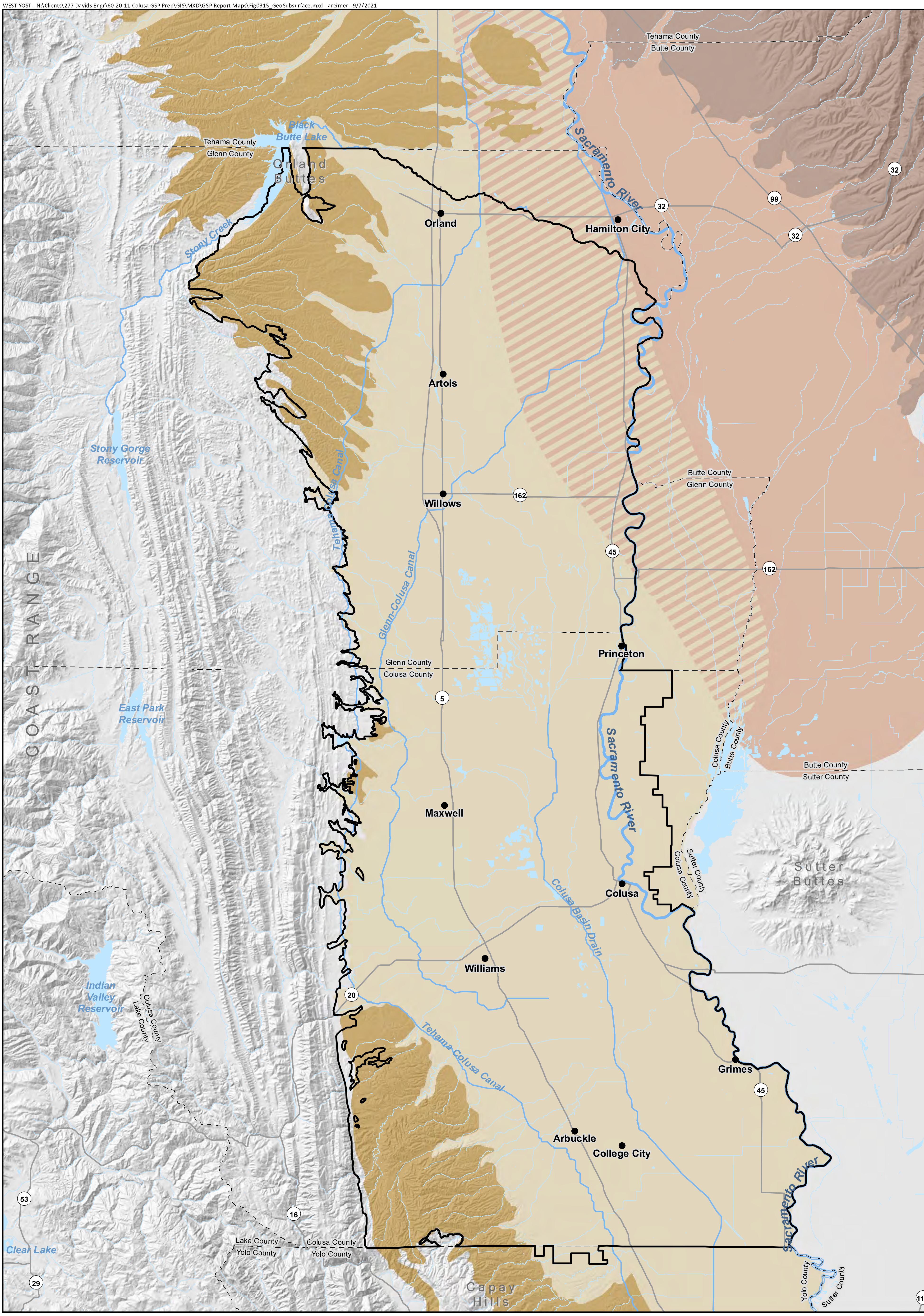
- Quaternary Alluvium and Basin Fill
- Tehama Formation
- Tuscan Formation
- Upper Princeton Valley Fill
- Lovejoy Basalt
- Ione Formation
- Lower Princeton Valley Fill
- Cretaceous Rocks (pre-Paleogene)

Figure 3-14

3D Hydrogeologic Conceptual Model

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin
Groundwater Sustainability Plan



Source: DWR, 2009, Glenn-Colusa Irrigation District Test-Production Well Installation and Aquifer Testing: prepared by the California Department of Water Resources (DWR) Northern District Groundwater Section in cooperation with Glenn-Colusa Irrigation District, March 2009, GIS shapefiles provided by DWR 2008.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

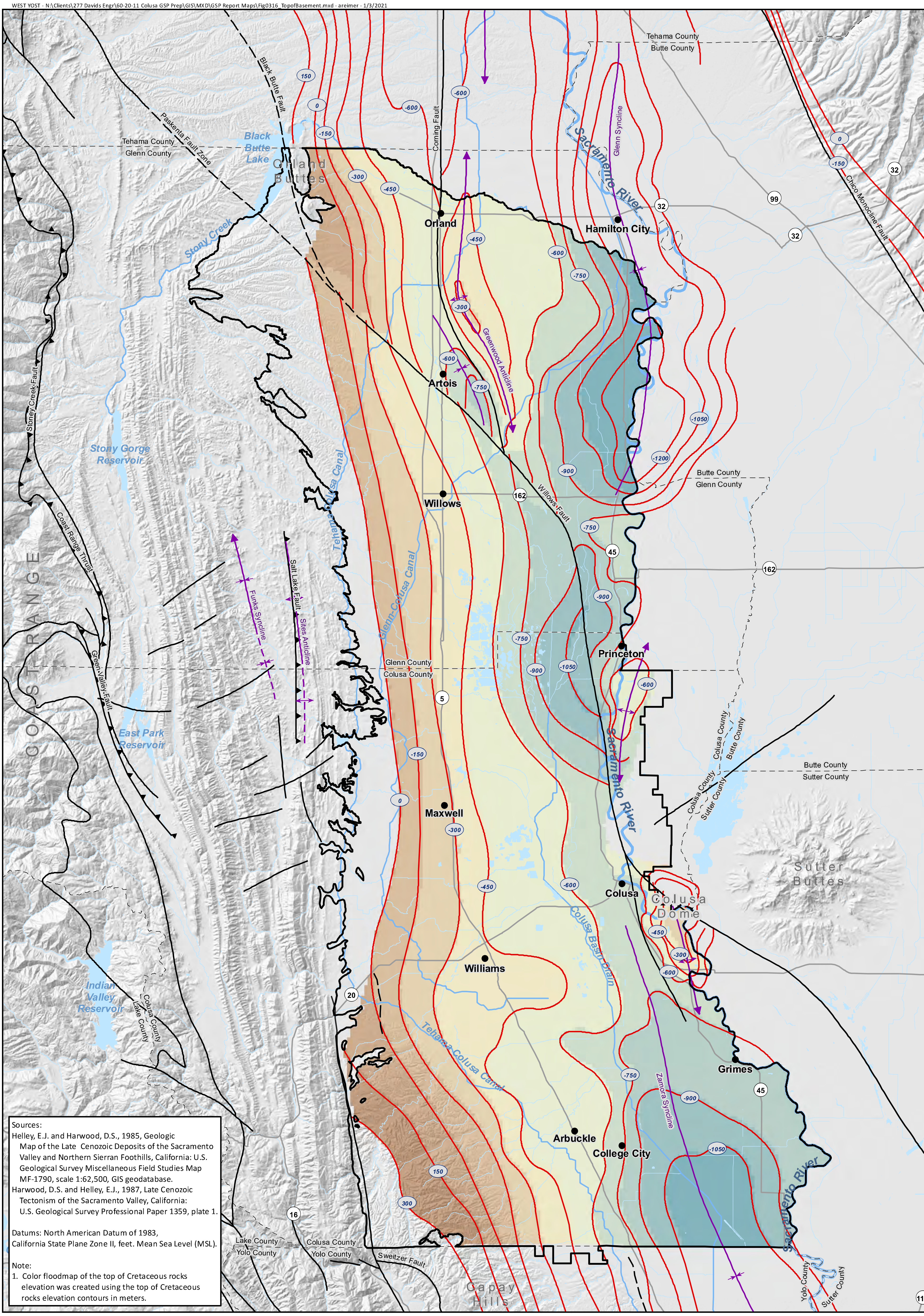
- Colusa Subbasin
- Tuscan Outcrop
- Tehama Outcrop
- Tehama-Tuscan Subsurface Transition Zone
- Tehama Subsurface
- Tuscan Subsurface

0 2.5 5
Scale in Miles

Figure 3-15

Extent of Tehama and Tuscan Formations

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan



Anticline, Certain
Syncline, Certain
Plunging Anticline, Certain
Plunging Syncline, Certain
Doubly Plunging Anticline, Certain
Anticline, Approximate
Syncline, Approximate

Fault, Certain
Thrust Fault, Certain
Fault, Approximate

Top of Cretaceous Rocks Elevation Contours (MSL, meters)
Colusa Subbasin

Top of Cretaceous Rocks Elevation (MSL, meters)

< -1,050
-1,050 - -900
-900 - -750
-750 - -600
-600 - -450
-450 - -300
-300 - -150
-150 - 0
0 - 150
> 150

0 2.5 5
Scale in Miles

Figure 3-16

Top of Cretaceous Rocks Structural Contours Map

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan

Glacial activity during the Pleistocene epoch resulted in the Riverbank and Modesto Formations (Busacca et. al., 1989). The age of the Riverbank Formation ranges from 0.13 to 0.45 Ma and corresponds to the Illinoisan and older glacial stages. The age of the Modesto Formation ranges from approximately 0.01 to 0.042 Ma and correlates to the Wisconsin glacial stage.

The youngest deposits of the Subbasin consist of Holocene-aged basin deposits and stream channel deposits.

3.1.7.2 Primary Freshwater-Bearing Formations

The geologic formations forming the freshwater aquifer comprise a single aquifer system. The geologic formations comprising the freshwater aquifer system are discussed below.

3.1.7.2.1 Tuscan Formation

Tuscan Formation deposits are characterized by their Cascade Range origin and volcanic signature. This extensive series of basaltic and andesitic volcanic flows, consolidated tuff breccia, tuffaceous sandstone, and volcanic ash is primarily located on the northeastern portion of the Sacramento Valley. Figure 3-10 and Figure 3-15 show the approximate surface and subsurface extents of the Tuscan Formation in the vicinity of the Subbasin. The Tehama-Tuscan Transition Zone is also visible in the 3D hydrogeologic conceptual model shown on Figure 3-14. The Tuscan Formation comprises the oldest freshwater aquifer in the eastern half of the northern Sacramento Valley. The Tuscan Formation is exposed on the eastern side of the Sacramento Valley and occurs as interfingering layers with the Tehama Formation at depth near the center of the Sacramento Valley. This interfingering of the Tehama Formation with Tuscan Formation units is referred to as the Tehama-Tuscan Transition Zone (Figure 3-15). In the Subbasin, these deposits occur at depths greater than the depths of most existing domestic wells.

Moderately to highly permeable volcanic sediments are hydraulically confined by layers of tuff breccias and clays within the Tuscan Formation. The Tuscan Formation contains four map units, which are designated A through D, with A being the oldest (DWR, 2006a). The low permeability lahar, or mudflow, deposits of Unit C are confining beds for the underlying older Tuscan Units A and B. Although Unit C contains permeable volcanic sandstone and conglomerate interbeds, this unit is characterized by an overall low yield of water to wells within the Subbasin. Units A and B are much coarser-grained than the overlying Unit C, and they are the primary water-bearing zones of the eastern Sacramento Valley. The lower Tuscan Formation (Tuscan Units A and B) is present at depths below 700 feet in the northeastern part of the Subbasin and consists of volcanic conglomerate, sandstone, siltstone, and interbedded lahars overlain by tuffaceous breccias, sandstone and conglomerate. Tuscan Unit D is not present within the Subbasin.

The permeability of the Tuscan Formation varies, and irrigation wells range in well yield from 7 to 4,000 gallons per minute (gpm).

3.1.7.2.2 Tehama Formation

Figure 3-10 and Figure 3-15 show the approximate surface exposures and subsurface extents of the Tehama Formation. The Tehama Formation forms the oldest, deepest, and thickest part of the freshwater aquifer in the western half of the northern Sacramento Valley. The Tehama Formation consists of up to nearly 2,000 feet of moderately compacted silt, clay, and silty fine sand enclosing thin, discontinuous lenses of sand and gravel deposited in a fluvial (river-borne) environment (DWR, 2006a; Olmsted and Davis, 1961). Based on the mineralogy of surface exposures, the sediments were derived from erosion of the Coast Ranges and Klamath Mountains to the west and northwest. They were deposited under floodplain conditions on the west side of a broad valley of low relief (Brown and Caldwell, 2007; Russell, 1931).

The Tehama and Red Bluff Formations are exposed at the land surface on the western side of the Sacramento Valley, in the northwest, and the southwest. The outcrop of the Tehama and Red Bluff Formations and pinchout of the younger valley sediments coincide with an increase in terrain, as seen in Figure 3-4. There are few wells drilled in these areas and local residents report that existing wells yield little groundwater. Geologic mapping shows outcropping of older Cretaceous-aged sedimentary rocks in the northwestern portion of the subbasin near the Orland Buttes and west of the Tehama-Colusa Canal (Figure 3-10). Based on these observations, the Tehama Formation is relatively thin and has a low permeability where it outcrops. The Tehama Formation is buried beneath younger sediments to the east and interfingers with the Tuscan Formation throughout the Tehama-Tuscan Transition Zone in the northeast portion of the Subbasin (Figure 3-15).

The permeability of the Tehama Formation varies but is generally less than in the overlying unconsolidated alluvial deposits. Because of the thickness of the producing zones, production from the Tehama Formation can be up to several thousand gallons per minute per well (DWR, 2006a), but is typically less than that exhibited by the Tuscan Formation.

3.1.7.2.3 Riverbank and Modesto Formations

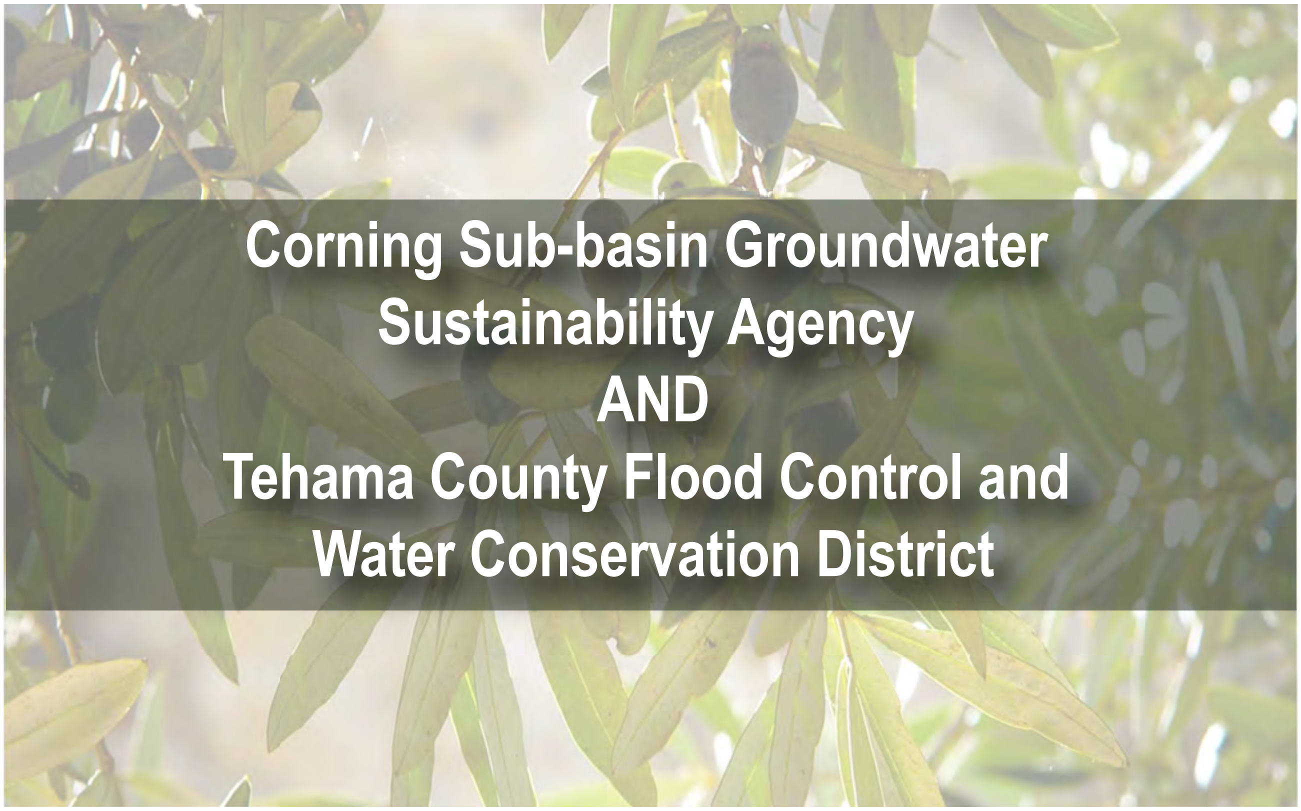
The late Pleistocene-aged Riverbank and Modesto Formations uncomfortably overlie the Tuscan and Tehama Formations. The thickness of the formation ranges from less than 10 feet to nearly 200 feet across the valley floor (DWR, 2006a; Helley and Harwood, 1985). These formations consist of loose to moderately compacted silt, silty clay, sand and gravel deposited in alluvial depositional environments during periods of world-wide glaciation (DWR, 2006a; Lettis, 1988; Weissmann et. al., 2002). The formations were deposited in response to changes in base level and increased precipitation during the glacial periods. The increased stream gradients and precipitation resulted in greater stream discharge and competency than observed today. The greater competency of the streams led to scouring of stream channels in preexisting geologic deposits, followed by transport, deposition and burial of sands and gravels in the channels as the glacial cycles progressed.

Figure 3-10 shows the spatial distribution of the Riverbank and Modesto Formation in the Subbasin. The formations are exposed at the land surface along the channels of creeks and along the western margin of the Subbasin, where they form a series of coalescing alluvial fans, emanating from the mouths of the creeks. The Riverbank and Modesto Formations typically form terraces along stream channels. The oldest terraces occur furthest from the channel and at the highest elevations. Successively younger terraces are incised into the next oldest deposit and, therefore, occur closer to the stream channel and at lower elevations. The Riverbank Formation forms the older terrace deposits that occur at a higher topographic level. In the Stony Creek Fan area, these terraces are well-defined, but they are absent or poorly defined along other minor streams in the Subbasin.

The Riverbank Formation consists of poorly to highly permeable pebble and small cobble gravels interbedded with reddish clay, sand, and silt. The Modesto Formation consists of moderately to highly permeable gravels, sands, and silts. The Riverbank Formation is distinguished from the Modesto Formation by interbedded clay layers. These formations contain fresh water (DWR, 2006a; Harwood and Helley, 1987).

Wells penetrating the sand and gravel units of the Riverbank and Modesto Formations produce up to about 1,000 gpm; however, the production varies depending on local formation thickness (DWR, 2006a). Wells screened in the Riverbank and Modesto Formations are generally domestic and shallow irrigation wells (DWR, 2006a).

Corning Subbasin Groundwater Sustainability Plan



Prepared by:

MONTGOMERY & ASSOCIATES
Water Resource Consultants

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Hydrolytics

KEARNS & WEST

CBI
CATALYZING COLLABORATION

WestWater Research LLC

3.1.5 Geologic Formations and Stratigraphy

Subbasin stratigraphy is marked by distinct depositional environments producing a diverse sequence of geologic formations including those of marine and continental origin. Marine formations were deposited early in the Subbasin's history, from the Jurassic through the Miocene. During this period, the majority of northern Sacramento Valley was a marine basin formed via action of the Pacific-North American plate subduction zone. Continental sedimentary formations and volcanic formations were deposited from the Pliocene onward, as uplift of the Coast Ranges created the Sacramento Valley as it stands today.

The following formations and units are present in the Corning Subbasin:

- Quaternary Alluvium (Qa)
- Tehama Formation (Tte)
- Tuscan Formation (Tt)
- Upper Princeton Valley Fill (Upvf)
- Lower Princeton Valley Fill (Lpvf)
- Great Valley Sequence (JKgvs)

Two other formations, the Lovejoy Basalt and the Ione Formation, have minor presence in the Subbasin at depth. Due to their limited presence, they are not discussed in detail in this section.

Figure 3-6 illustrates the Subbasin's surficial geology. Quaternary formations and deposits are displayed individually to detail surficial geology, though cross sections displayed in Section 3.1.6.3 group these as (Qa) for simplicity. Quaternary formations were similarly grouped in the Glenn-Colusa HCM, which covers the southern portion of Corning Subbasin in Glenn County (Davids Engineering and West Yost, 2018). Geologic formations present in the Subbasin area are presented stratigraphically on Figure 3-7 including age of deposition, lithology, and approximate maximum thickness in the Subbasin.

Hydrogeologic properties of freshwater-bearing units, as estimated through a variety of aquifer tests and hydrogeologic modeling are summarized in Table 3-1. The Quaternary Alluvium aquifer layers storage parameter is specific yield as this aquifer is primarily unconfined and the deeper aquifers, such as the Tehama and Tuscan aquifers, have storativity values as they are confined. This table shows that hydrogeologic parameter information is missing for several hydrogeologic units, and where available, data from different sources are not consistent. This points to a data gap that could be resolved during GSP implementation. Brief definitions of the aquifer parameter terminology used in this section are presented in the sections below.

Hydraulic Conductivity: Property of geologic materials that moderates the speed of groundwater flow. Higher hydraulic conductivity allows water to travel faster through media. Units with very low hydraulic conductivity slow or may prevent groundwater flow. Usually presented as [length/time].

Transmissivity: The hydraulic conductivity of an aquifer unit multiplied by its total thickness. High transmissivity may reflect units very conductive to groundwater flow, very thick units, or both. Usually presented as [length^2/time] or occasionally as [volume/length/time].

Storativity: The volume of water (i.e., cubic feet) released from a square unit of geologic material (i.e., square foot), given a unit decline in groundwater (i.e., foot). Storativity is applied to aquifers under local or regional confinement and is roughly equivalent to specific yield in an unconfined aquifer. High storativity suggests a productive aquifer unit. Storativity is a volumetric ratio and therefore unitless.

Specific Yield: The amount of water released from a cubic unit of geologic material if allowed to drain completely under force of gravity. Specific yield is used to characterize unconfined aquifers; high specific yield indicates a productive aquifer unit. Specific yield is a volumetric ratio and therefore unitless.

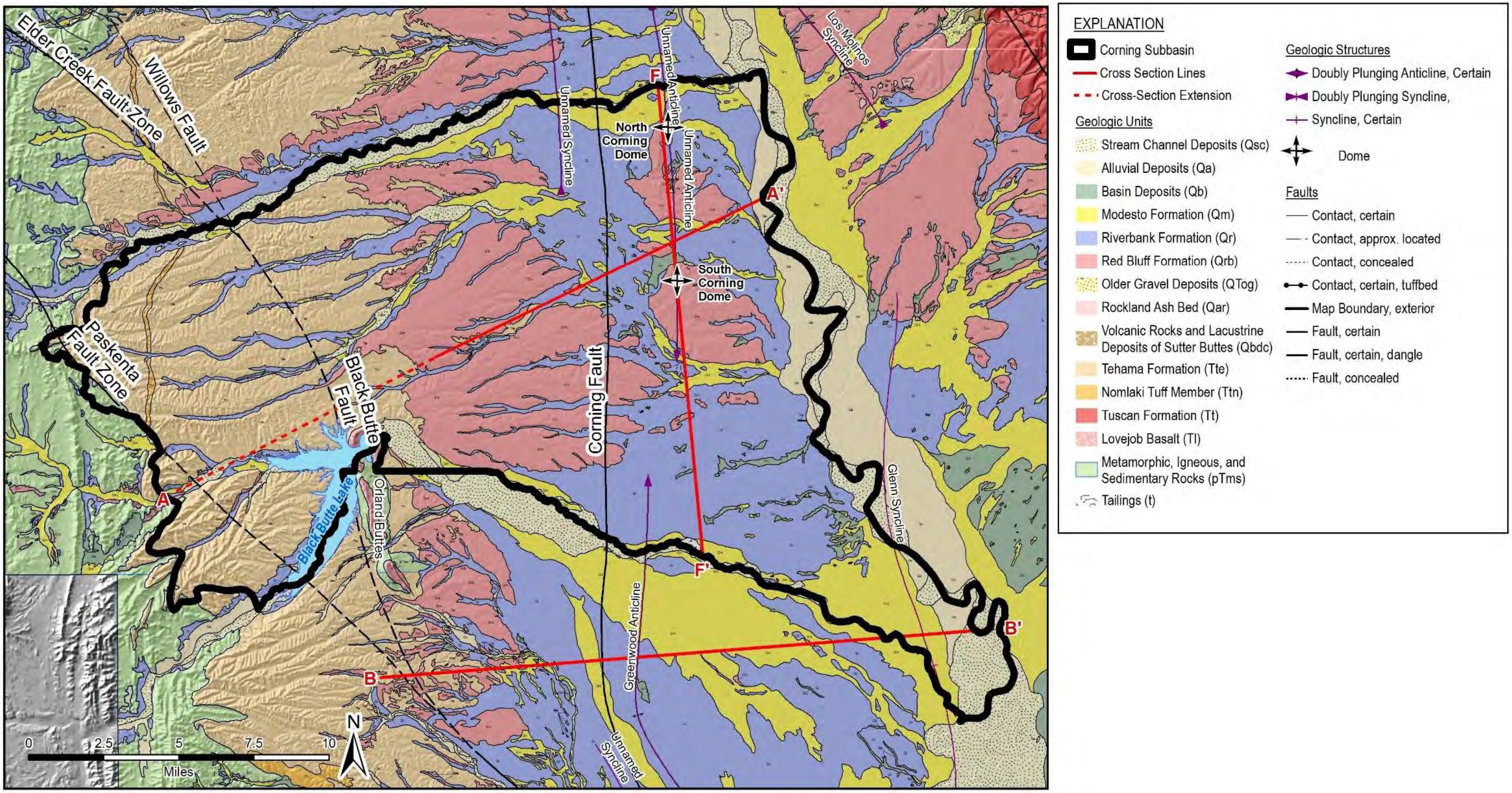


Figure 3-6. Surface Geology

Era	Period	Series	Geologic Formation		Lithology	Approximate Thickness in Subbasin (feet)
Cenozoic	Quaternary	Holocene	Alluvial Deposits and Stream Channel Deposits (Qa/Qsc)		Unconsolidated gravel, sand, silt, and clay	< 80
Cenozoic	Quaternary	Holocene	Basin Deposits (Qb)		Unconsolidated fine-grained silts and clays	< 150
Cenozoic	Quaternary	Pleistocene	Modesto Formation (Qm)		Poorly sorted unconsolidated gravel, sand, silt, and clay.	10-200
Cenozoic	Quaternary	Pleistocene	Riverbank Formation (Qr)		Poorly sorted, unconsolidated to semi-consolidated pebble and small cobble gravels inter-lensed with clay, silt, and sand.	1- 200
Cenozoic	Quaternary	Pleistocene	Red Bluff Formation (Qrb)		Highly weathered sandy gravels	< 33
Cenozoic	Quaternary / Tertiary	Pleistocene / Pliocene	Tehama Formation (Tte)*		Fluviatile moderately consolidated pale green, gray, and tan sandstone and siltstone containing lenses of sand and gravel, silt and gravel, and cemented conglomerate	< 2,000
Cenozoic	Tertiary	Pliocene	Tuscan Formation (Tt)*	Tuscan C (Ttc)	Low permeability lahars	< 300
Cenozoic	Tertiary	Pliocene	Tuscan Formation (Tt)*	Tuscan B (Ttb)	Volcanic conglomerate, sandstone, siltstone, and interbedded lahars overlain by tuffacous breccias, sandstone, and conglomerate	< 700
Cenozoic	Tertiary	Pliocene	Tuscan Formation (Tt)*	Tuscan A (Tta)		
Cenozoic	Tertiary	Miocene	Upper Princeton Valley Fill (UPvf)		Non-marine sandstone containing mudstone, conglomerate, and sandstone interbeds.	< 1,400
Cenozoic	Tertiary	Eocene	Lower Princeton Submarine Valley Fill (LPvf)		Marine conglomerate and sandstone interbedded wih silty shale	< 1,500
Mesozoic	Cretaceous		Great Valley Sequence (Jkgvs)		Marine siltstone, shale, sandstone, and conglomerate	< 45,000

** Tt and Tte were deposited concurrently during the late Pliocene and Pliestocene*

Low Permeability Unit

Unconformity

Freshwater Aquifer

Brackish Aquifer

Saline Aquifer

Figure 3-7. Geologic Formations Stratigraphic Column

Table 3-1. Freshwater Aquifer Hydrogeologic Properties

<table>
<tr><th colspan="2">Principal Hydrogeologic Unit</th><th>Data Sources</th><th>Horizontal Hydraulic Conductivity (ft/day)</th><th>Vertical Hydraulic Conductivity (ft/day)</th><th>Transmissivity (ft²/day)</th><th>Storativity</th><th>Specific Yield</th></tr>
<tr><td colspan="2" rowspan="2">Quaternary Alluvium (Qa)</td><td>Olmsted and Davis, 1961[1]</td><td>---</td><td>---</td><td>---</td><td>---</td><td>0.034 – 0.185</td></tr>
<tr><td>WRIME, 2003[2]</td><td>10 – 299</td><td>---</td><td>---</td><td>---</td><td>---</td></tr>
<tr><td colspan="2">Tehama Formation (Tte)</td><td>West Yost, 2012[3]</td><td>26.6</td><td>---</td><td>2,466 – 4,727</td><td>0.0003 – 0.001</td><td>---</td></tr>
<tr><td rowspan="6">Tuscan Formation (Tt)</td><td rowspan="2">Tuscan C (Ttc)</td><td>Brown and Caldwell, 2013b[3]</td><td>321 – 571</td><td>---</td><td>11,550 – 20,540</td><td>0.0003 – 0.0005</td><td>---</td></tr>
<tr><td>West Yost, 2012[3]</td><td>---</td><td>0.0036</td><td>---</td><td>---</td><td>---</td></tr>
<tr><td rowspan="2">Tuscan B (Ttb)</td><td>Brown and Caldwell, 2013b[3]</td><td>66 – 88</td><td>---</td><td>2,322 – 3,078</td><td>0.00004 – 0.00009</td><td>---</td></tr>
<tr><td>West Yost, 2012[3]</td><td>11.4 – 13.2</td><td>---</td><td>2,705 – 8,902</td><td>0.0009 – 0.003</td><td>---</td></tr>
<tr><td rowspan="2">Tuscan A (Tta)</td><td>Brown and Caldwell, 2013b[3]</td><td>41 - 79</td><td>---</td><td>12,230 – 23,650</td><td>0.00004 – 0.001</td><td>---</td></tr>
<tr><td>West Yost, 2012[3]</td><td>11.4 – 13.2</td><td>---</td><td>2,705 – 8, 902</td><td>0.0009 – 0.003</td><td>---</td></tr>
</table>

1- Data from geologic sample analysis 2- Modeled data 3- Data from aquifer pump test analysis.

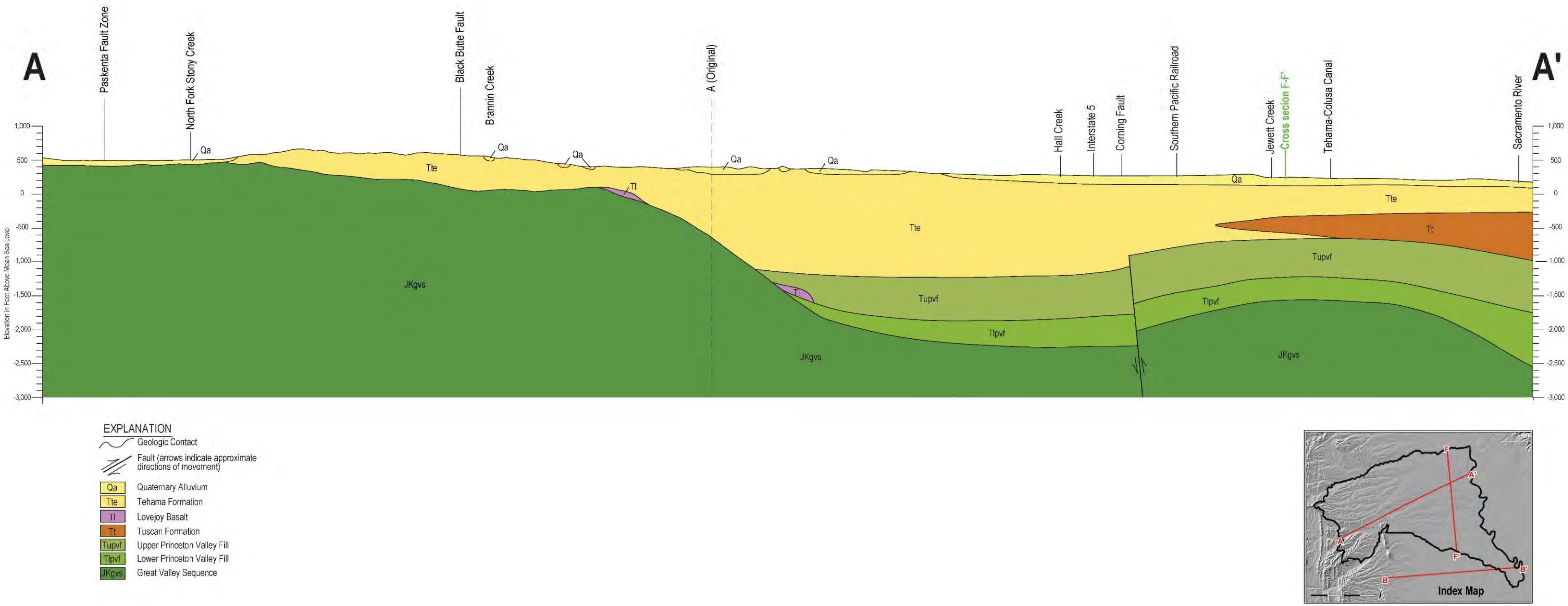
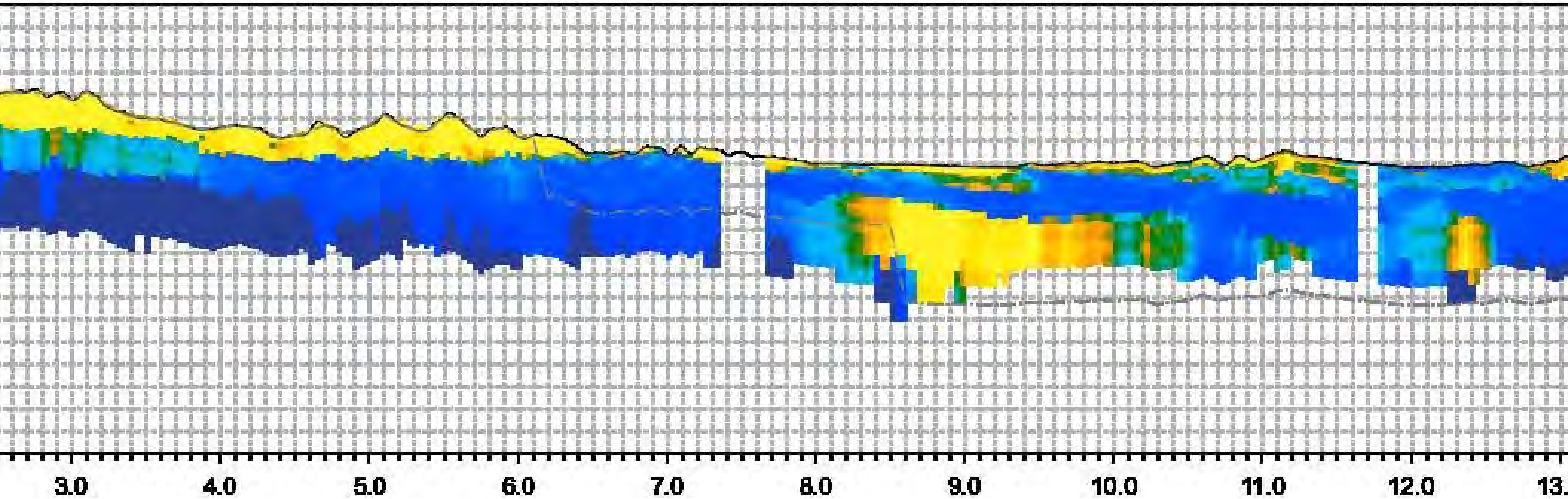
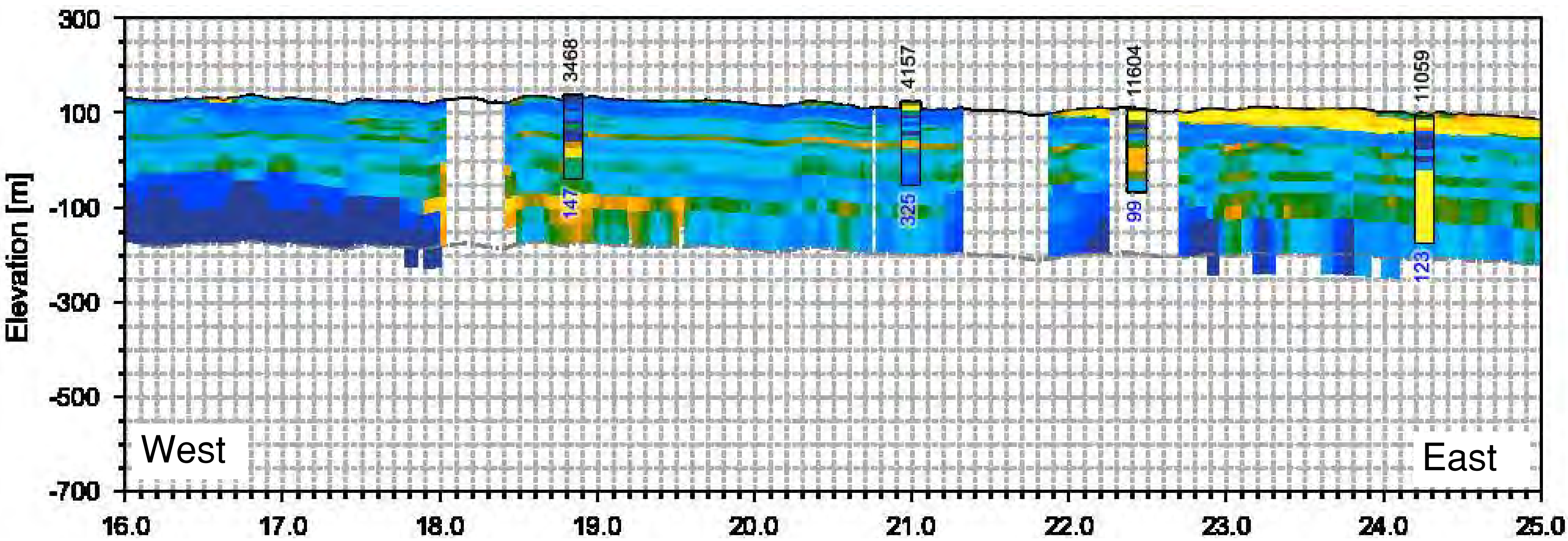


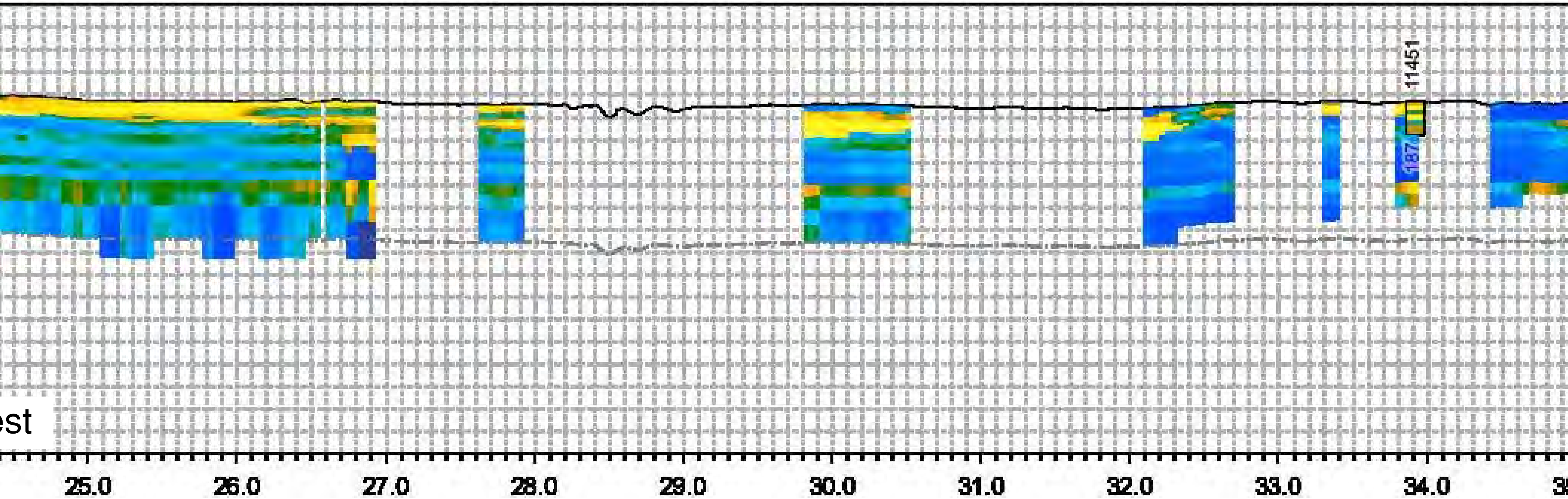
Figure 3-9. Cross Section A-A' [Adapted from DWR, 2014]

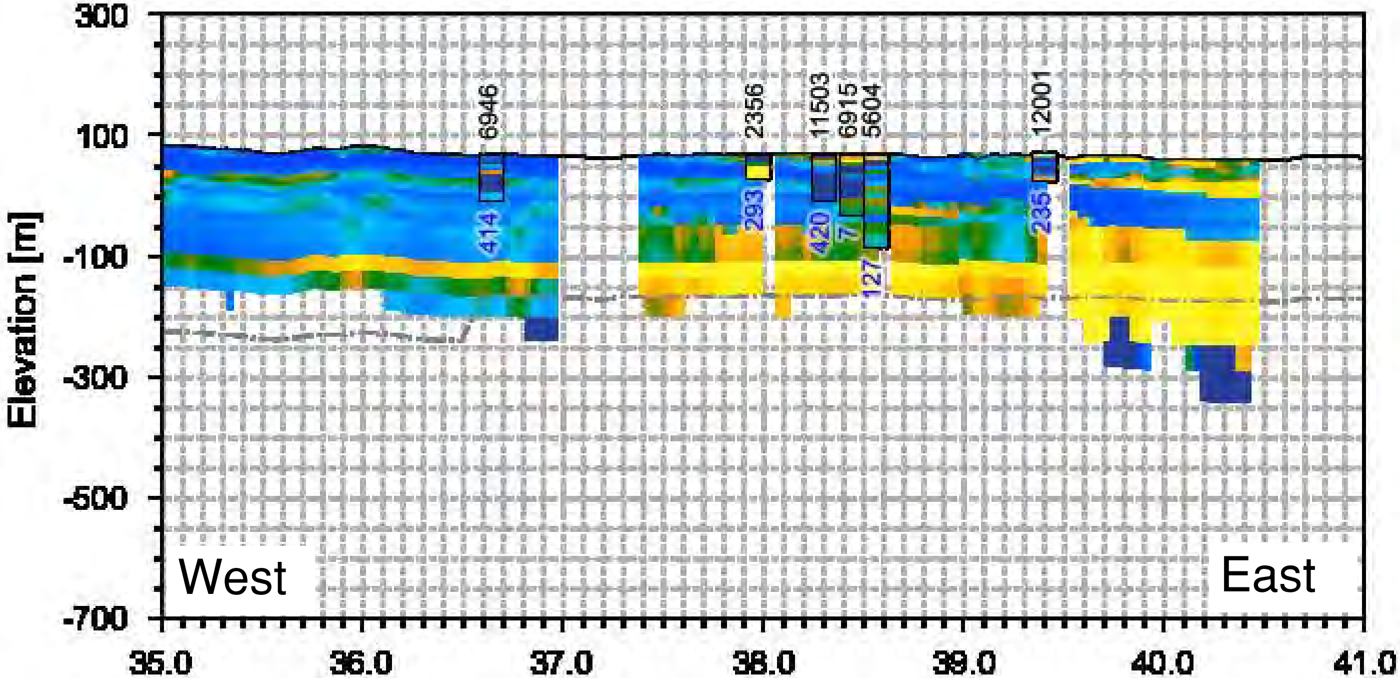
A - A' Nearest AEM Log





A - A' Nearest AEM Log





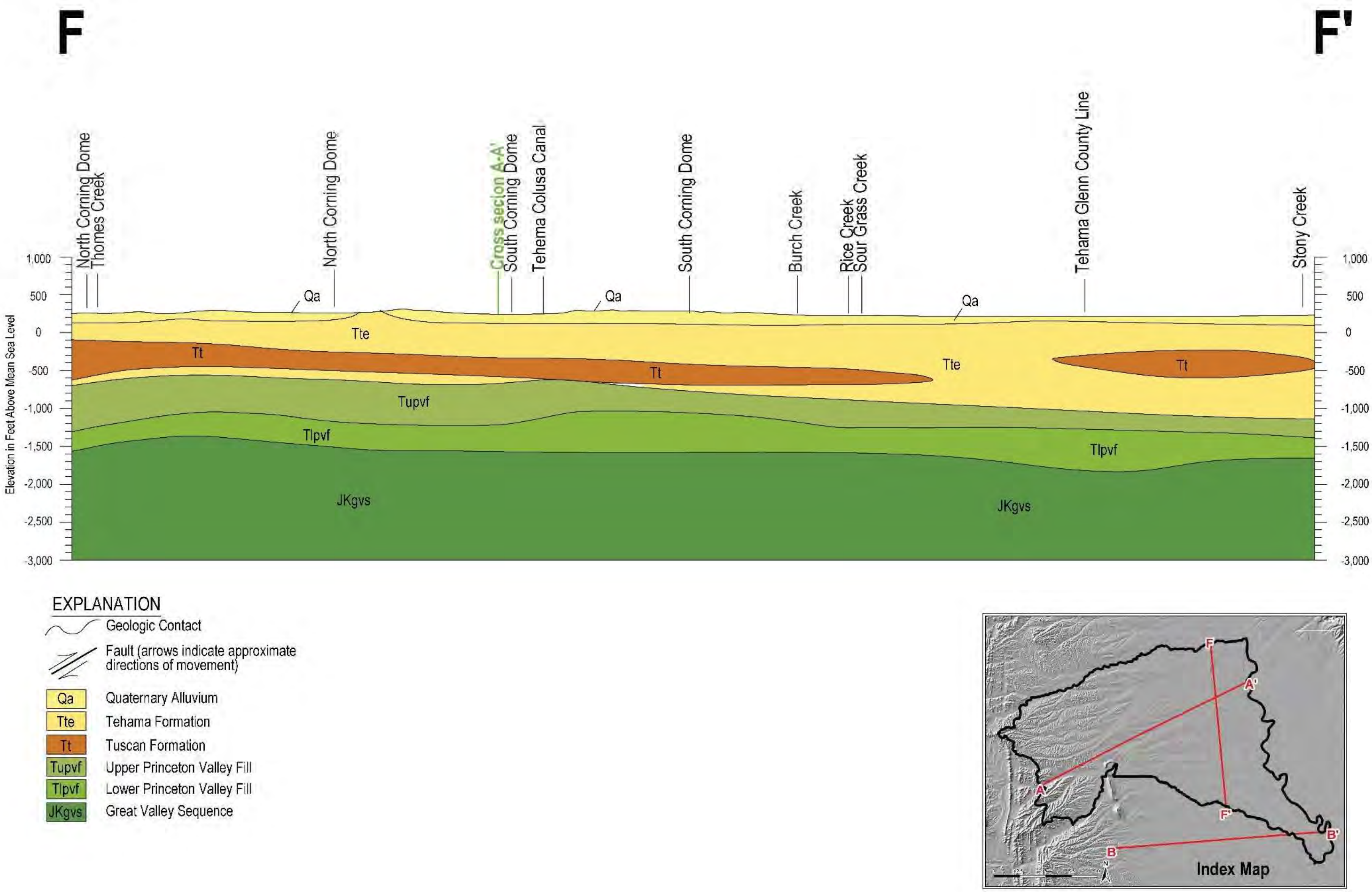
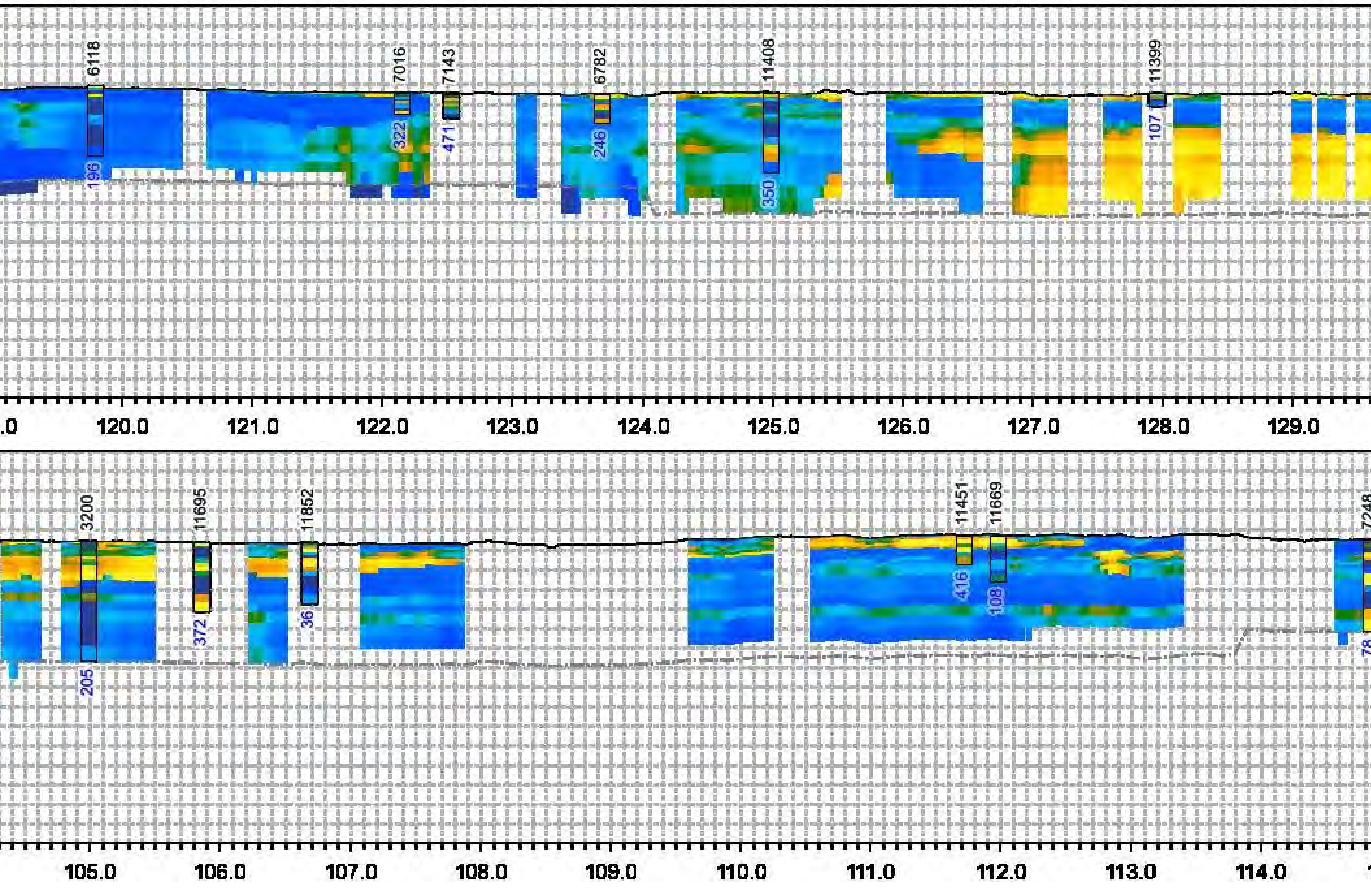


Figure 3-10. Cross Section F-F' [Adapted from DWR, 2014]

F - F' Nearest AEM Log



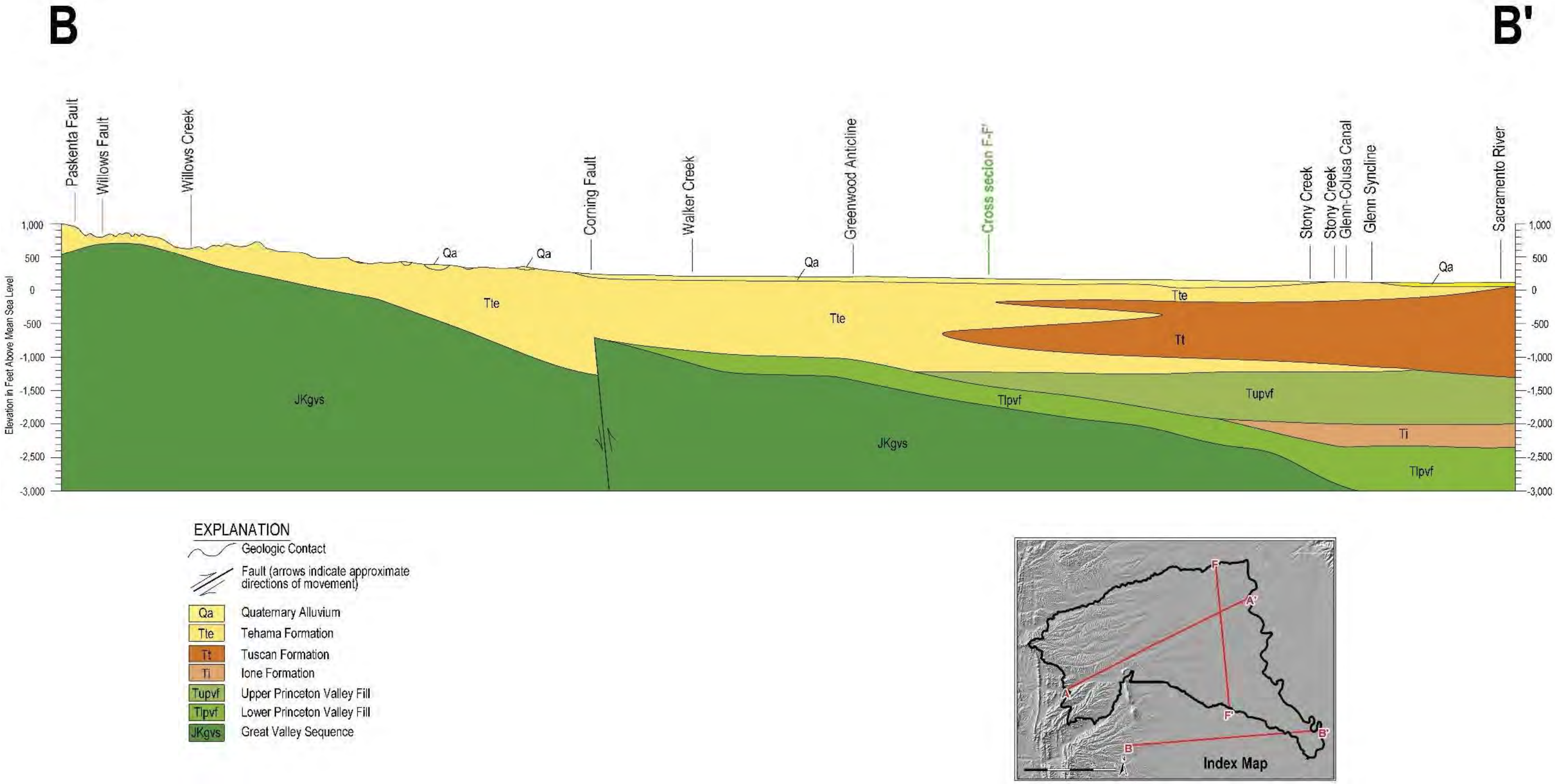
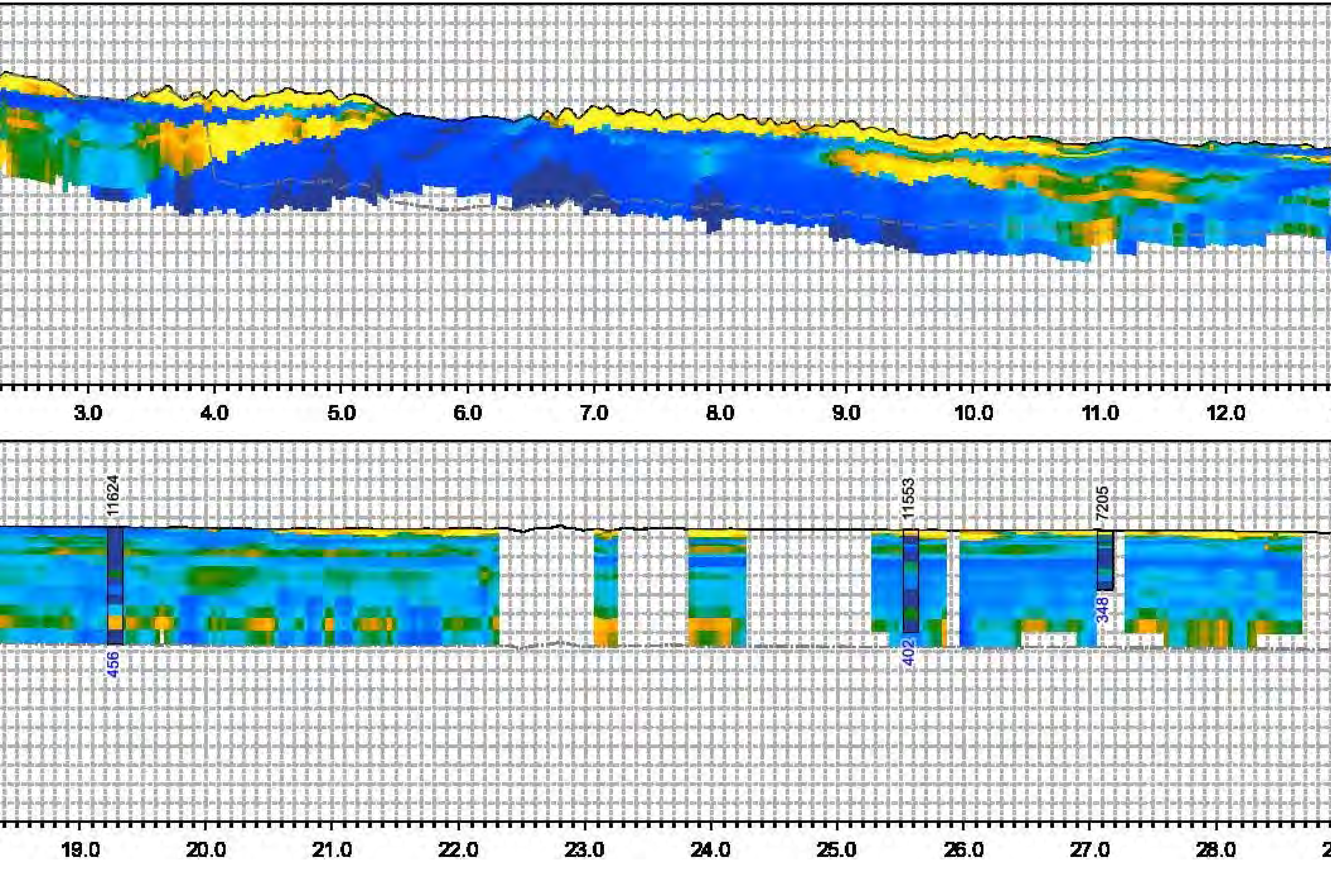
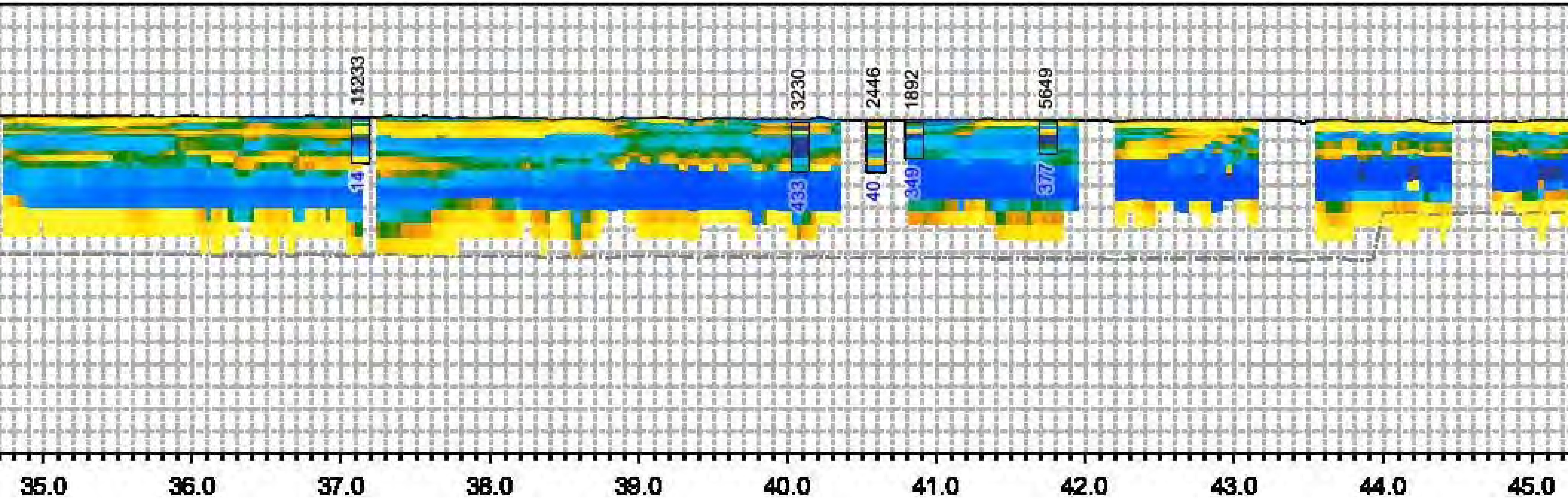


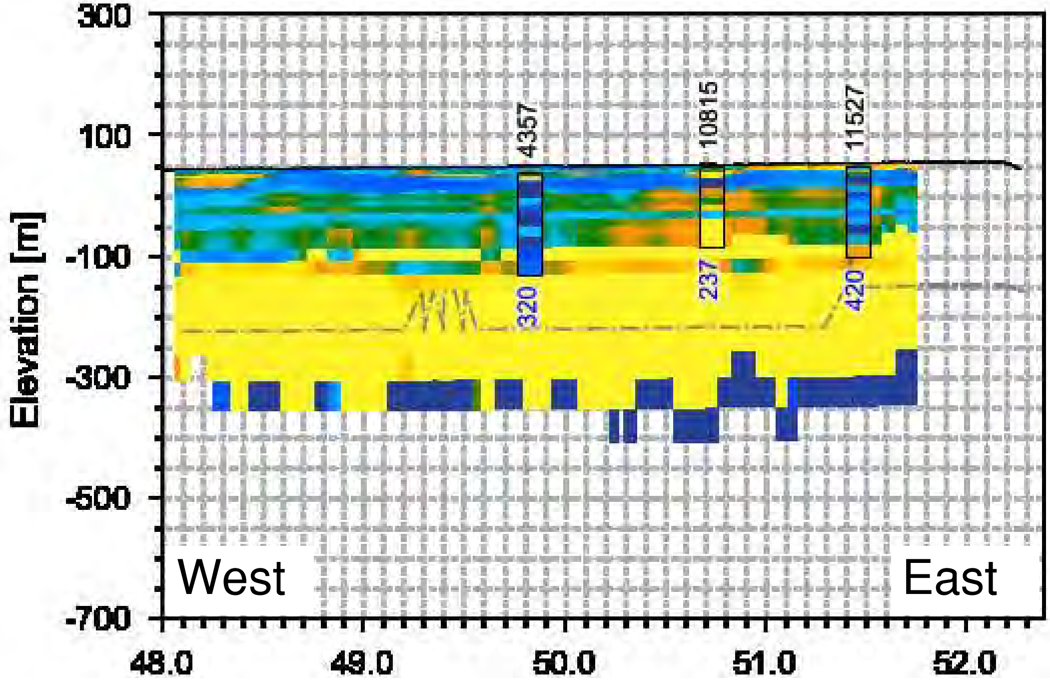
Figure 3-11. Cross Section B-B' [Adapted from DWR, 2014]

B - B' Nearest AEM Log



B - B' Nearest AEM Log





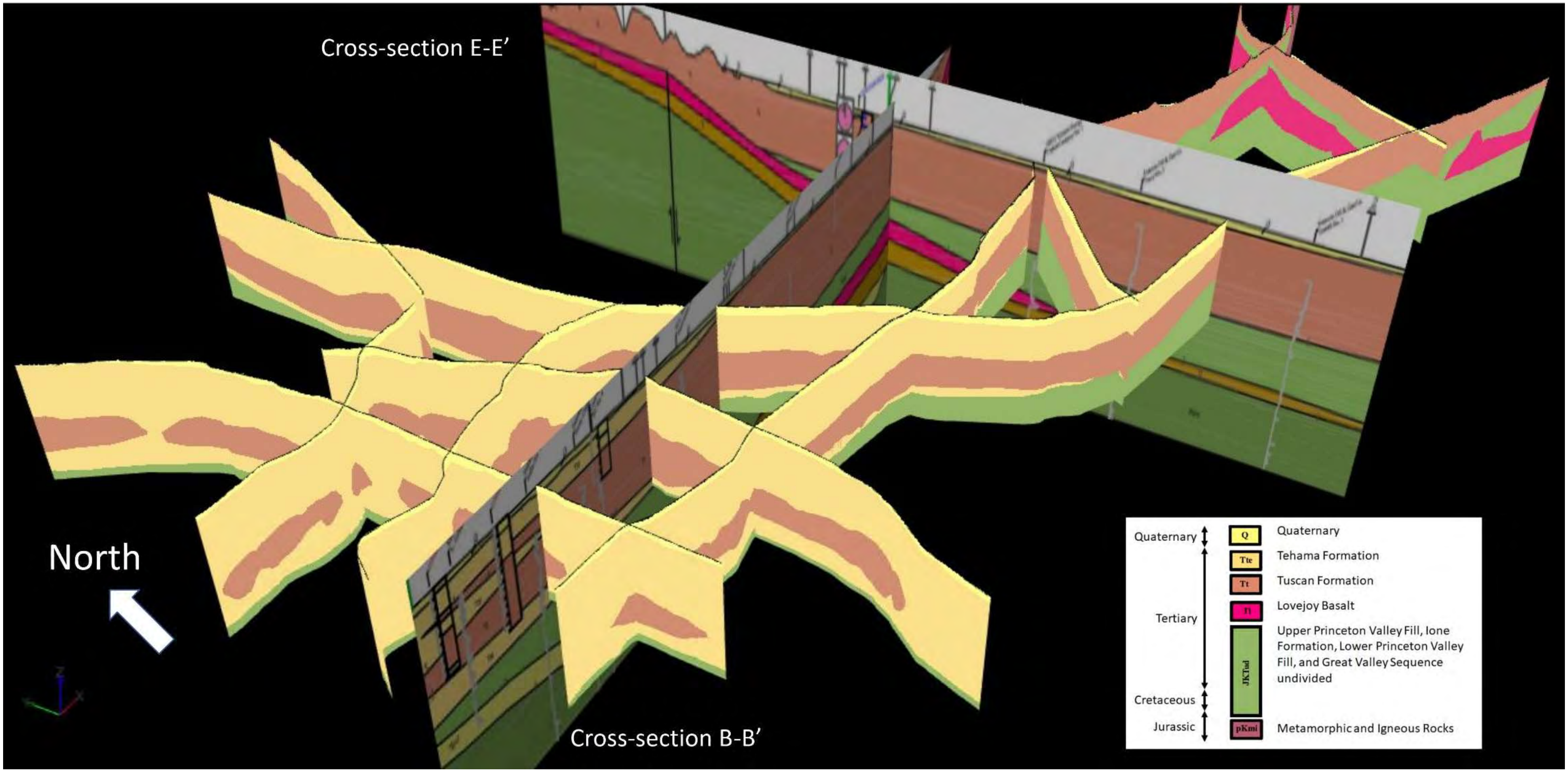
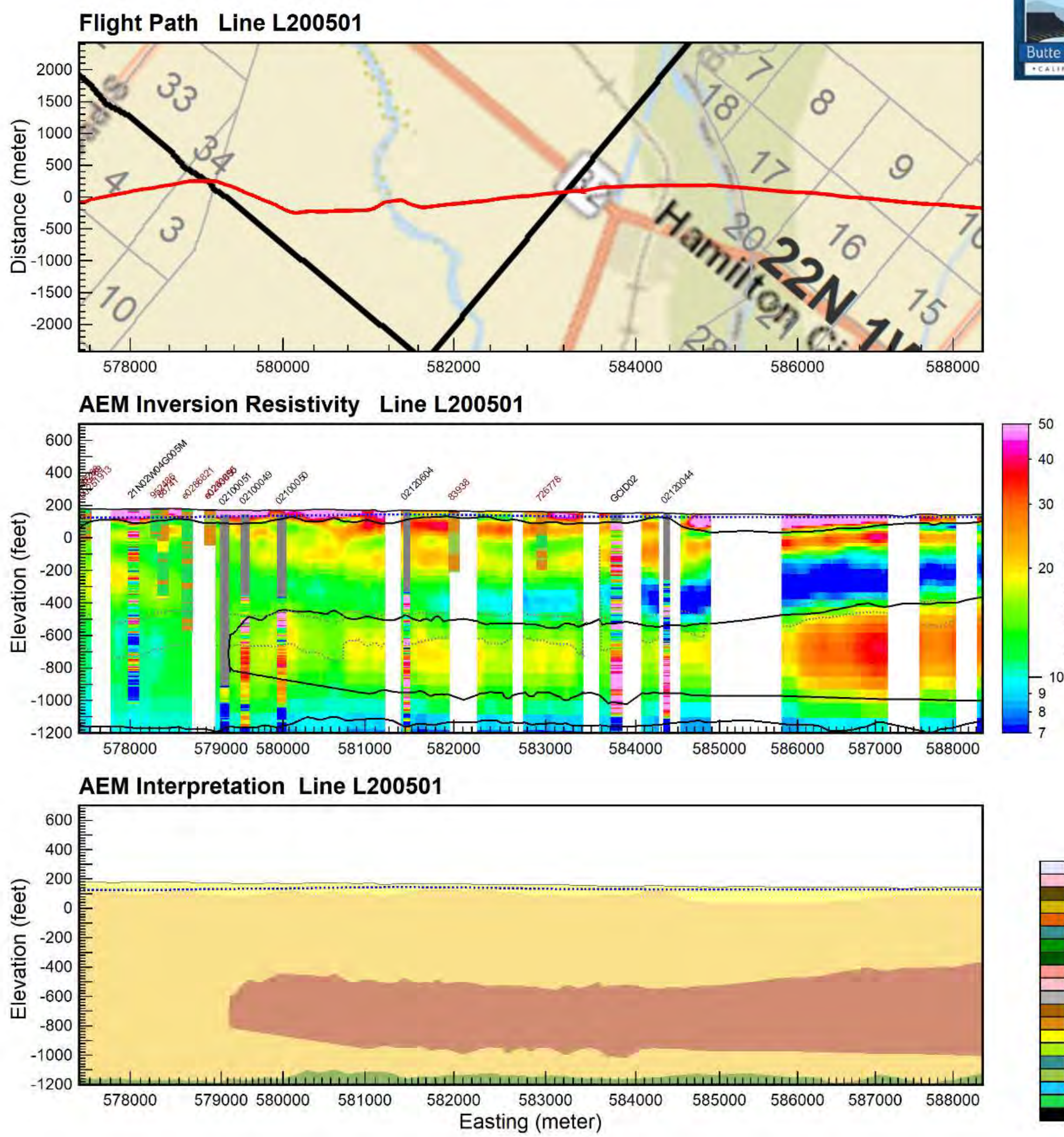
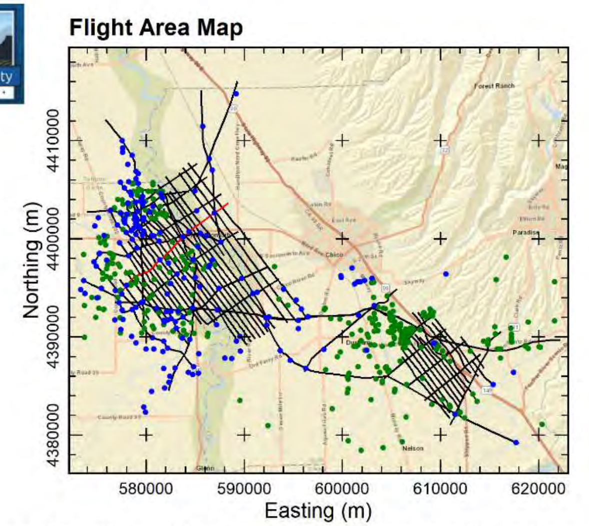


Figure 3-12. AEM Interpretation with DWR Cross Sections [AGF, 2019]





Results of the final inversion of Airborne Electromagnetic (AEM) data collected along flight lines within Butte and Glenn Counties November 30 to December 3, 2018. The red line on the Flight Path Map and the Flight Area map indicates the location of the current displayed profile. The Flight Area Map indicates the flight lines flown. The blue dots are the lithology logs and the green dots are the geophysical logs provided by Dr. Todd Greene, Associate Professor of Geological and Environmental Sciences at California State University, Chico on Oct 18 – Nov 2, 2018.
The AEM inversion profiles shown are Spatially-Constrained using the Aarhus Geo Software Workbench, version 5.8.3 with the indicated electrical resistivity color scale. Boreholes displayed on the AEM inversion profile are within 500 meters of the flight line. Lithology (maroon labels) is indicated by the legend and the geophysical logs (black labels) are at the same scale as the AEM inversions. Gray-dashed lines, when visible, on the AEM inversion profiles indicate the estimated depth of investigation (DOI). White gaps in the AEM inversion profile indicate gaps in data coverage due to electromagnetic coupling and areas that were not flown due to infrastructure. The solid-black lines on the AEM inversion profile indicate the interpreted stratigraphic contacts of the Q=Quaternary, Tte=Tertiary Tehama FM; Tt= Tertiary Tuscan FM, Tl=Tertiary Lovejoy Basalt. The Tertiary Upper Princeton Valley Fill (Tupvf), the Tertiary Ione FM (Ti), and the Jurassic/Cretaceous Great Valley Sequence (JKgvs) are grouped together and undifferentiated. pKmi = The Pre-Cretaceous metamorphic and igneous rocks. The CA-DWR Fall 2017 water table is represented by a dashed blue line.
The AEM interpretation profiles shows the stratigraphic units as indicated in the legend.
Prepared for the Butte County and Stanford University by Aqua Geo Frameworks., LLC.

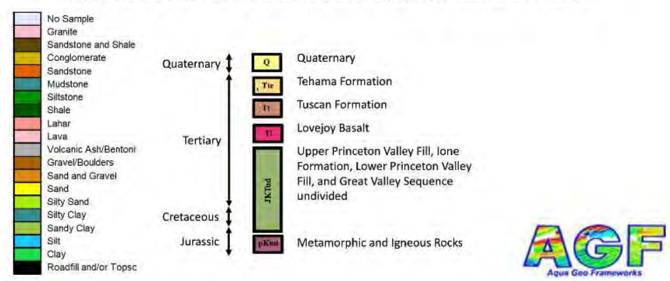


Figure 3-13. East-West AEM Cross Section in Eastern Corning Subbasin near Hamilton City

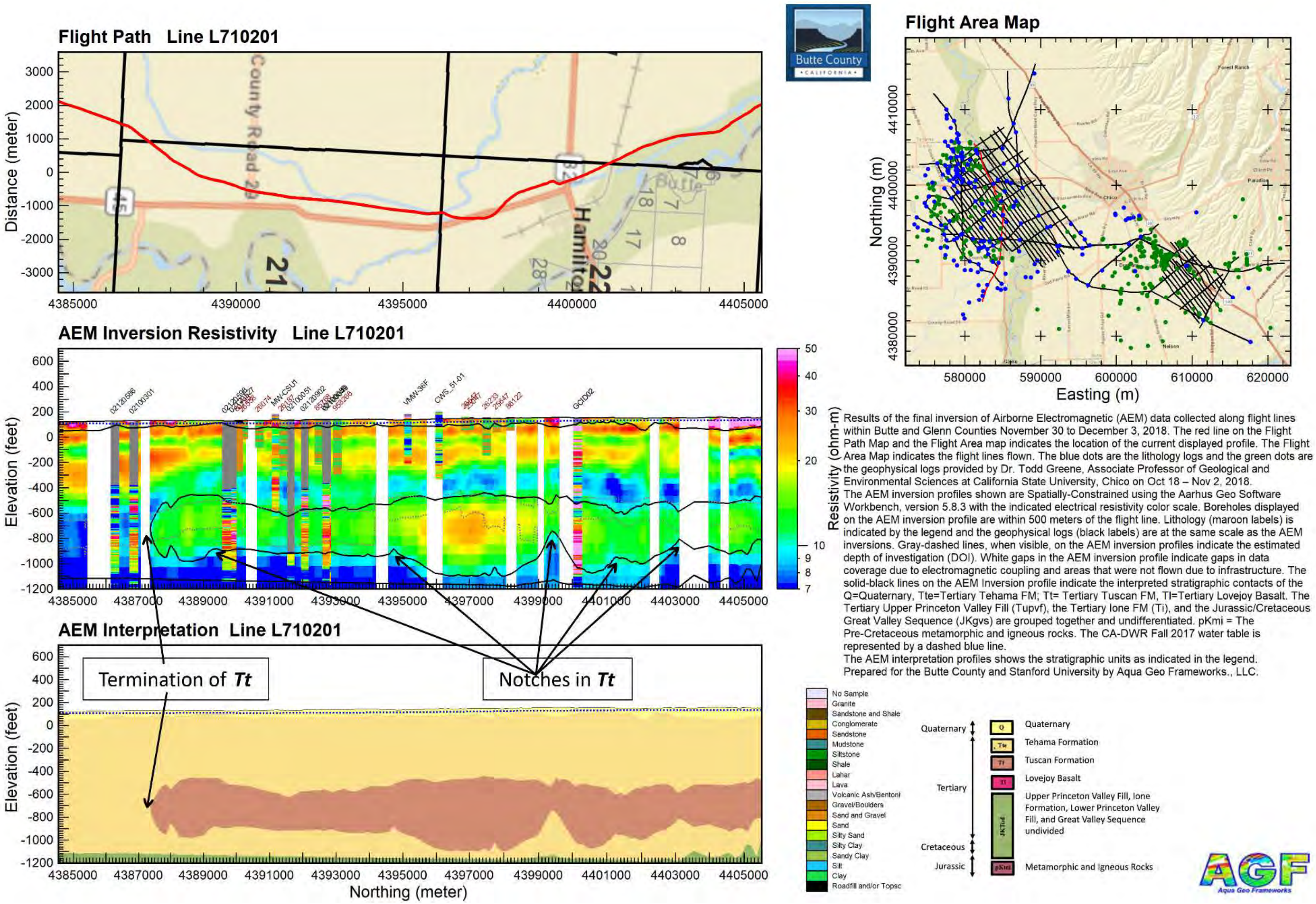


Figure 3-14. North-South AEM Cross Section in Eastern Corning Subbasin near Hamilton City

3.1.7 Designation of Principal Aquifer in Corning Subbasin

This section defines and describes the Subbasin's principal aquifer as defined by the GSP regulations [§ 351.aa]: *"principal aquifers refer to aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems."*

Aquifers are separated by continuous impervious layers (aquitards) that impede or slow flow between different main aquifers (as an example, the Corcoran Clay layer in the San Joaquin Valley constitutes such an aquitard).

The Subbasin's largest freshwater bearing formations were deposited contemporaneously, creating expansive zones of interlayering formations as discussed in Section 3.1.5. These were then overlain by conductive quaternary alluvial formations, which are unlikely to create boundaries to flow (DWR, 2014). Interlayering of these formations may facilitate groundwater flow between units by increasing the surface area at which units are in contact (DWR, 2009). Interlayering also increases the likelihood that wells are screened in multiple units, further facilitating vertical groundwater transmission. While some areas may experience localized differences in geology and groundwater flow patterns, the Subbasin does not contain expansive contiguous impervious aquitards that may cause regional differences in flow patterns and water quality.

This depositional history results in a hydrogeologically interconnected aquifer system where impacts to one unit have the potential to impact the larger aquifer network. Further, in this Subbasin, no regionally continuous impervious layers are found, wells are often screened within several geologic units, and water flows mostly freely between vertical aquifer units. As such, the Subbasin is best described as having one principal aquifer comprised of the interlayered freshwater bearing formations within the Subbasin. These are:

- Quaternary Alluvium,
- The Tuscan Formation, and
- The Tehama Formation.

This determination is based on the best available information at the time of GSP development. There is potential for data refinement and/or collection of additional information during GSP implementation to either more fully support or refine aquifer designation.

The hydrogeological properties, stratigraphic occurrence, and groundwater extraction patterns of these formations are described in detail in Section 3.1.5.

Groundwater quality in the Corning Subbasin principal aquifer is predominantly of a calcium-magnesium bicarbonate or magnesium-calcium bicarbonate type. There are also some localized areas of calcium bicarbonate groundwater near Stony Creek (DWR, 2006a). Overall, the Corning Subbasin contains groundwater that generally meets or exceeds primary and secondary water quality standards. Similarly, anthropogenic contamination of groundwater is not extensive in the Subbasin. However, there are some known areas of naturally occurring and non-point source groundwater quality constituents, including nitrate and salinity. Specific groundwater quality constituents of concern (COCs) are described in more detail in Section 3.2 of the groundwater conditions.

As further described in the Plan Area Section, beneficial uses of groundwater in the Corning Subbasin include agricultural (primary use), industrial (minor use), municipal (only two main areas), tribal use (one main area) and domestic use (widespread over the entire Subbasin). Groundwater also supports designated wildlife and habitat protection areas. Groundwater dependent ecosystems near the Sacramento River and other larger creeks are present in the Subbasin and are further described in the Groundwater Conditions Section.

Enterprise Subbasin Groundwater Sustainability Plan

Draft

January 2022

Enterprise Anderson Groundwater Sustainability Agency

3.1.6 Local Hydrogeology

3.1.6.1 Lateral Basin Boundary

The RAGB is bounded by the foothills of the Cascade Range to the east, the Klamath Mountains to the north and northwest, the Coast Range to the west, and the Red Bluff Arch to the south (Pierce, 1983). Unlike the RAGB, the Enterprise Subbasin is not bounded by structural features, but rather by hydrologic features. The Enterprise Subbasin is bounded by Little Cow Creek and Cow Creek to the east, and by the Sacramento River to both the west and south. Because the lateral subbasin boundaries are defined by surface streams, there is likely hydraulic communication between adjacent subbasins. That is, there may be groundwater underflow into Enterprise Subbasin from adjacent subbasins and from the Enterprise Subbasin into adjacent subbasins.

3.1.6.2 Definable Bottom of Basin

The base of fresh water defines the bottom of the basin. In the RAGB, this is the top of the Chico Formation (Figure 3-9). Although water-bearing formations exist below this depth, the saline nature of the groundwater and the depth to formation prevent the Chico Formation from being a viable aquifer. The top of the Chico Formation in the Enterprise Subbasin ranges from a depth of less than 100 feet in the north to a depth of greater than 1,000 feet in the south (DWR, 1968).

3.1.6.3 Principle Aquifers and Aquitards

Major water supplies in the Enterprise Subbasin, and in the greater RAGB, are stored in surface reservoirs; and as a result, the communities in the region are less dependent on groundwater. This may contribute to the fact that groundwater elevations in the RAGB do not show evidence of continuous decline (as will be discussed further in subsequent sections). Depths to groundwater are shallowest near the Sacramento River and Cow Creek, and are generally within a few feet of land surface. In the more central portions of Enterprise Subbasin, depths to groundwater range between 100 to 150 feet and approach depths of nearly 200 feet in a few streams water bodies. Shallow, alluvial deposits have moderate to high permeabilities in the subbasin, but deposits are not significant sources for groundwater use in the subbasin because of the limited lateral and vertical extents. The Red Bluff Formation is generally present above the regional water table; however, local perched zones may yield small quantities of water to domestic wells (DWR, 1968, Pierce, 1983). The principle water-bearing formations in the Enterprise Subbasin, the Tuscan and Tehama Formations, together function as one large, leaky unconfined aquifer with increasing degrees of confinement with depth. Groundwater use of the principle aquifer is for urban, industrial, and agricultural purposes, and is described in greater detail in Chapter 2. Due to the reliability of surface-water storage and the readily available groundwater supply within the Tuscan and Tehama aquifers, few resources have been dedicated to describing other aquifers within the RAGB. As shown on Figures 3-7 and 3-8, although laterally discontinuous fine-grained lenses/beds are present within the subbasin, there is no regional aquitard.

3.1.6.4 Aquifer Properties

Aquifer systems function as a combination of subsurface reservoirs for storage of groundwater and conduits for the transmission of groundwater. The following sections describe the aquifer system properties in the Enterprise Subbasin. The magnitude and distribution of hydrogeologic properties of the principal aquifers in the subbasin have not been well characterized or documented. The scarcity of available quantitative estimates of the aquifer properties of the subbasin's principal aquifers results in uncertainties that will be further refined during implementation of this GSP. This will be accomplished through evaluation of hydraulic data collected during development of new monitoring wells and through calibration of the numerical model being developed as part of this GSP.

Transmissivity and Hydraulic Conductivity

There are two general terms that are used to describe the capacity of an aquifer to transmit water, hydraulic conductivity and transmissivity. Hydraulic conductivity is defined as the coefficient of proportionality describing the rate at which a fluid can move through a permeable medium and is dependent on the fluid density and fluid viscosity and the intrinsic permeability. Transmissivity is defined as the capacity of an aquifer to transmit groundwater through a unit width of the aquifer under a unit hydraulic gradient. Transmissivity is equal to the product of the hydraulic conductivity (which is reported in units of feet per day [ft/day]) and saturated thickness, and is generally reported in units of gallons per day per foot or square feet per day (ft^2/day).

A number of the well completion logs filed with DWR include information that can be used to estimate the specific capacity of the associated well, which can then be used to approximate the transmissivity (CNRA, 2020). In general, estimated transmissivity values are lower in the northern portion of the Enterprise Subbasin and increase to the south, where the thickness of unconsolidated deposits increases. Estimated transmissivities based on reported specific capacity values on well logs by well type are as follows for the Enterprise Subbasin:

- Domestic Wells (100 logs): 2 to 4,000 ft^2/day with a geometric mean of 210 ft^2/day
- Public Wells (4 logs): 120 to 13,750 ft^2/day with a geometric mean of 1,600 ft^2/day
- Industrial and Irrigation Wells (7 logs): 150 to 25,000 ft^2/day with a geometric mean of 1,000 ft^2/day
- Monitoring and Test Wells (6 logs): 35 to 1,600 ft^2/day with a geometric mean of 210 ft^2/day

Hydraulic conductivity was estimated from specific capacity data by dividing the estimated transmissivity by the well screen length, where available. Estimated hydraulic conductivity values for the Enterprise Subbasin are as follows:

- Domestic Wells (66 logs): 0.2 to 350 ft/day with a geometric mean of 9.5 ft/day
- Public Wells (3 logs): 8 to 230 ft/day with a geometric mean of 45 ft/day
- Industrial and Irrigation Wells (4 logs): 1.5 to 40 ft/day with a geometric mean of 9 ft/day
- Monitoring and Test Wells (6 logs): 0.2 to 160 ft/day with a geometric mean of 7 ft/day

Excluding lower yield wells (those with reported pumping rates less than 50 gpm) and relatively shallow wells (those with depths less than 150 feet below ground surface [bgs]), transmissivity ranges from 100 to 25,000 ft^2/day (hydraulic conductivity of 1.5 to 230 ft/day) with a geometric mean of 650 ft^2/day (hydraulic conductivity of 10 ft/day).

In addition to estimating transmissivity based on specific capacity measurements, aquifer properties have been estimated through the process of numerical model calibration, which is a process of adjusting model inputs (such as transmissivity) to achieve a reasonable match to field observations of interest. The most recent version of the Redding Basin Finite Element Model (REDFEM) included transmissivity estimates of less than 1,000 ft^2/day (hydraulic conductivity of 5 ft/day) in the northern portion of the subbasin to more than 200,000 ft^2/day (hydraulic conductivity of 300 ft/day) in the southern portion of the subbasin (CH2M HILL, 2011). These values represent the estimated transmissivity for the entire thickness of unconsolidated materials overlying the Chico Formation (see Figure 3-9) as opposed to aquifer thickness associated with a well screen (as is the case for specific capacity estimates). Estimates of transmissivity and hydraulic conductivity will be further refined in the numerical groundwater flow model being developed to support this GSP.

Storativity

Storativity (or storage coefficient) is the volume of water released from (or taken into) storage in the aquifer system per unit area per unit change in head (i.e., groundwater elevation). In general, unconfined aquifer systems have relatively higher storativity values (typically known as specific yield), whereas confined aquifer systems have lower storativity values. Point estimates of aquifer storage from hydraulic testing within the Enterprise Subbasin are currently unavailable. Values incorporated into REDFEM include a specific yield of 10 percent of the shallow aquifer and a specific storage of the deeper aquifer layers of 2×10^{-6} per foot. Storativity values are computed by multiplying the specific storage value by the aquifer thickness. The assumed resulting storativity values for the deeper model layers in REDFEM range from 1×10^{-4} to 4×10^{-3} (CH2M HILL, 2011). Similar to transmissivity, storage properties will be further refined in the numerical groundwater flow model that is being developed as part of this GSP.

3.1.6.5 Natural Recharge Areas

Recharge to the primary aquifer units (i.e., Tuscan and Tehama Formations) in the Enterprise Subbasin and the shallower, overlying water-bearing units occurs through a combination of the following (DWR, 1968; Pierce, 1983):

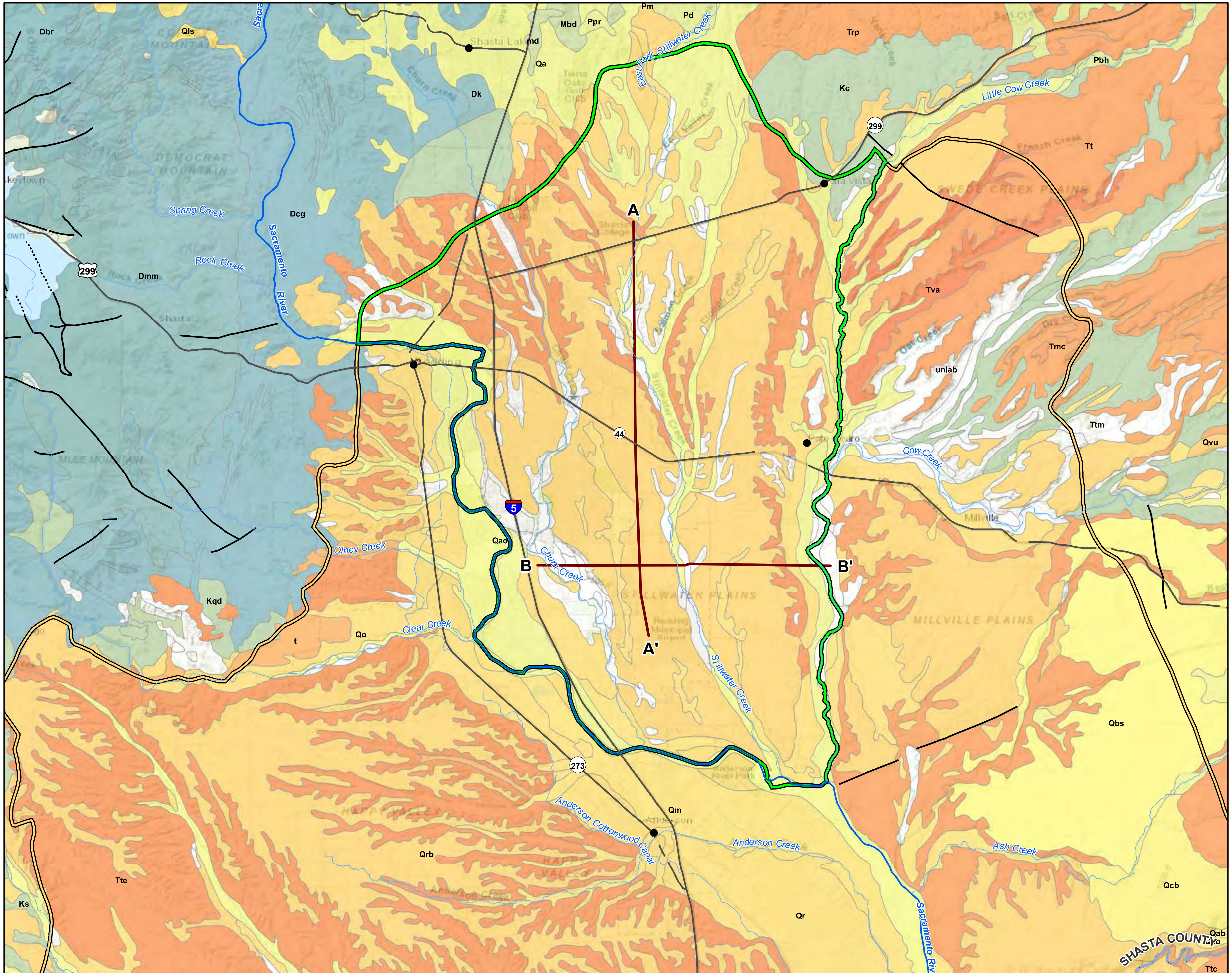
- Groundwater recharge from precipitation
- Groundwater recharge from applied water
- Groundwater recharge from streams and irrigation canals
- Subsurface inflow from adjacent subbasins

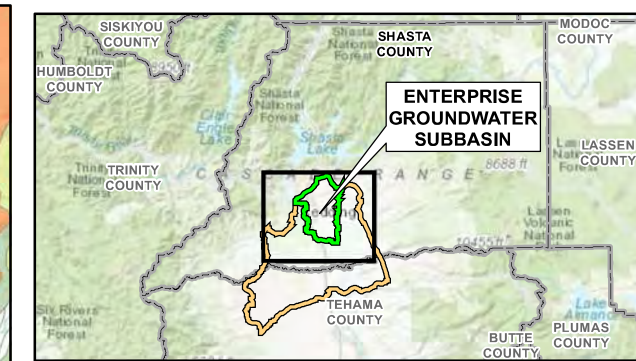
Recharge to aquifer systems is influenced by a number of parameters including (but not limited to) the following: surface soil infiltration capacity, land use/vegetative cover, topography, lithology, and the frequency, intensity, duration, and volume of precipitation. Figure 3-10 presents the distribution of the Soil Agricultural Groundwater Banking Index (SAGBI) for the Enterprise Subbasin. The SAGBI was developed by the University of California–Davis as part of a study of the potential to bank groundwater, while maintaining healthy crops as a drought management strategy (O'Geen et al., 2015). The SAGBI data presented on Figure 3-10 are based on the following factors: infiltration capacity of soils, the duration that the root zone would be anticipated to remain saturated, topography, potential for leaching of high-salinity soils to degrade groundwater quality, and the susceptibility of soils to compact and erode. As shown on Figure 3-10, the SAGBI indicates that much of the eastern (between Stillwater and Cow Creeks) and northern portions of the subbasin overlie areas with a poor potential for groundwater recharge while locations within and along stream channels represent areas of good to excellent potential for groundwater recharge. This distribution provides good guidance on where natural recharge to the groundwater system likely occurs. Quantitative estimates of natural and anthropogenic recharge are discussed further in Chapter 4 Water Budgets.

3.1.6.6 Natural Discharge Areas

Natural groundwater discharge areas within the Enterprise Subbasin include groundwater discharge to surface-water bodies (streams, ponds, wetlands), subsurface outflow to adjacent subbasins, and shallow groundwater ET by phreatophytes. Although groundwater discharge to streams has not been mapped, previous numerical modeling efforts indicate that the Sacramento River and at least the lower portions of primary tributaries are gaining streams. REDFEM output indicate that the Sacramento River gains approximately 700,000 acre-feet per year (on average) from groundwater as it flows through the RAGB. Updated estimates of the location and magnitude of natural groundwater discharge are discussed further in Chapter 4 Water Budgets.

Figure 3-11 presents the distribution of potential GDEs within the Enterprise Subbasin contained in the DWR Natural Communities (NC) dataset (DWR, 2020b). The NC dataset is the product of a collaborative effort between DWR, California Department of Fish and Wildlife, and The Nature Conservancy. These agencies compiled and screened information from 48 datasets (such as the National Hydrography Dataset, National Wetlands Inventory, Vegetation Classification and Mapping Program, and Classification





LEGEND

- CITY
- LOCATION OF CROSS SECTION
- FAULT LINE
- FAULT LINE (CONCEALED)
- SACRAMENTO RIVER
- RIVER/STREAM
- INTERSTATE/HIGHWAY
- COUNTY BOUNDARY LINE
- ENTERPRISE GROUNDWATER SUBSASIN (5-006.04, PLAN AREA)
- REDDING AREA GROUNDWATER BASIN

NOTES:

GEOLOGY DERIVED FROM THE DIGITAL GEOLOGIC MAP OF THE REDDING 1° X 2° DEGREE QUADRANGLE, SHASTA, TEHAMA, HUMBOLDT, AND TRINITY COUNTIES, CALIFORNIA (USGS, 2012). FIGURE 3-6b PRESENTS EXPLANATION OF MAP UNITS.

SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY

0 2 4 Miles

FIGURE 3-6a
ENTERPRISE SUBBASIN GEOLOGY
Enterprise Subbasin Groundwater Sustainability Plan

JACOBS

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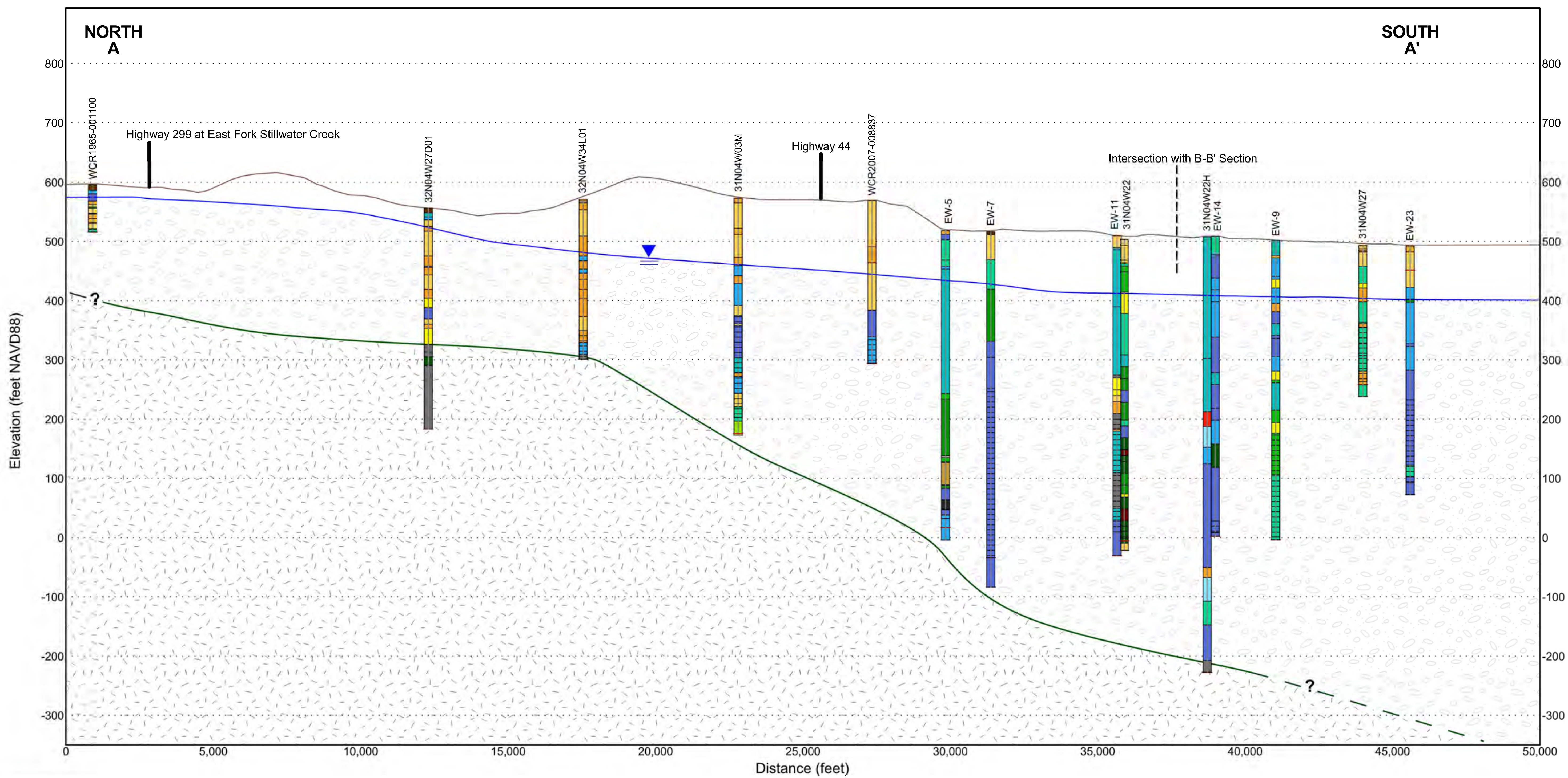


GROUND SURFACE ELEVATION (feet NAVD88)

TOP OF CHICO FORMATION (DASHED WHERE UNCERTAIN)

GROUNDWATER ELEVATION (feet NAVD88)

SCREEN INTERVAL

SCALE EXAGGERATION – 20:1 (H:V)

SOIL AND LITHOLOGY

SAND	GRAVEL	CLAY	BASALT
CLAYEY SAND	CLAYEY GRAVEL	SANDY CLAY	HARD PAN
GRAVELLEY SAND	SANDY GRAVEL	GRAVELLEY CLAY	SHALE
SILTY SAND	SILTY GRAVEL	SILT	UNDIFFERENTIATED ROCK
SANDSTONE	TUFF	SILTSTONE	UNDIFFERENTIATED SOIL

PRINCIPAL AQUIFER

BEDROCK

NOTES:

LOCATION OF CROSS SECTION SHOWN ON FIGURE 3-6.

GROUNDWATER ELEVATION IS ESTIMATED FROM GROUNDWATER LEVELS MEASURED BETWEEN OCTOBER 16 AND OCTOBER 26, 2018 (DWR, 2019b) (SEE FIGURE 3-13).

TOP OF CASING (AND GROUND SURFACE) ELEVATION OF SOME WELLS DIFFER FROM THE ELEVATION OF THE PROFILE BECAUSE THOSE WELLS WERE PROJECTED ONTO THE PLANE OF THE CROSS SECTION FROM VARYING DISTANCES.

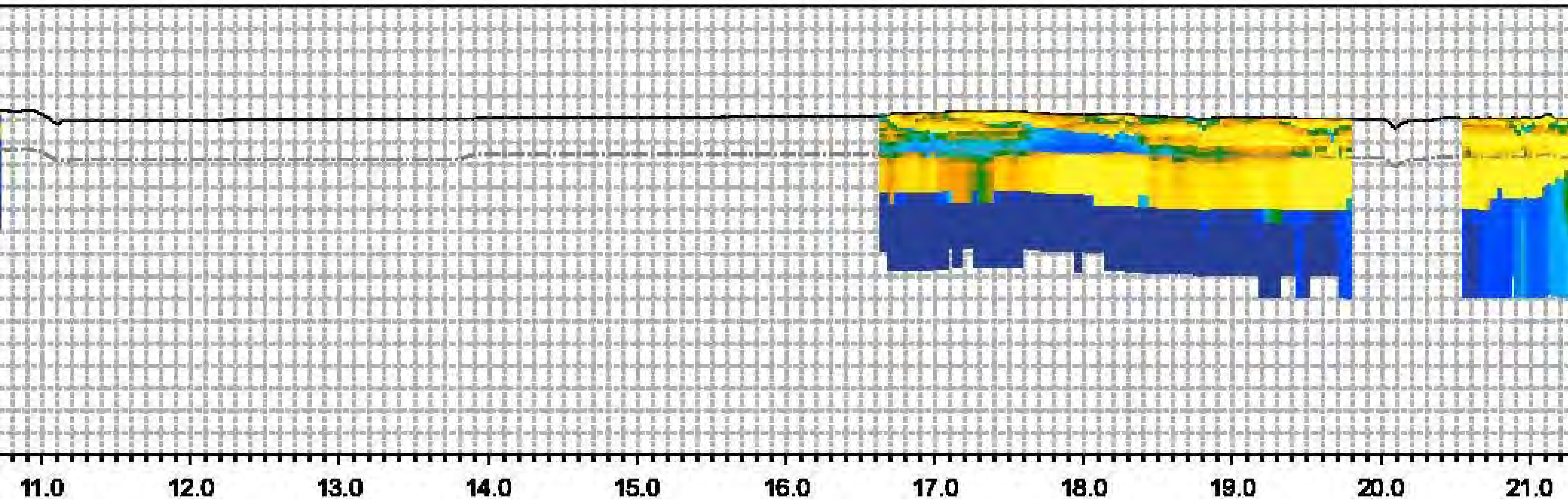
NAVD88 = NORTH AMERICAN VERTICAL DATUM OF 1988.

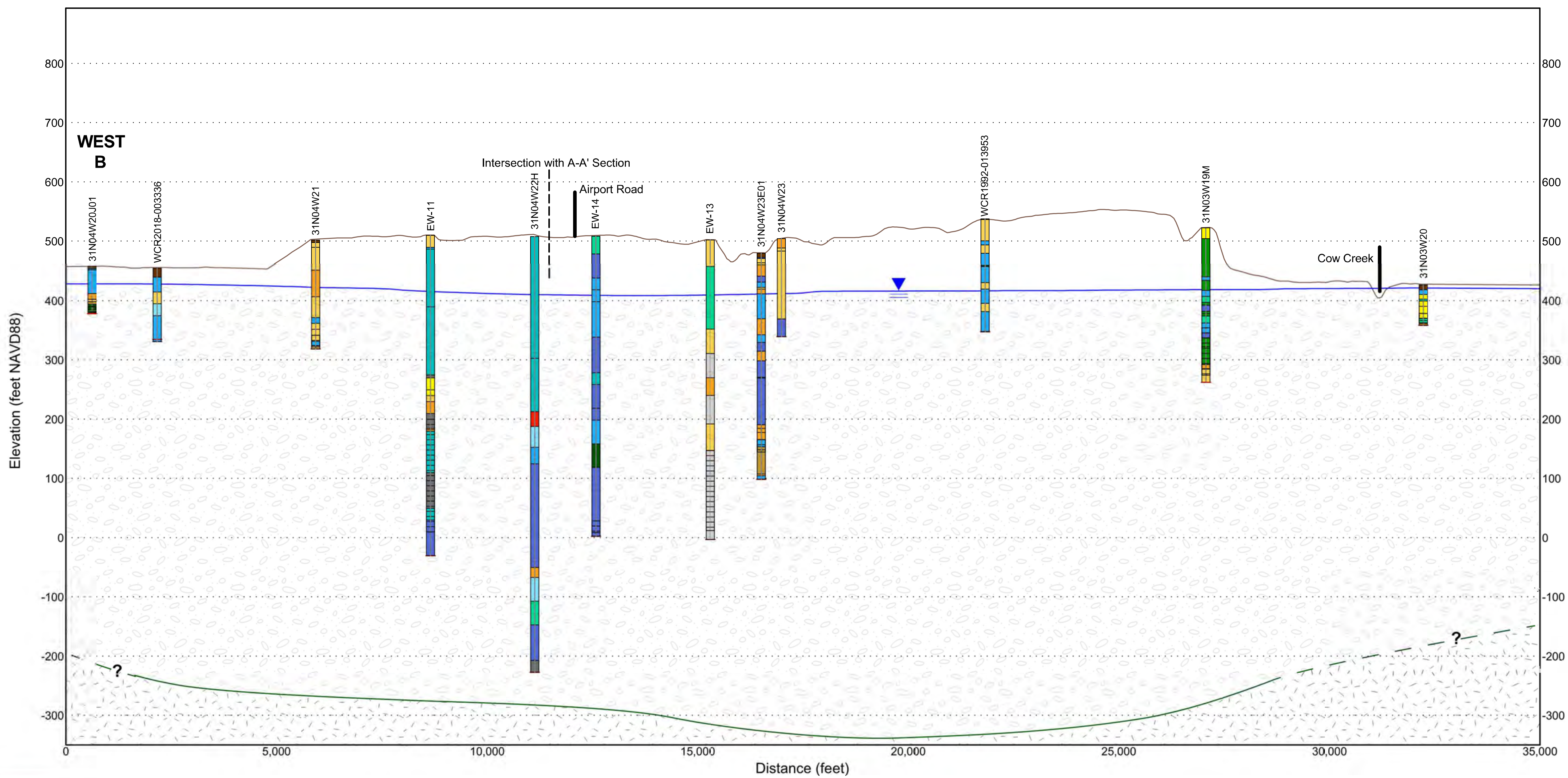
D:\REDDINGCACITYOF\GINT\EAGSA_SECTIONS.GPJ;

FIGURE 3-7
GEOLOGIC CROSS SECTION A-A'
Enterprise Subbasin Groundwater Sustainability Plan

Jacobs

A - A' Nearest AEM Log





GROUND SURFACE ELEVATION (feet NAVD88)

TOP OF CHICO FORMATION (DASHED WHERE UNCERTAIN)

GROUNDWATER ELEVATION (feet NAVD88)

SCREEN INTERVAL

SOIL AND LITHOLOGY

SAND	GRAVEL	CLAY	BASALT
CLAYEY SAND	CLAYEY GRAVEL	SANDY CLAY	HARD PAN
GRAVELLEY SAND	SANDY GRAVEL	GRAVELLEY CLAY	SHALE
SILTY SAND	SILTY GRAVEL	SILT	UNDIFFERENTIATED ROCK
SANDSTONE	TUFF	SILTSTONE	UNDIFFERENTIATED SOIL

PRINCIPAL AQUIFER

BEDROCK

SCALE EXAGGERATION – 14:1 (H:V)

NOTES:

LOCATION OF CROSS SECTION SHOWN ON FIGURE 3-6.

GROUNDWATER ELEVATION IS ESTIMATED FROM GROUNDWATER LEVELS MEASURED BETWEEN OCTOBER 16 AND OCTOBER 26, 2018 (DWR, 2019b) (SEE FIGURE 3-13).

TOP OF CASING (AND GROUND SURFACE) ELEVATION OF SOME WELLS DIFFER FROM THE ELEVATION OF THE PROFILE BECAUSE THOSE WELLS WERE PROJECTED ONTO THE PLANE OF THE CROSS SECTION FROM VARYING DISTANCES.

NAVD88 = NORTH AMERICAN VERTICAL DATUM OF 1988.

FIGURE 3-8
GEOLOGIC CROSS SECTION B-B'
Enterprise Subbasin Groundwater Sustainability Plan

Jacobs

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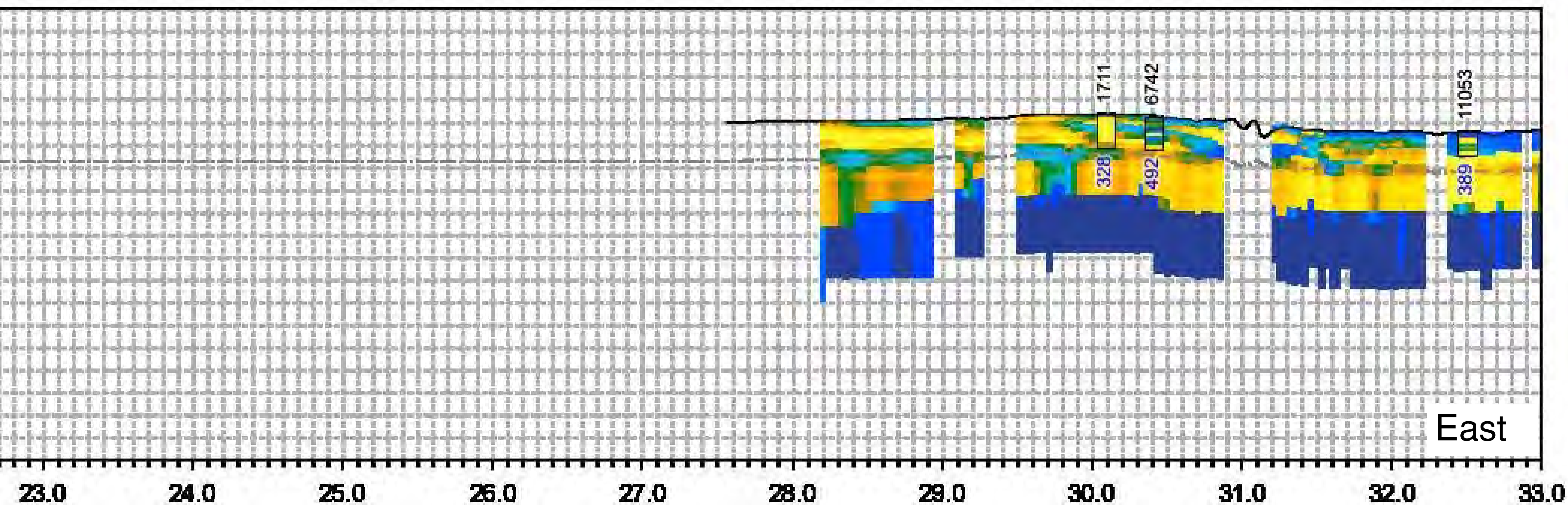
B - B' Nearest AEM Log



TEHAMA COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT

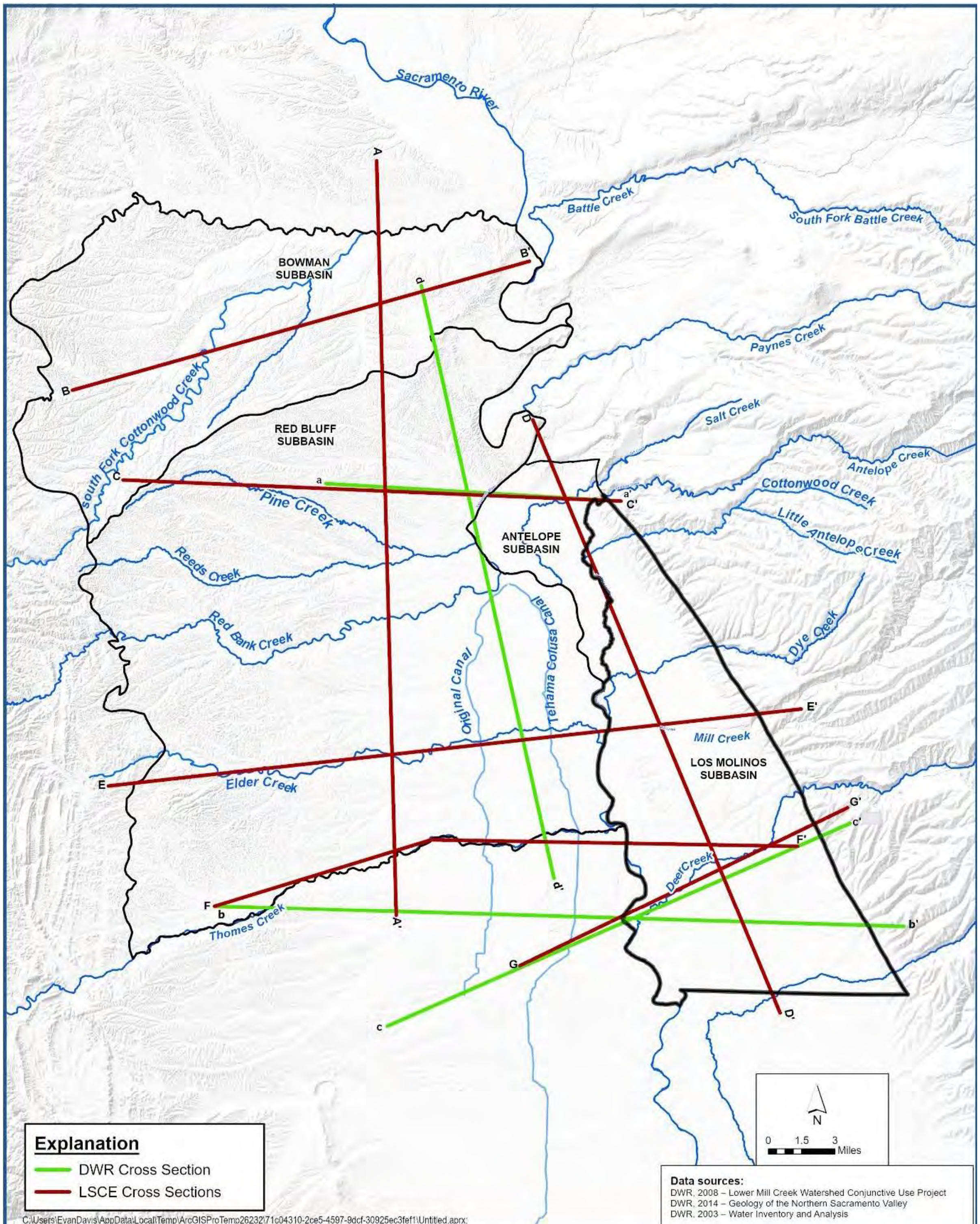
Groundwater Sustainability Plan

Los Molinos Subbasin

JANUARY 2022

PREPARED BY

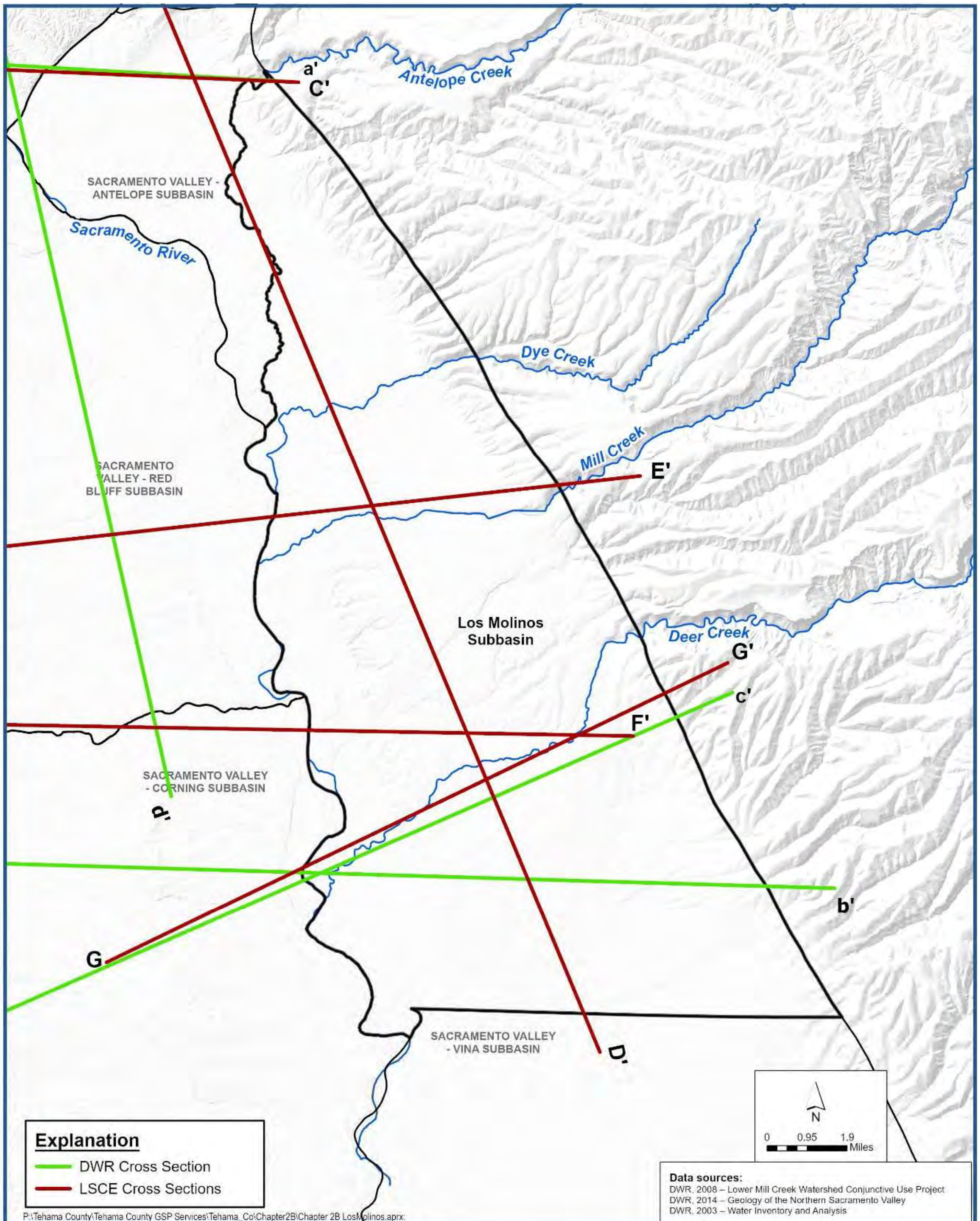
Luhdorff & Scalmanini
Consulting Engineers



Map of Cross Section Locations

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-21



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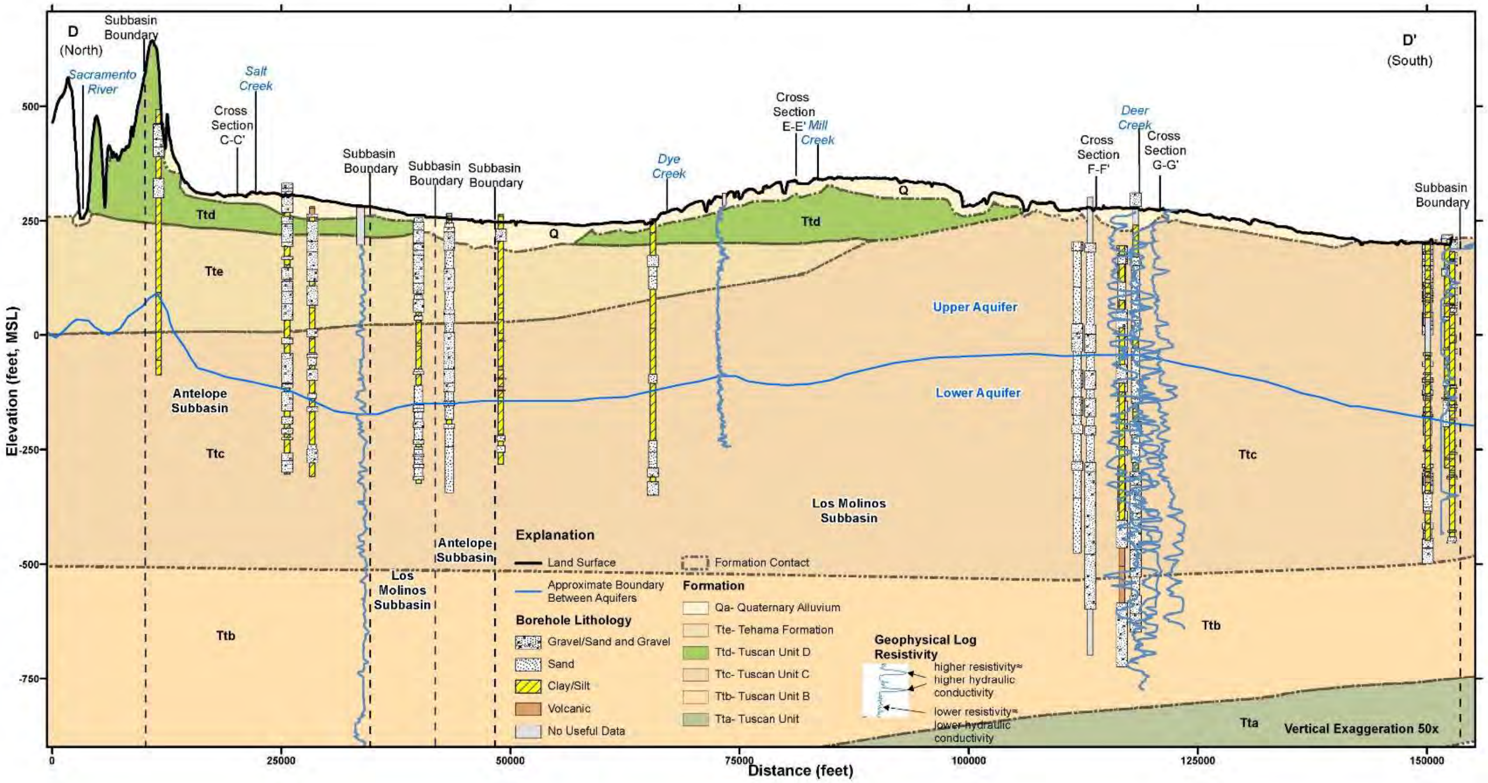
Map of Cross Section Locations

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-21B



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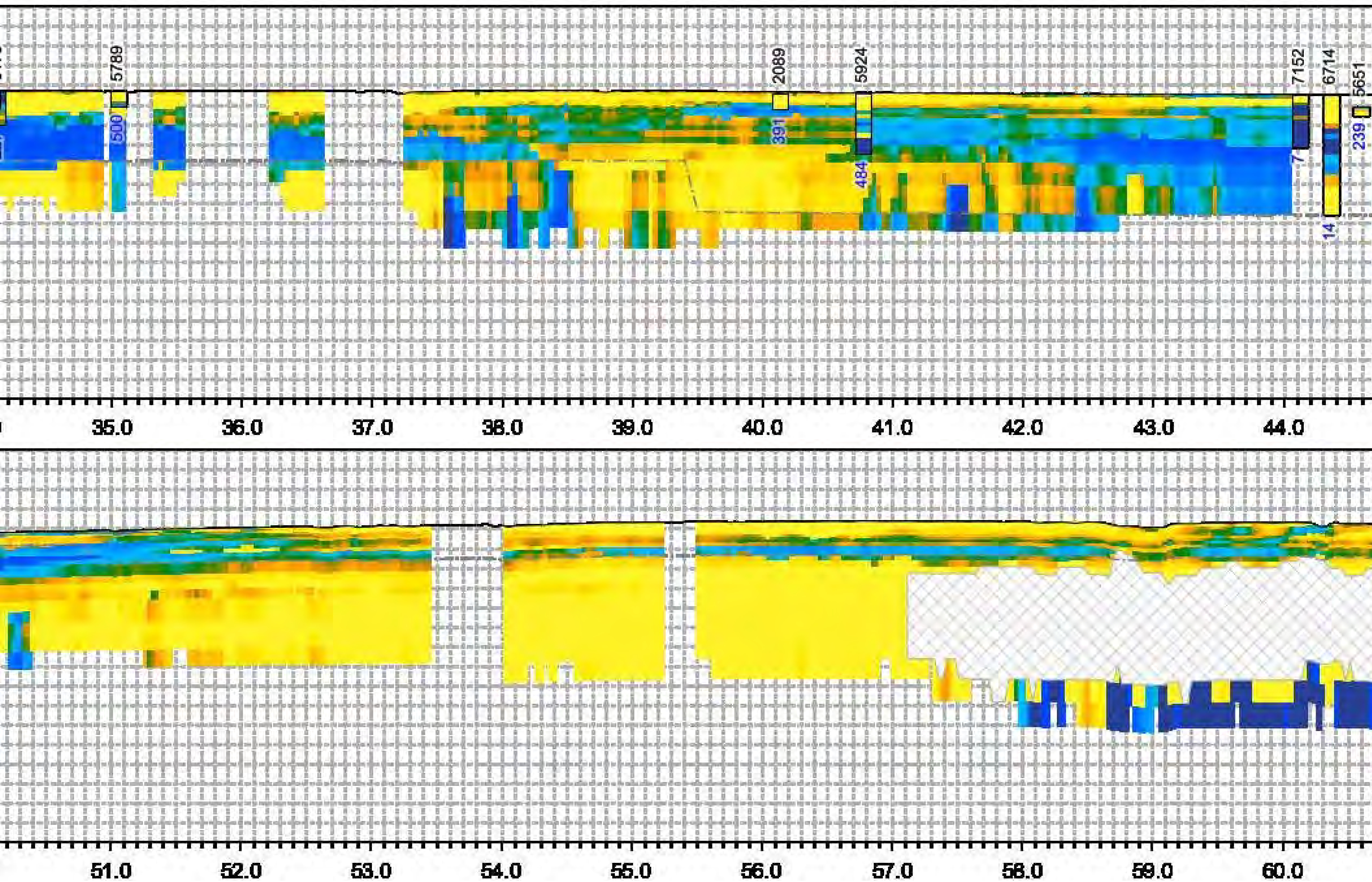
Cross Section D-D'

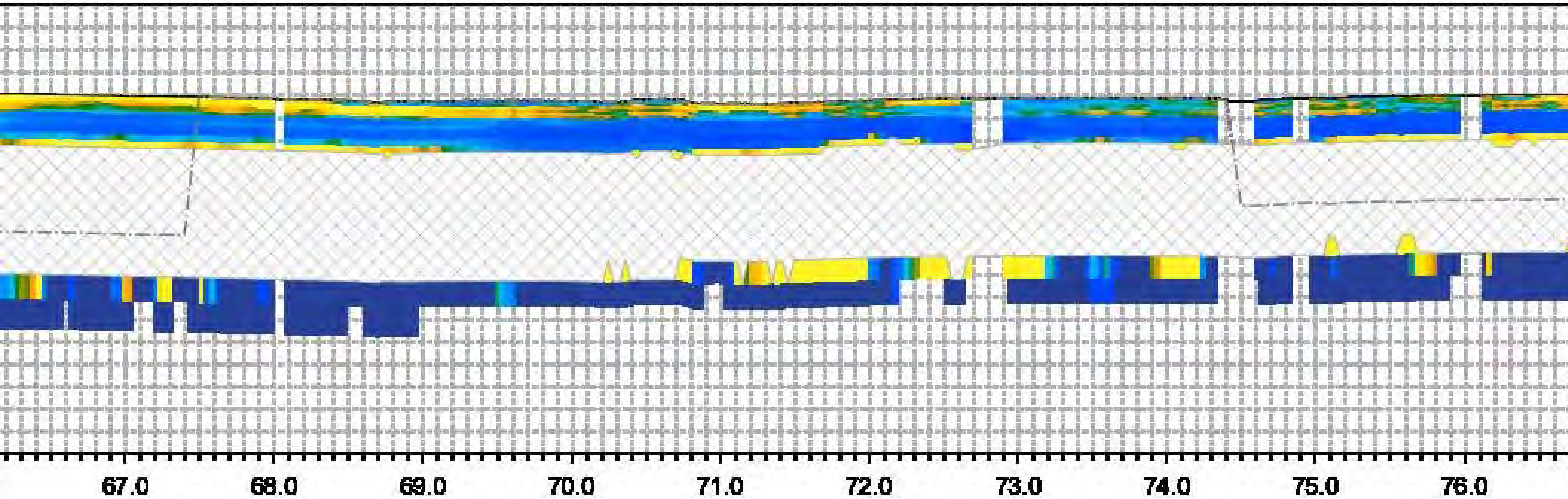
Figure 2-22

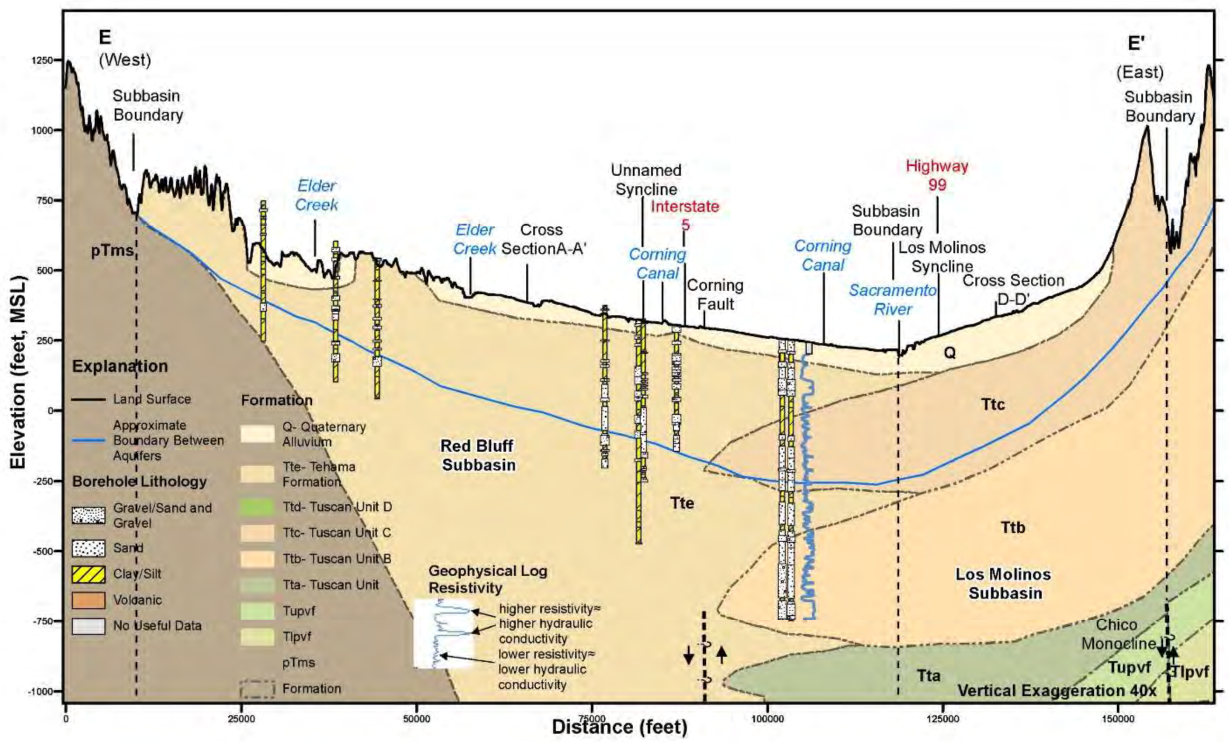
Groundwater Sustainability Plan
Los Molinos Subbasin

D - D' Nearest AEM Log



D - D' Nearest AEM Log





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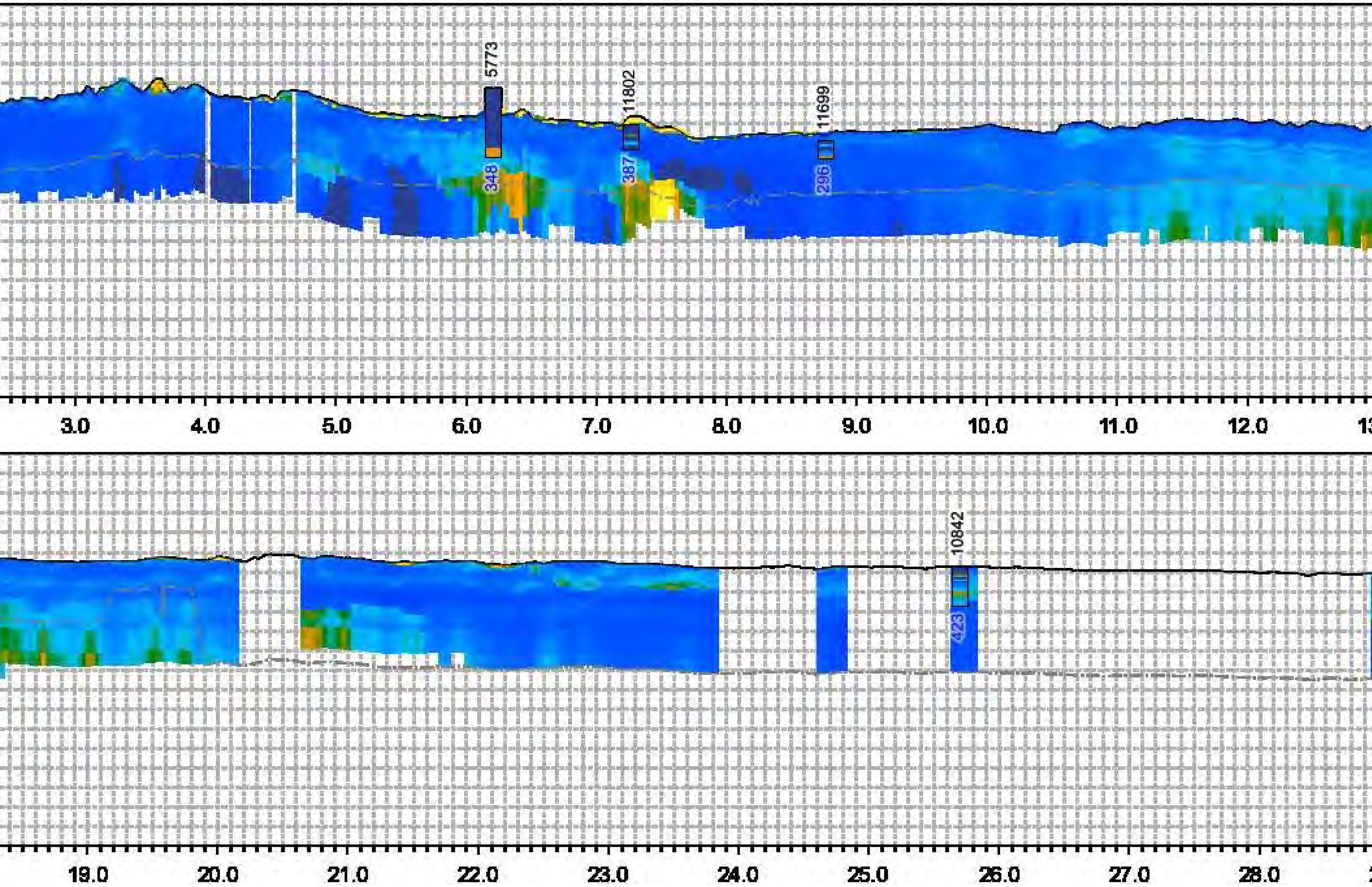
Cross Section E-E'

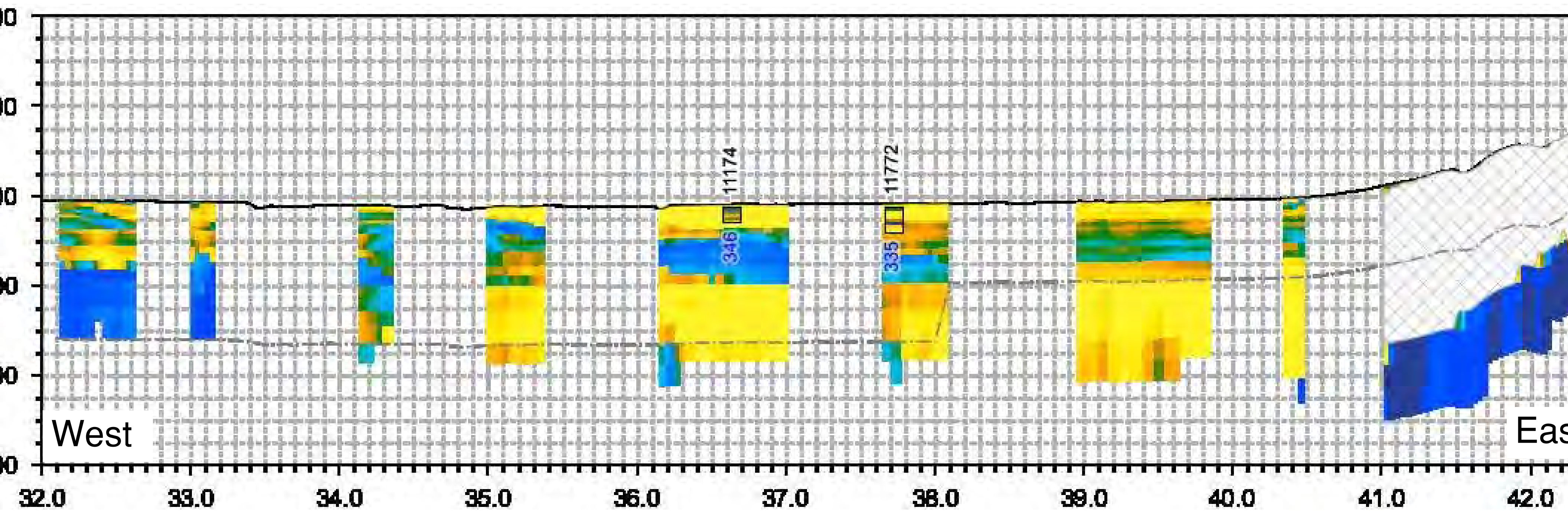
Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-23

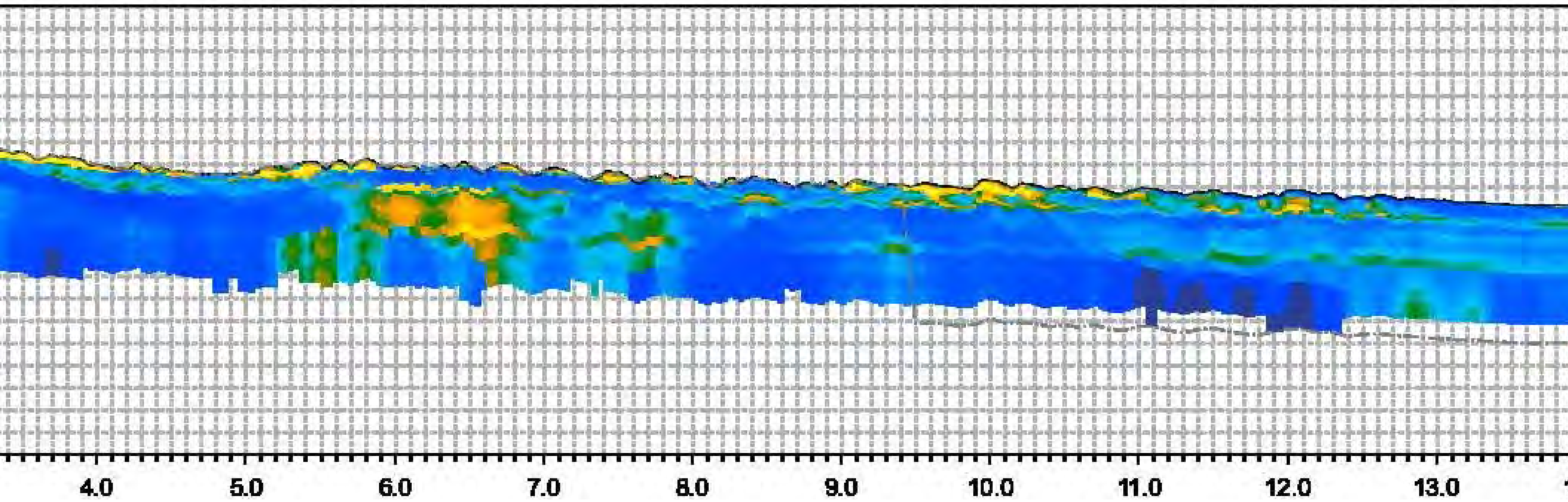
E - E' Nearest AEM Log, North

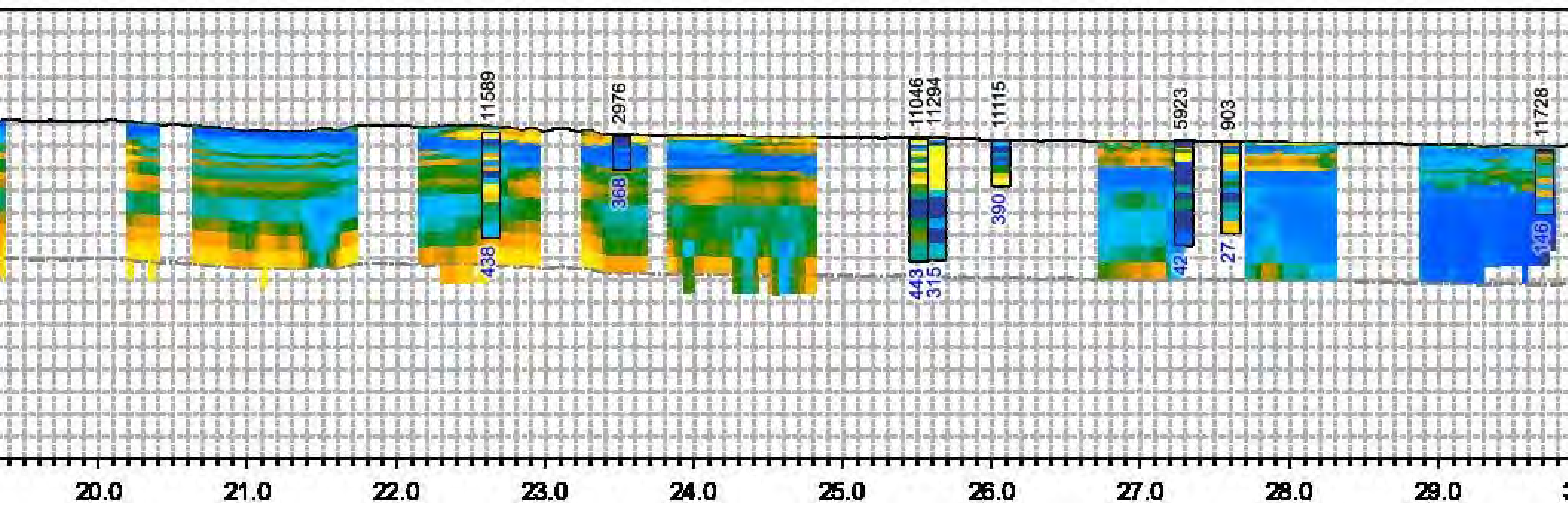


E - E' Nearest AEM Log, North

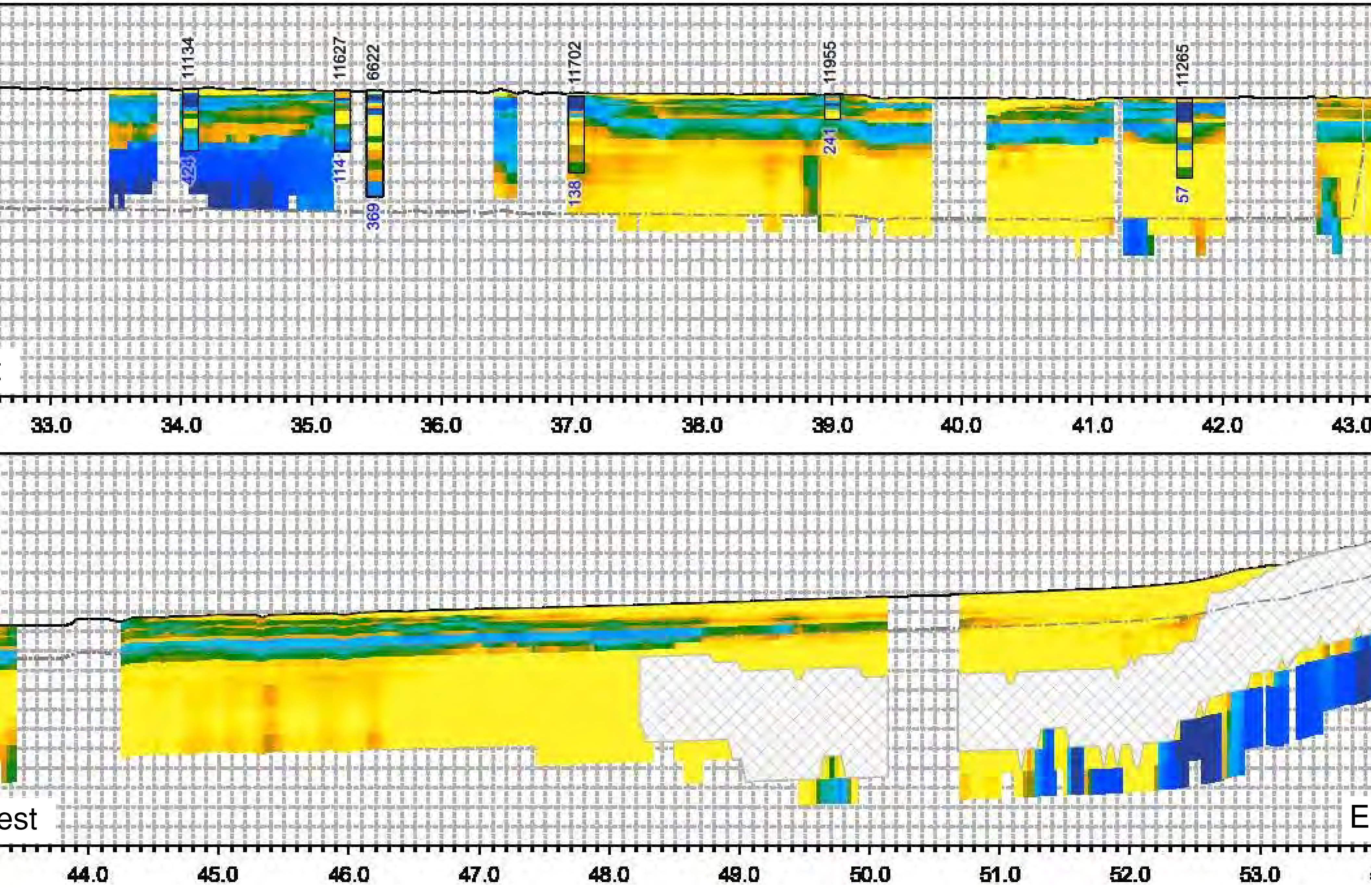


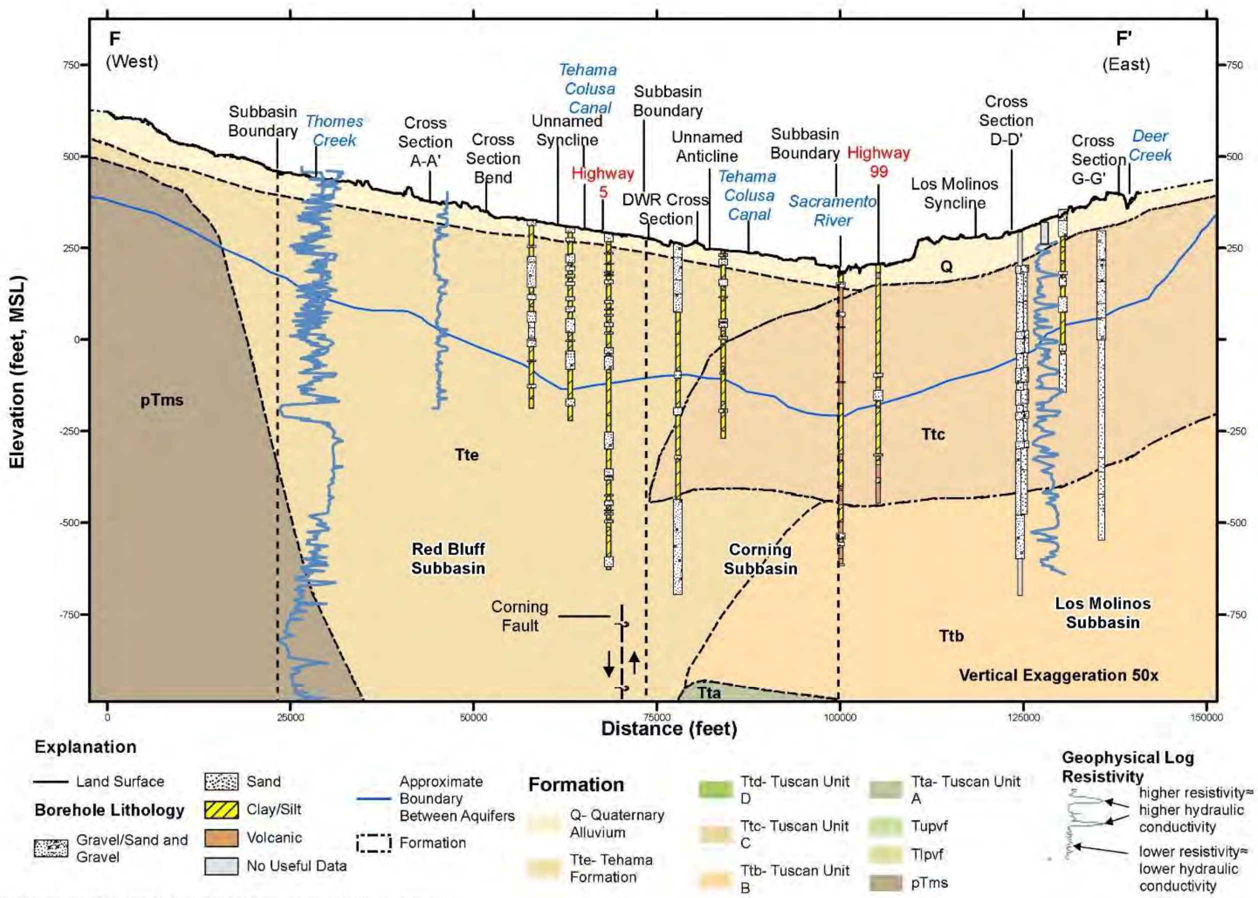
E - E' Nearest AEM Log, South.
F - F' Nearest AEM Log





E - E' Nearest AEM Log, South.
F - F' Nearest AEM Log





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

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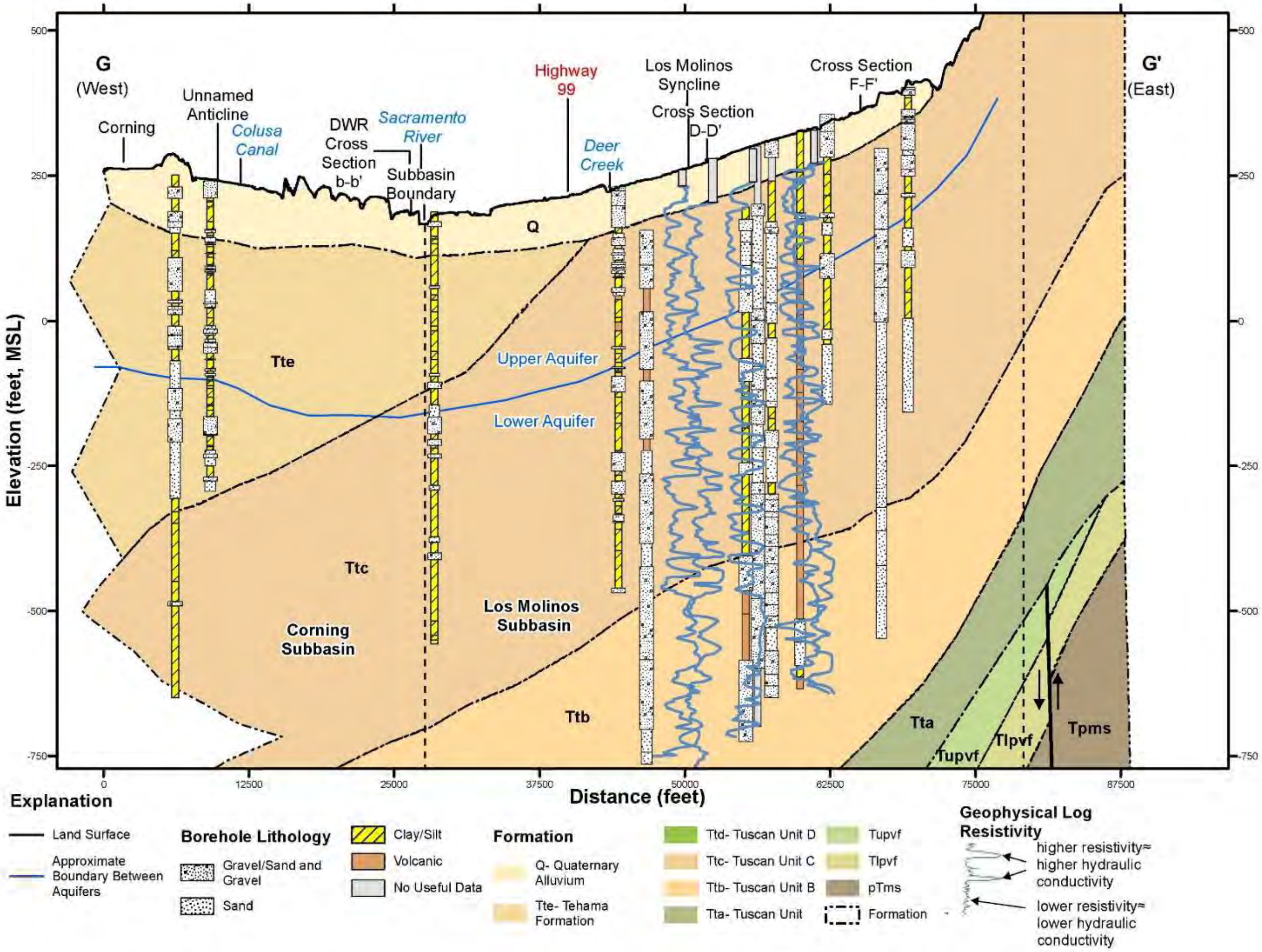
Cross Section F-F'

Figure 2-24

Groundwater Sustainability Plan
Los Molinos Subbasin



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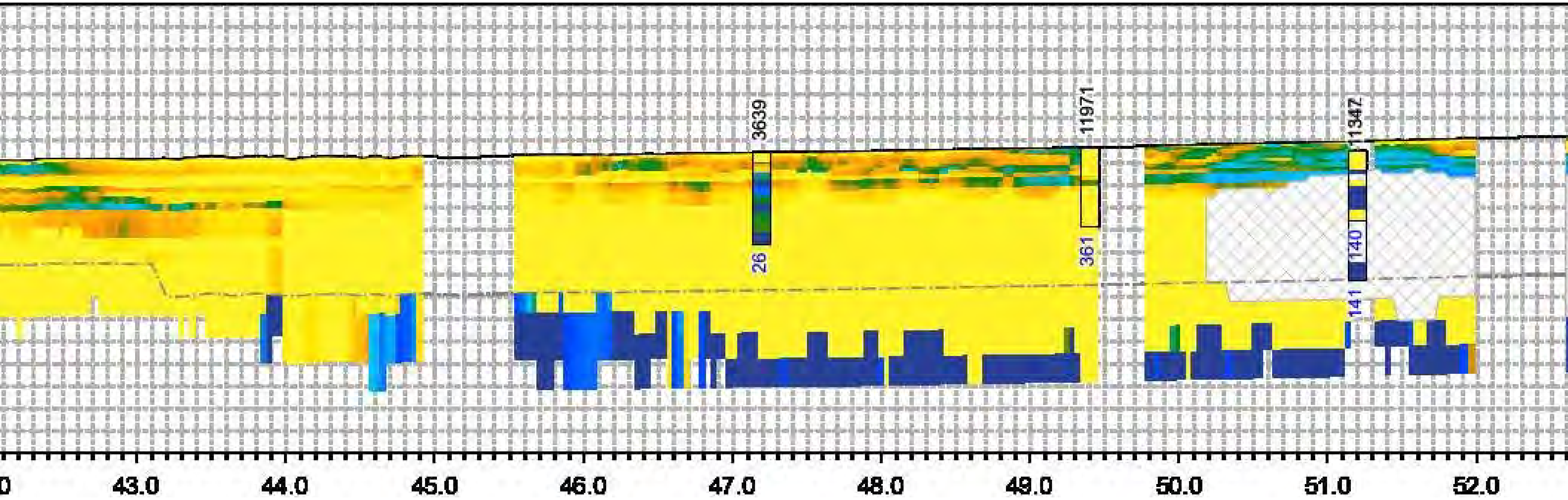
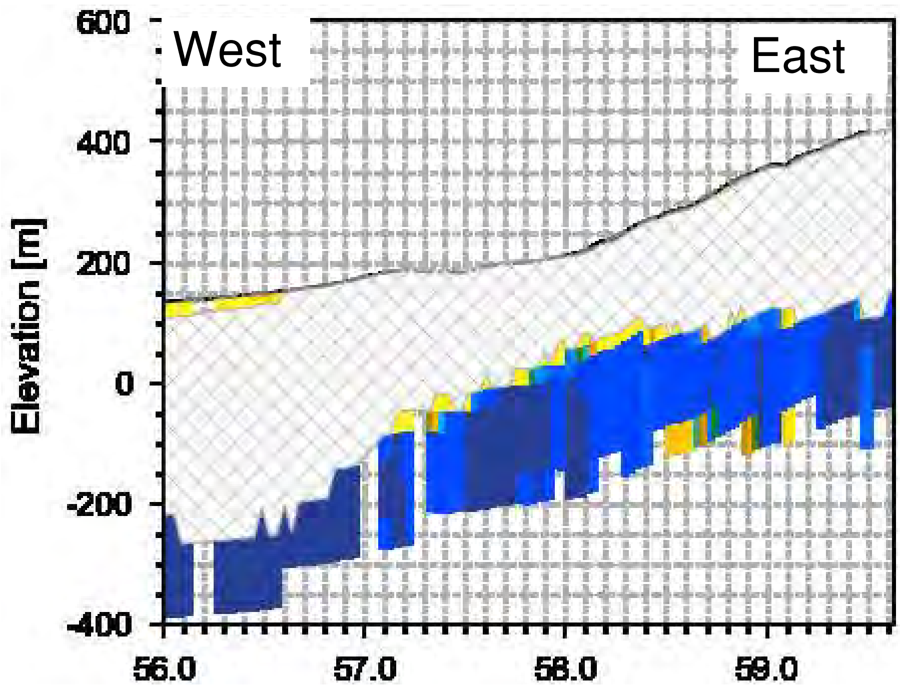
Cross Section G-G'

Figure 2-25

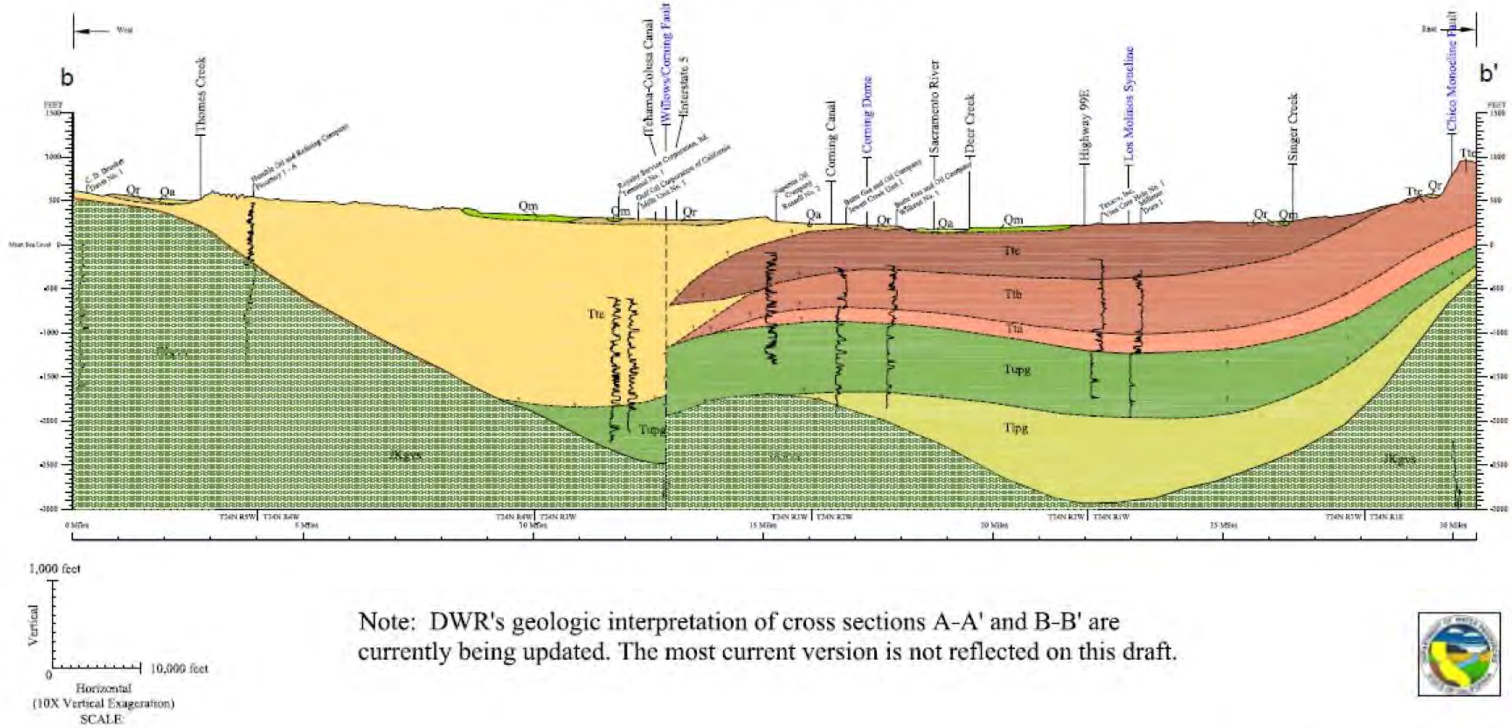
Groundwater Sustainability Plan
Los Molinos Subbasin

G - G' Nearest AEM Log





Cross Section b-b'



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

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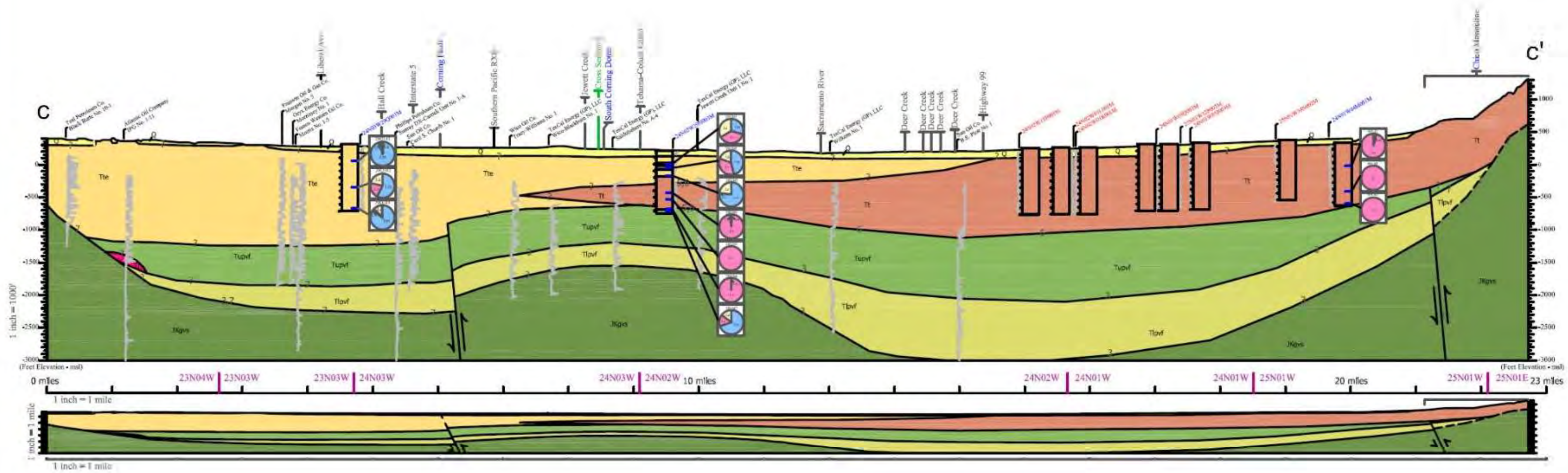
DWR Cross Section b-b'

Figure 2-26

Groundwater Sustainability Plan
Los Molinos Subbasin

Cross Section c-c'



Data sources:
DWR, 2014 - Geology of the Northern Sacramento Valley

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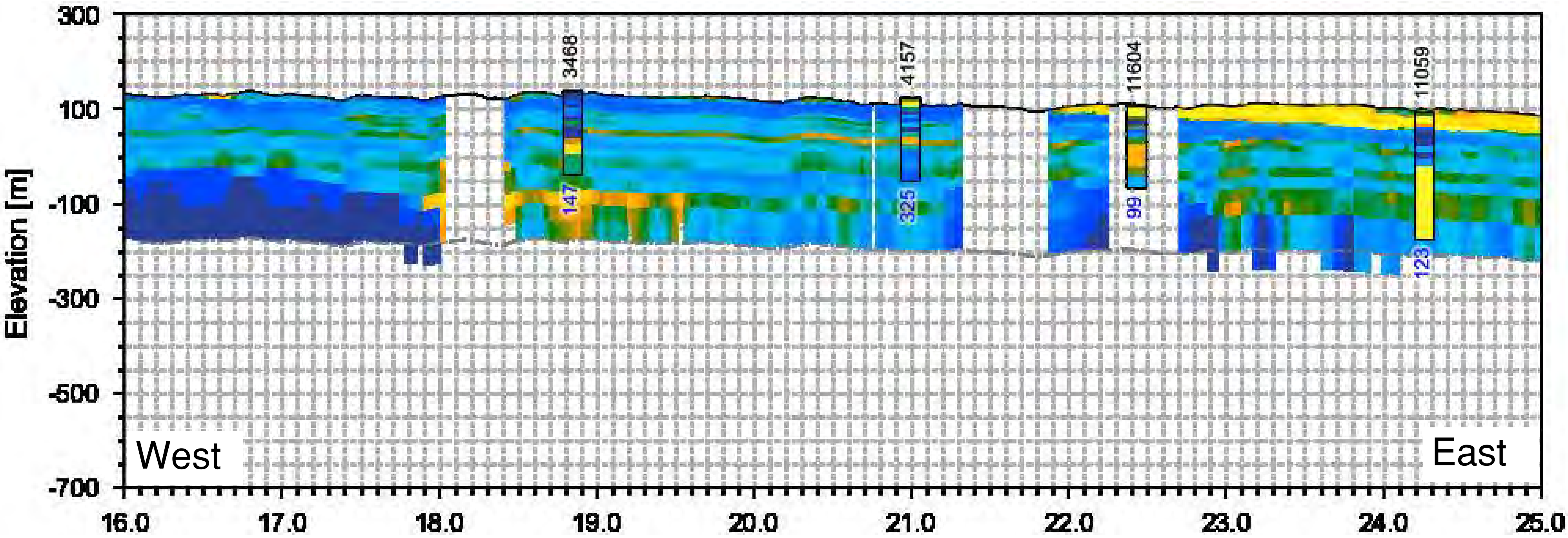
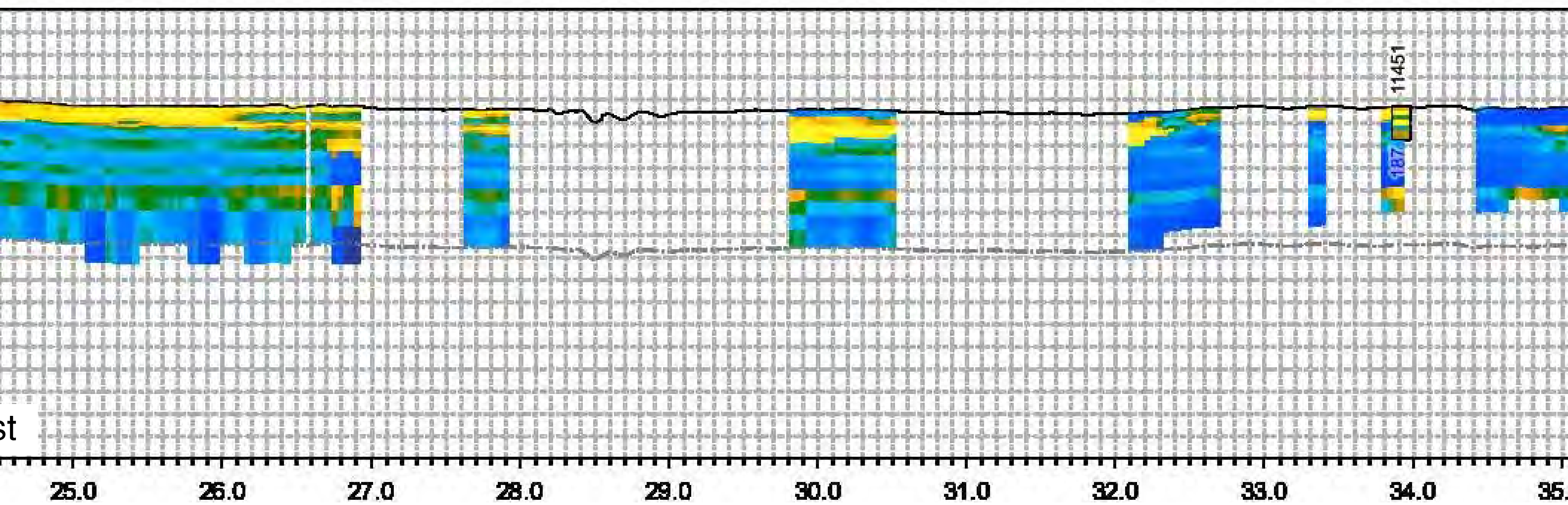
DWR Cross Section c-c'

Figure 2-27

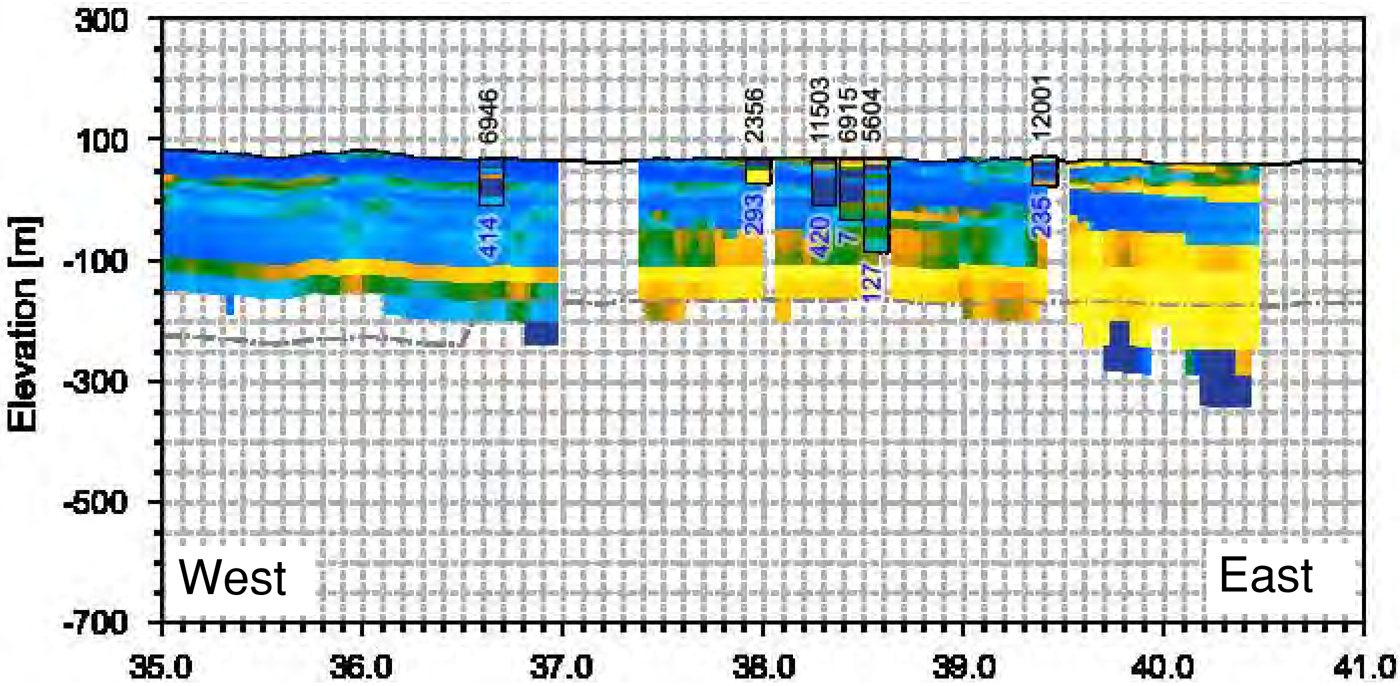
Groundwater Sustainability Plan
Los Molinos Subbasin

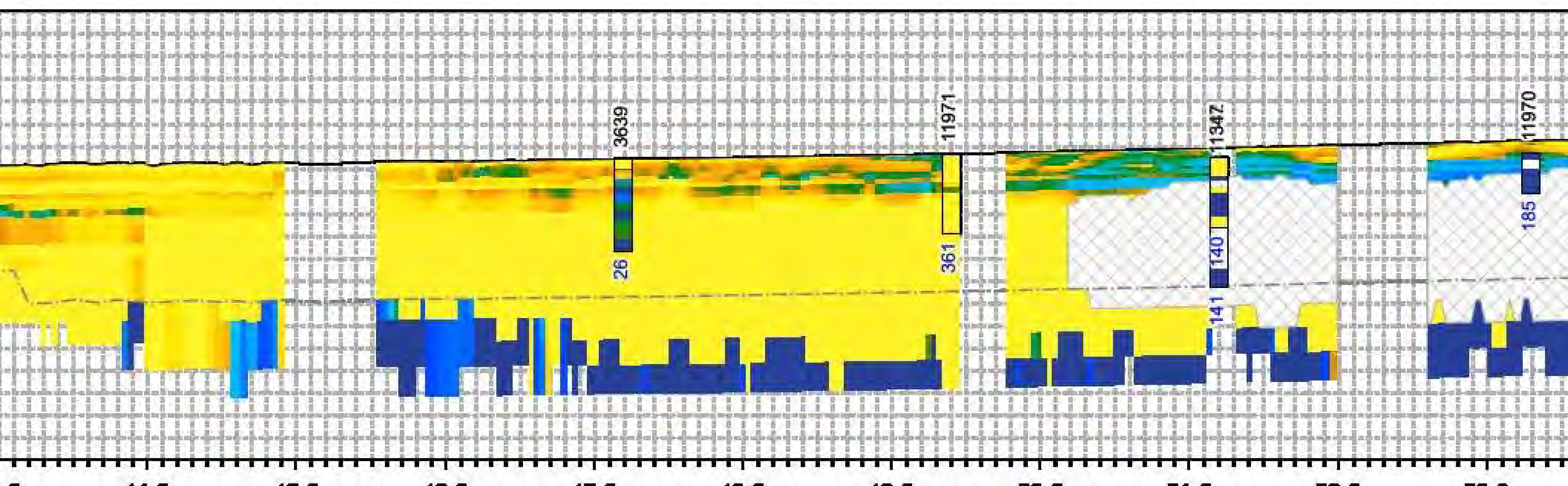
c - c' Nearest AEM Log



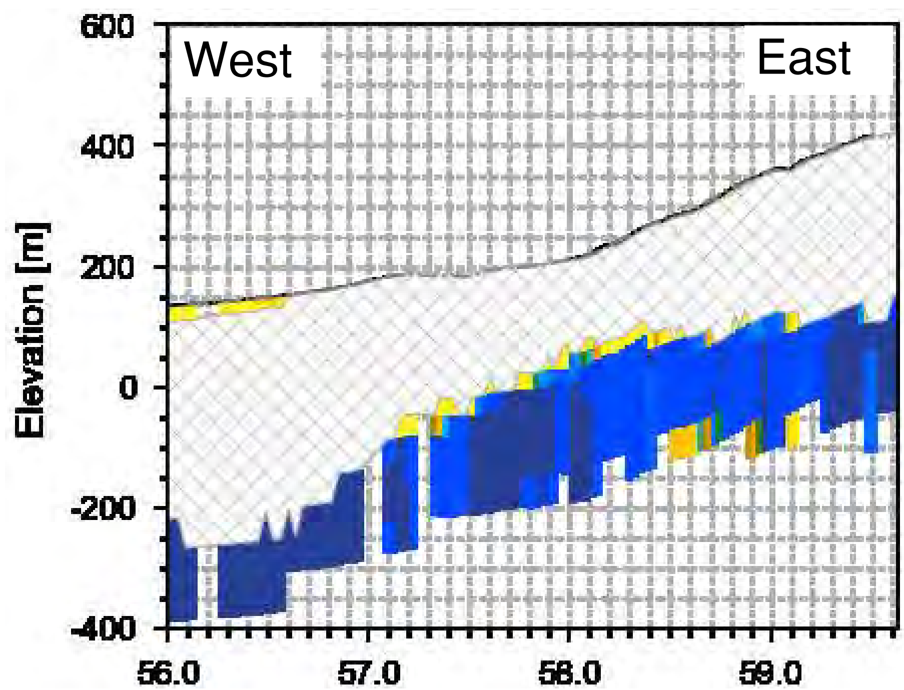


c - c' Nearest AEM Log





c - c' Nearest AEM Log



DESCRIPTION OF MAP UNITS

Qa	**Alluvium** (Holocene)-Includes surficial alluvium and stream channel deposits of unweathered gravel, sand and silt, maximum thickness 80 ft. *(adapted from Helley & Harwood, 1985).*
Qb	**Basin Deposits** (Holocene)-Fine-grained silt and clay derived from adjacent mountain ranges, maximum thickness up to 200 ft. *(adapted from Helley & Harwood, 1985).*
Qm	**Modesto Formation**, undifferentiated (Pleistocene)-Alluvial fan and terrace deposits consisting of unconsolidated weathered and unweathered gravel, sand, silt and clay; maximum thickness approximately 200 ft. *(adapted from Helley & Harwood , 1985).*
Qr	**Riverbank Formation**, undifferentiated (Pleistocene)-Alluvial fan and terrace deposits consisting of unconsolidated to semi-consolidated gravel, sand and silt; maximum thickness approximately 200 ft. *(adapted from Helley & Harwood, 1985).*
Tte	**Tehama Formation** (Plio-Pleistocene)-Includes Red Bluff Formation on west side. Pale green, gray and tan sandstone and siltstone with lenses of pebble and cobble conglomerate; maximum thickness 2,000 ft. *(adapted from Helley & Harwood, 1985).*
Ttd	**Tuscan Unit D** (Plio-Pleistocene)-Fragmental flow deposits characterized by monolithic masses containing gray hornblende and basaltic andesites and black pumice, maximum thickness 160 ft. *(adapted from Helley & Harwood, 1985).*
Ttc	**Tuscan Unit C** (Plio-Pleistocene)-Includes Red Bluff Formation on east side. Volcanic lahars with some interbedded volcanic conglomerate and sandstone, and reworked sediments; maximum thickness 600 ft. *(adapted from Helley & Harwood, 1985, DWR Bulletin 118-7, 2001, draft report).*
Ttb	**Tuscan Unit B** (Pliocene)-Layered, interbedded lahars, volcanic conglomerate, volcanic sandstone and siltstone; maximum thickness 600 ft. *(adapted from Helley and Harwood, 1985; DWR Bulletin 118-7, 2001, draft report).*
Tta	**Tuscan Unit A** (Pliocene)-Interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone containing metamorphic rock fragments; maximum thickness 400 ft. *(adapted from Helley & Harwood, 1985; DWR Bulletin 118-7 (in progress), 2001).*
Tl	**Lovejoy Basalt** (Miocene)-Black, dense, hard microcrystalline basalt; maximum thickness 65 ft. *(adapted from Helley & Harwood, 1985).*
Tupg	**Upper Princeton Valley Fill** (Late Oligocene to Early Miocene)-Non-marine sediments composed of sandstone with interbeds of mudstone and occasional conglomerate and conglomerate sandstone; maximum thickness 1,400 ft. *(adapted from Redwine, 1972).*
Ti	**Ione Formation** (Eocene)-Marine to non-marine deltaic sediments, light colored, commonly white conglomerate, sandstone and siltstone, which is soft and easily eroded; max. thickness 650 ft. *(adapted from DWR Bulletin 118-6, 1978; Creely, 1965).*
Tlpg	**Lower Princeton Submarine Valley Fill** (Eocene)-includes Capay Formation. Marine sandstone, conglomerate and interbedded silty shale, maximum thickness 2,400 ft. (*adapted from Redwine, 1972*)
JKgvs	**Great Valley Sequence** (Late Jurassic to Upper Cretaceous)-Marine clastic sedimentary rock consisting of siltstone, shale, sandstone and conglomerate; maximum thickness 15,000 ft.
JKf	**Franciscan Formation** (Jurassic to Cretaceous)-Dominated by greenish-grey greywackes with lesser amounts of dark shale, limestone and radiolarian chert, maximum thickness up to 25,000 ft. *(adapted from strand, 1962 and Norris & Webb, 1990).*

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

TEHAMA COUNTY

LSCE Team

Description of Map Units for DWR Cross Sections b-b' and c-c'

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-26B and Figure 2-27B Combined

2.2.1.5 Identification/Differentiation of Principal Aquifers

Two principal aquifer units are defined in the Subbasin: Upper Aquifer and Lower Aquifer. The two-aquifer designation is based on an examination of time-series groundwater elevation hydrographs, electric resistivity data from geophysical logs, lithologic logs, well construction details, and review of previous studies in the Subbasin. The northern Sacramento Valley depositional environment is dominated by fluvial and alluvial deposition after the Eocene marine depositional environment transitioned to a subaerial one. The Pliocene depositional environment is similar to the current depositional conditions, with eastern depositional streams sourced from the Cascade Range and western depositional streams sourced from the Coast Ranges draining onto a central floodplain. This depositional environment resulted in a complex and varied series of water bearing sedimentary deposits and the Tuscan/Tehama Formations that collectively form a two-aquifer system in the Subbasin and beyond. Within singular water bearing formations there are areas where confined or unconfined conditions can be dominant. Generally, confined aquifer conditions are encountered at depth and unconfined conditions are seen in the shallower porous media. The complexity of the geologic materials and among the formations makes it difficult to define a singular widespread aquitard or distinctive change in geologic materials separating an upper and lower aquifer. To delineate between areas with a higher likelihood of confined conditions, well construction data throughout the Subbasin were examined. Most of the wells in the Subbasin are screened or completed above 400 feet below ground surface (ft bgs). The bottom of numerical model layer 5 best corresponds with this depth. The bottom of model layer 5 is used as the delineation between the Upper and the Lower Aquifer. This model layer boundary also generally corresponds to fine grained lithology from available well completion reports (**Figure 2-22** through **Figure 2-25**). Lastly, the degree of heterogeneity and anisotropy (directional preferable flow) is likely significant, but not easy to define based on current information.

Upper Aquifer

The Upper Aquifer is defined as the water bearing material from ground surface to the bottom of model layer 5 (approximately 350-450 ft bgs in the Subbasin). The aquifer has unconfined to semi-confined water conditions. Water bearing geologic units in the Upper Aquifer include the Quaternary formations and the upper portions of the Tehama and Tuscan Formations. Wells screened in the Upper Aquifer are used for agricultural and mainly domestic purposes. The depth to the bottom of the Upper Aquifer is approximately 350-450 ft bgs (**Figure 2-22 through Figure 2-25**). The storage capacity of the Los Molinos Subbasin Upper Aquifer is estimated to be approximately 400,000 acre-feet to a depth of 200 feet in the area between Mill Creek and Deer Creek (DWR, 2004).

Site-specific Aquifer properties obtained from aquifer tests were available for specific areas of the Subbasin, additional aquifer tests were also conducted in surrounding subbasins. In the Deer Creek area of the Subbasin, transmissivity (hydraulic conductivity multiplied by aquifer thickness) of the upper portion of the Tuscan Formation is estimated to be approximately 14,000 square feet per day (ft^2/d) to approximately 55,000 ft^2/d (DWR, 2003). These values were estimated based on aquifer tests conducted in a well screened from 70 ft bgs to 530 ft bgs (DWR, 2003). This depth interval covers a portion of the Lower Aquifer but is mostly within the Upper Aquifer.

Hydraulic conductivity (rate at which water moves through an aquifer) and storage coefficients (ability of the aquifer to store water, commonly expressed as specific yield for water table/unconfined aquifers and storativity for confined aquitards) have been estimated for the Tehama Formation in the neighboring Red Bluff Subbasin. The Tehama Formation has an average transmissivity of approximately 4,000 ft^2/d, an average storativity of 0.00089, and an average hydraulic conductivity of 120 feet per day (ft/d) based on a 1989 constant discharge aquifer test at the Rancho Tehama Reserve in the Red Bluff Subbasin (McManus, 1993; DWR, 2003).

Lower Aquifer

The Lower Aquifer is defined as the freshwater bearing geologic units throughout the Subbasin from the bottom of model layer 5 at approximately 350-450 ft bgs, to the bottom of the Subbasin. The aquifer has confined to semi-confined conditions. Water bearing geologic units include the lower portions of the Tehama and Tuscan Formations. Wells screened in the Lower Aquifer are largely for non-domestic purposes. Lack of a continuous confining layer in the Subbasin creates challenges for defining the top of the Lower Aquifer.

Transmissivity between 350 ft bgs and 600 ft bgs is approximately 5,600 ft^2/d to 17,000 ft^2/d in the Dye Creek area of the Subbasin (Harrison, 1989; Ely, 1994; DWR, 2003). In the same areas, average hydraulic conductivity ranges from approximately 40 ft/d to 60 ft/d, and the average storage coefficient is 0.0025 (Harrison, 1989; Ely, 1994; DWR, 2003).

The lower Tuscan Formation (Units A and B) has a hydraulic conductivity estimate (via an aquifer test south of Deer Creek and North of Little Chico Creek) of 41-88 ft/d (Brown and Caldwell, 2013). Transmissivity of the lower parts of the Tuscan Formation (340-920 ft bgs) ranges from 5,415 ft^2/d to 49,986 ft^2/d south in the Deer Creek area of the Subbasin (DWR, 2003). In the same areas, storativity is estimated to be 0.0025 and hydraulic conductivity is estimated to be 43 ft/d (DWR, 2003). The Tehama Formation has an average transmissivity of 4,341 ft^2/d, an average storativity of 0.00089, and an average hydraulic conductivity of 120 feet per day (ft/d) based on a 1989 constant discharge aquifer test at the Rancho Tehama Reserve in the Red Bluff Subbasin (McManus, 1993; DWR, 2003).

2.2.1.6 Definable Bottom of Basin

The base of the post-Eocene continental deposits is defined as the bottom of the basin. The post-Eocene deposits are the deepest locations where fresh water may exist. Contours of the base of post-Eocene deposits (**Figure 2-20)** are on the base of the Upper Princeton Valley Fill in the majority of the Subbasin. The Upper Princeton Valley Fill is a transitional formation from marine to terrestrial deposition. Interstitial fresh and brackish water is contained in the Upper Princeton Valley Fill and fresh water can intersect with the formation in places (USGS, 1974; Tehama County FCWCD, 2012). Fresh water is defined as having a maximum electrical conductivity of 3,000 micromhos per centimeter (µmhos/cm) (Berkstresser, 1973). The base of fresh water in the Subbasin is shallowest in the east and southeast at elevations shallower than -1,200 ft, mean sea level (msl) and deepest in the west at elevations deeper than -2,000 ft, msl (**Figure 2-15;** Berkstresser, 1973). The elevation of the base of fresh water as depicted by the equal elevation contour lines is interrupted in the northeast where the Chico Monocline possibly affects the depth to fresh water. Fresh water depth based on electrical conductivity is corroborated by studies by DWR (2014).

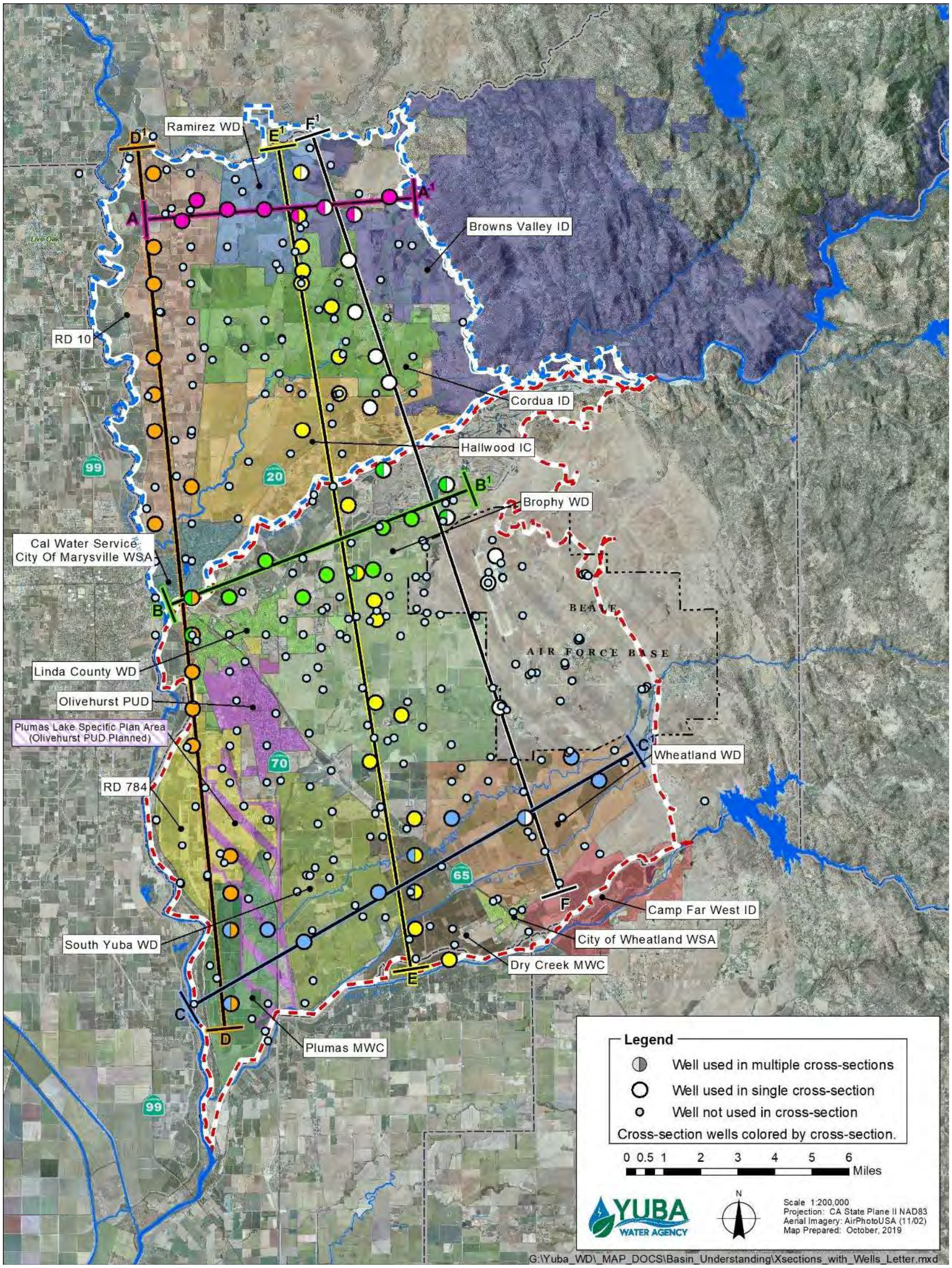
Cordua Irrigation District

YUBA WATER AGENCY

CITY OF MARYSVILLE, YUBA COUNTY, CAL. INCORPORATED FEB. 5, 1851

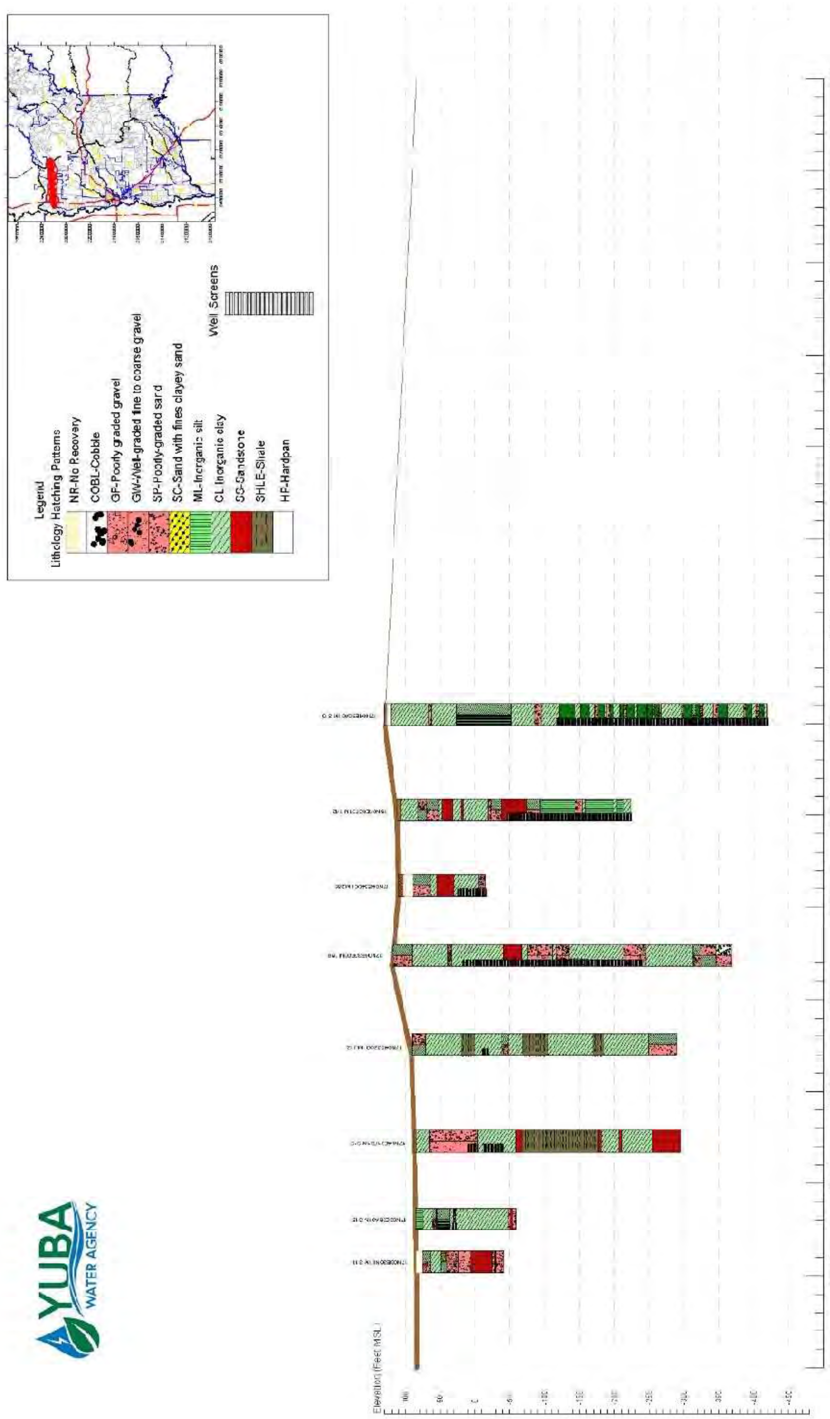
Yuba Subbasins Water Management Plan: **A Groundwater Sustainability Plan**

December 2019



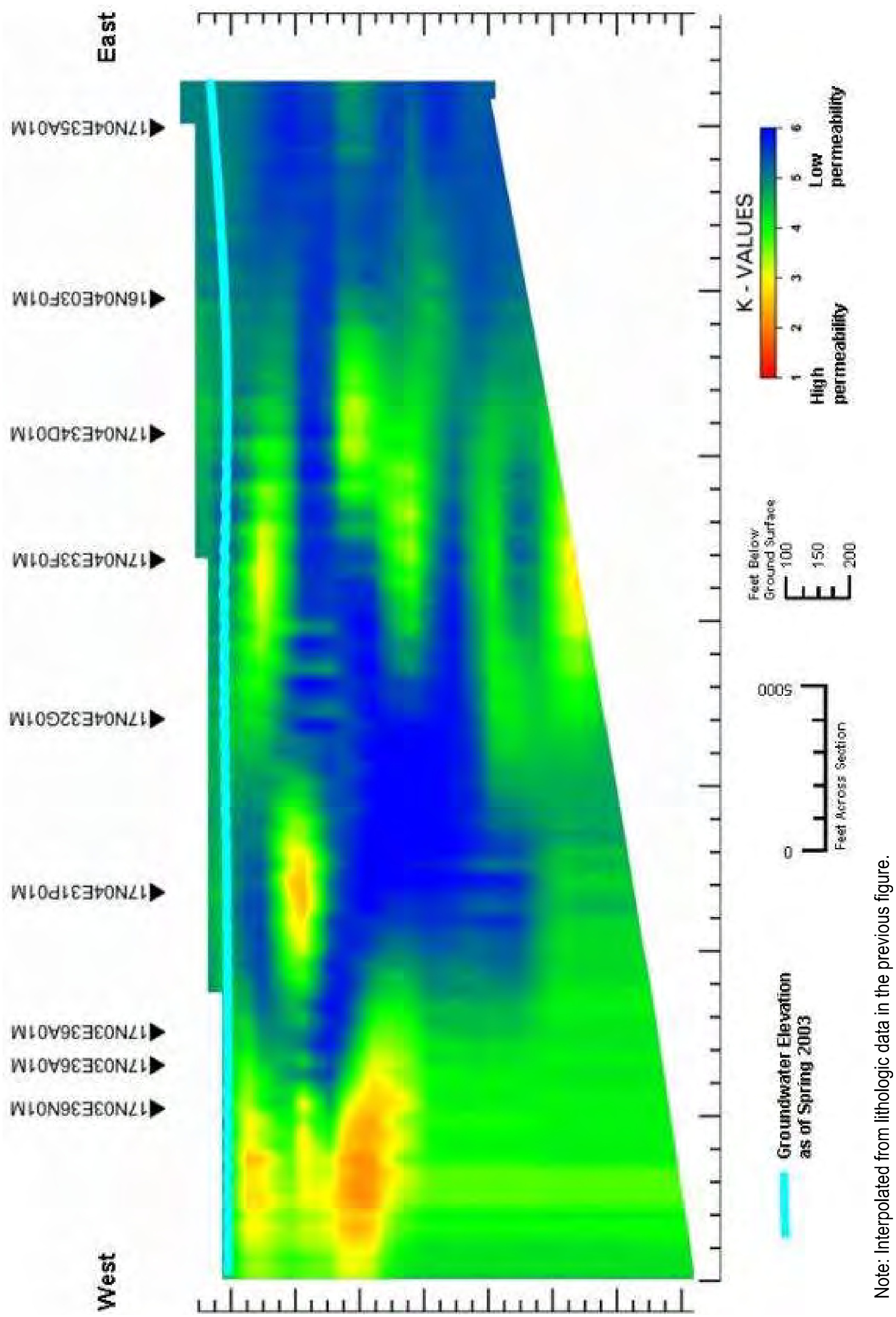
Source: YCWA, 2008

Figure 2-19: Lithologic Cross Sections



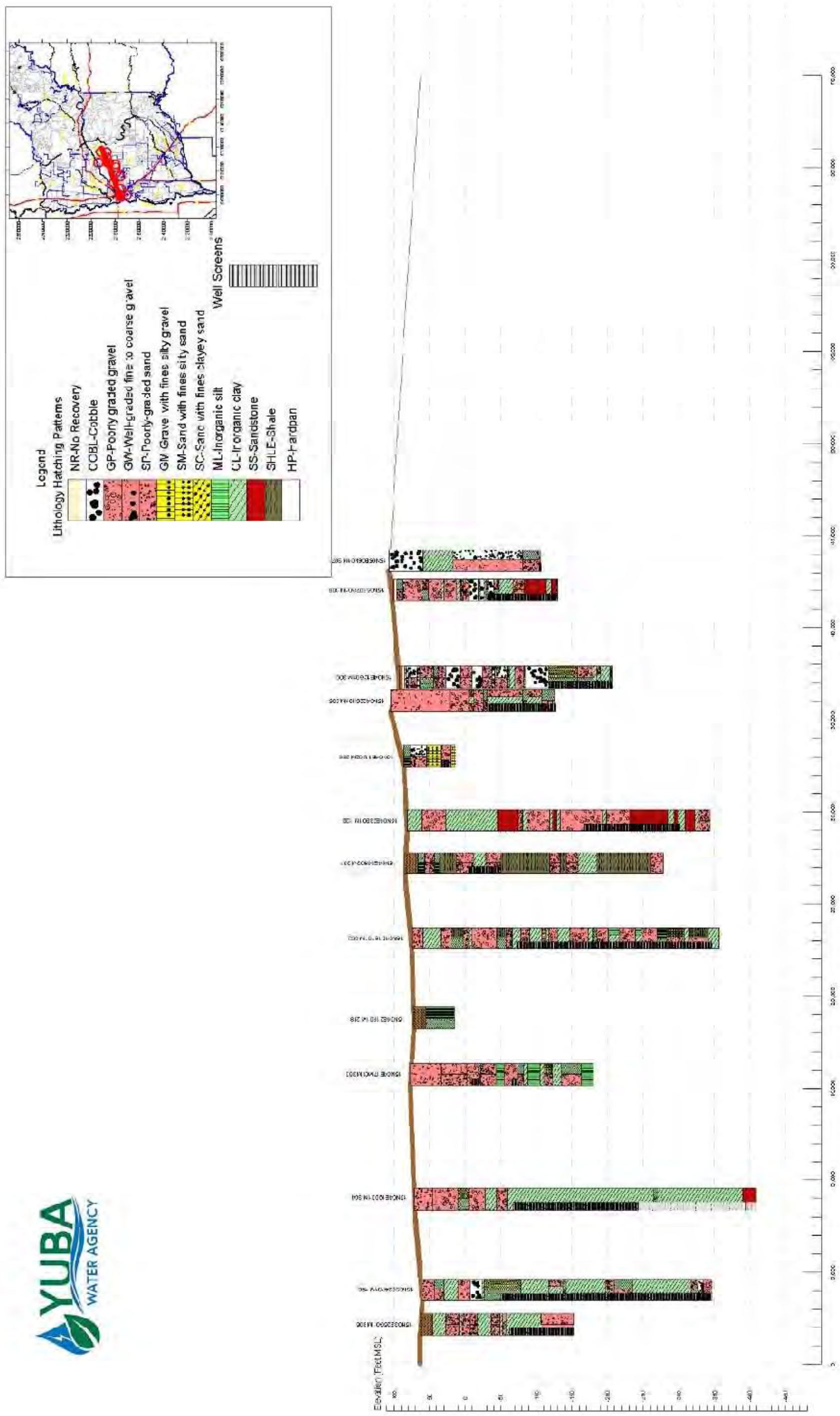
Source: YCWA, 2008

Figure 2-20: Lithologic Data for Cross Section A-A’



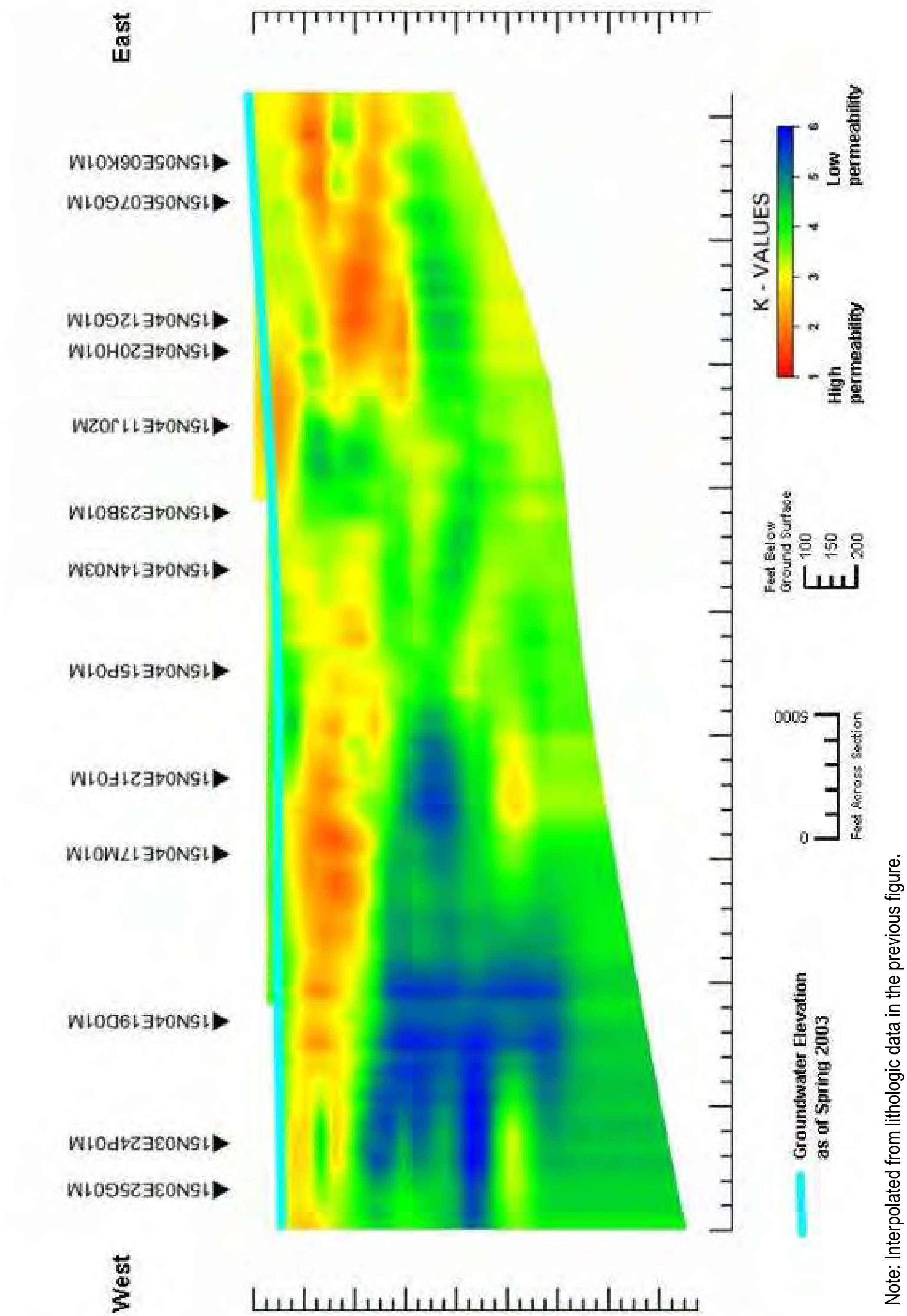
Source: YCWA, 2008

Figure 2-21: Interpolated Conceptual Cross Section A-A'



Source: YCWA, 2008

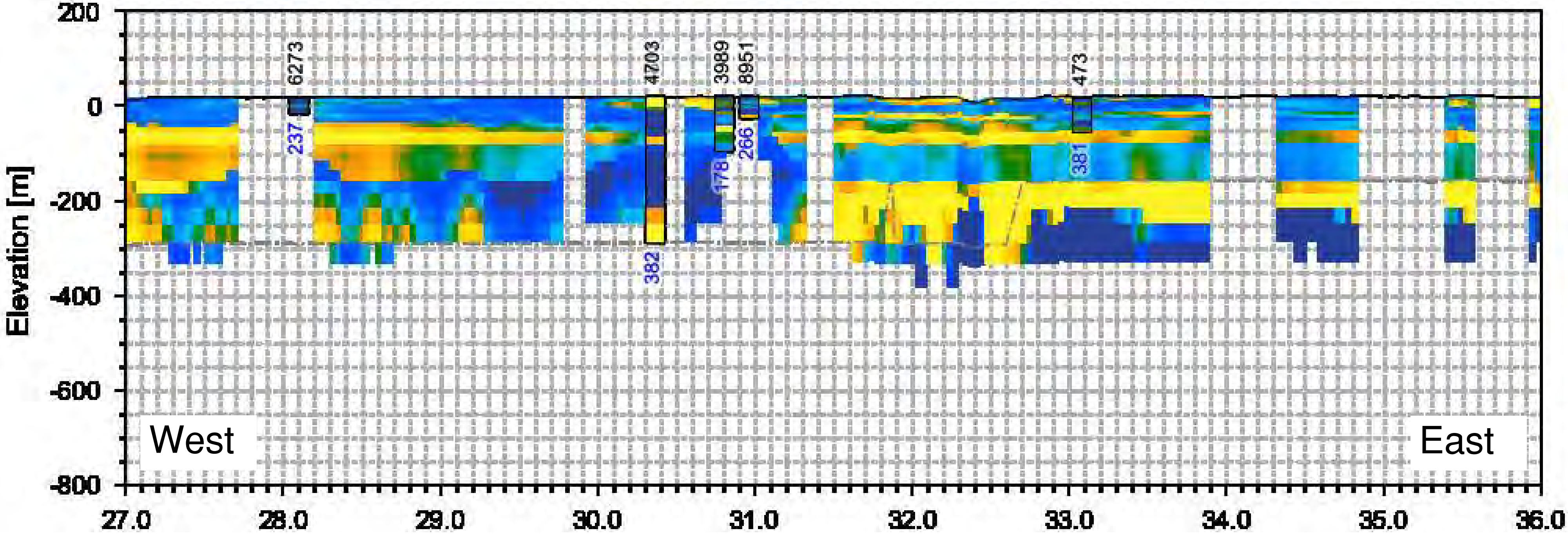
Figure 2-22: Lithologic Data for Cross Section B-B'

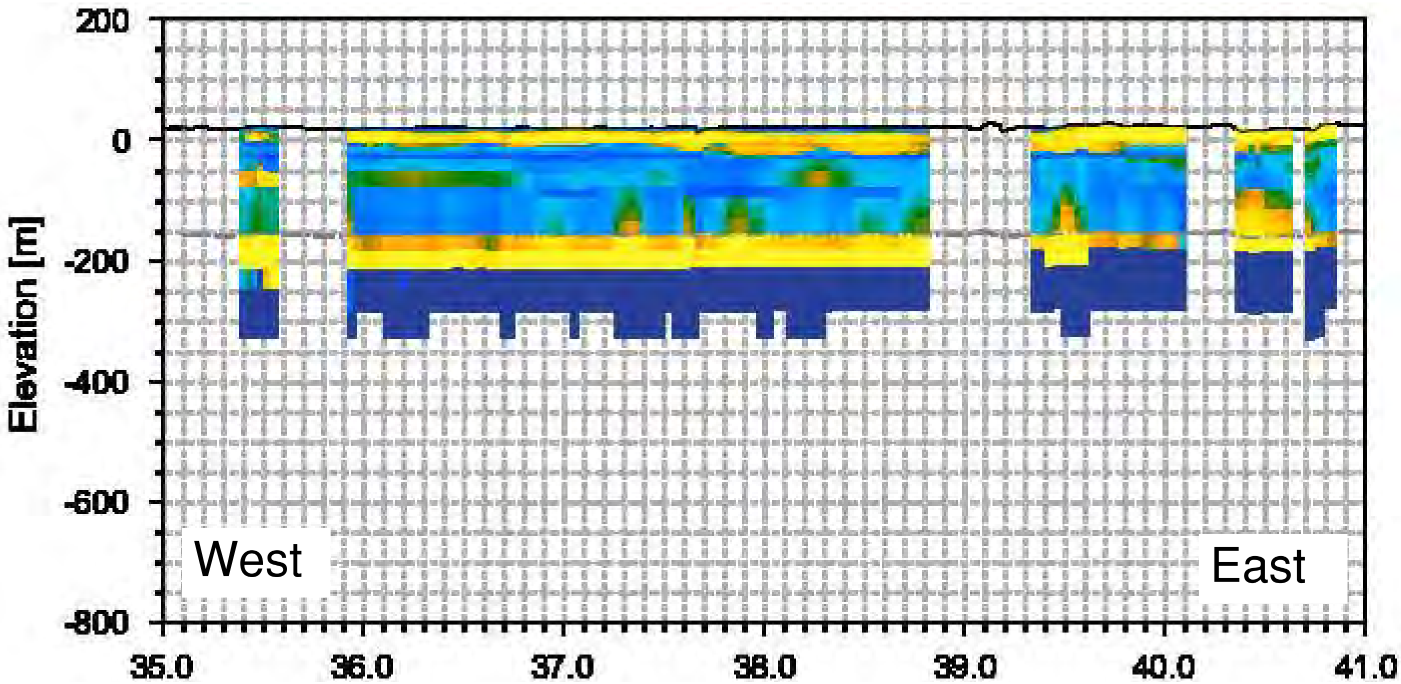


Source: YCWA, 2008

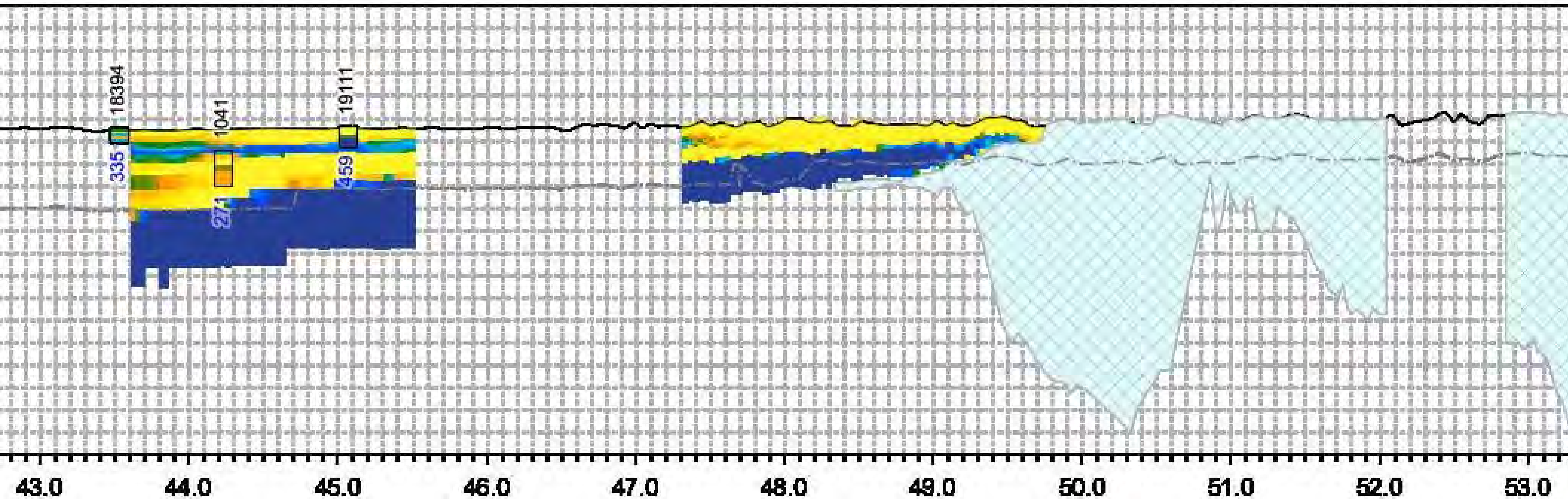
Figure 2-23: Interpolated Conceptual Cross Section B-B’

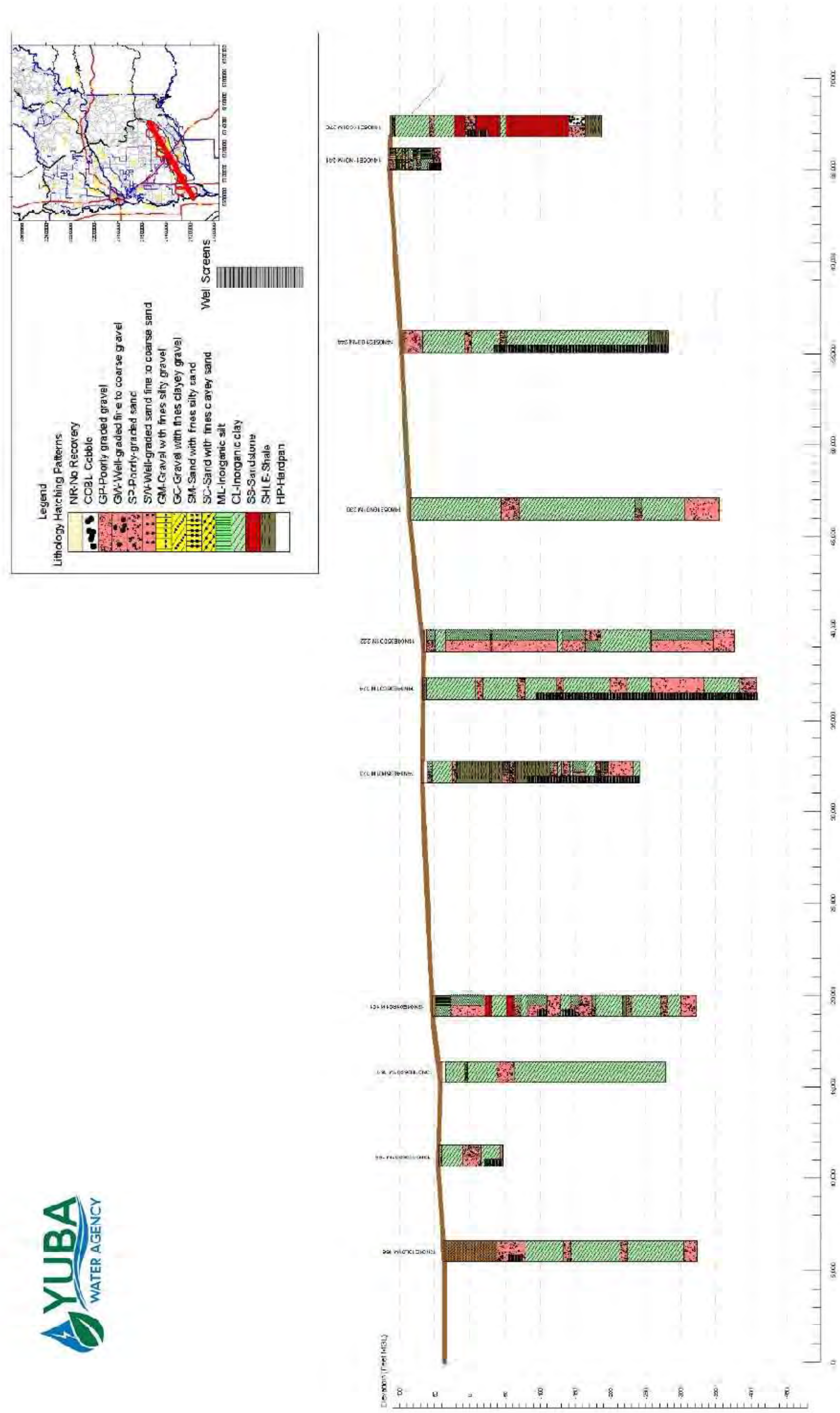
B - B' Nearest AEM Log





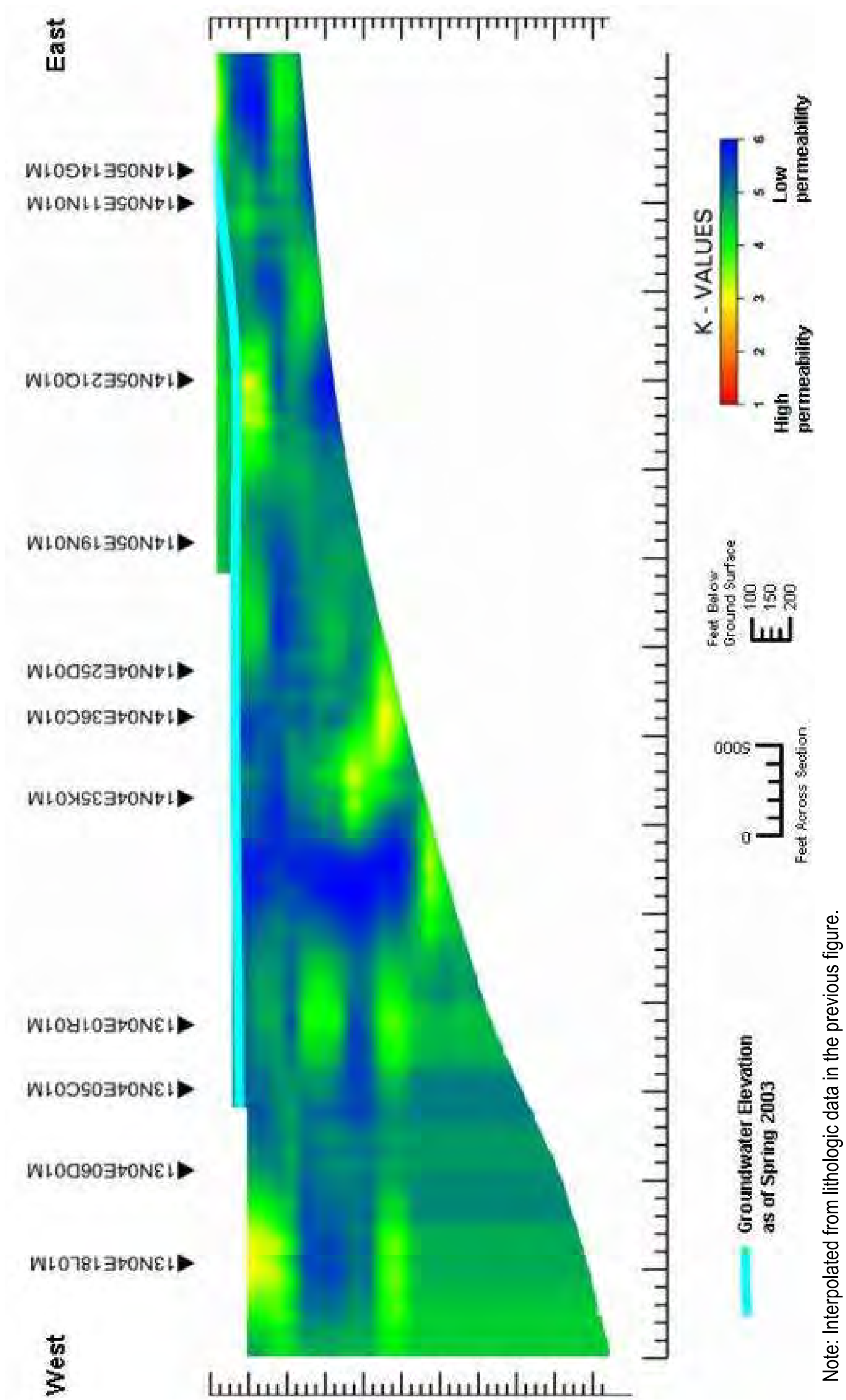
B - B' Nearest AEM Log





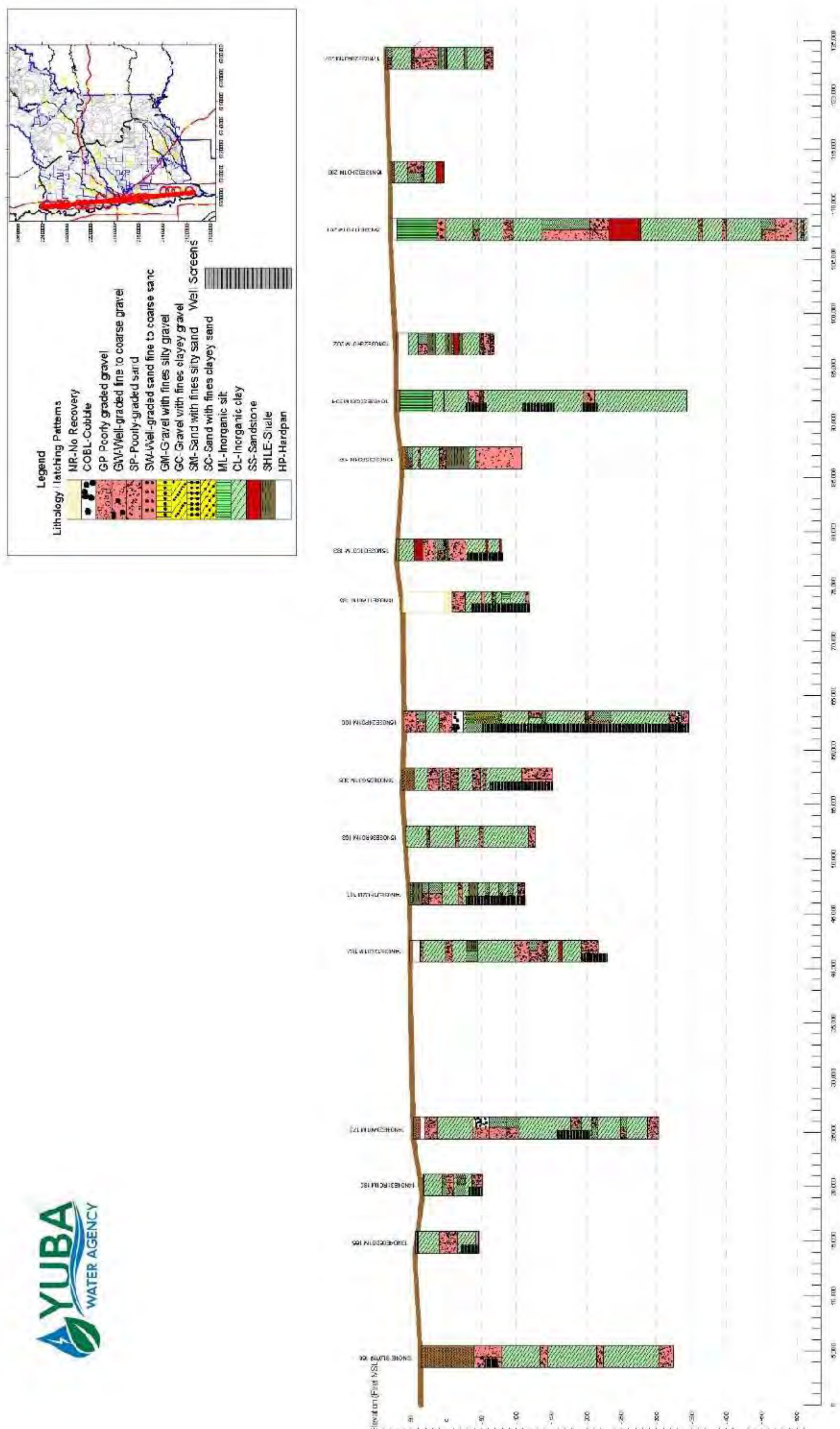
Source: YCWA, 2008

Figure 2-24: Lithologic Data for Cross Section C-C’



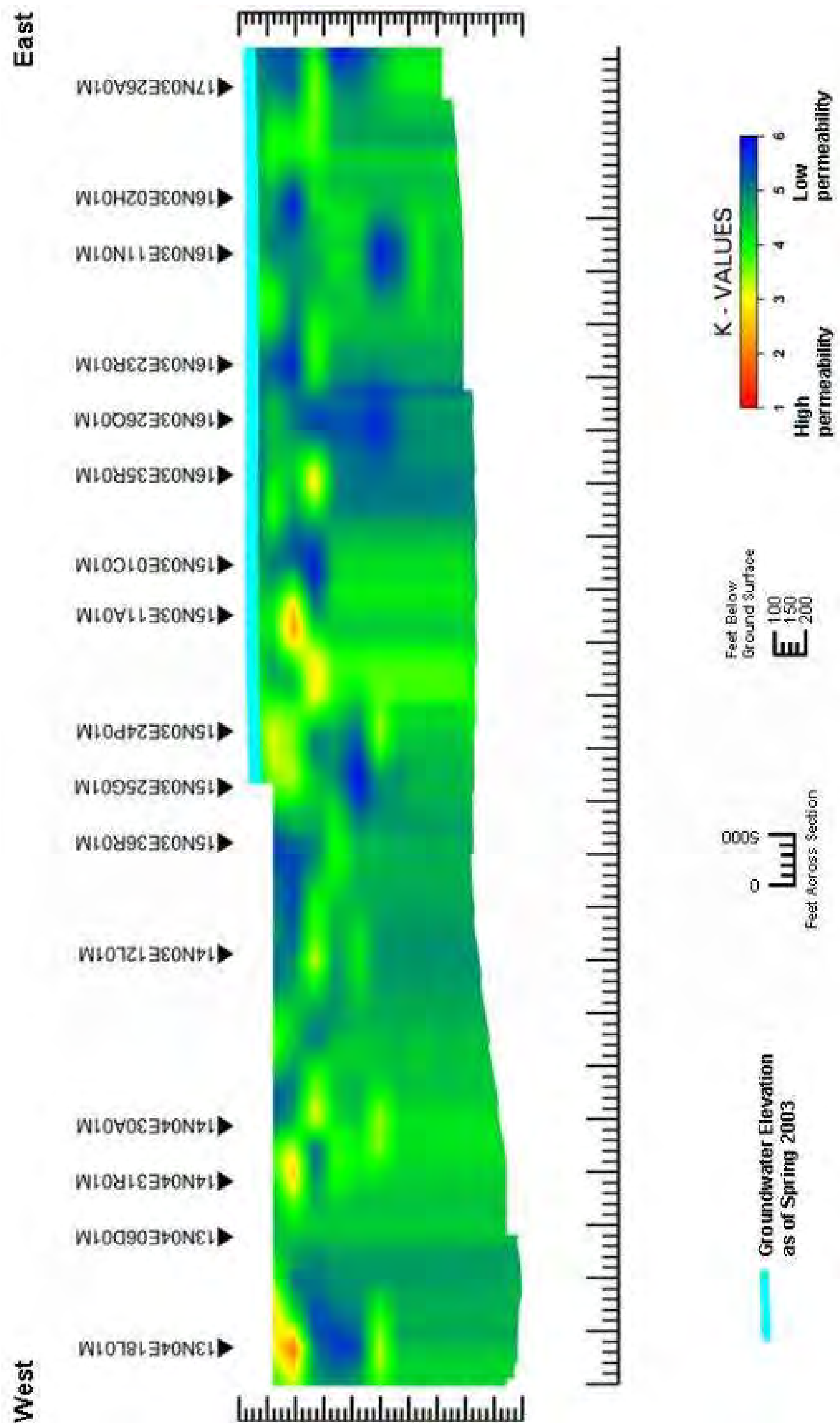
Source: YCWA, 2008

Figure 2-25: Interpolated Conceptual Cross Section C-C'



Source: YCWA, 2008

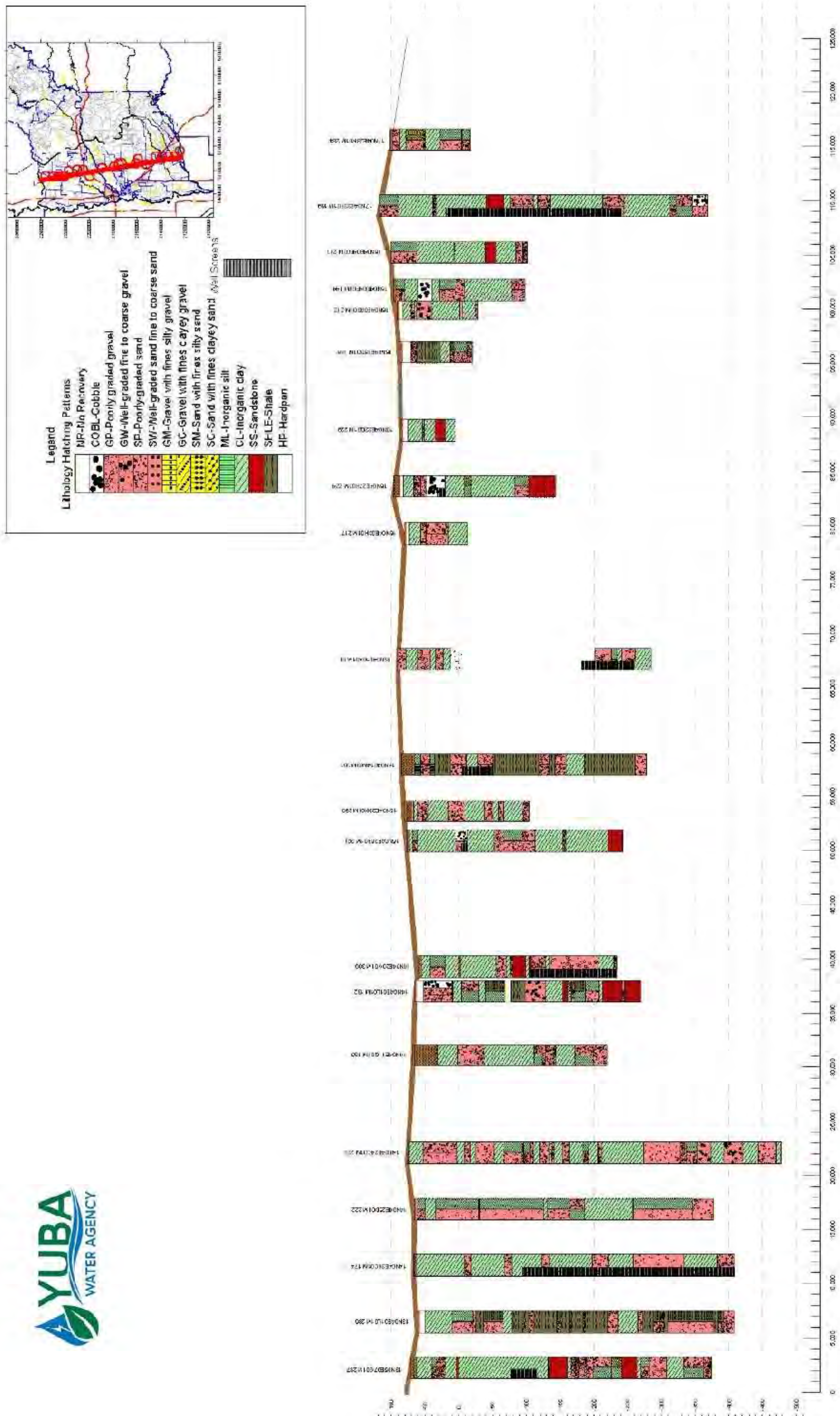
Figure 2-26: Lithologic Data for Cross Section D-D’



Note: Interpolated from lithologic data in the previous figure.

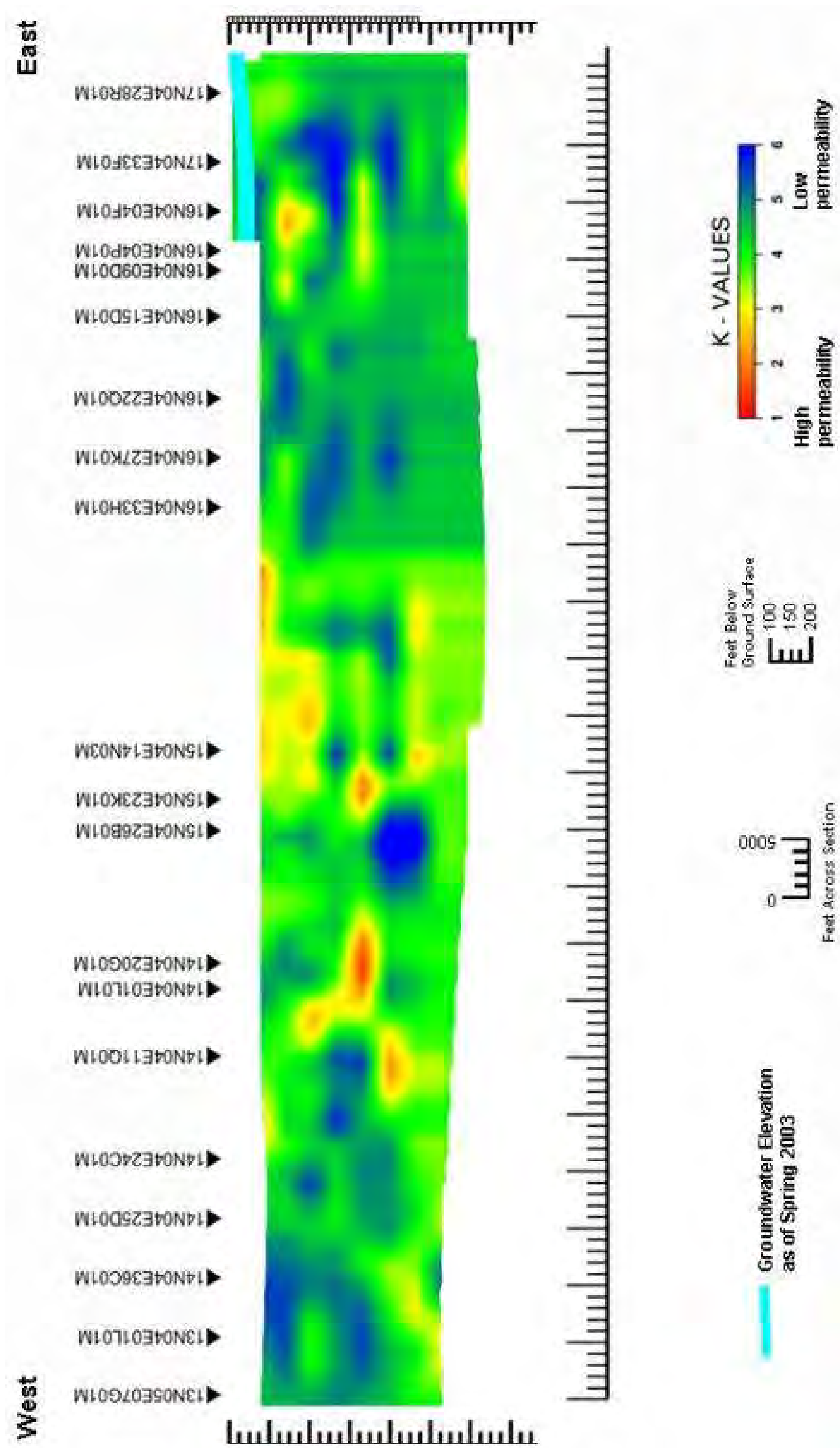
Source: YCWA, 2008

Figure 2-27: Interpolated Conceptual Cross Section D-D'



Source: YCWA, 2008

Figure 2-28: Lithologic Data for Cross Section E-E'

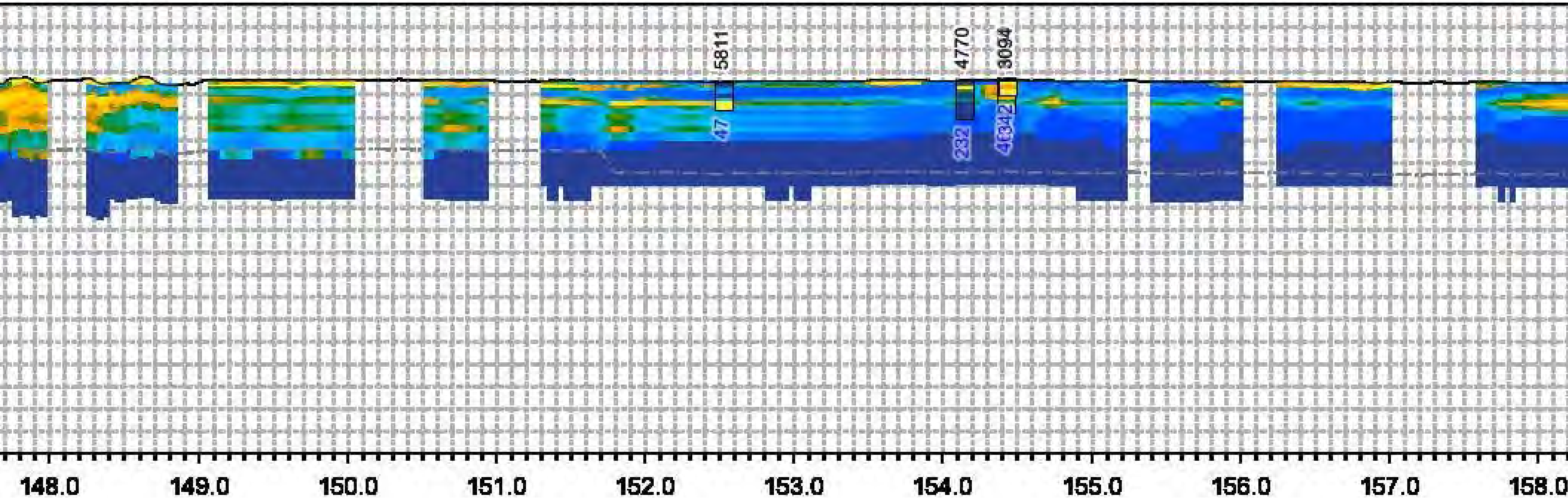


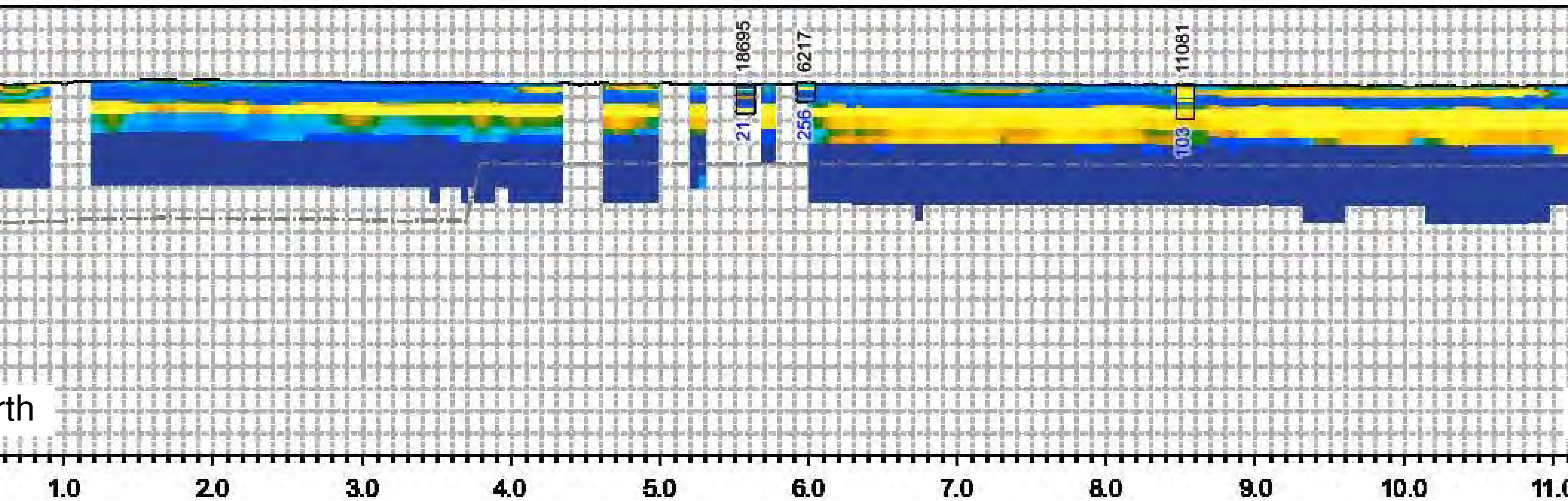
Note: Interpolated from lithologic data in the previous figure.

Source: YCWA, 2008

Figure 2-29: Interpolated Conceptual Cross Section E-E’

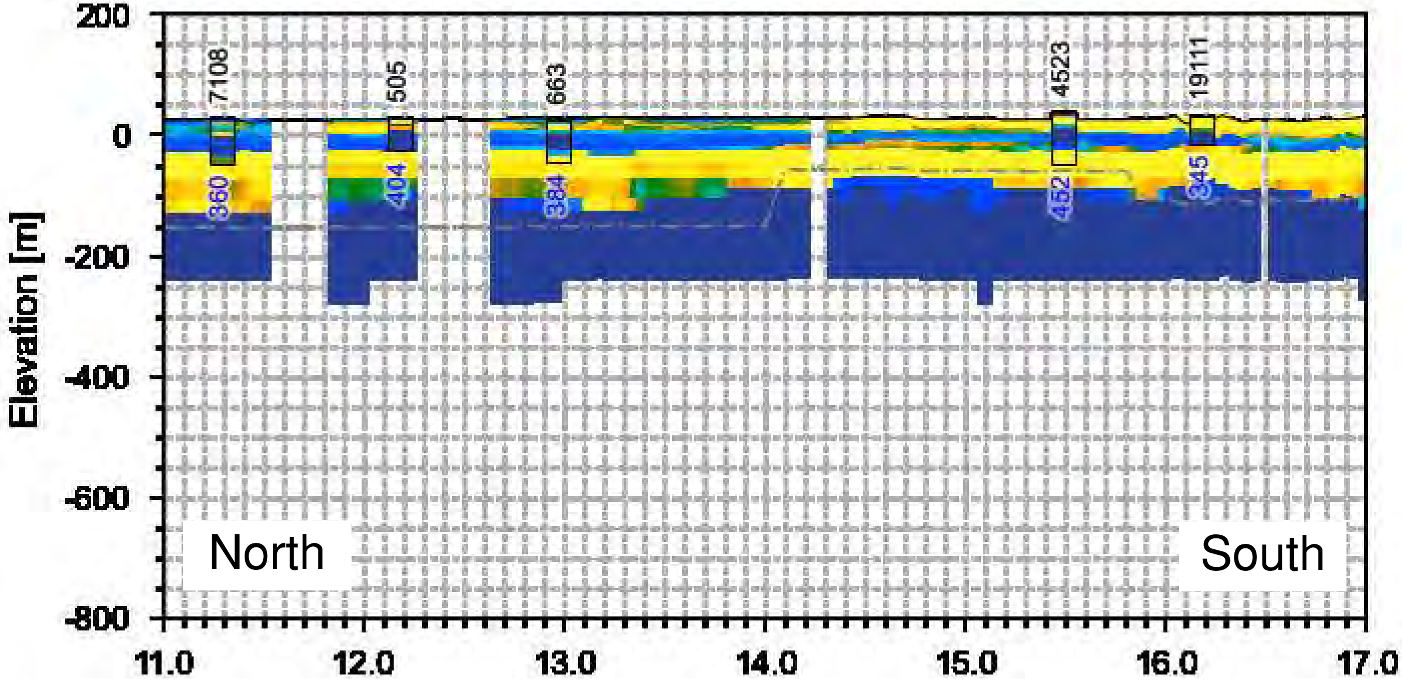
E - E' Nearest AEM Log

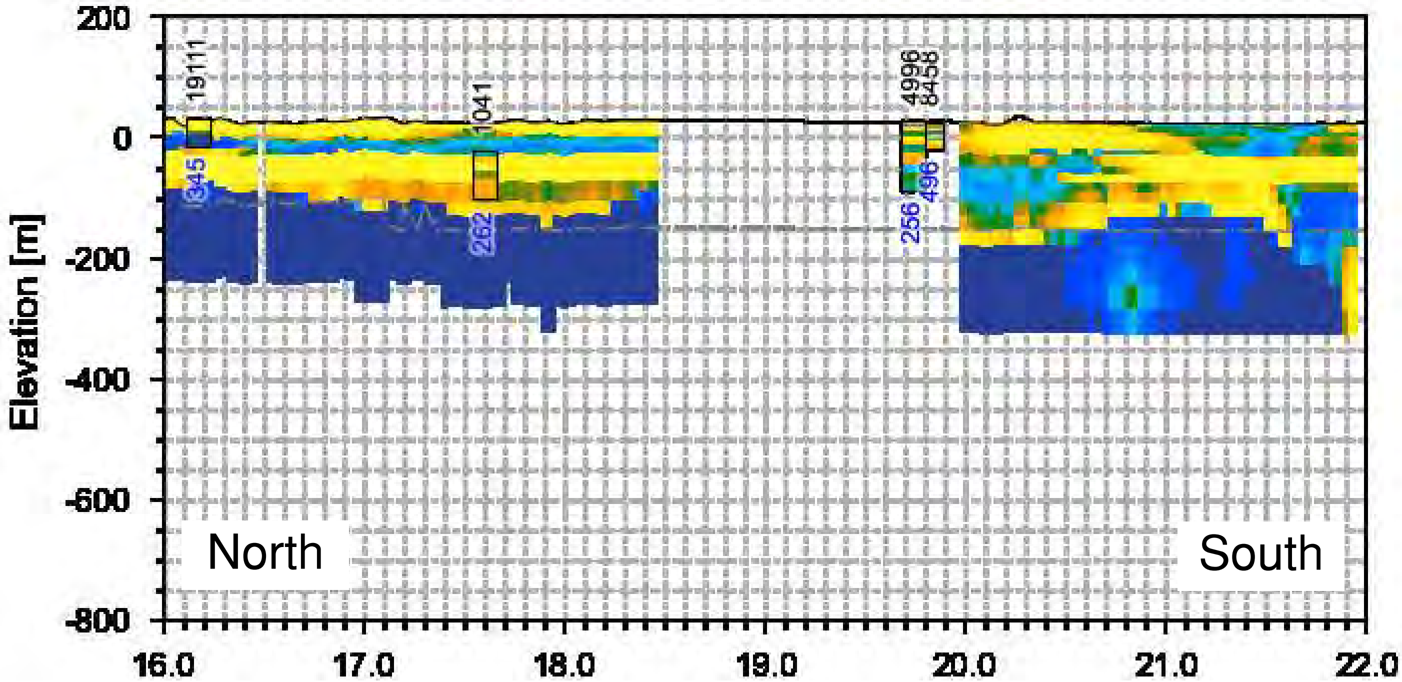




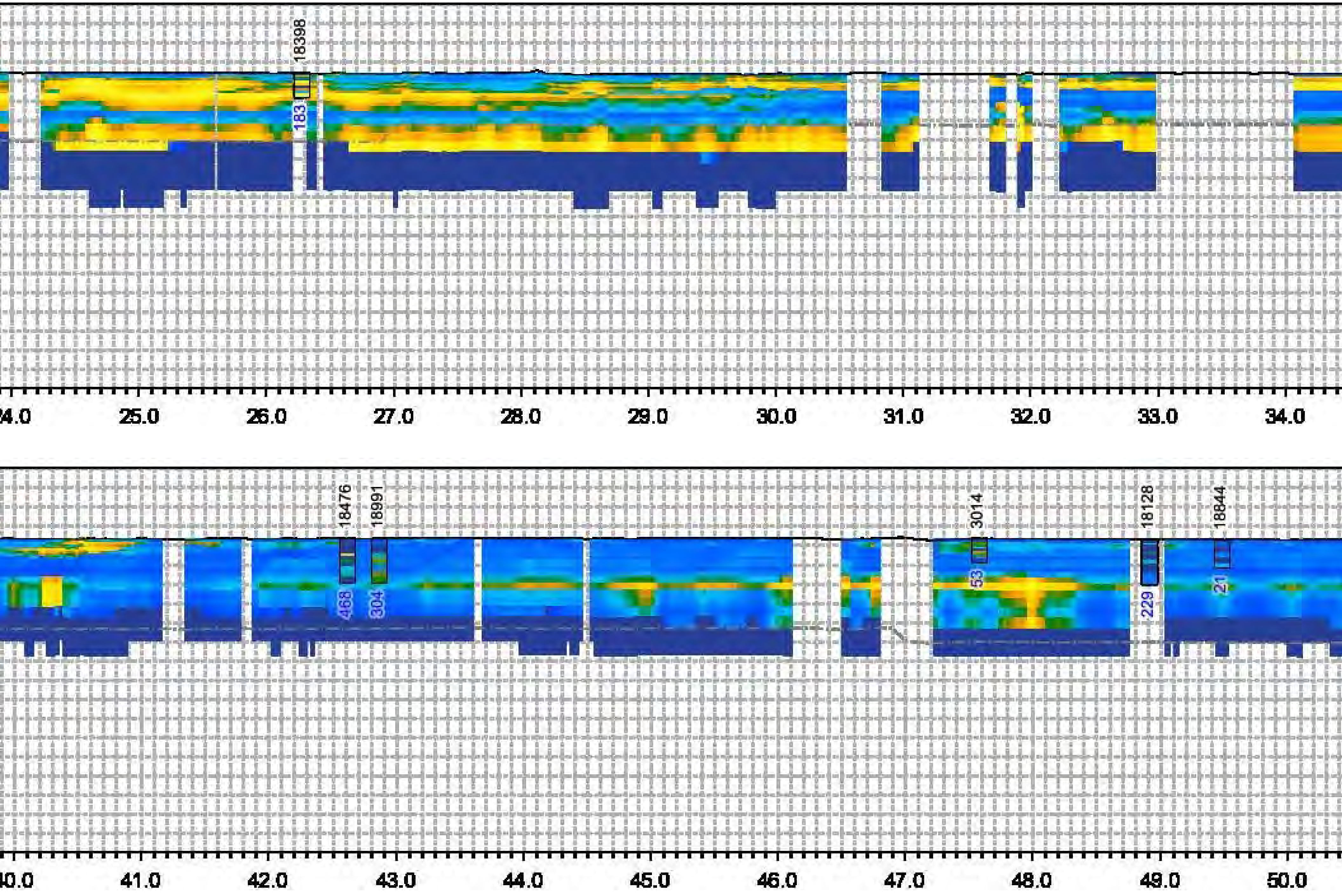
This AEM log is NOT continuous with the previous AEM log.

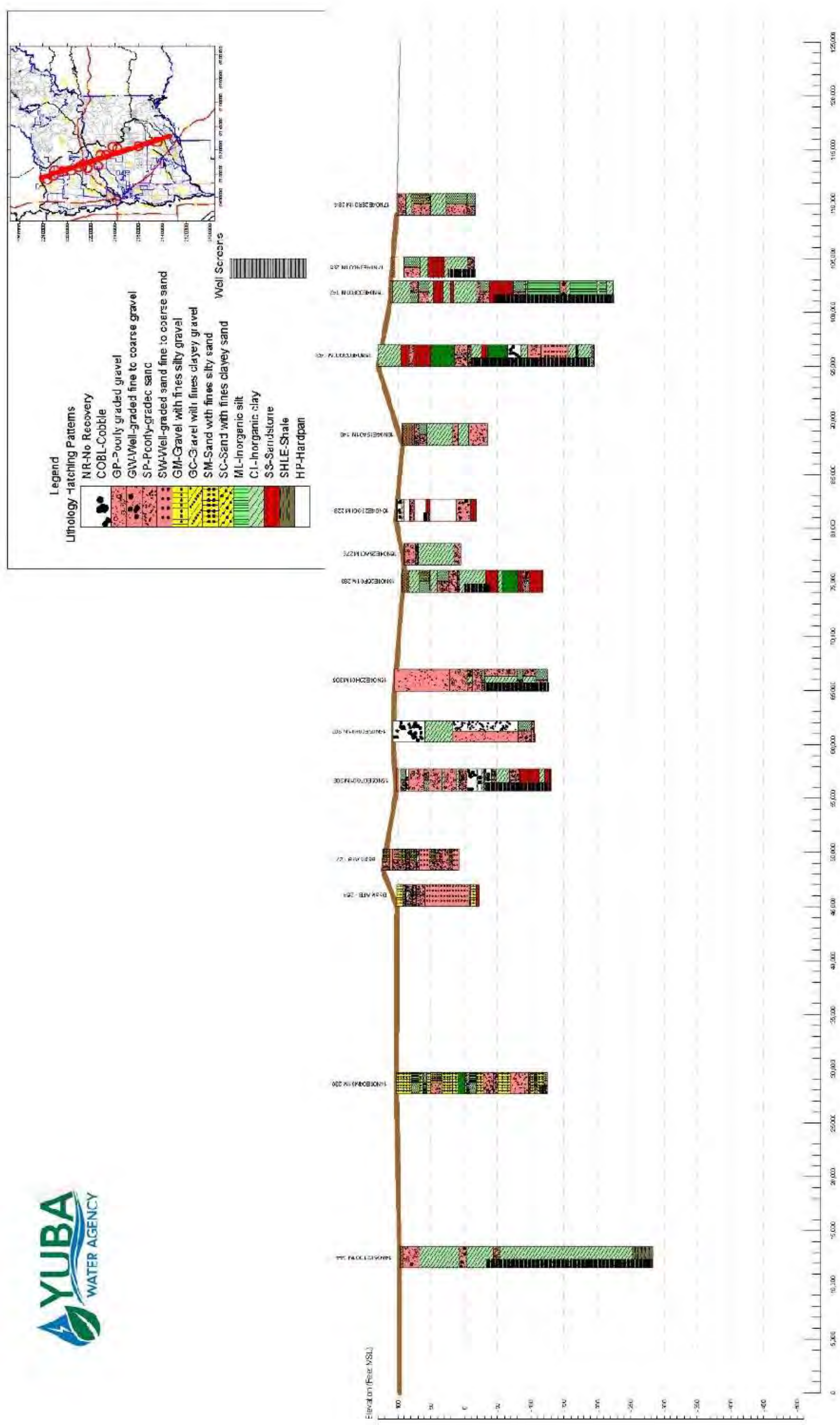
E - E' Nearest AEM Log





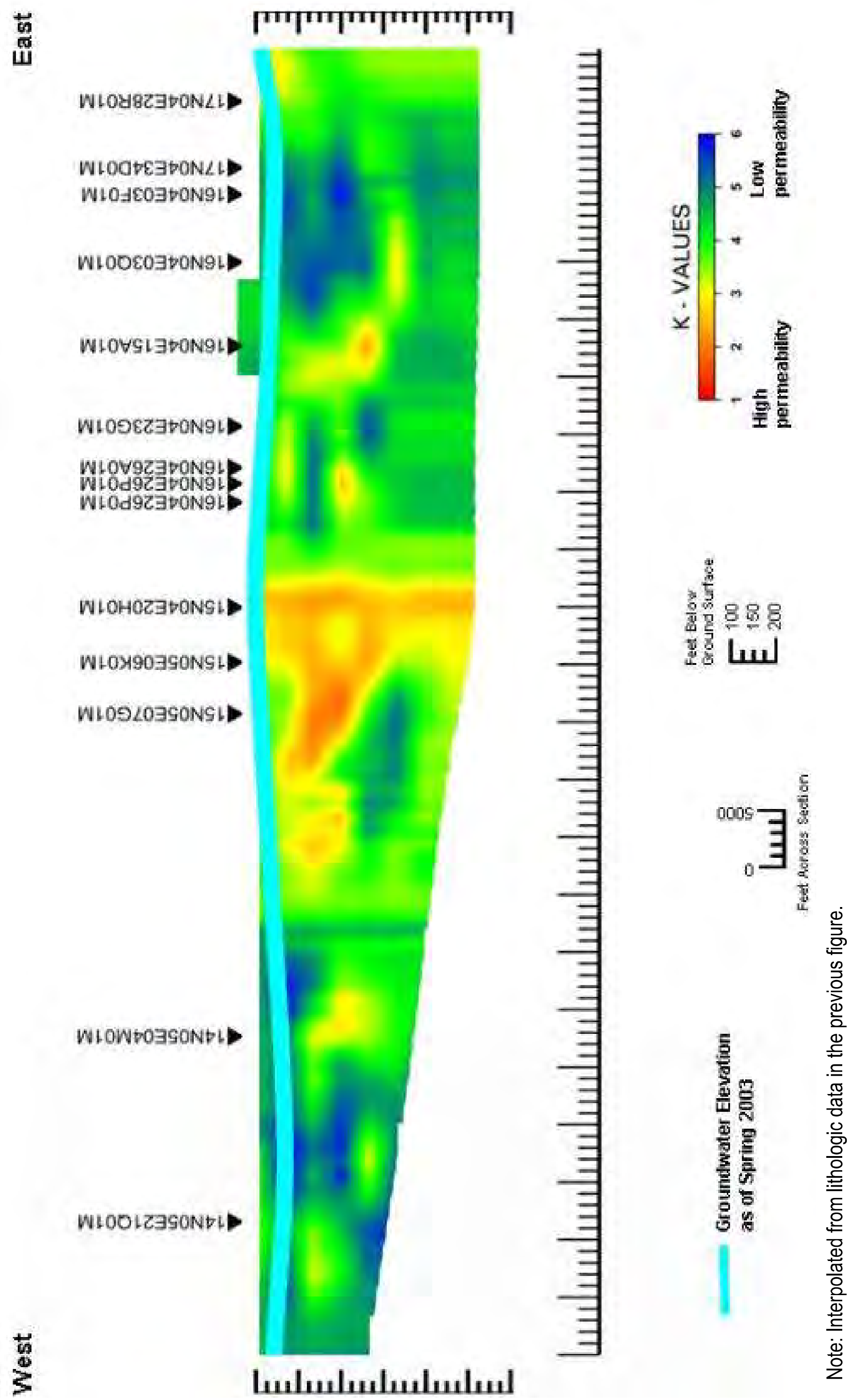
E - E' Nearest AEM Log





Source: YCWA, 2008

Figure 2-30: Lithologic Data for Cross Section F-F’



Source: YCWA, 2008

Figure 2-31: Interpolated Conceptual Cross Section F-F’

Yuba Subbasins, north of Yuba City, one data point suggests a significantly shallower BFW (-378 ft msl), possibly related to subsurface structure or possibly an outlier, as surrounding wells typically have a BFW closer to -1,000 ft msl.

The BFW surface appears to be above Eocene marine strata and is currently within Pliocene to Miocene continental deposits. This is most likely caused by high artesian pressures and upward vertical gradients in deep aquifers in the subbasins, which have been documented in the DWR Yuba River Monitoring well (DWR, 2007b, as cited in YCWA, 2008). This suggests that migration of poor-quality water into continental sediments that previously contained freshwater has occurred over geologic time. Based on water chemistry data, the brackish water in the lower part of aquifers near the BFW is classified as sodium-chloride type water. The presence of brackish water in the deeper aquifer combined with upward vertical gradients presents the potential for upward migration of brackish water into overlying freshwater aquifers, or upconing beneath areas of pumping. Prolonged groundwater extraction in these areas may result in regional water quality degradation and may ultimately reduce the thickness of the fresh groundwater aquifers in the Yuba Subbasins.

2.2.1.9 Principal Aquifers and Aquitards

One principal aquifer exists across the Yuba Subbasins. The aquifer consists of the Riverbank, Laguna, and Mehrten formations deposited during the Miocene to Pliocene. There are no known structural properties that significantly restrict groundwater flow within the Yuba Subbasins within the portion of the aquifer that stores, transmits, and yields significant quantities of water.

It is noted that there are vertical gradients in the subsurface, largely between the shallow subsurface and the deeper portions of the aquifer (see **Section 2.2.2.1.3**). It is further noted that significant clays and restrictive units in the shallow subsurface are present and that these features support the ability to pond water for rice cultivation and likely yield water to surface water bodies or environmental uses of water. However, this shallow system is thin and not thought to store, transmit, and yield significant quantities of water, and is thus not a principal aquifer as defined by SGMA. The deeper portion of the aquifer is the principal aquifer. DWR defines "principal aquifers" under SGMA as the "aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems" (Cal. Code of Regs., title 23, § 351(aa)).

2.2.1.9.1 Primary Uses

Water produced from the principal aquifer is primarily used to meet irrigation, domestic, and municipal water demand. Domestic and municipal supply is largely used to meet demand from cities and towns such as Marysville, Wheatland, and Olivehurst. Beale AFB uses groundwater to meet about half of its operational demand (ACC, 2012).

2.2.1.9.2 Storage Coefficient

The storage coefficient of an aquifer is defined as the volume of water yielded per unit surface area per unit change in water levels (Fetter, 1994 as cited in YCWA, 2008). For an unconfined aquifer, as is the situation in the majority of the upper portion of the Yuba Subbasins along the eastern boundary, the storage coefficient is equal to specific yield, which is the ratio of volume of water released from a unit volume of saturated aquifer material drained by a falling water table compared to the total volume of the aquifer material, typically expressed as a percentage.

Based on the previous investigation, the average specific yield in the South and North Yuba Subbasins was estimated to be 6.9 and 6.8 percent, respectively (Bookman-Edmonston Engineering Inc., 1992 as cited in YCWA, 2008). Although average specific yields for the subbasins are similar, a wide variation was found. The highest specific yields, ranging from 10 to 12 percent, were estimated in the upper zones along the Yuba River. Specific yields are lower on the east side of the South Yuba Subbasin and near Wheatland where the Laguna Formation is either exposed or is at a very shallow depth. Specific yields also decrease with depth.

2.2.1.9.3 Transmissivity

Transmissivity of an aquifer quantifies the ability of an aquifer to transmit water. It is defined as the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. The transmissivity of an aquifer (T) is usually determined from aquifer pumping tests on wells. The aquifer hydraulic conductivity (K) quantifies the rate of groundwater flow and is related to the transmissivity and aquifer thickness (b) by the following formula: T = K x b. Estimated transmissivity for the majority of the North Yuba Subbasin is approximately 260,000 gallons per day per foot (gpd/ft) of aquifer width or 34,800 square feet per day (ft^2/day). A higher estimate of 390,000 gpd/ft, or 52,100 ft^2/day, was reported for the western border of the study area along the Feather River (Bookman-Edmonston Engineering Inc., 1992 as cited in YCWA, 2008).

The hydraulic conductivity of subsurface materials was also characterized by the HUR along the six lithologic cross sections. Materials with similar hydraulic properties were grouped into six categories ("K-classes"). **Table 2-7** presents the categories.

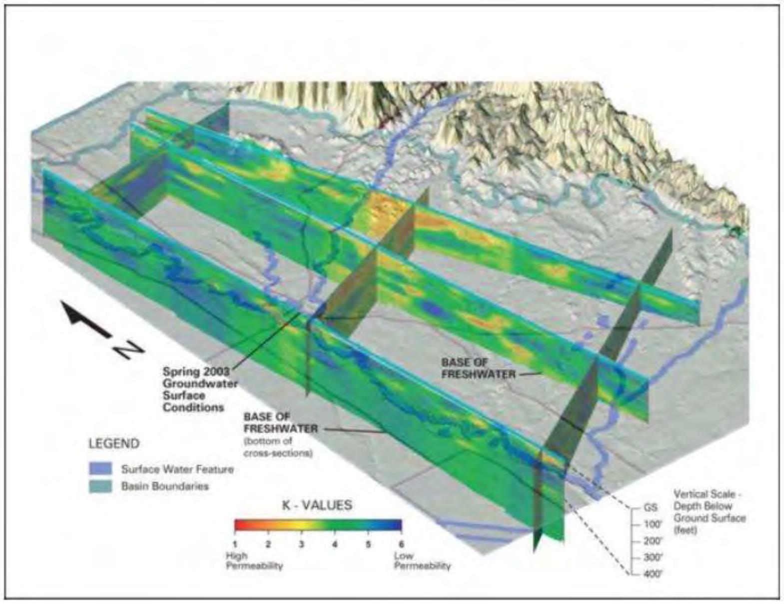
Table 2-7: Lithologic Classification System Used by HUR for Yuba Subbasin Lithologic Data

K-Class	Description of Lithologies
1	Coarse sand and bigger gravel, cobble
2	Sand and smaller gravel, coarse to fine gravel, conglomerate
3	Coarse to fine sand, silty sand, fractured lithified rock
4	Sandy clay, clayey gravel, silty gravel
5	Gravel with fines, sand with fines, sandy silt, clayey sand, clay, silt, sand with shale
6	Clay, shale, sandstone and other lithified material of sedimentary, igneous, and metamorphic origin, crystalline rock, and hardpan

Source: (YCWA, 2008a)

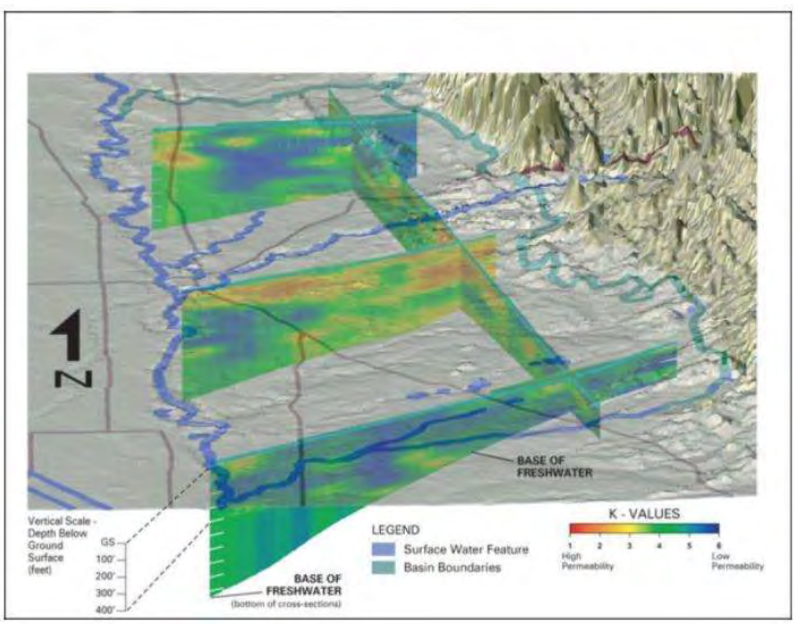
In addition to constructing the six lithologic cross sections, geostatistical methods were employed to capture the quantitative importance of the hydrogeologic features. The same transect lines used for the six cross sections were used to perform kriging interpolation to estimate values of K-classes at locations where K-classes are unknown. The information was displayed using design software that plots the location of known wells and their corresponding lithologic data.

The two figures below show the cross sections created as part of the HUR. The figures show the interpolated hydraulic conductivity distribution through the subbasins from the southwest (**Figure 2-35**) and the south (**Figure 2-36**). The HUR remarks that the overall trend in lithology type is fining westward, with coarse-grained materials in the eastern mountain front regions. Also, along the Feather, Bear, and Yuba rivers, lithologic evidence exists of fluvial deposits, such as cobbles and coarse-grained sand and gravel. Several lenses of interconnected clay with silt, sand, and gravel are located throughout the subbasins and thin out toward the north and south.



Source: (YCWA, 2008a)

Figure 2-35: Interpolated Hydraulic Conductivity Distribution– View from the Southwest



Source: (YCWA, 2008a)

Figure 2-36: Interpolated Hydraulic Conductivity Distribution– View from the South

NORTH AMERICAN SUBBASIN

Groundwater Sustainability Plan

PREPARED FOR:

RD1001 GSA
Sacramento Groundwater Authority GSA
South Sutter Water District GSA
Sutter County GSA
West Placer County GSA

DECEMBER 2021

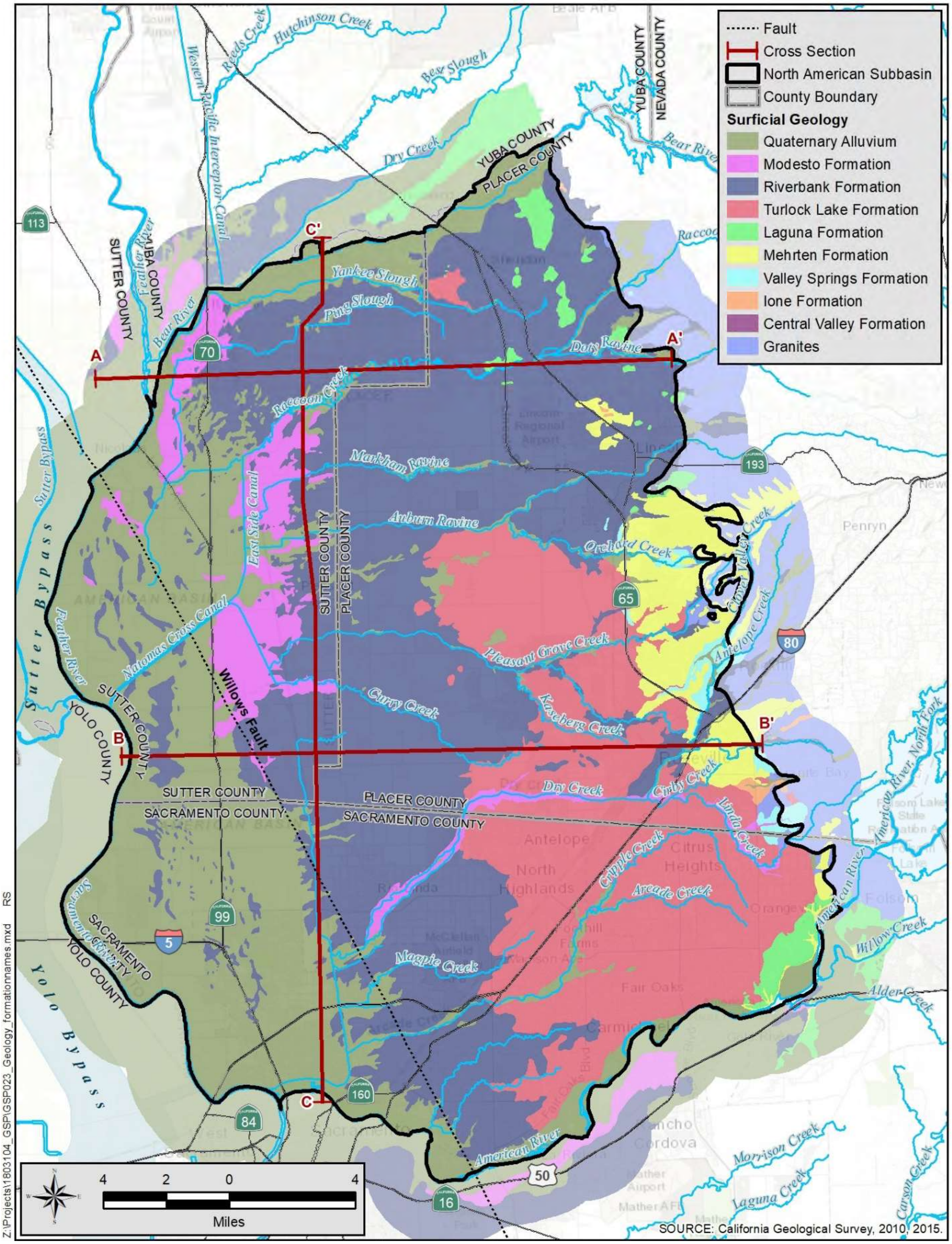
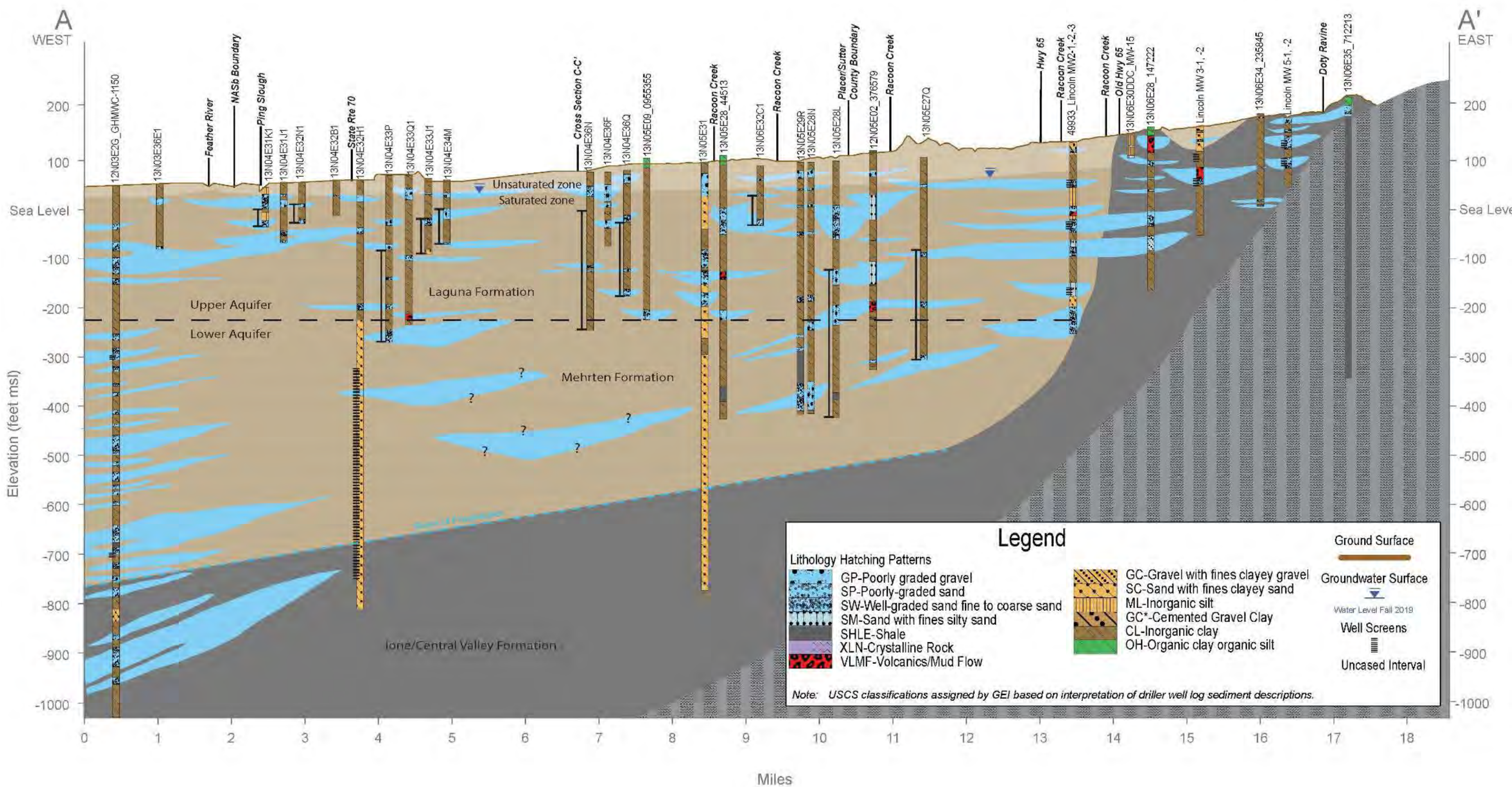


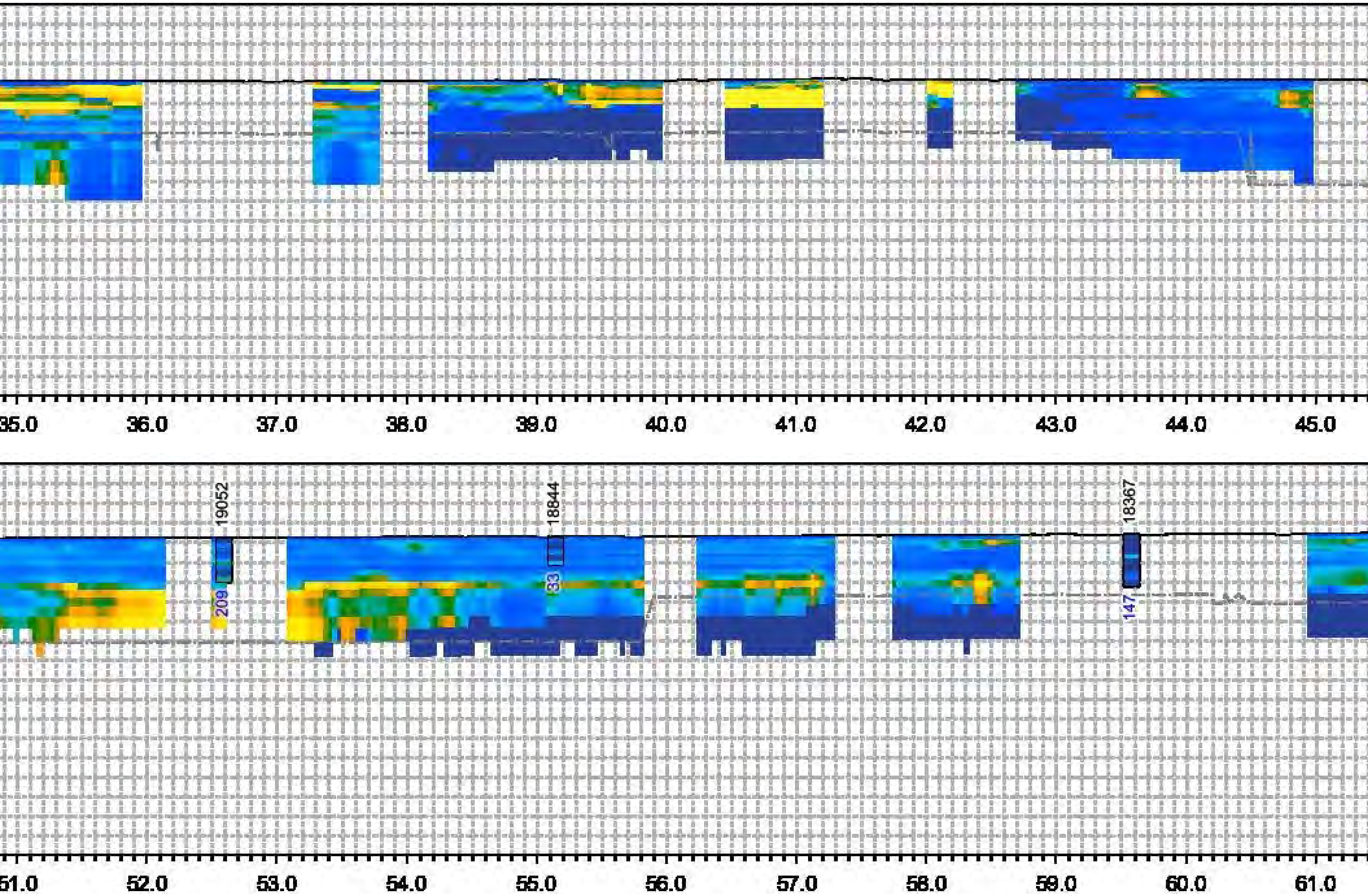
Figure 4-7. Geologic Section Locations



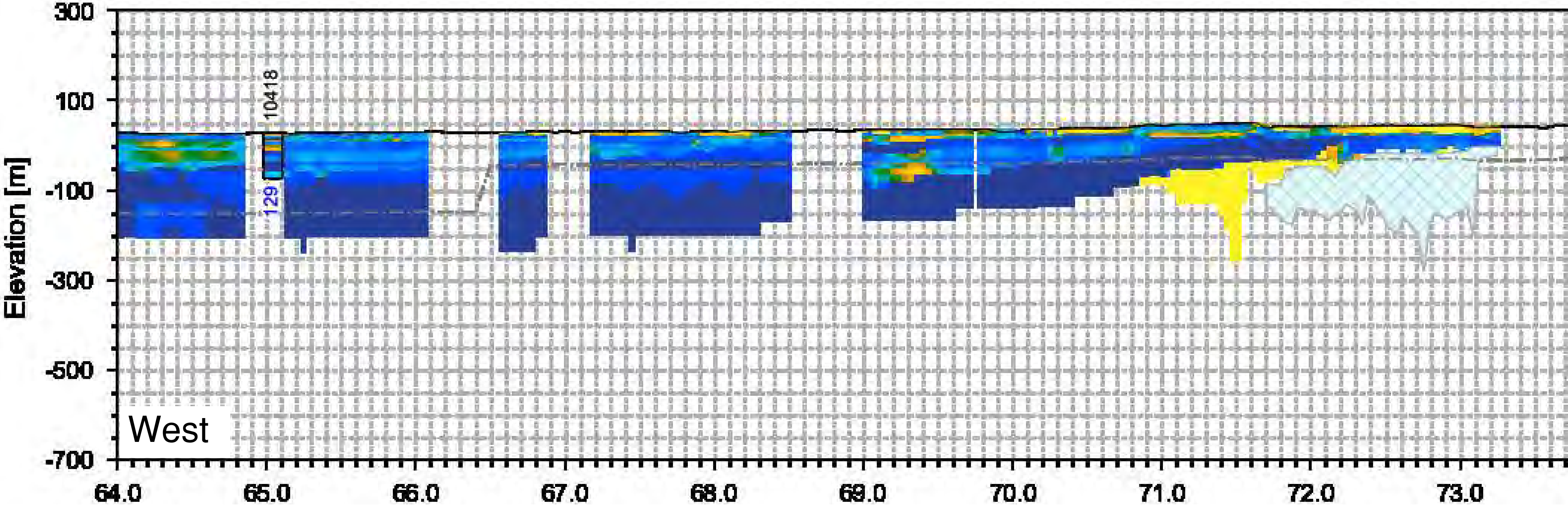
Source: DWR, 1995. Modified by GEI 2019. Berkstresser, 1973.

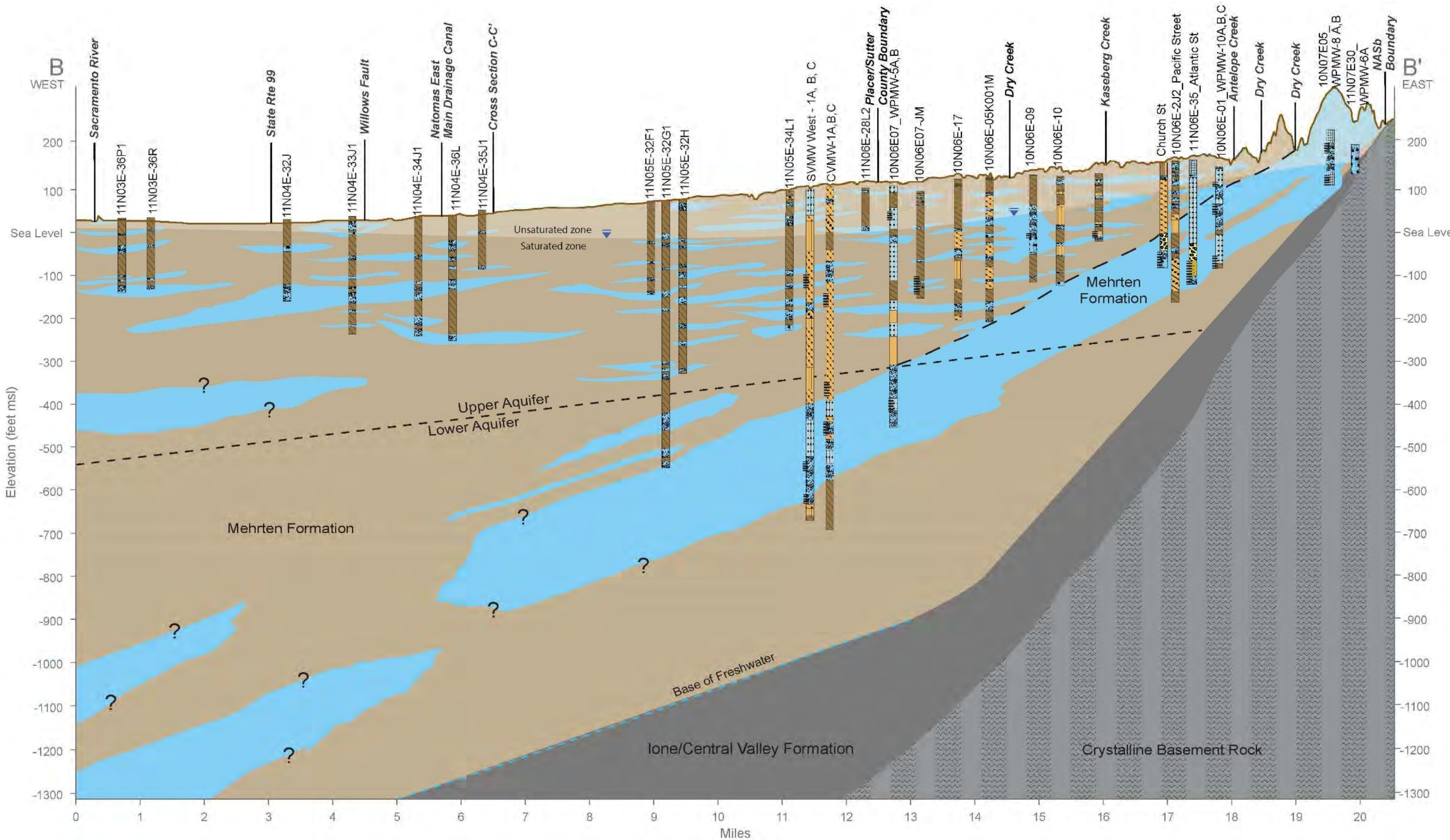
Figure 4-9. Geologic Section A-A'

A - A' Nearest AEM Log



A - A' Nearest AEM Log

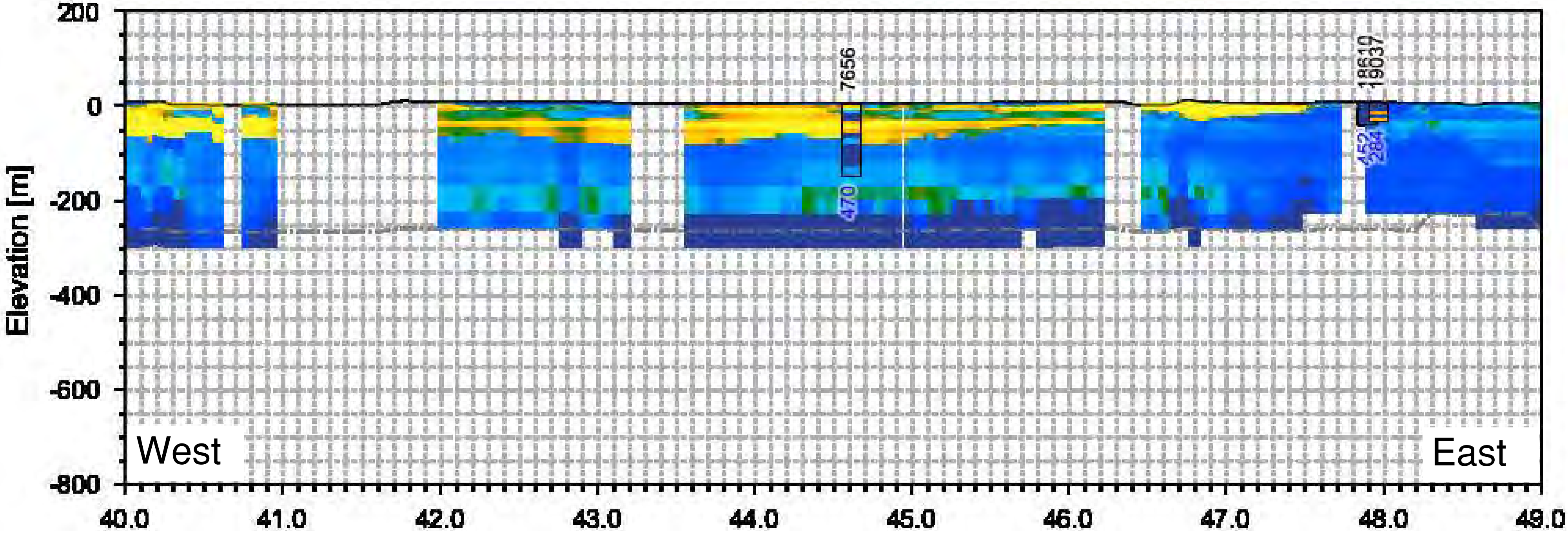


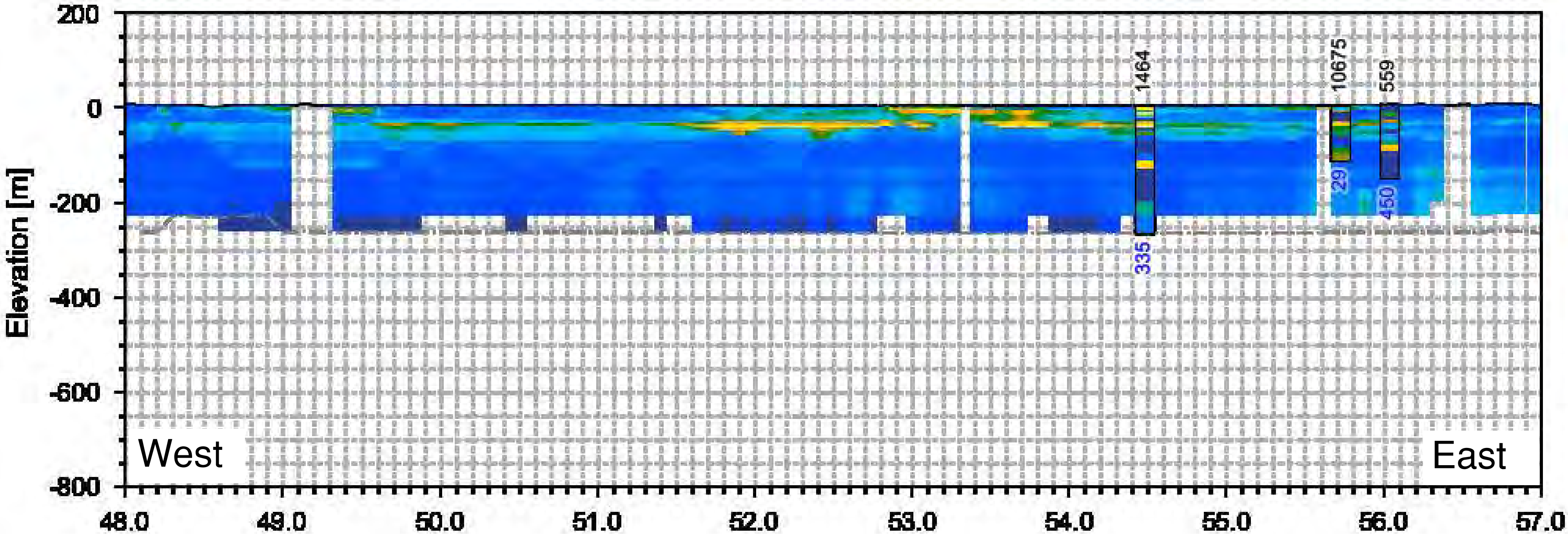


Source: DWR, 1995. Modified by GEI 2019. Berkstresser, 1973.

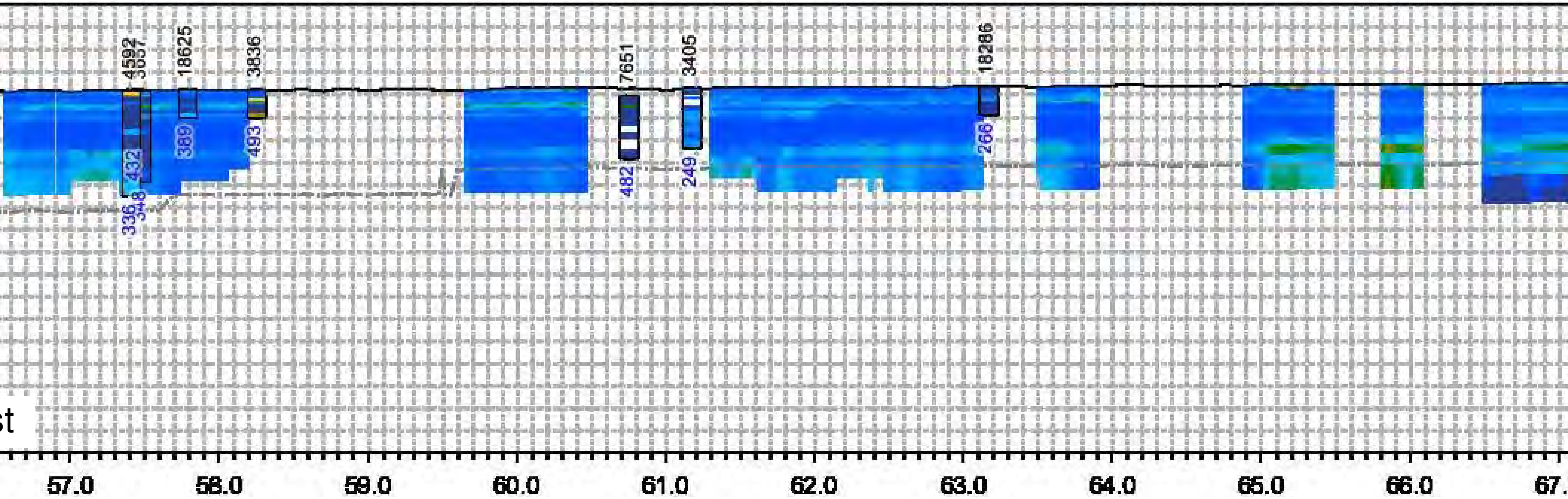
Figure 4-10. Geologic Section B-B'

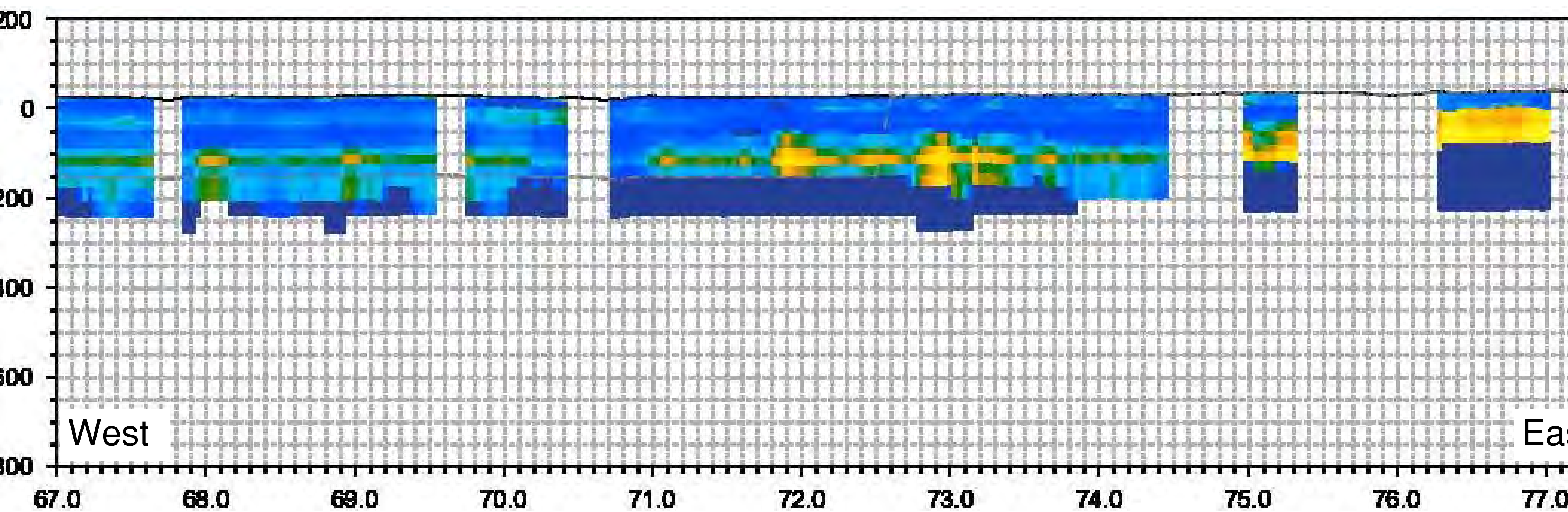
B - B' Nearest AEM Log

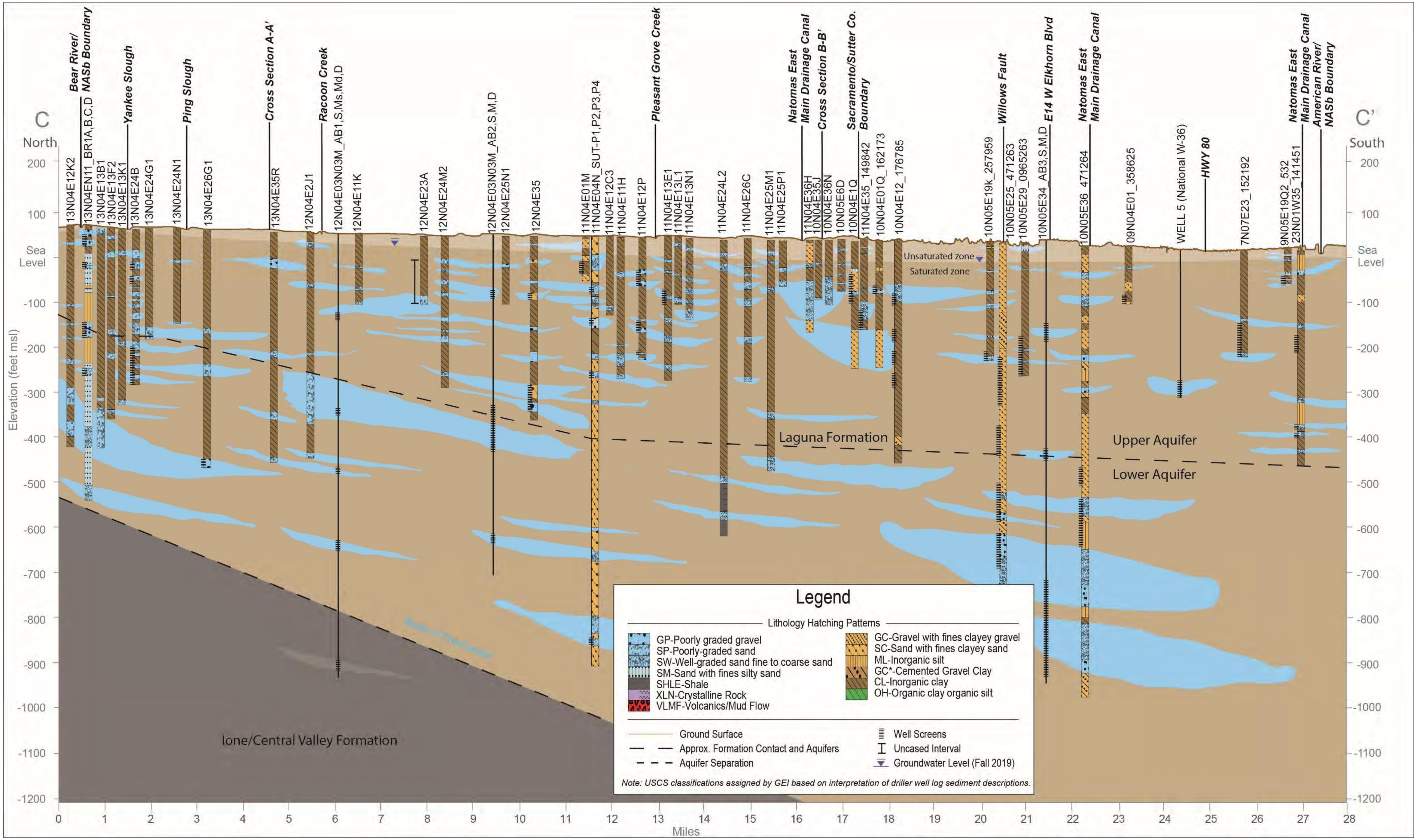




B - B' Nearest AEM Log



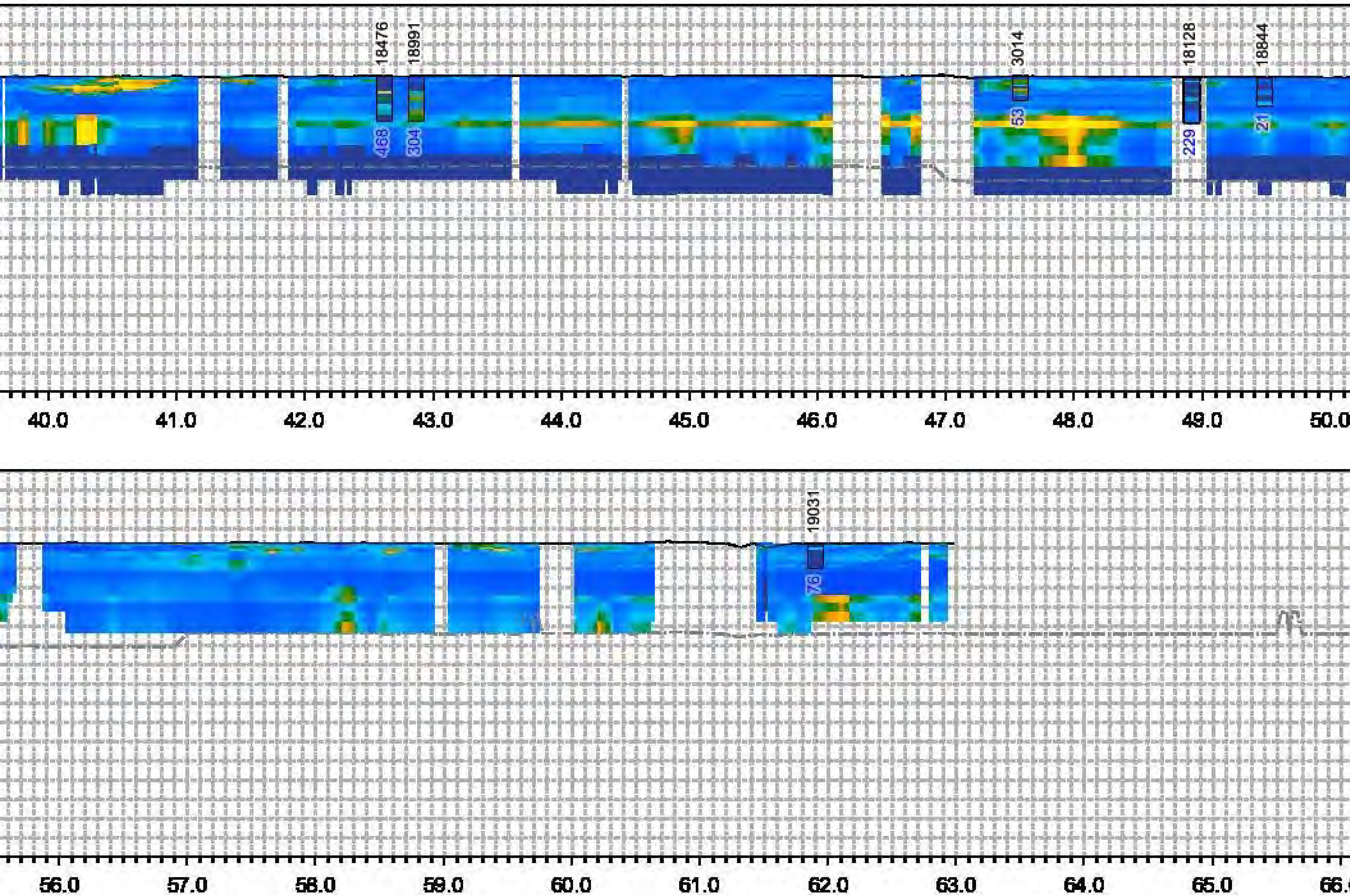




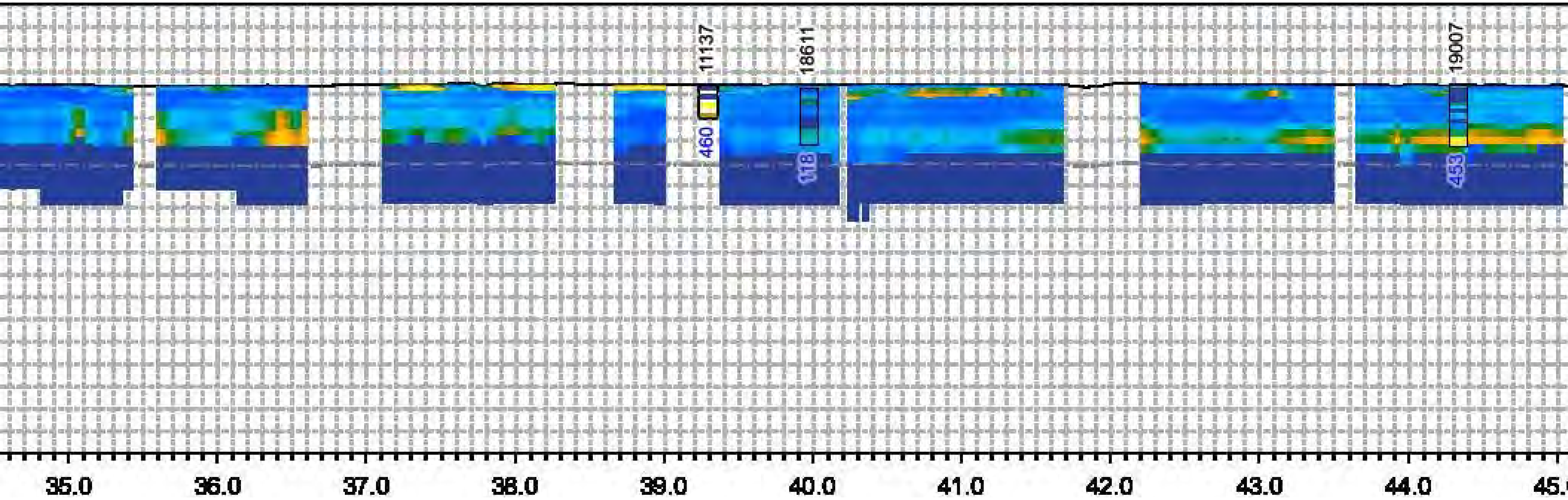
Source: DWR, 1995. Modified by GEI 2019. Berkstresser, 1973.

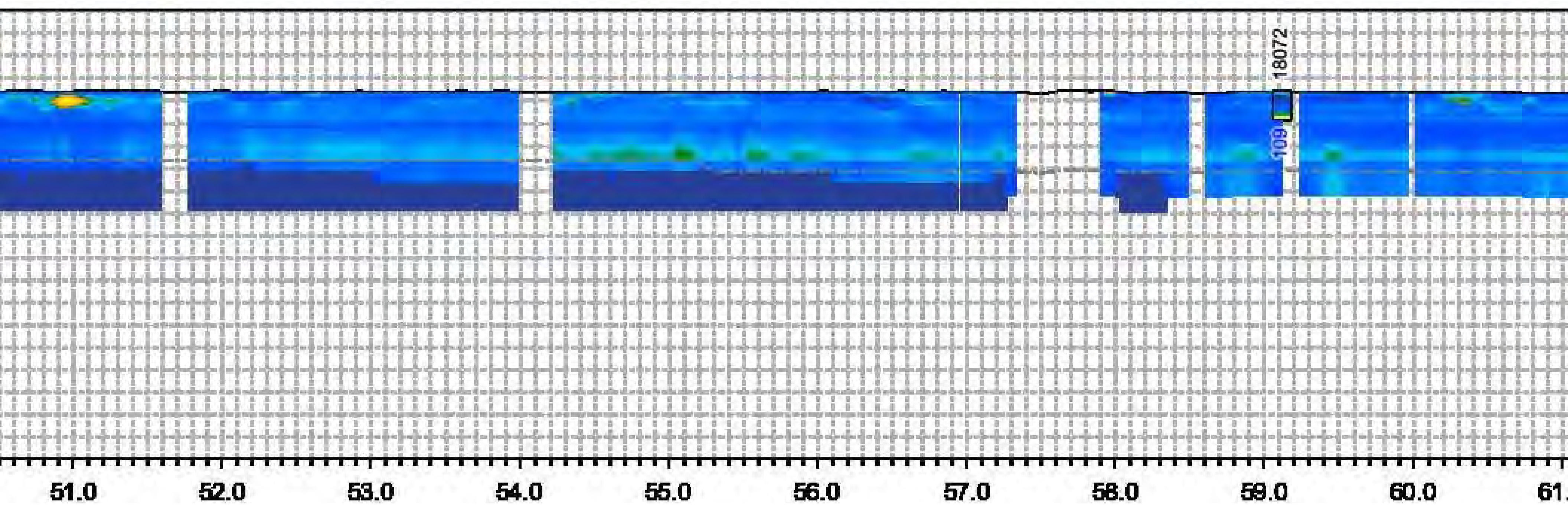
Figure 4-11. Geologic Section C-C'

C - C' Nearest AEM Log, East

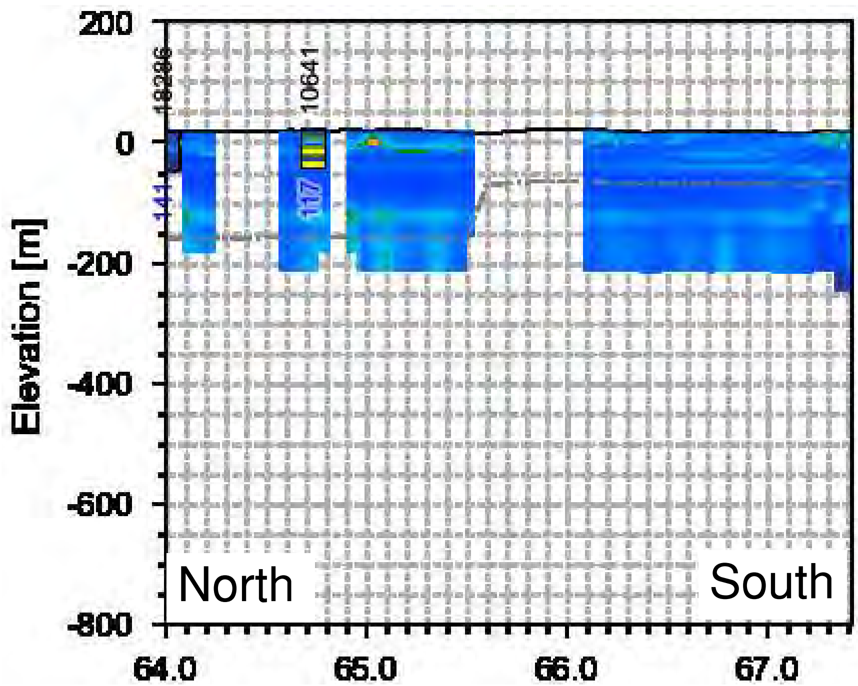


C - C' Nearest AEM Log, West





C - C' Nearest AEM Log, West



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 ”perched” 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? Yes	No	Maybe	Comments / Evidence
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

Sierra Valley Subbasin Groundwater Sustainability Plan

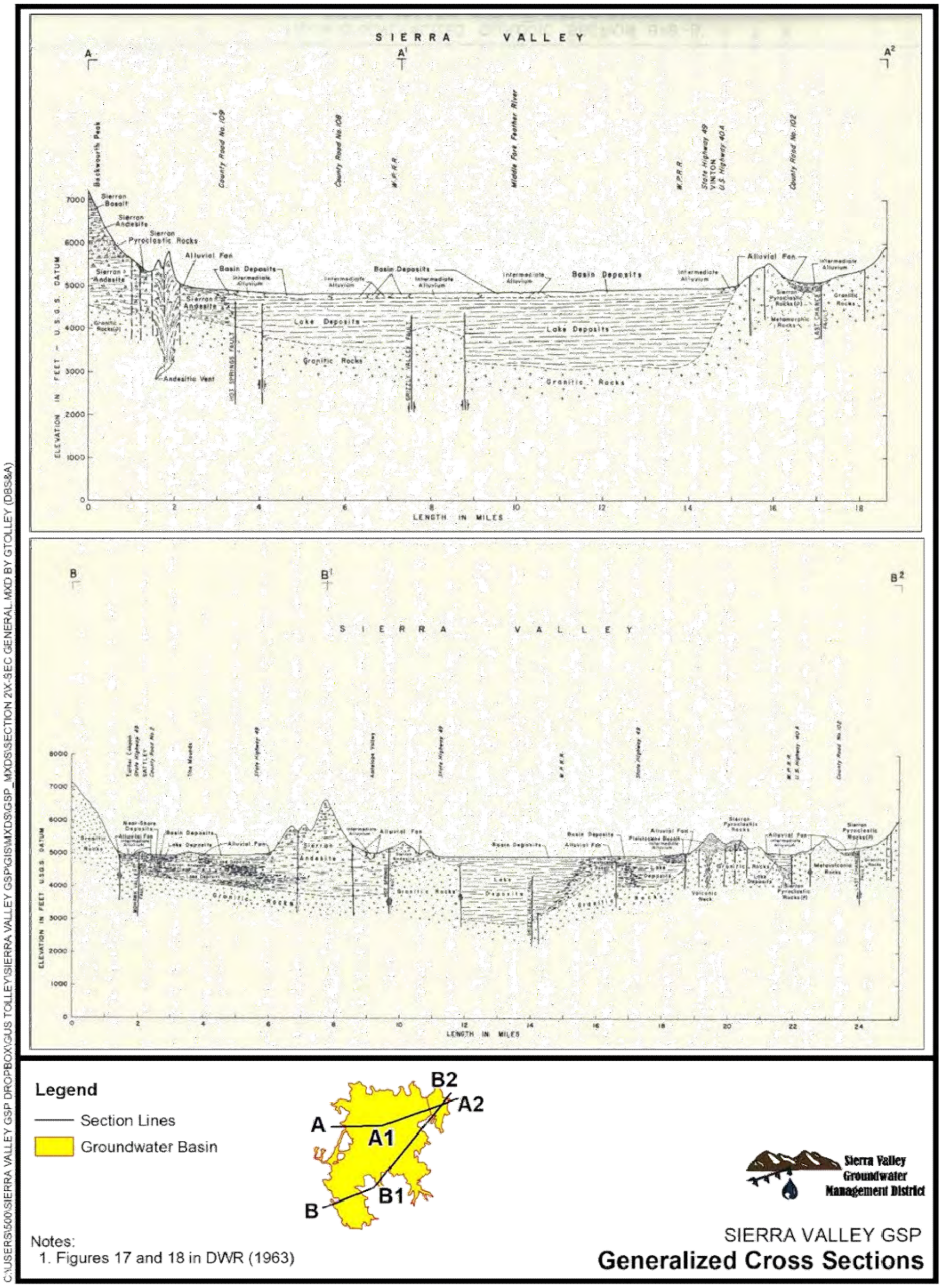
Sierra Valley Groundwater Management District

Adopted on January 17, 2022

PLUMAS COUNTY CALIFORNIA 1854

Adopted on January 18, 2022

Figure 2.2.1-12: Generalized Cross Sections

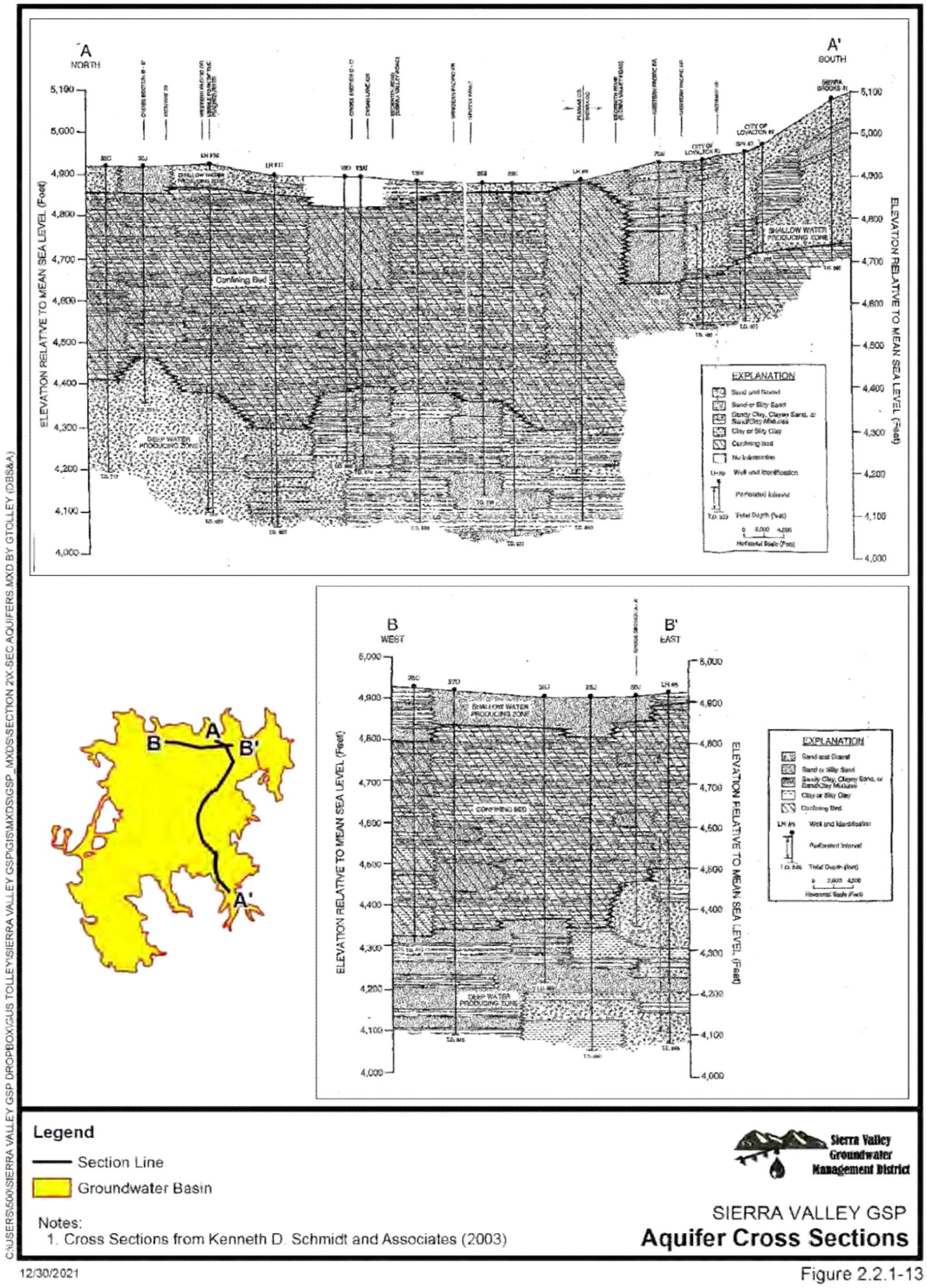


12/30/2021

Figure 2.2.1-12

C:\USERS\500\SIERRA VALLEY GSP DROPBOX\GUS TOLLEY\SIERRA VALLEY GSP\GIS\MXDS\GSP_MXDS\SECTION 2\X-SEC GENERAL.MXD BY GTOLLEY (DBS&A)

Figure 2.2.1-13: Aquifer Cross Sections



6.2 Outputs

Outputs from the 3D geologic model are contact surfaces between each of the simulated units and resulting volumes. The hydrogeology extension provides the ability to map the categorical aquifer sediments onto the MODFLOW grid. Parameter values required by MODFLOW such as hydraulic conductivity, storage coefficients, etc., can then be assigned to the aquifer sediment categories. This allows for heterogeneity to be accounted for without over parameterizing the model.

6.2.1 Bedrock Surface

Figure 6-4 shows the bedrock surface geometry used in SVHSM. Depth to bedrock is generally shallowest along the margins of the valley and greatest near the center. Maximum depth to bedrock in SVHSM is estimated to be about 1,530 feet (466 m) near the Lost Marbles Ranch (intersection of Dyson Lane and Marble Hot Spring road) based on geophysical data (Gold and others, 2013). Bedrock outcrops within the valley are present at various locations and are likely remnant topographic highs or volcanic features.

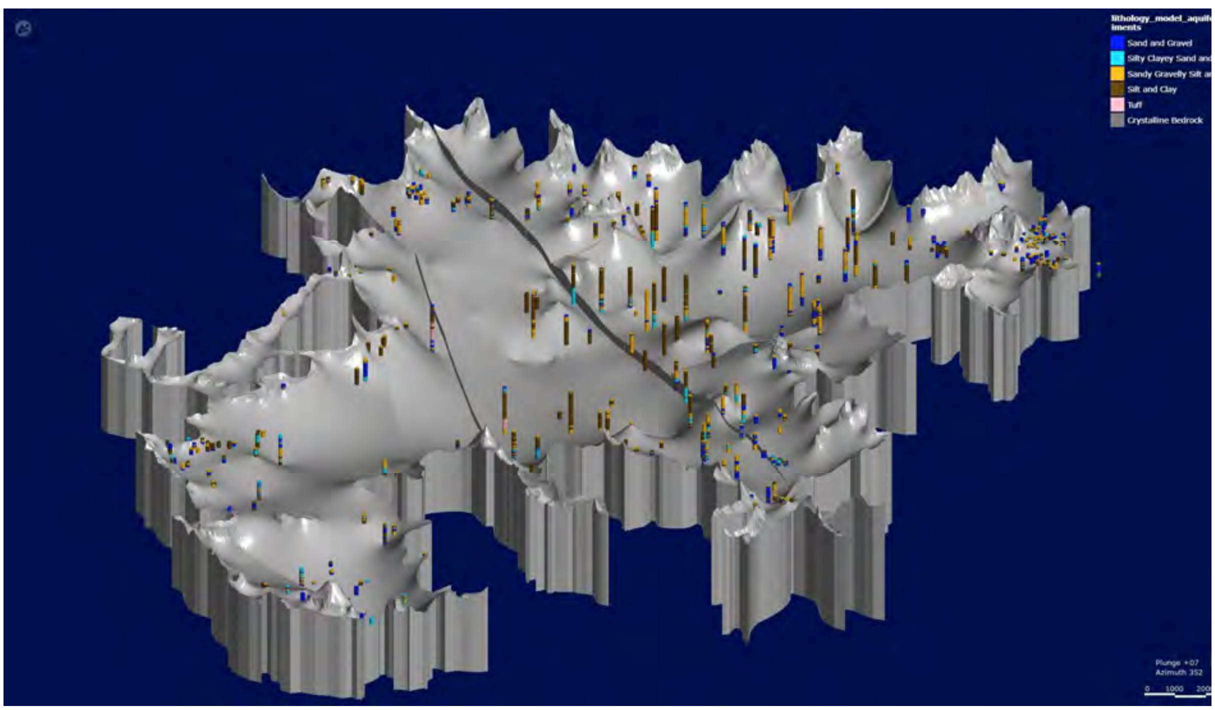


Figure 6-4. Exported image (looking north) of bedrock contact surface and volume simulated in SVHSM . Cylinders show wells with colors representing lithologic units. 5x vertical exaggeration.

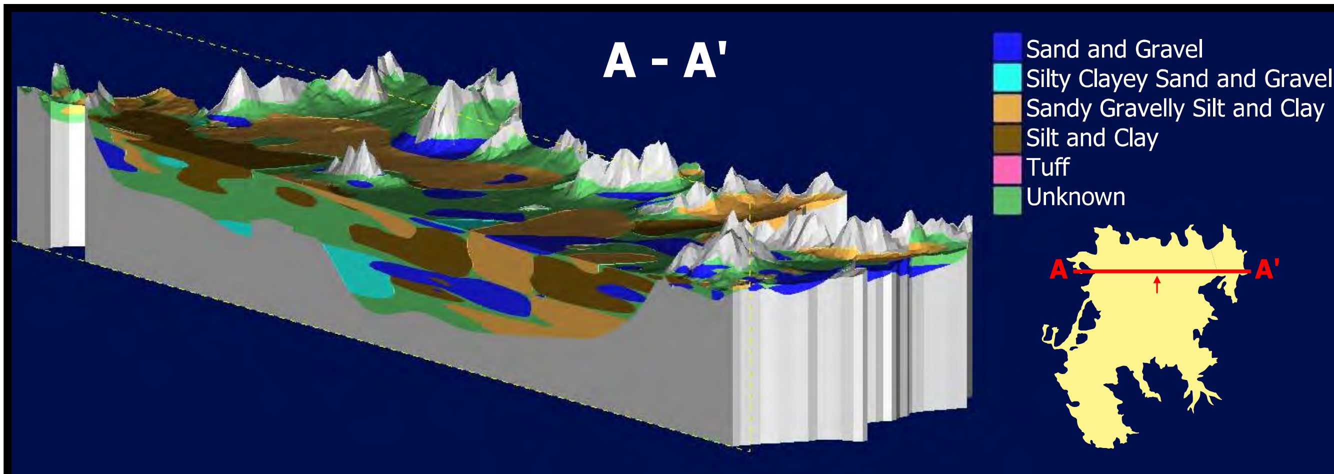
6.2.2 Sediment Volumes and Principal Aquifers

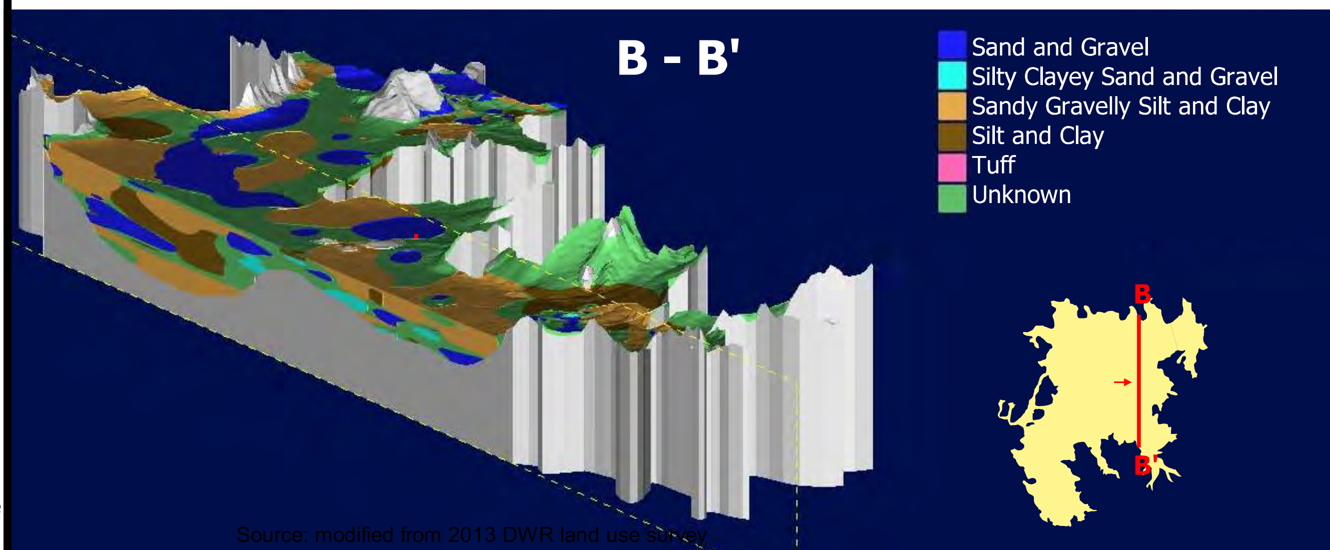
Fine-grained units dominate in the model, with coarse units (lithology groups 1 and 2) comprising only about 10 to 15% of the total sediment volume (Table 6-1). This is consistent with the conceptual model for the basin where lacustrine conditions were prevalent for a large portion of the depositional history. The unknown volume makes up over one-third of the total model volume, indicating that some areas of the model have significant data gaps.

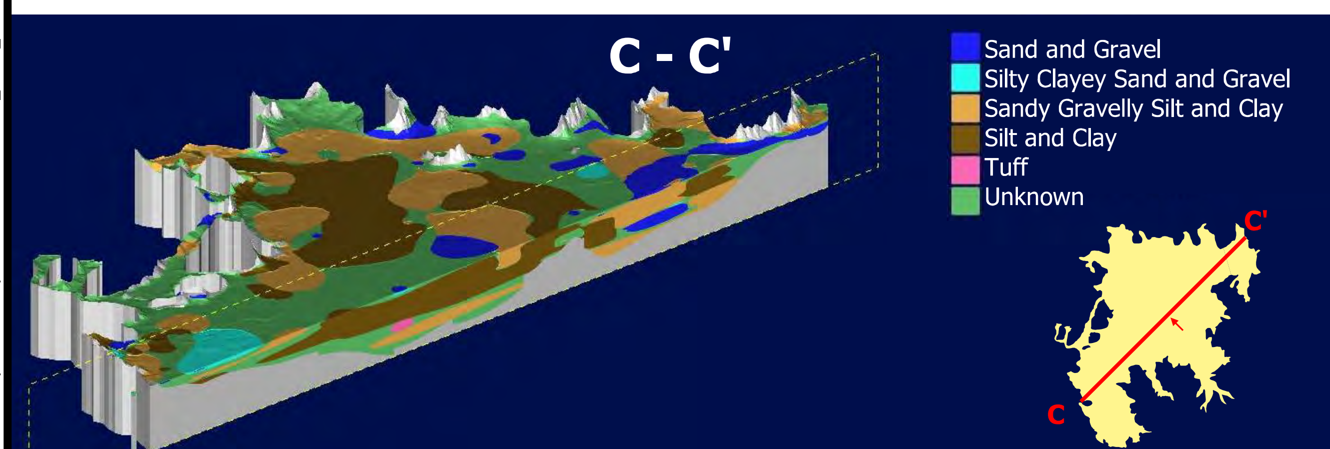
Table 6-1. SVHSM 3D geologic model lithology unit volumes.

ID	Lithology	Volume m^3	Volume mi^3	Volume km^3	Percentage (%)
1	Sand and Gravel	5.80E+09	1.4	5.8	7%
2	Silty Clayey Sand and Gravel	3.69E+09	0.9	3.7	4%
3	Sandy Gravelly Silt and Clay	1.78E+10	4.3	17.8	20%
4	Silt and Clay	3.06E+10	7.3	30.6	35%
5	Tuff	1.76E+08	0	0.2	0%
6	Unknown	3.01E+10	7.2	30.1	34%
	Total	*8.81E+10*	*21.1*	*88.1*	*100%*

Several cross sections of the 3D model as various angles are shown in Figure 6-5. In general, there is much better subsurface characterization on the east side of the basin compared to the west side, largely due to the limited number and shallower depth of wells found on the west side. The model indicates the presence of a shallow unconfined aquifer and a deep confined aquifer on the northeastern portion of the basin in the vicinity of most of the agricultural production wells. Water levels in the area also indicate the presence of an upper and lower aquifer. Although a laterally continuous confining layer has not been observed, silt and clay units in some areas are estimated to be up to about 860 feet (262 m) thick and laterally extensive enough to provide confining conditions. Water levels collected from multiple depth completion wells (e.g., DMW 2 and DMW 3) indicate that the hydrologic connection between the upper and lower aquifer units on the west side of the basin may vary spatially, but cannot be confirmed in the 3D geologic model due to data sparsity in that area.







Notes:
1. Arrows indicate viewing direction
2. Vertical exaggeration = 5x
3. Faults and wells not shown

Sierra Valley Groundwater Management District

SVHSM Documentation

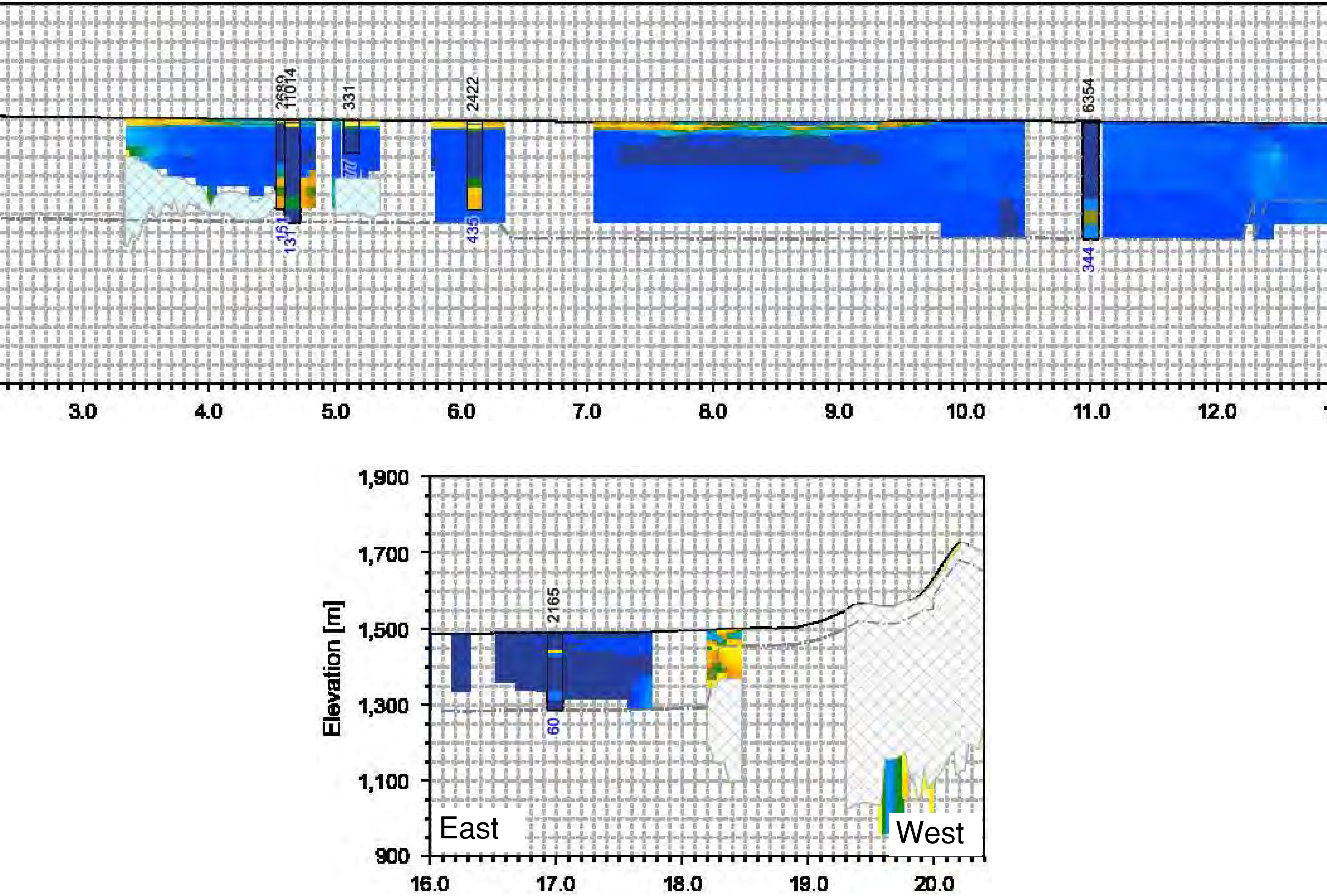
3D Geologic Model Cross Sections

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

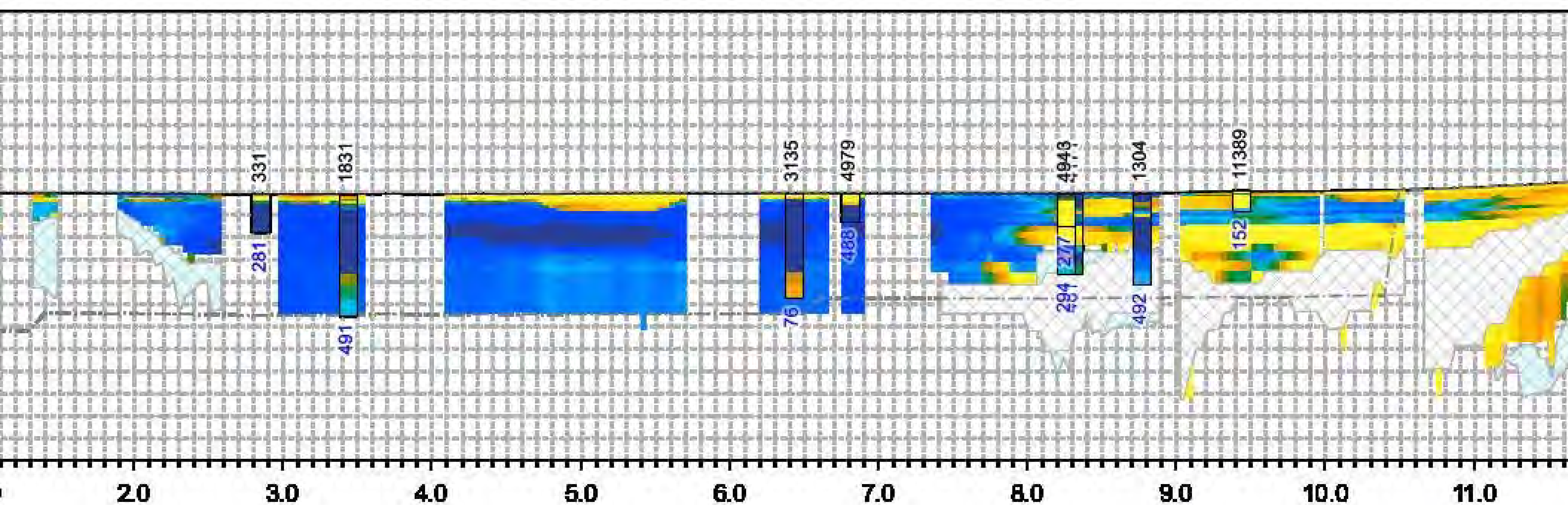
12/14/2021

Figure 6-5

A - A' Nearest AEM Log

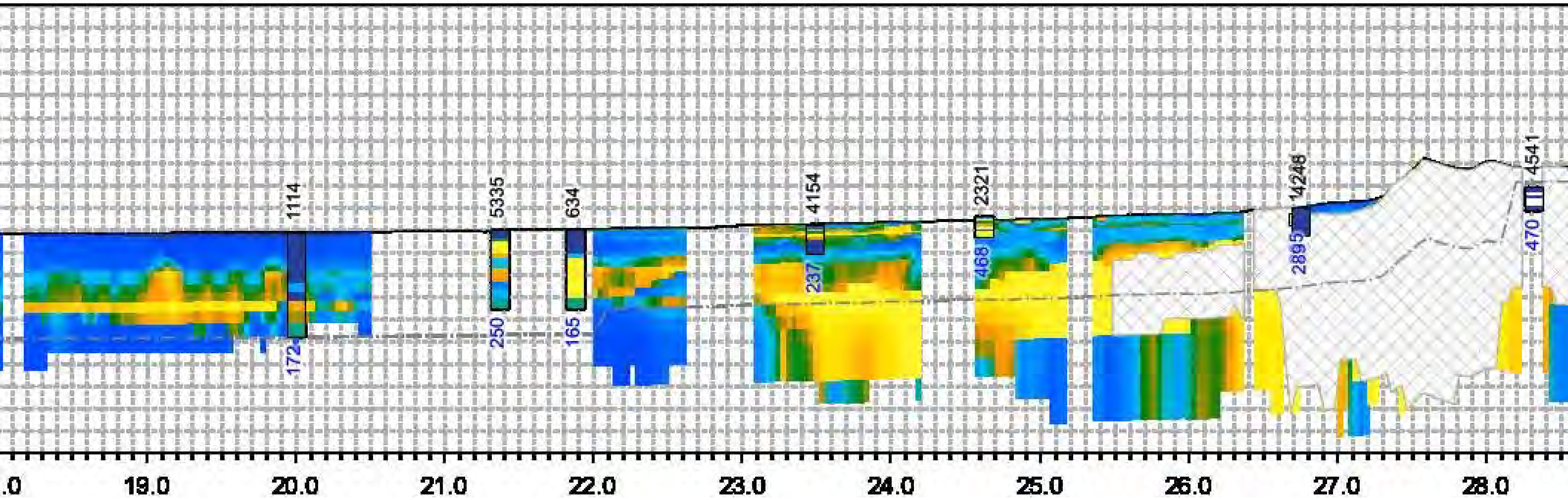


B - B' Nearest AEM Log, North



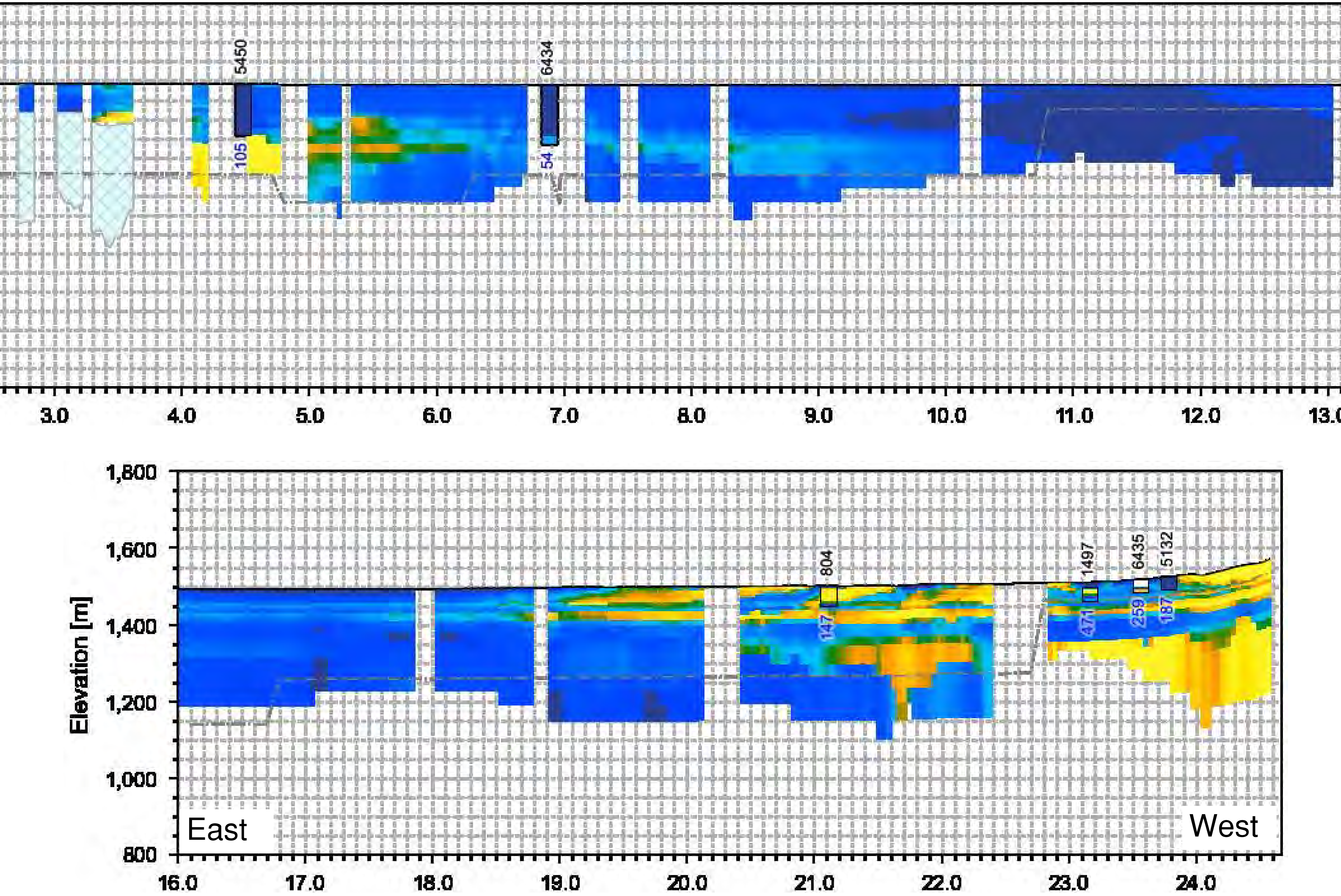
B - B' Logs are NOT continuous.

B - B' Nearest AEM Log, South



B - B' Logs are NOT continuous.

C - C' Nearest AEM Log



SOLANO SUBBASIN

GROUNDWATER SUSTAINABILITY PLAN

November 30, 2021
Volume 1 - Main Report

VACAVILLE · SACRAMENTO COUNTY · Solano Irrigation District · Solano GSA · ND GSA

RECLAMATION DISTRICT 3 GSA • RECLAMATION DISTRICT 349 GSA • RECLAMATION DISTRICT 554 GSA
RECLAMATION DISTRICT 556 GSA • RECLAMATION DISTRICT 2111 GSA

3.2.2. Principal Aquifers and Aquitards (§ 354.14 b-4) (HCM Section 2.6.2)

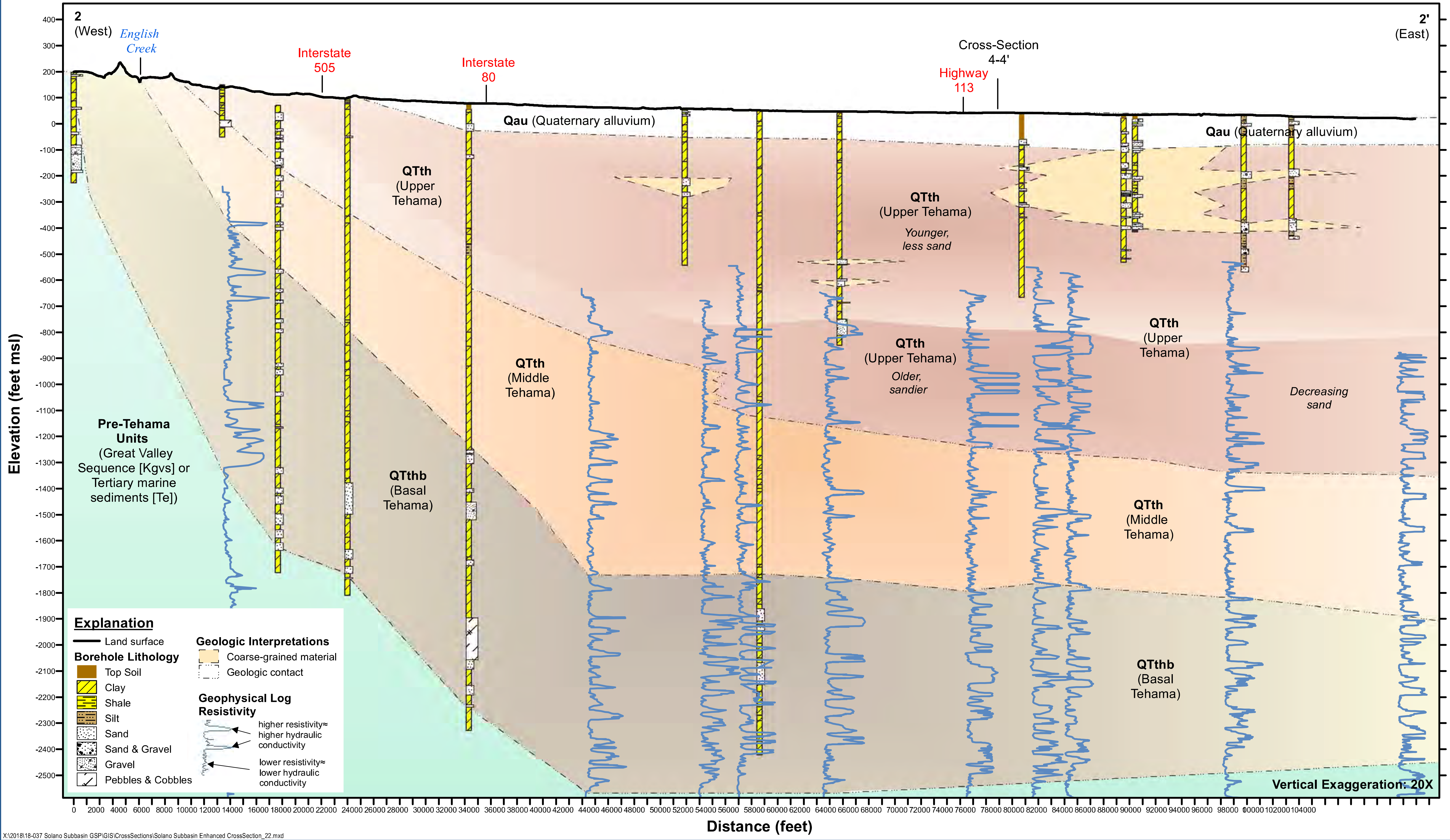
For purposes of understanding and managing groundwater conditions in the Subbasin and for the GSP, there are two primary aquifer zones defined for the Subbasin: 1) the Alluvial Aquifer consisting of Quaternary alluvium and the Montezuma and Upper Tehama zone, and 2) the Basal Tehama zone. The Quaternary alluvium, Montezuma Formation, and Upper Tehama have similar hydrogeologic characteristics and behave as a hydraulically connected aquifer zone and represent a single primary aquifer in the GSP referred to as the Alluvial Aquifer and Upper Tehama zone. The Basal Tehama zone, which coincides with the Basal Tehama formation, is not utilized throughout the entire Subbasin, but it is generally found at great depth and under confined (i.e., under pressure) conditions within the Subbasin, except for along parts of the western Subbasin boundary where it is steeply dipping and crops out at the surface. The Middle Zone of the Tehama Formation, or Middle Tehama, is generally fine-grained with only relatively thin sandy intervals of limited lateral extent. As a result, the Middle Tehama does not serve as a major water-yielding unit in the Subbasin. Because of its fine-grained nature, the Middle Tehama functions as an aquitard in much of the Subbasin, confining the underlying Basal Tehama zone and limiting vertical movement of water between the shallower Alluvial Aquifer and Upper Tehama zone and the deeper Basal Tehama zone.

Cross Sections were developed for the Subbasin to enhance understanding of the hydrogeology in the upper part of the groundwater system. These cross-sections include a focus on interpretation of the hydrostratigraphy to depths less than 2,000 feet using lithology from water well drillers' reports (Well Completion Reports [WCRs]) and available water well geophysical logs. **Figure 3-7** (**Appendix 3A Figure 2-22**) provides enhanced interpretation of the upper part of the groundwater system that was not apparent from earlier studies. Multiple other cross sections were developed as shown on **Figure 3-5** and described in **Appendix 3A**.

3.2.3. Recharge and Discharge Areas (§ 354.14 b-3 and 4) (HCM Section 2.8)

Groundwater recharge and discharge are key components of the Subbasin HCM that influence groundwater conditions and the Subbasin water budget. Groundwater recharge within the Solano Subbasin occurs primarily through infiltration and deep percolation of precipitation falling directly on the landscape within the Subbasin and through applied water (e.g., irrigation), seepage from natural surface waterways, seepage from water conveyance systems (e.g., leaky canals, ditches, and pipes), and deeper subsurface recharge from adjacent and upland recharge source areas outside of the Subbasin.

Groundwater discharge can occur in the Subbasin through baseflow contributions to surface waterways, discharges at springs and wetlands in the Subbasin when the top of the groundwater table is at ground surface. Groundwater discharge can also occur as subsurface flows of groundwater to adjacent Subbasins. Not all discharge processes result in a net discharge or outflow from the Subbasin.



Solano Subbasin Geologic Cross-Section 2-2'

Groundwater Sustainability Plan
Solano Subbasin

Figure 3-7

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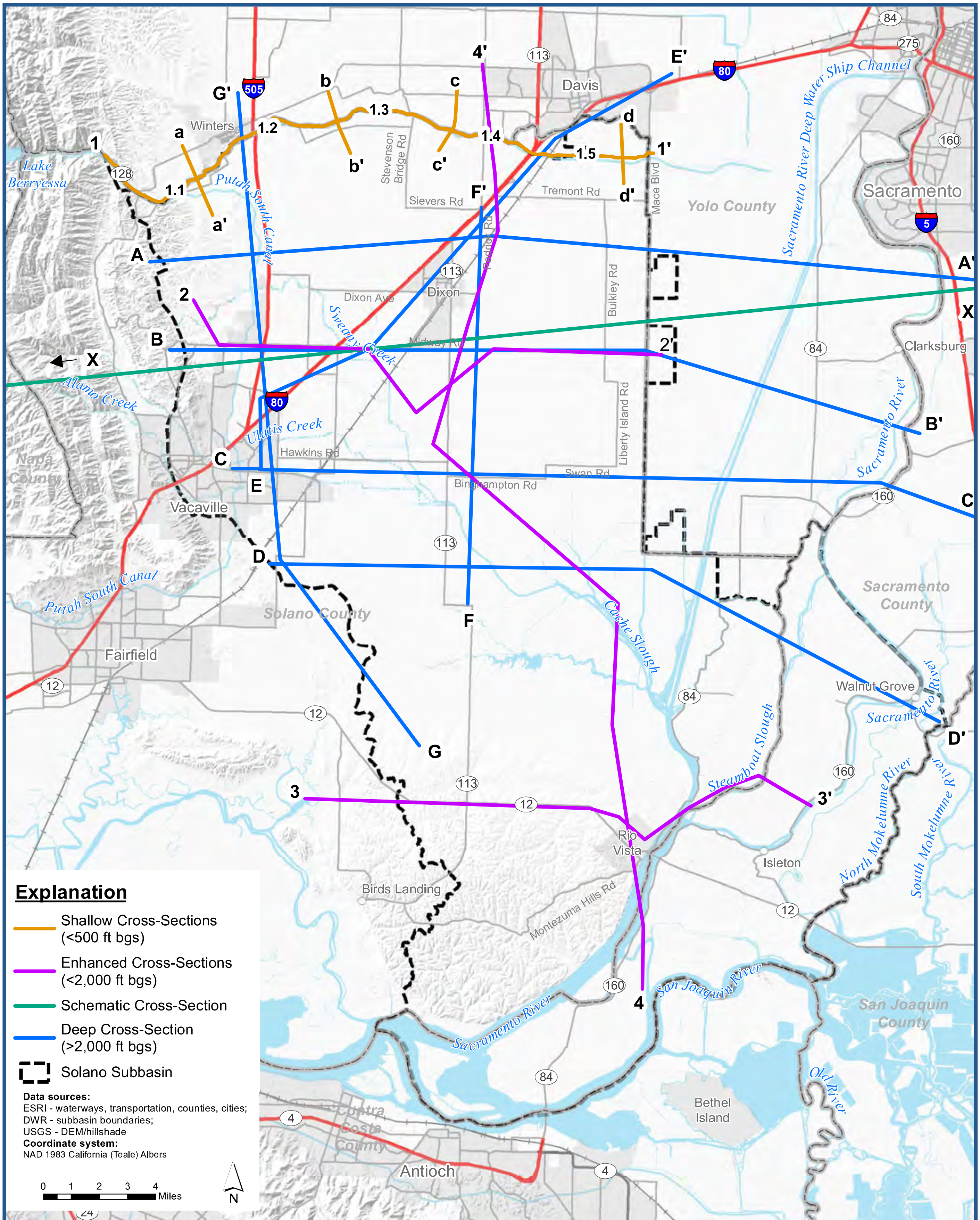

Geologic Cross-Section Location Map

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-12

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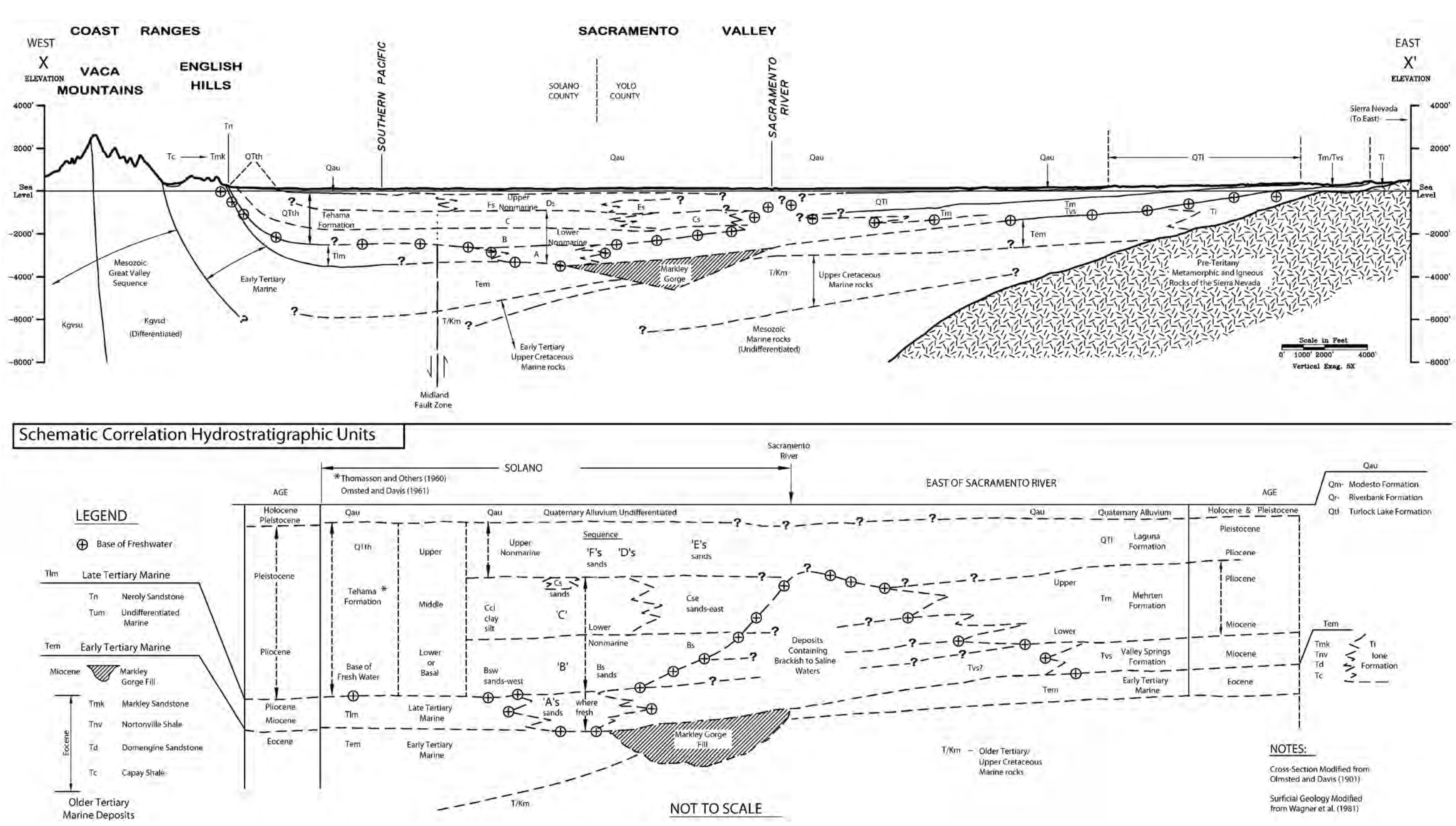

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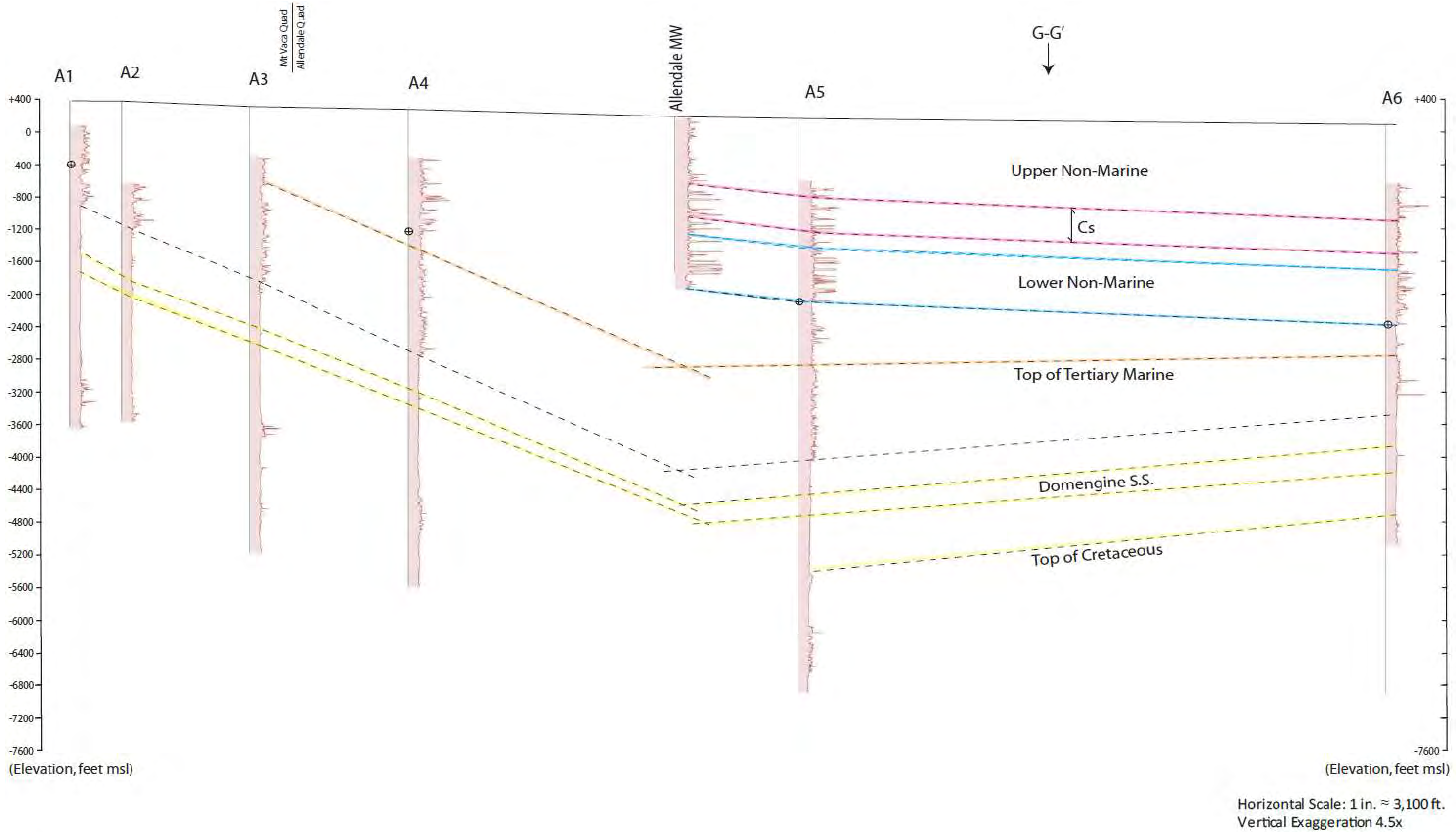
Sacramento Valley Schematic Cross-Section X-X'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-13



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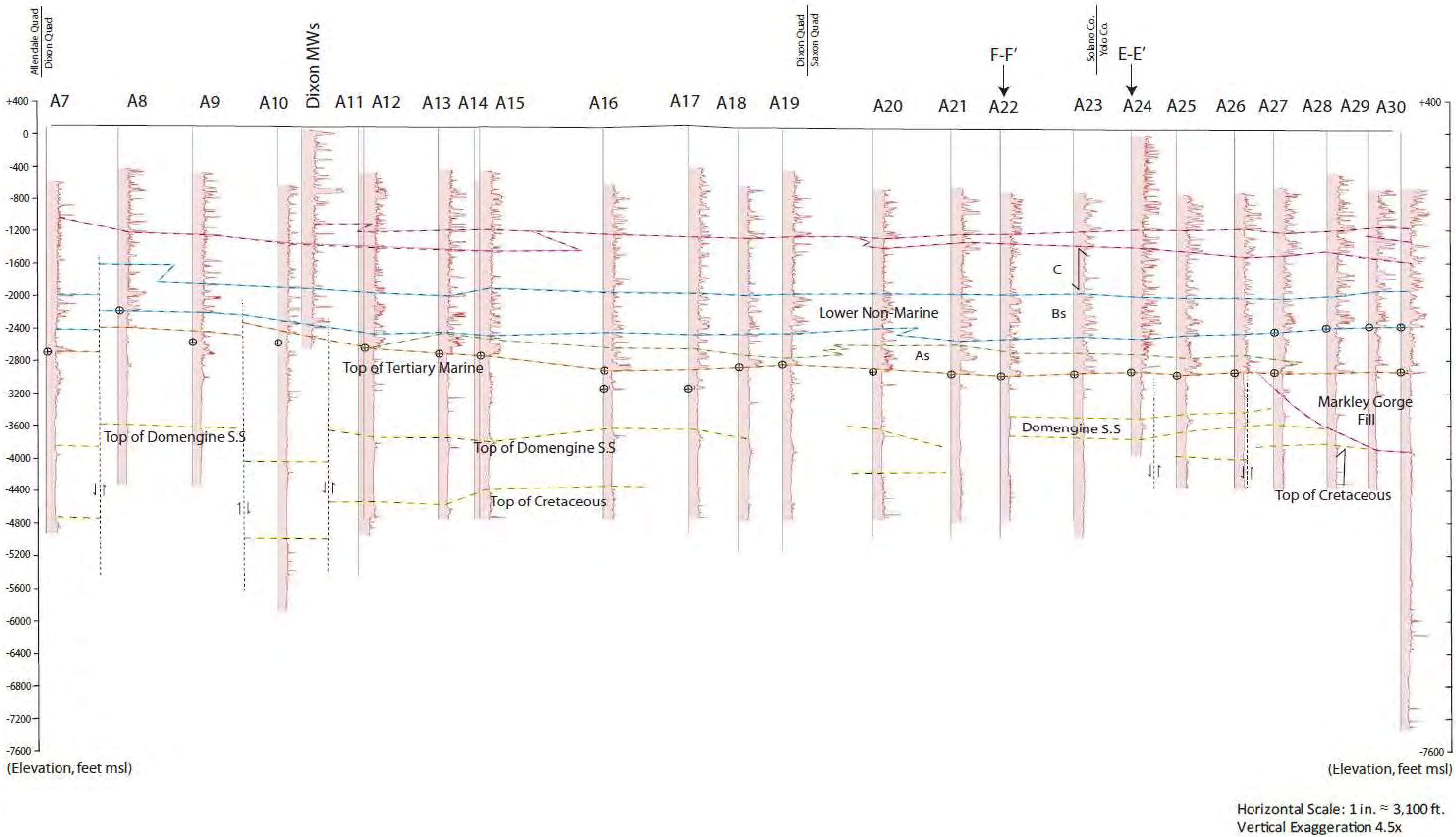
Cross Section A

Solano Subbasin Groundwater Sustainability Plan
Solano County, California

Figure 2-14a



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Cross Section A

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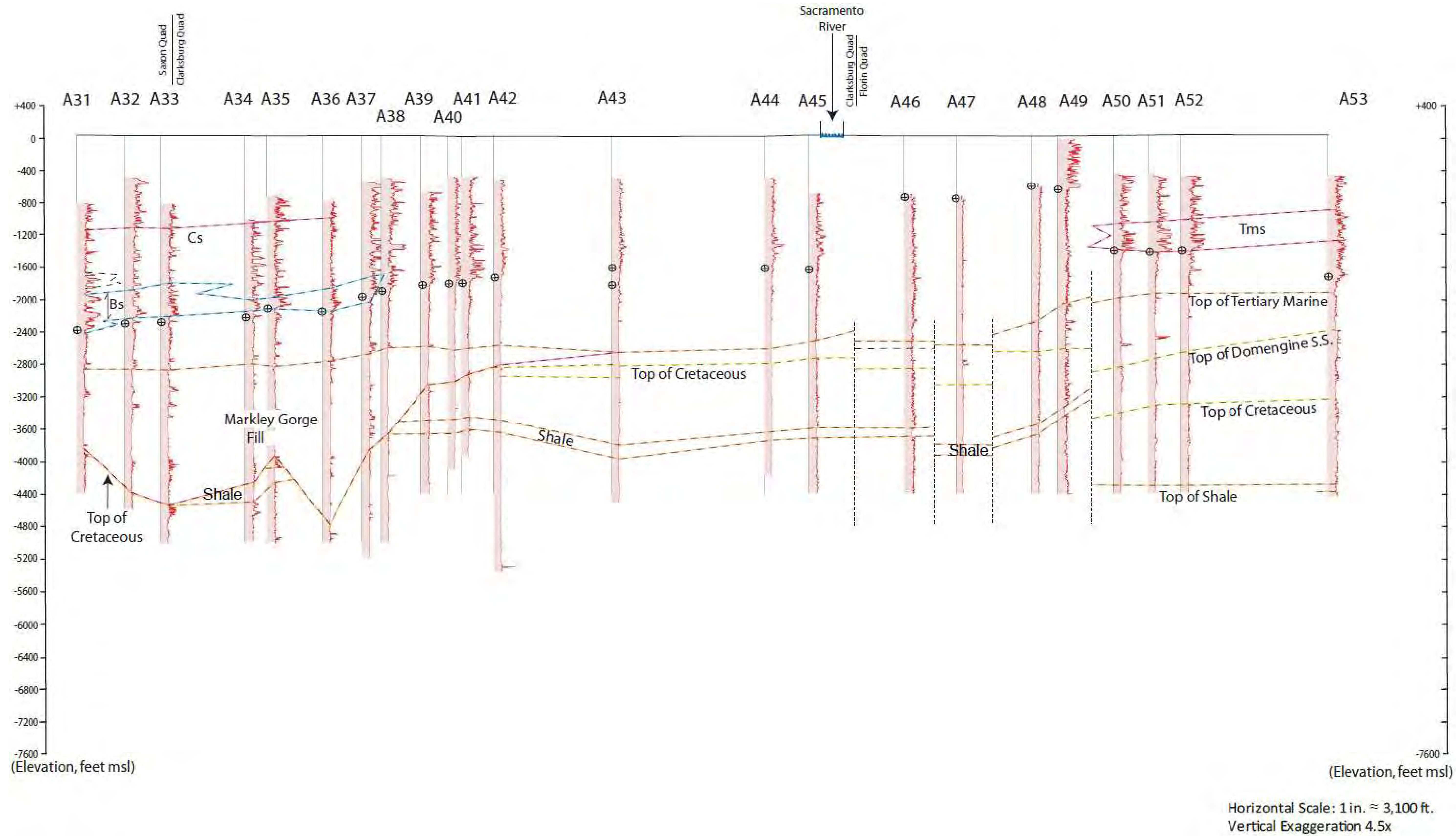
Solano Subbasin

Figure 2-14b



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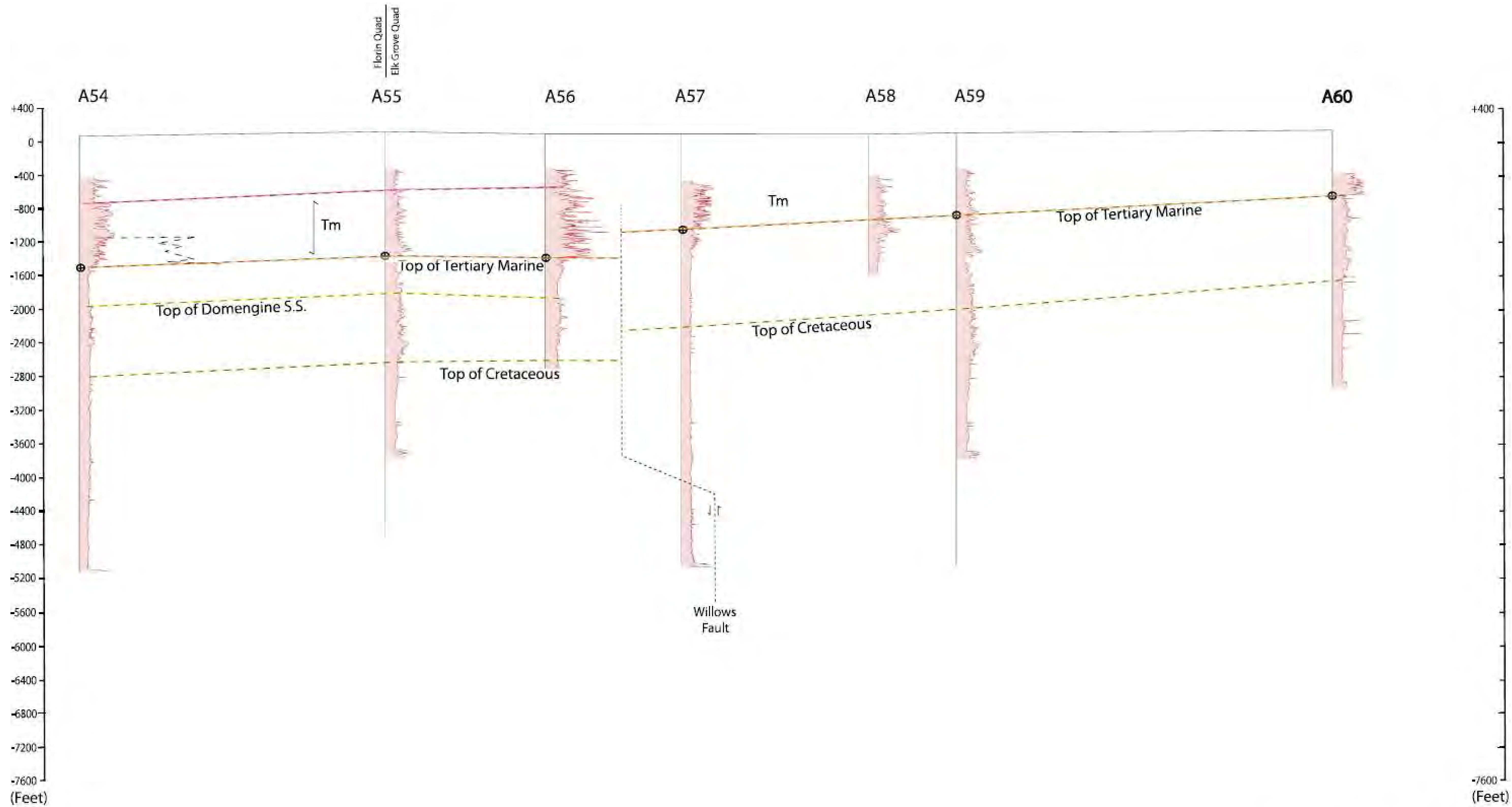
Cross Section A

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-14c



Horizontal Scale: 1 in. ≈ 3,100 ft.
Vertical Exaggeration 4.5x

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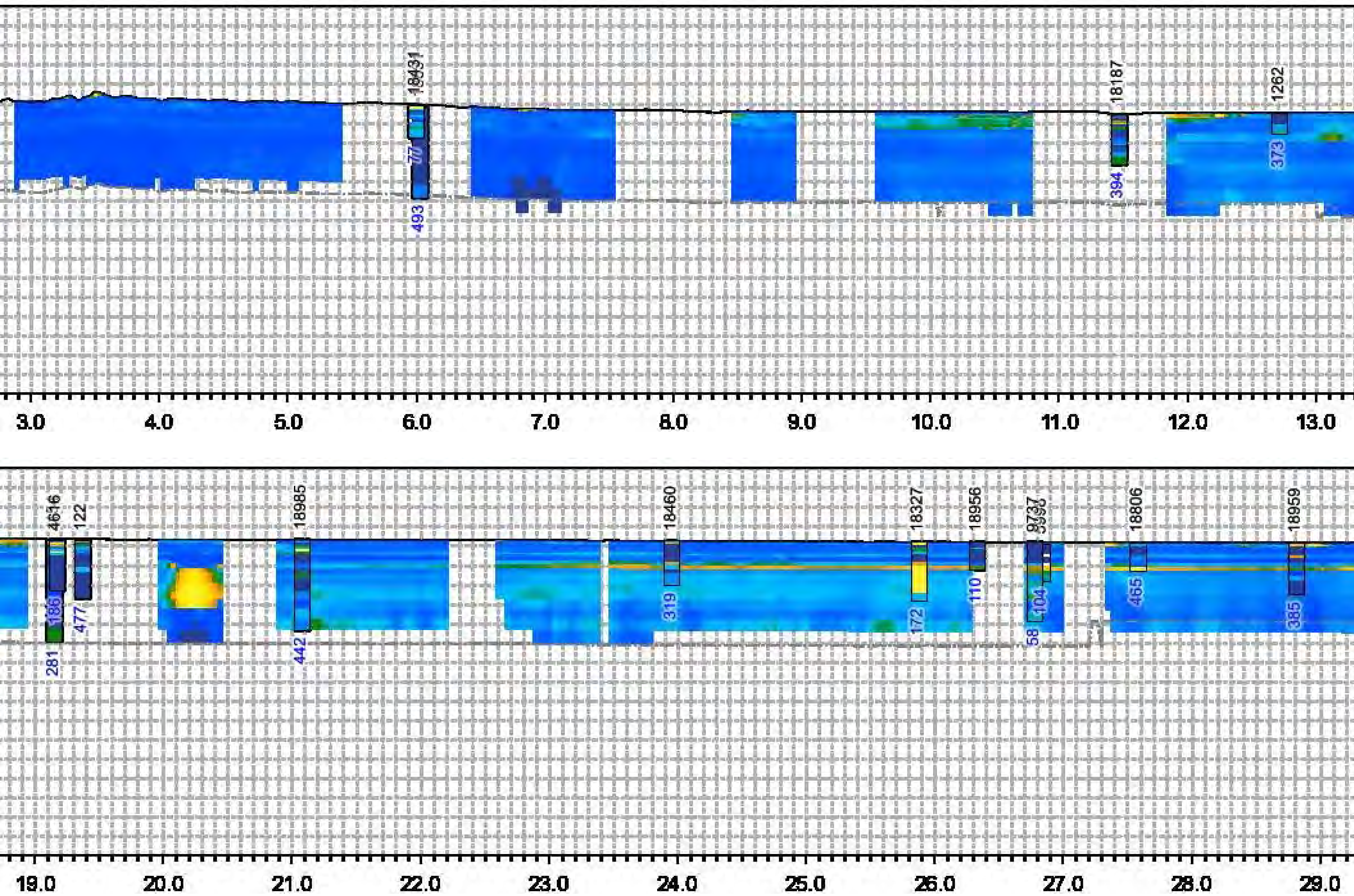
Cross Section A

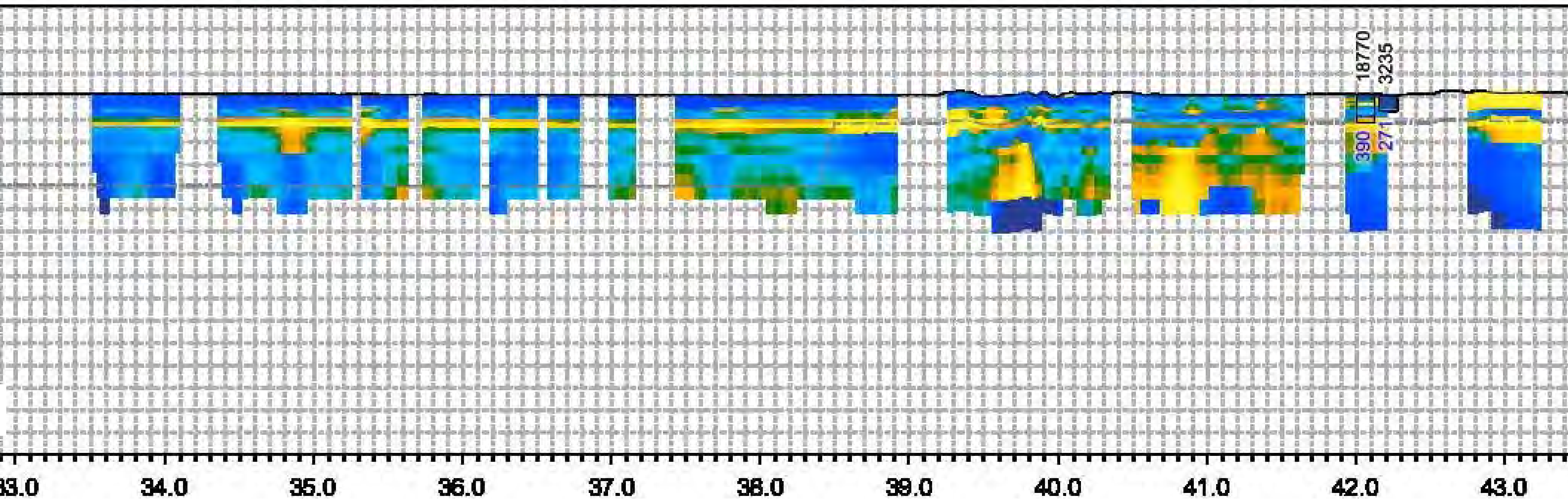
Groundwater Sustainability Plan
Solano Subbasin

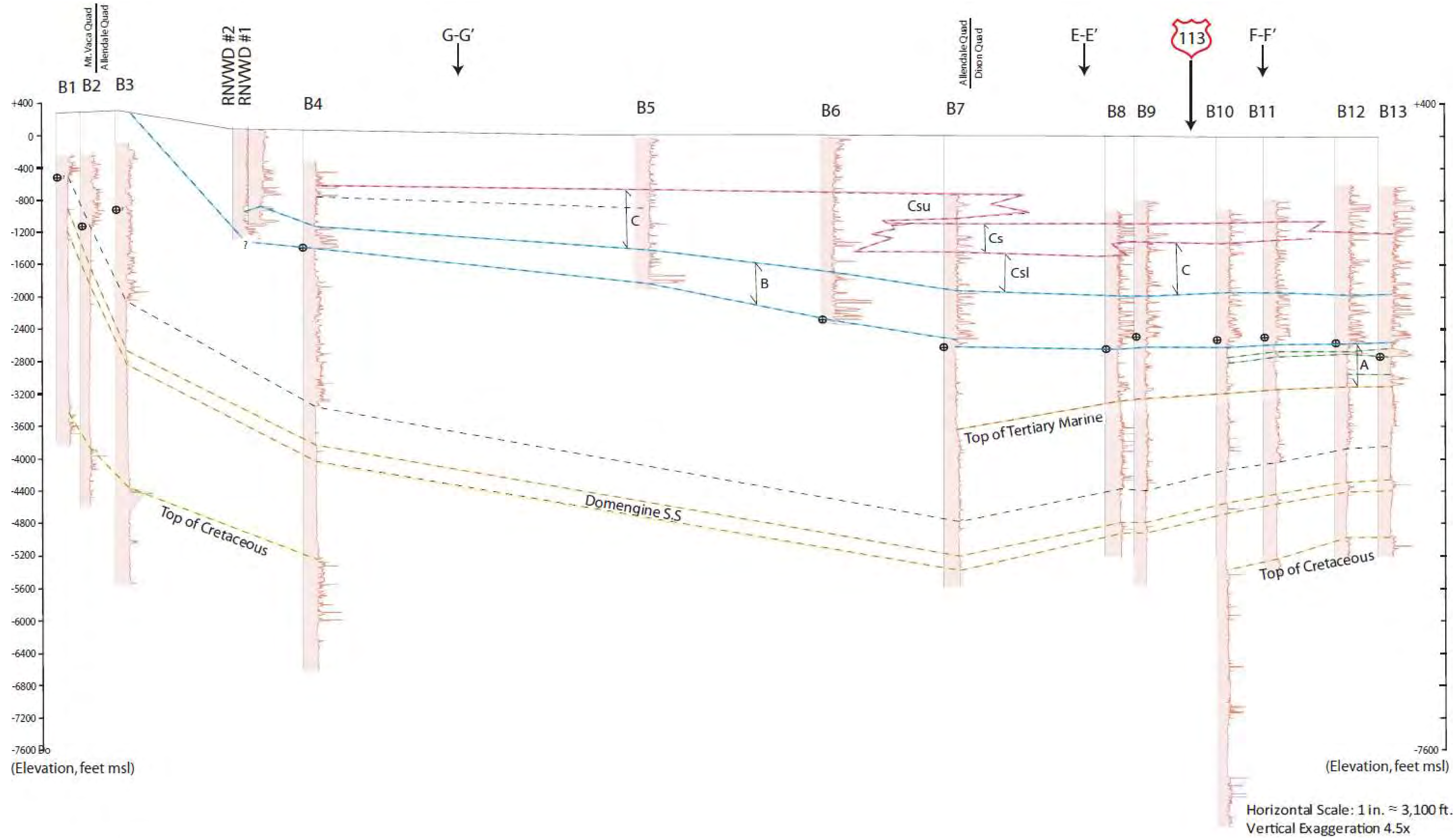
Figure 2-14d

A - A' Nearest AEM Log



A - A' Nearest AEM Log





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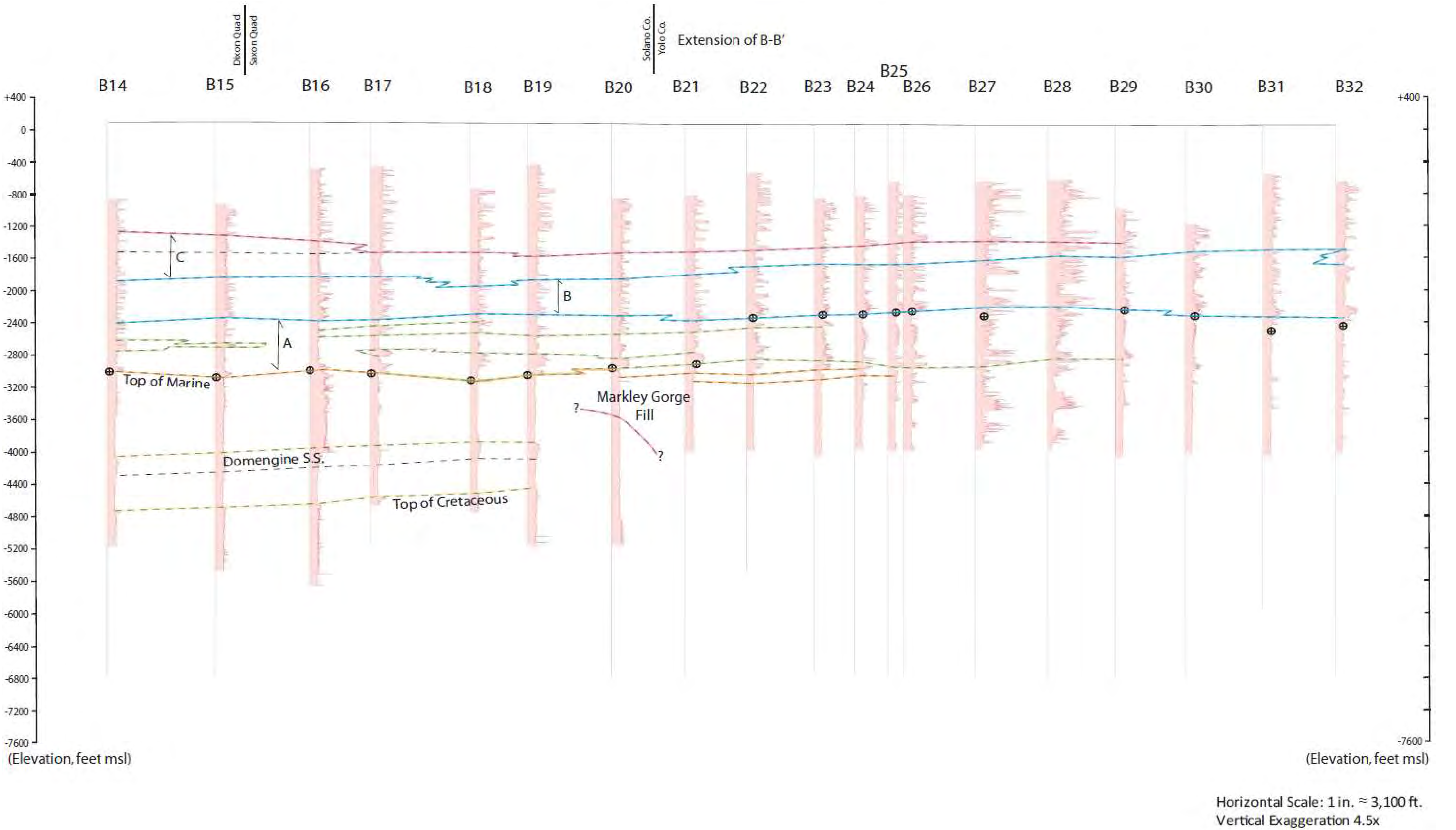
Cross Section B

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-15a



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Cross Section B

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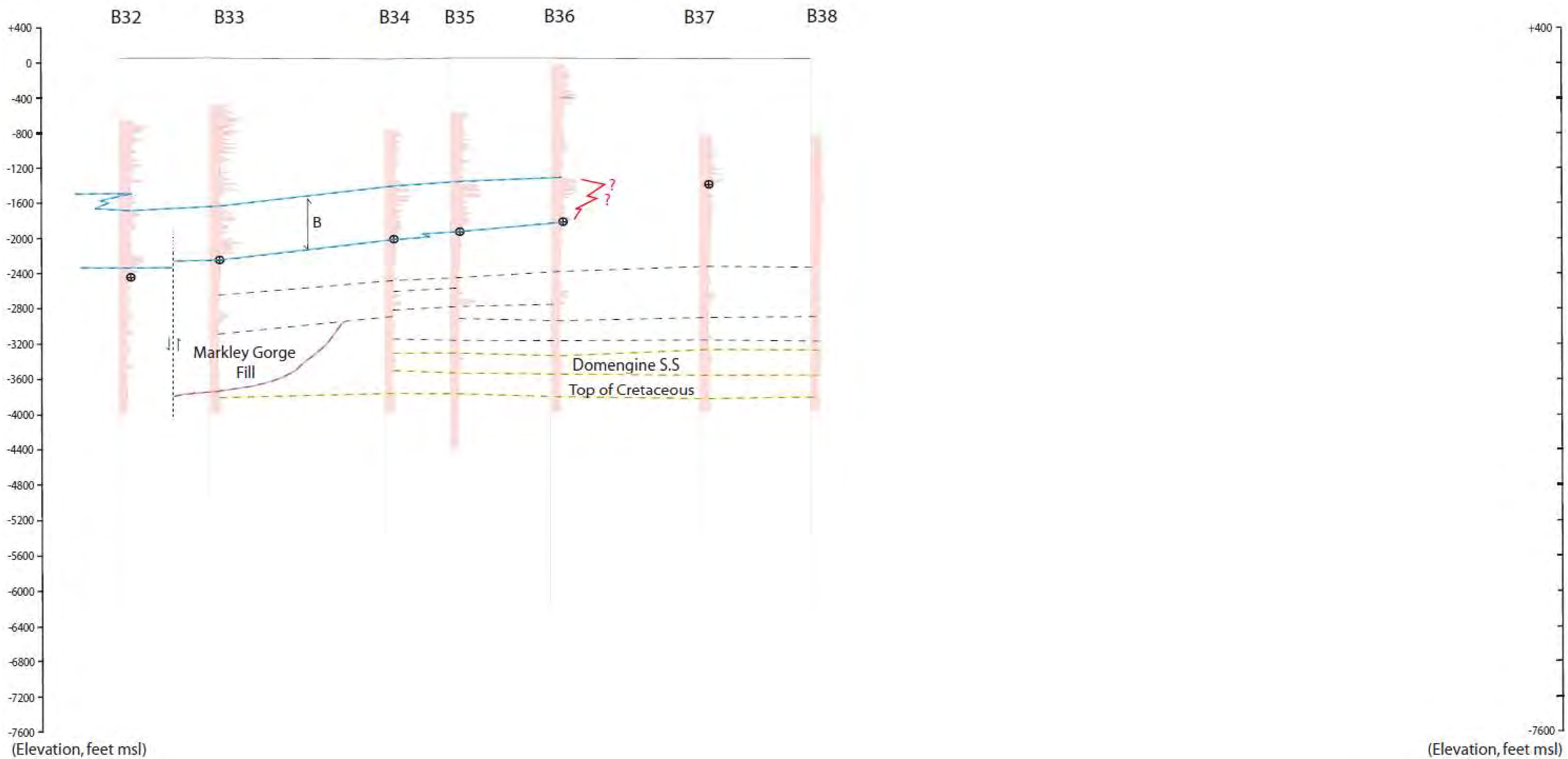
Solano Subbasin

Figure 2-15b



Horizontal Scale: 1 in. ≈ 3,100 ft.
Vertical Exaggeration 4.5x

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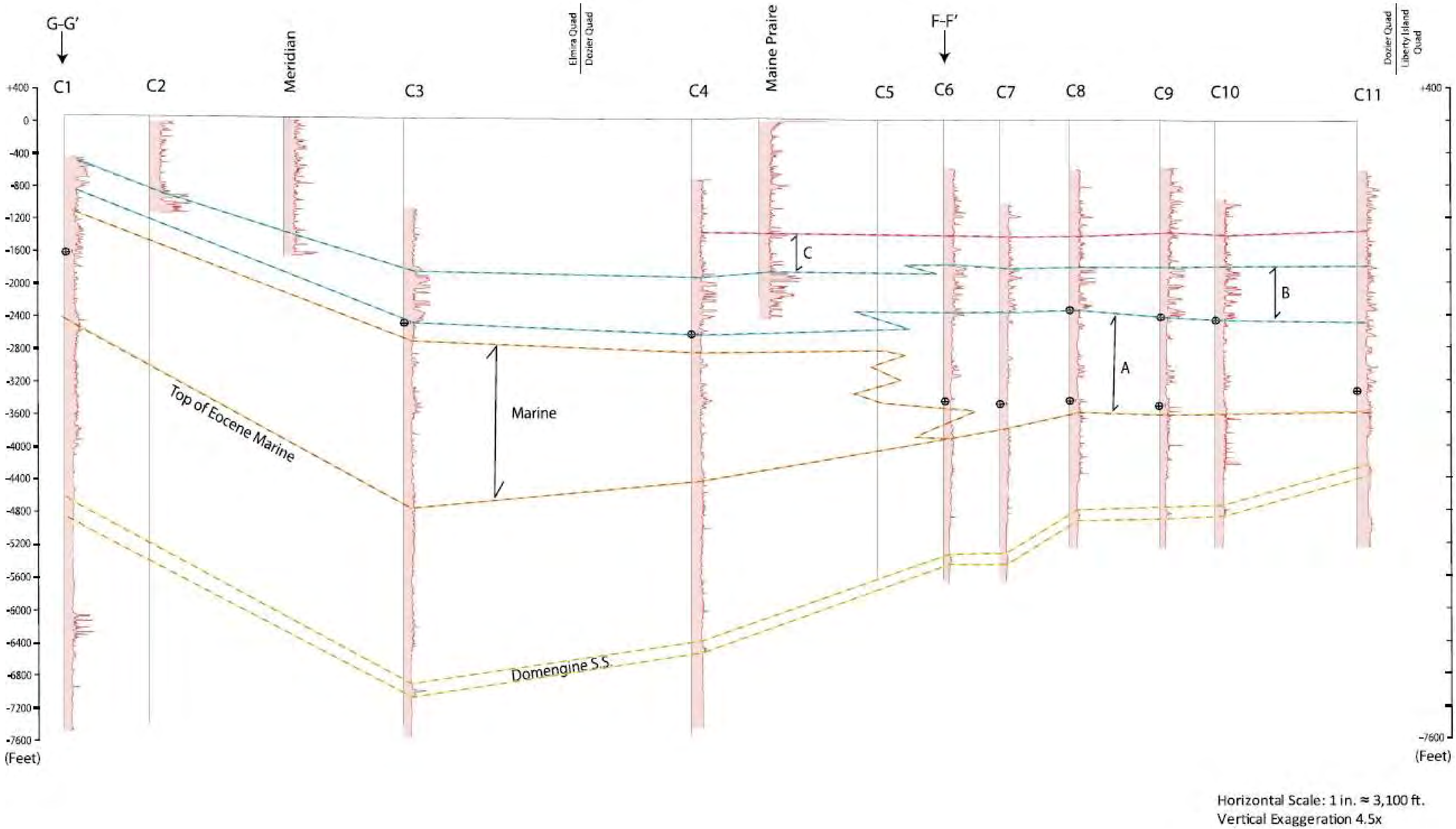
Cross Section B

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-15c



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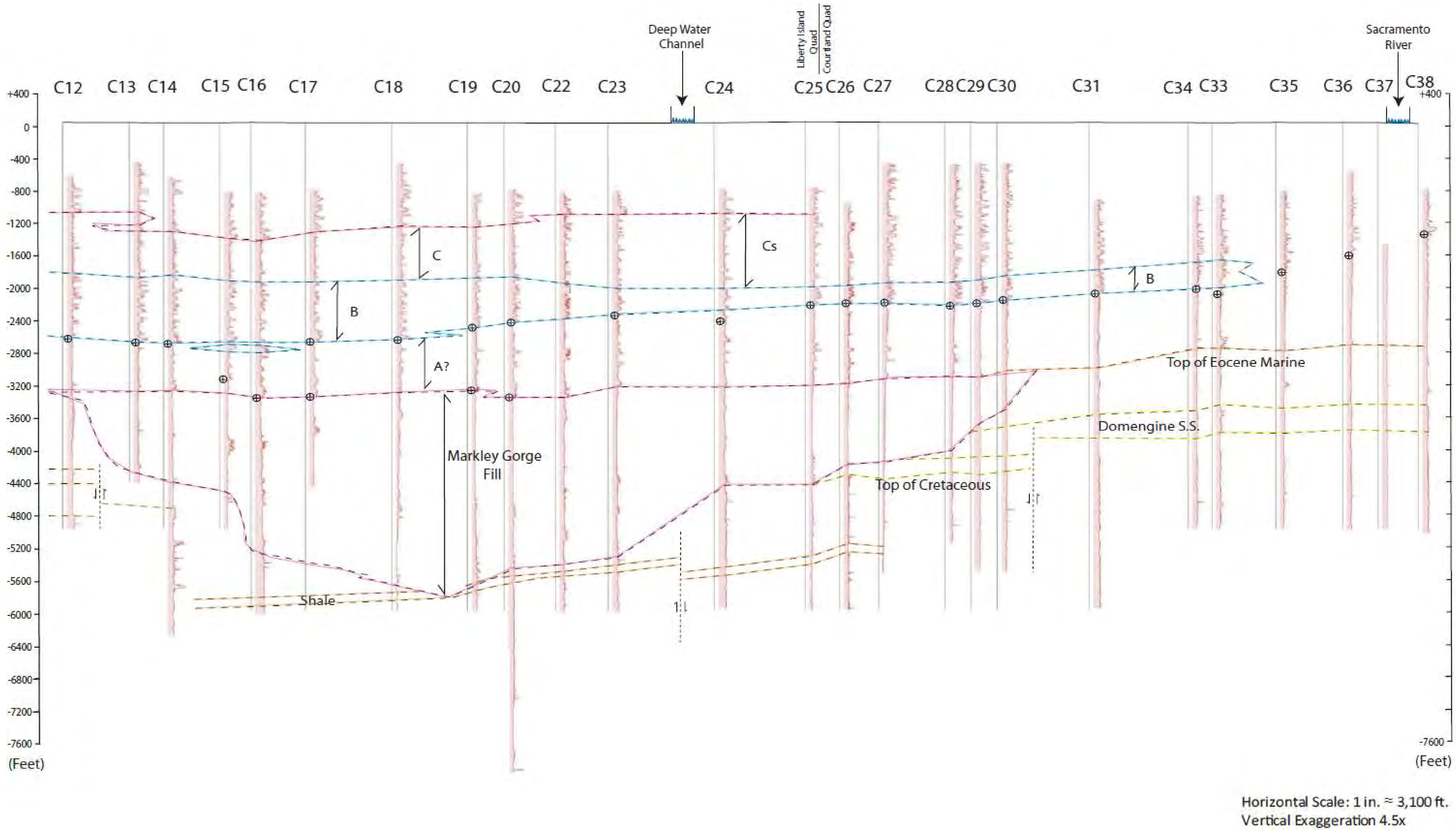
Cross Section B

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-16a



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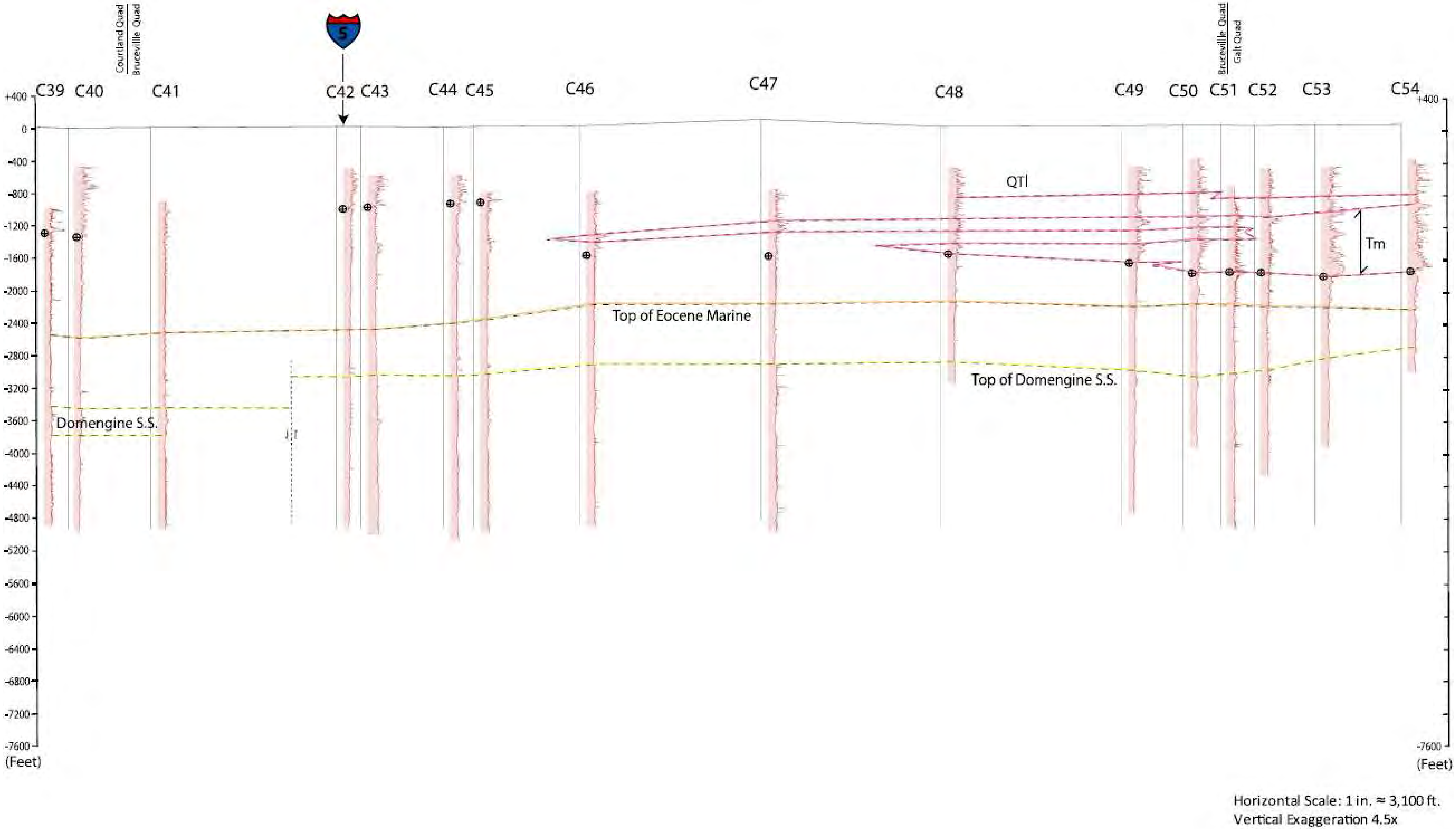
Cross Section C

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-16b



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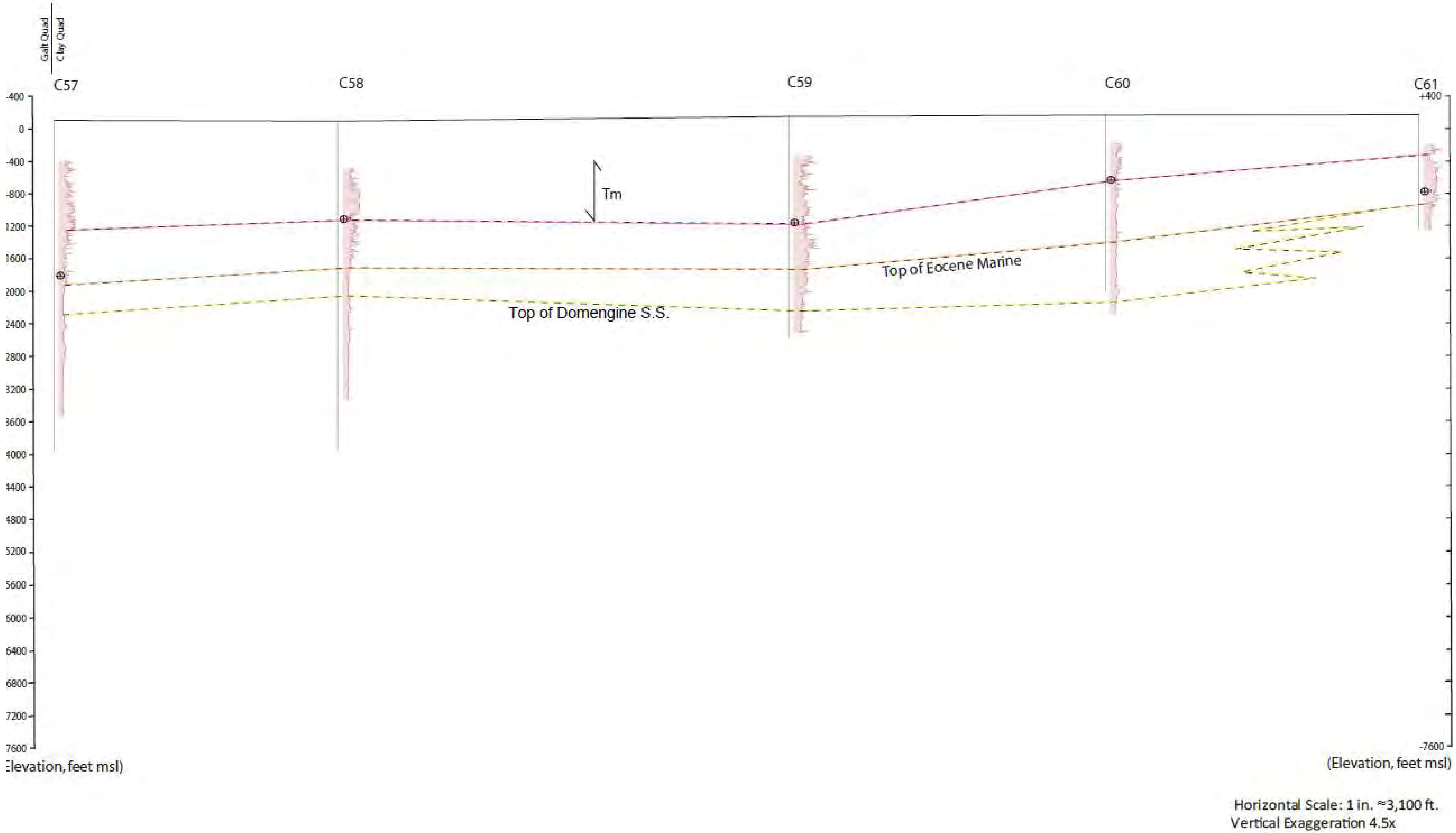
Cross Section C-C'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-16c



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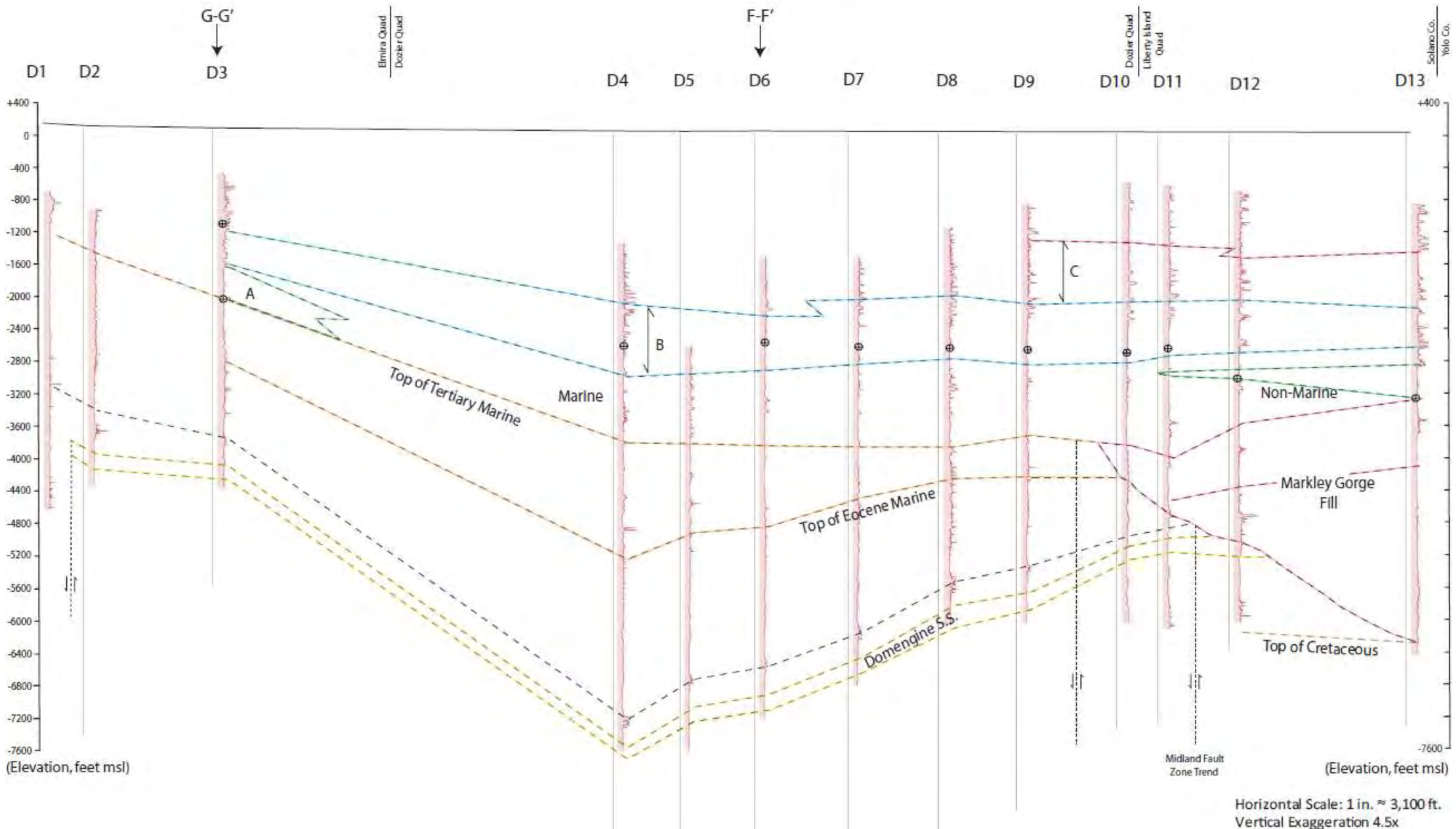
Cross Section C-C'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-16d



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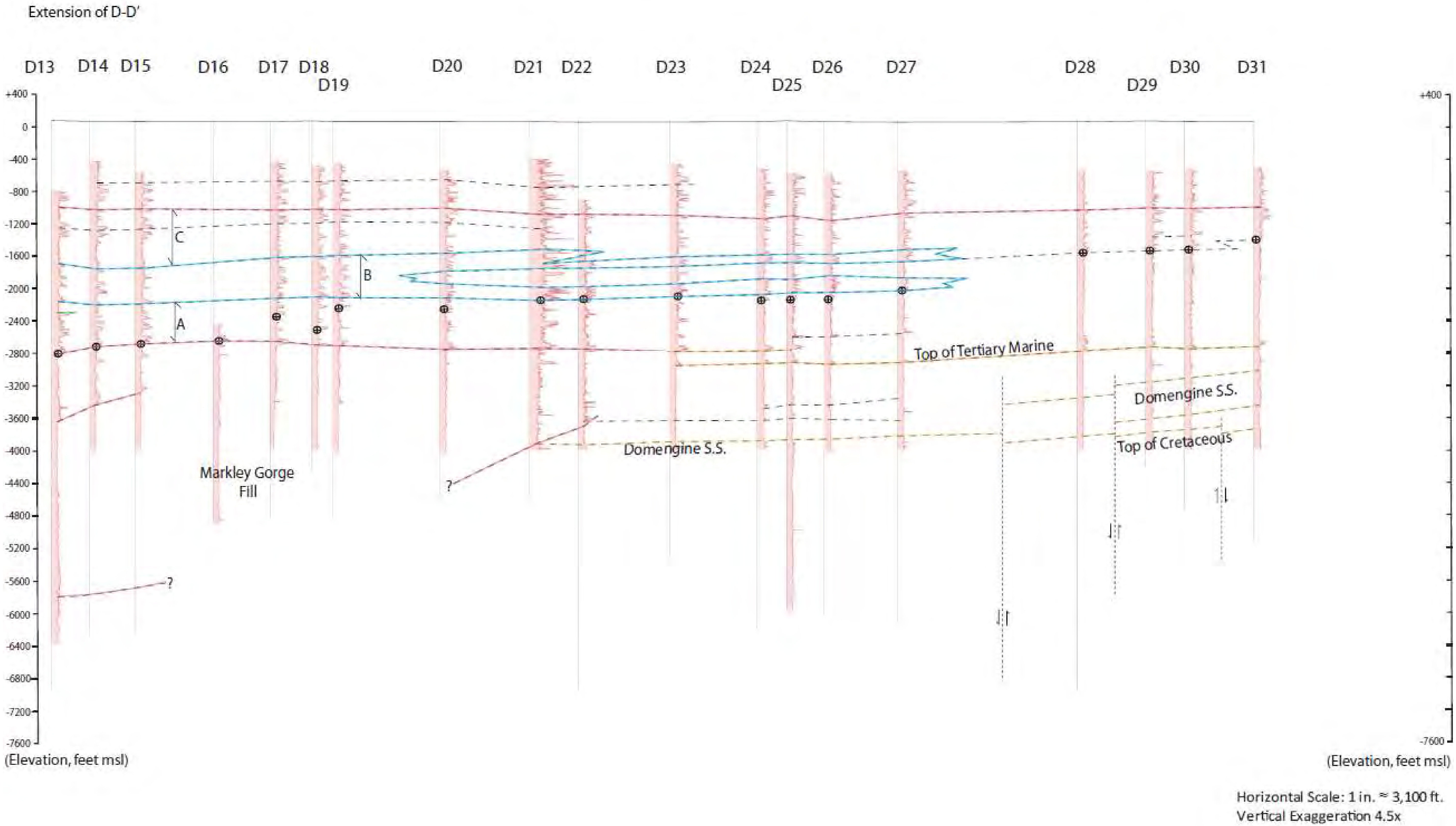
Cross Section C-C'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-17a



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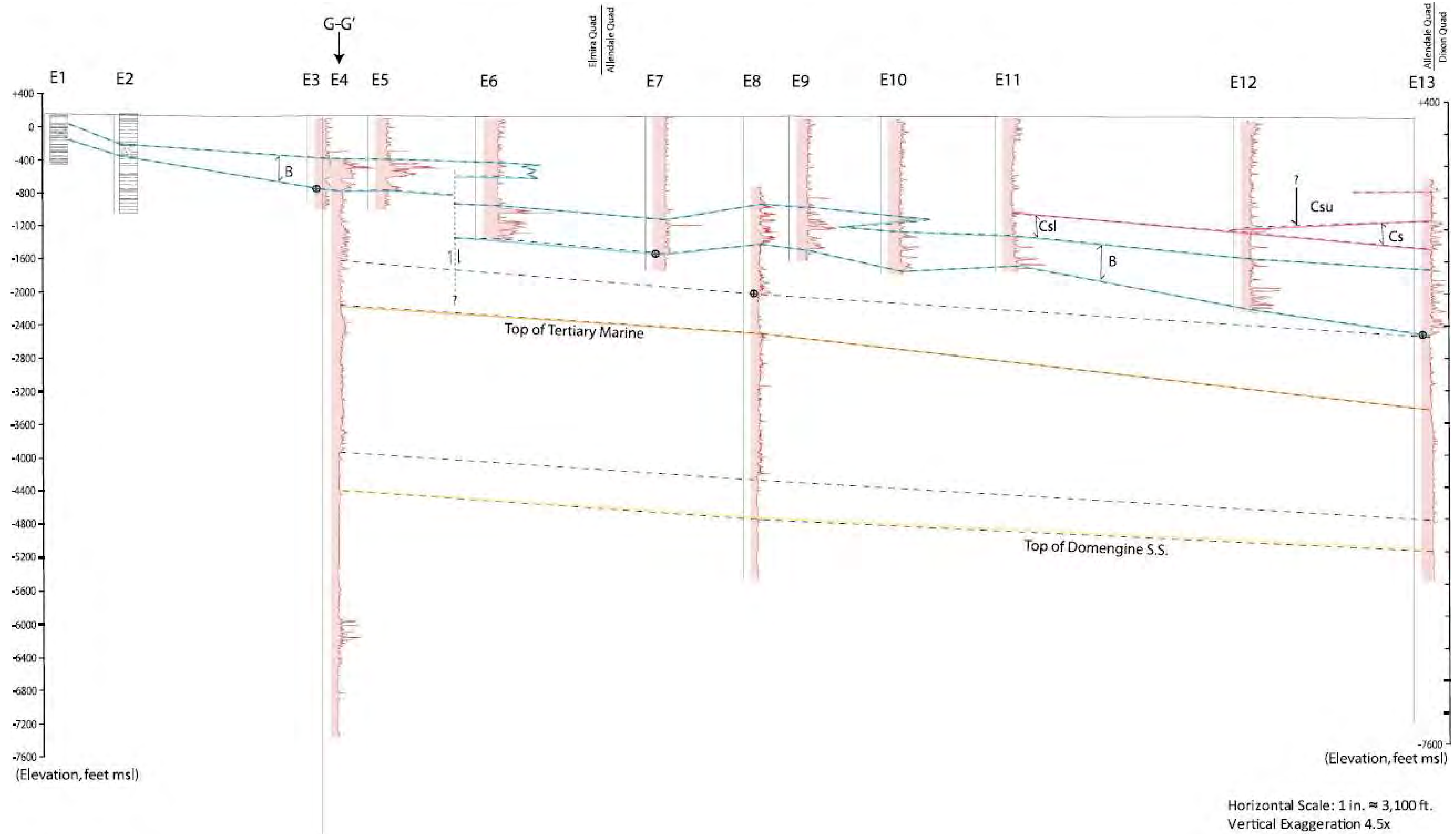
Cross Section D-D'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-17b



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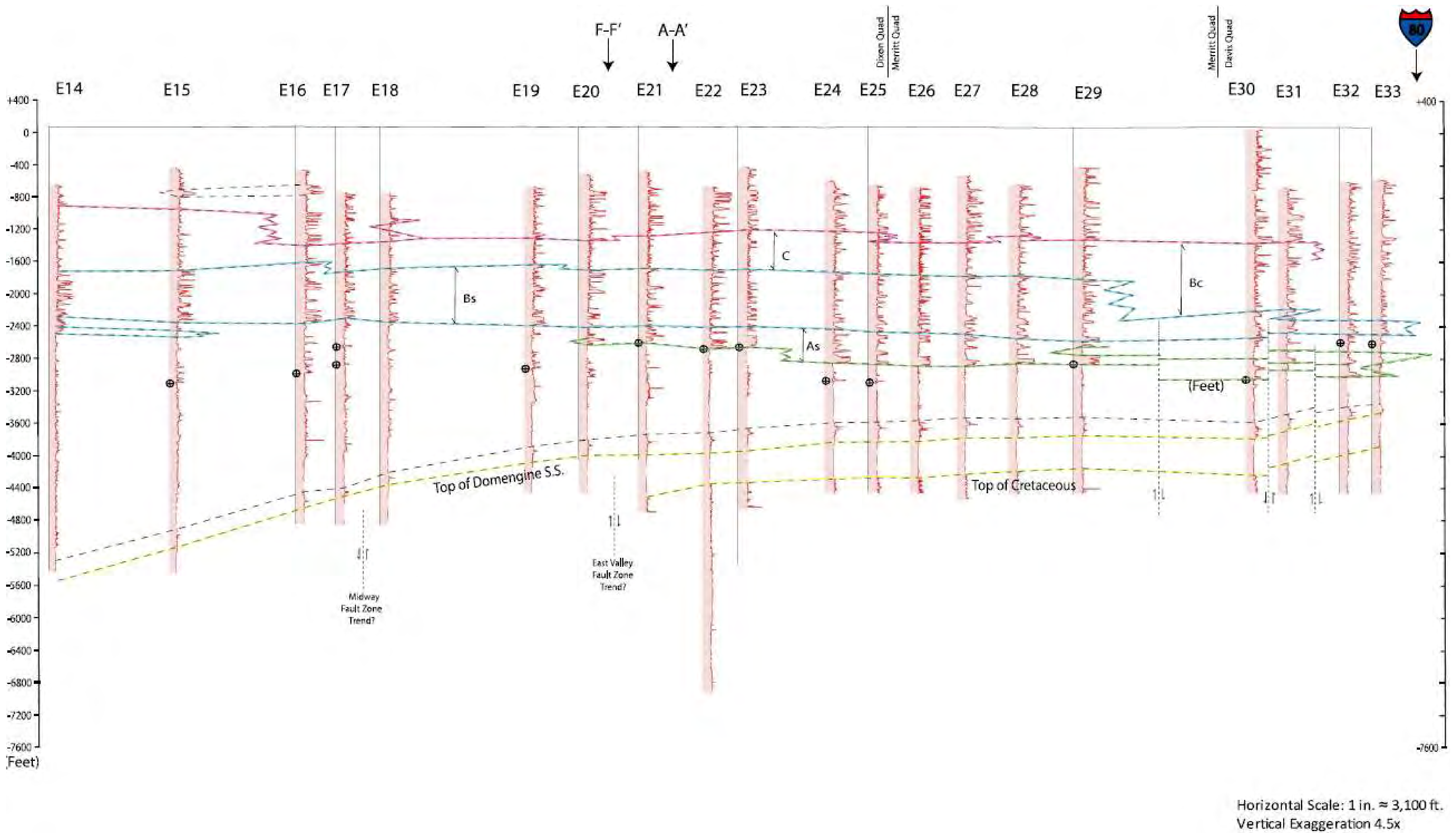
LSCE Team

Cross Section E-E'

Solano Subbasin Groundwater Sustainability Plan
Solano County, California

Figure 2-18a



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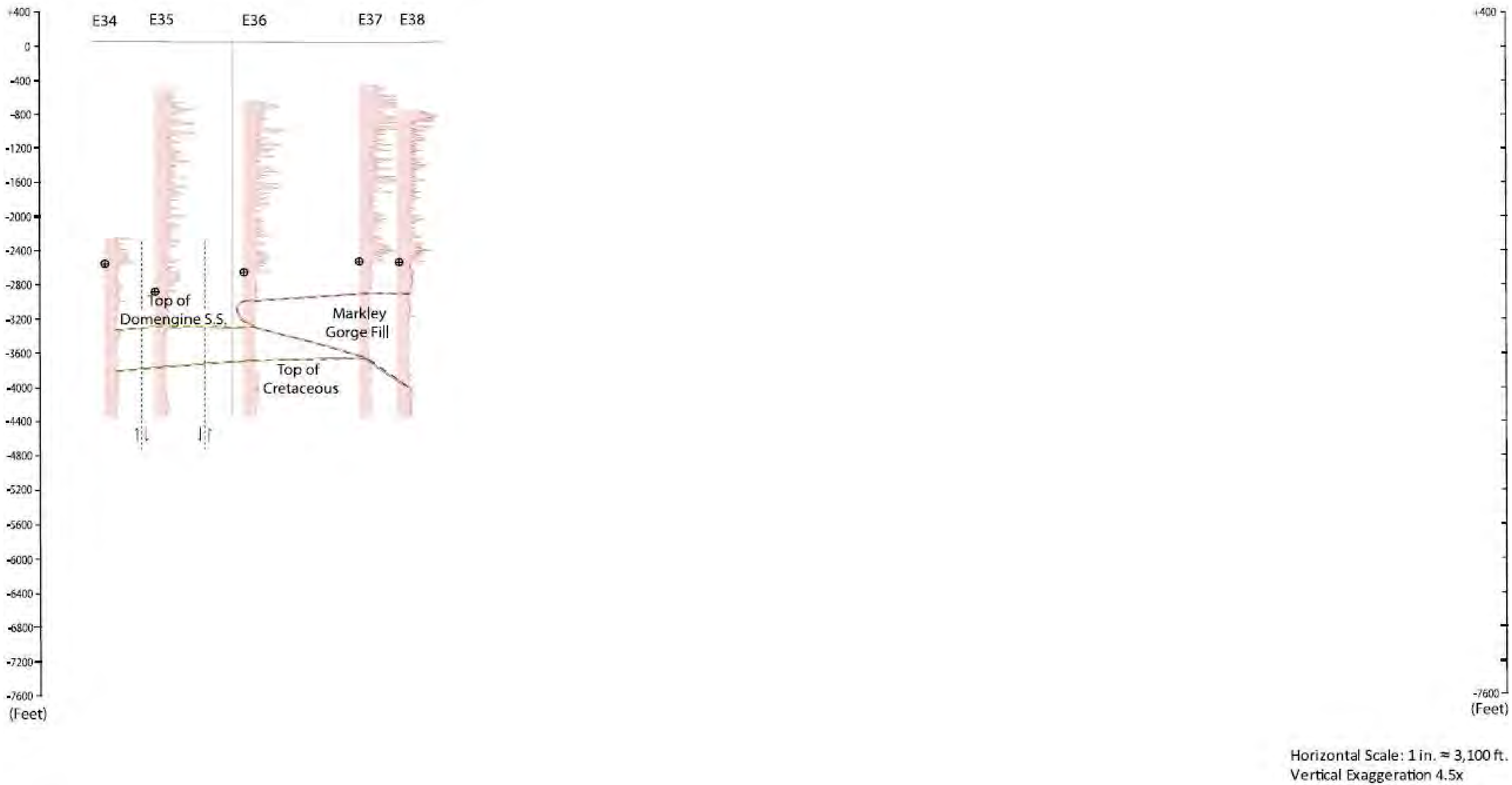
LSCE Team

Cross Section E-E'

Solano Subbasin Groundwater Sustainability Plan
Solano County, California

Figure 2-18b



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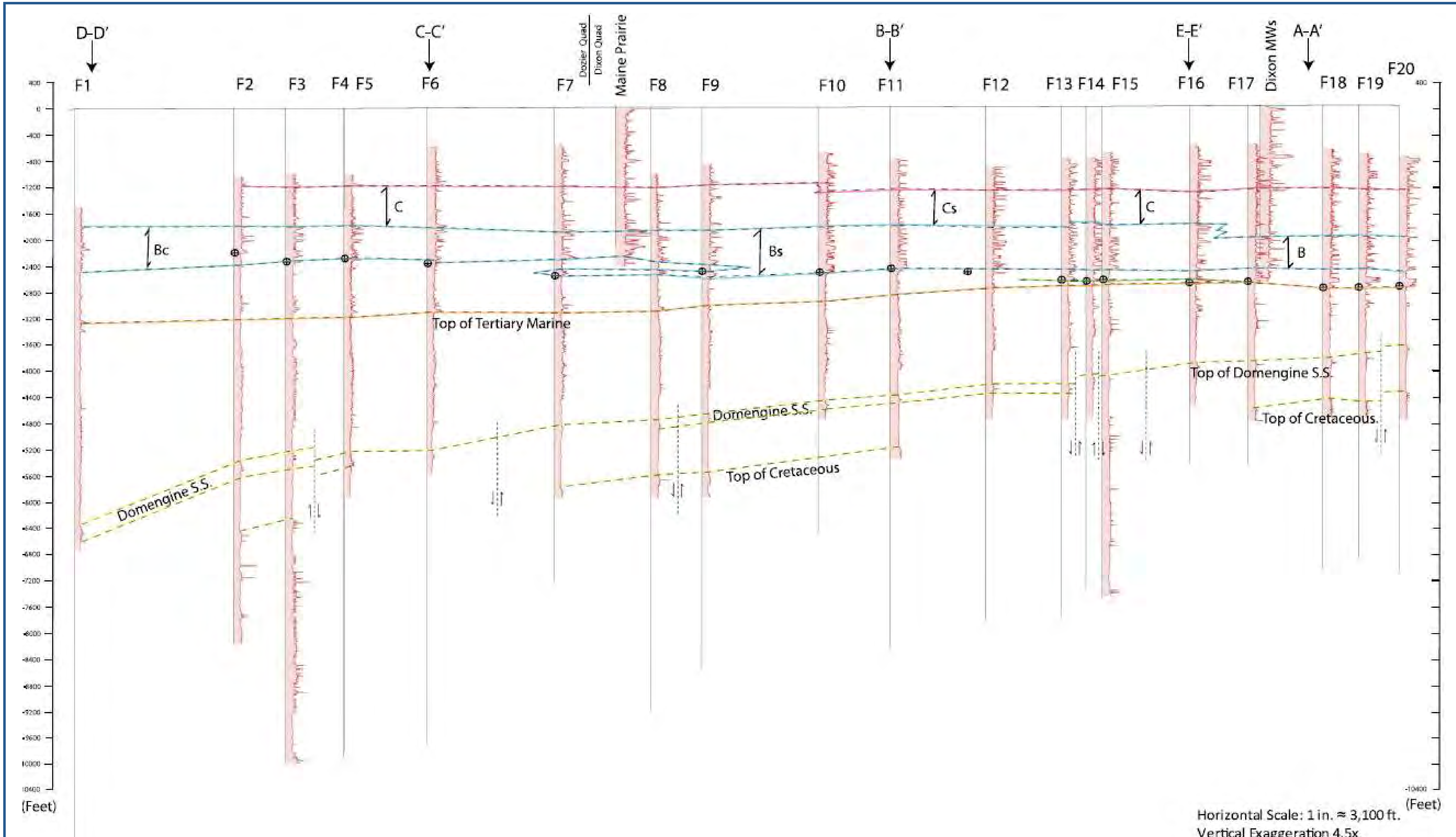
LSCE Team

Cross Section E-E'

Solano Subbasin Groundwater Sustainability Plan
Solano County, California

Figure 2-18c



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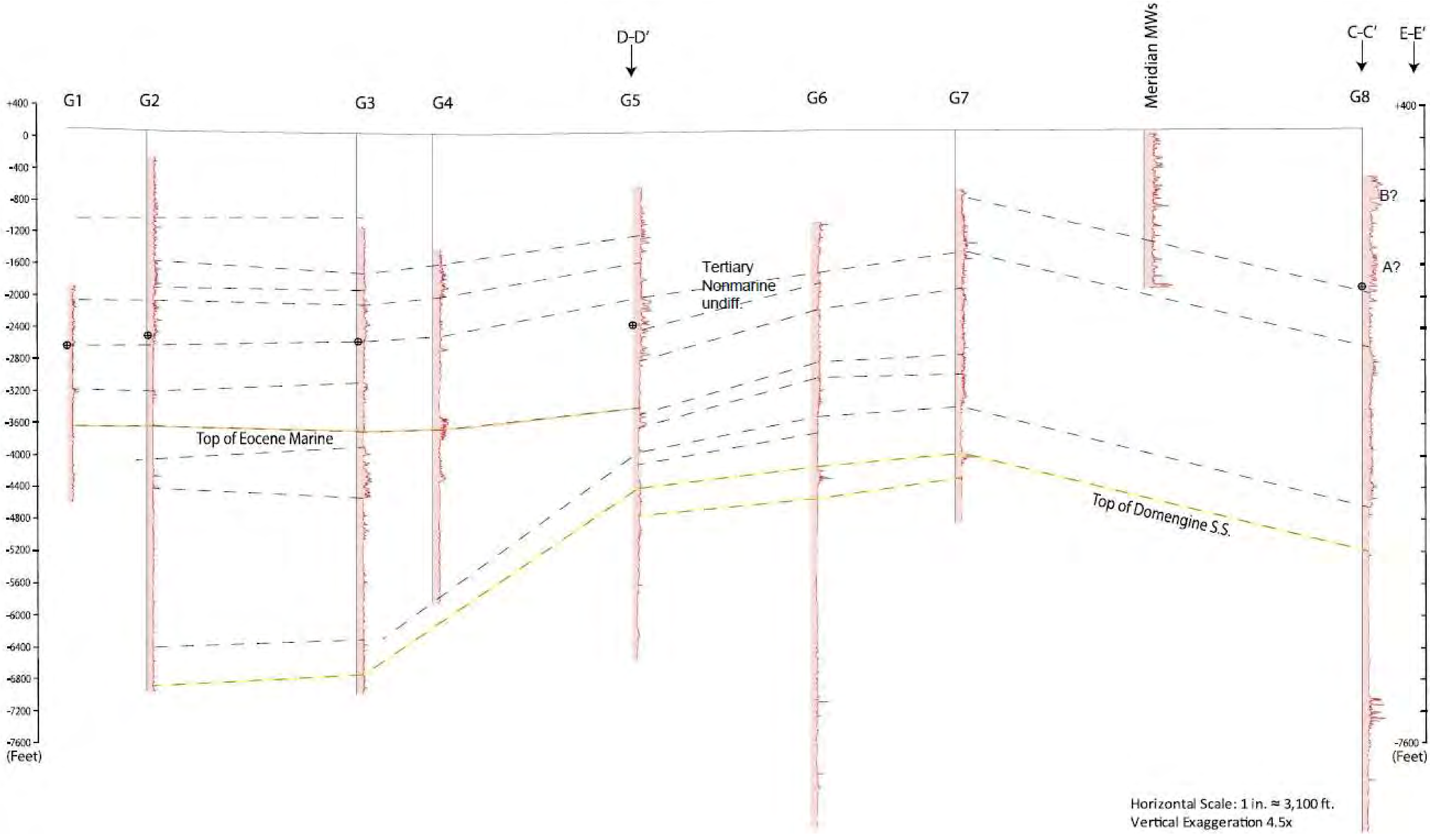
LSCE Team

Cross Section F-F'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-19



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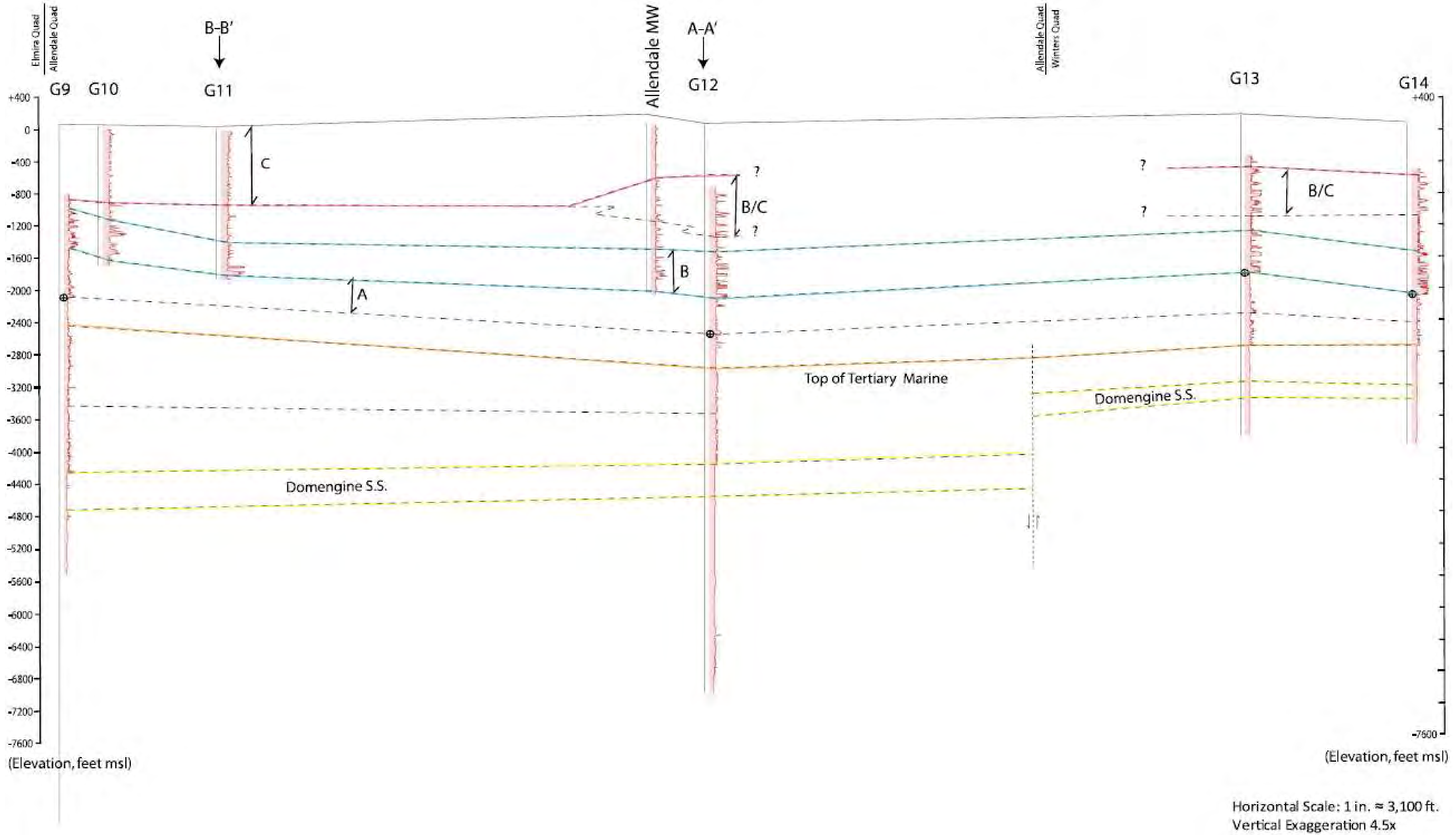
Cross Section G-G'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-20a



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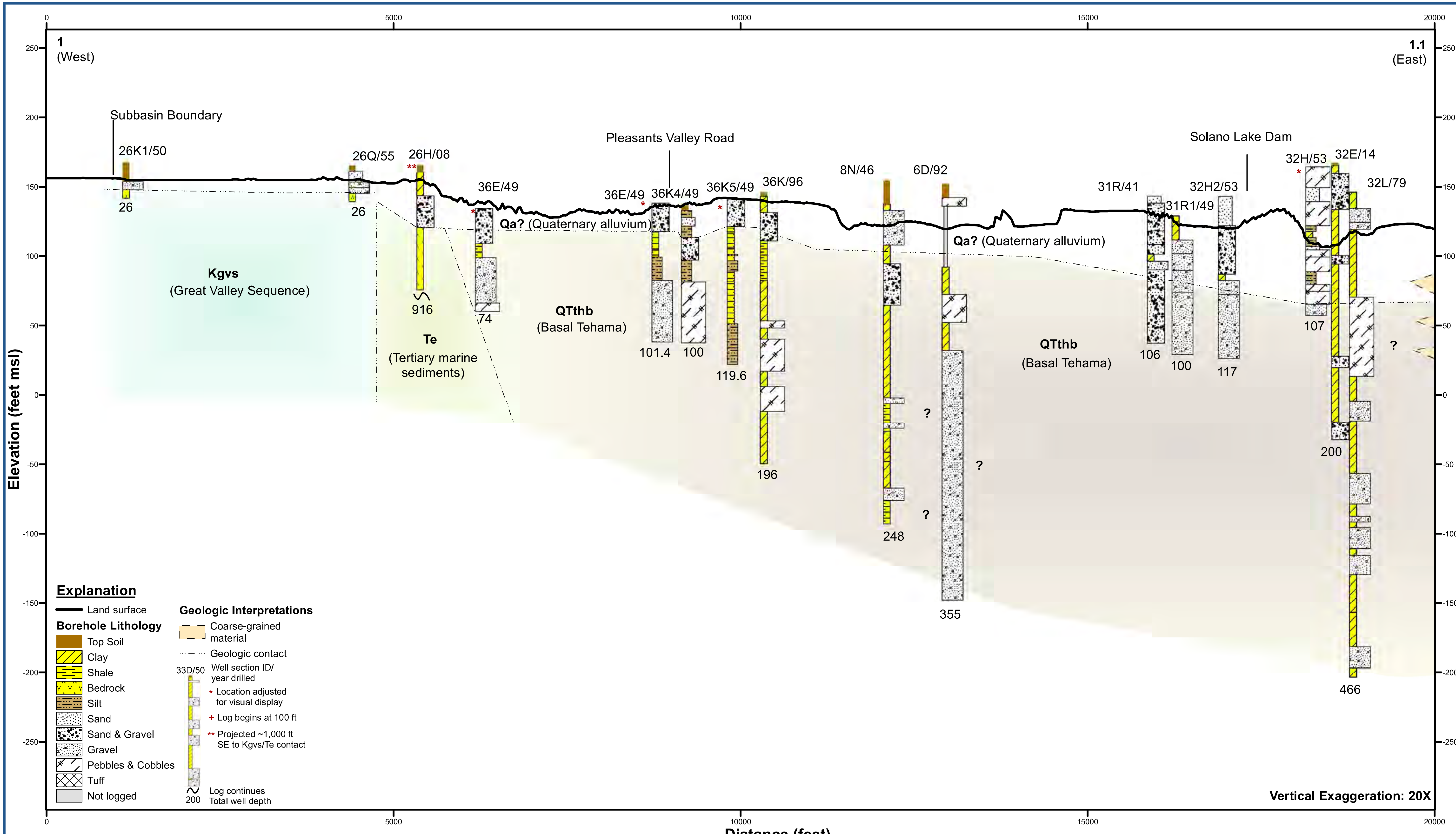
Cross Section G-G'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-20b



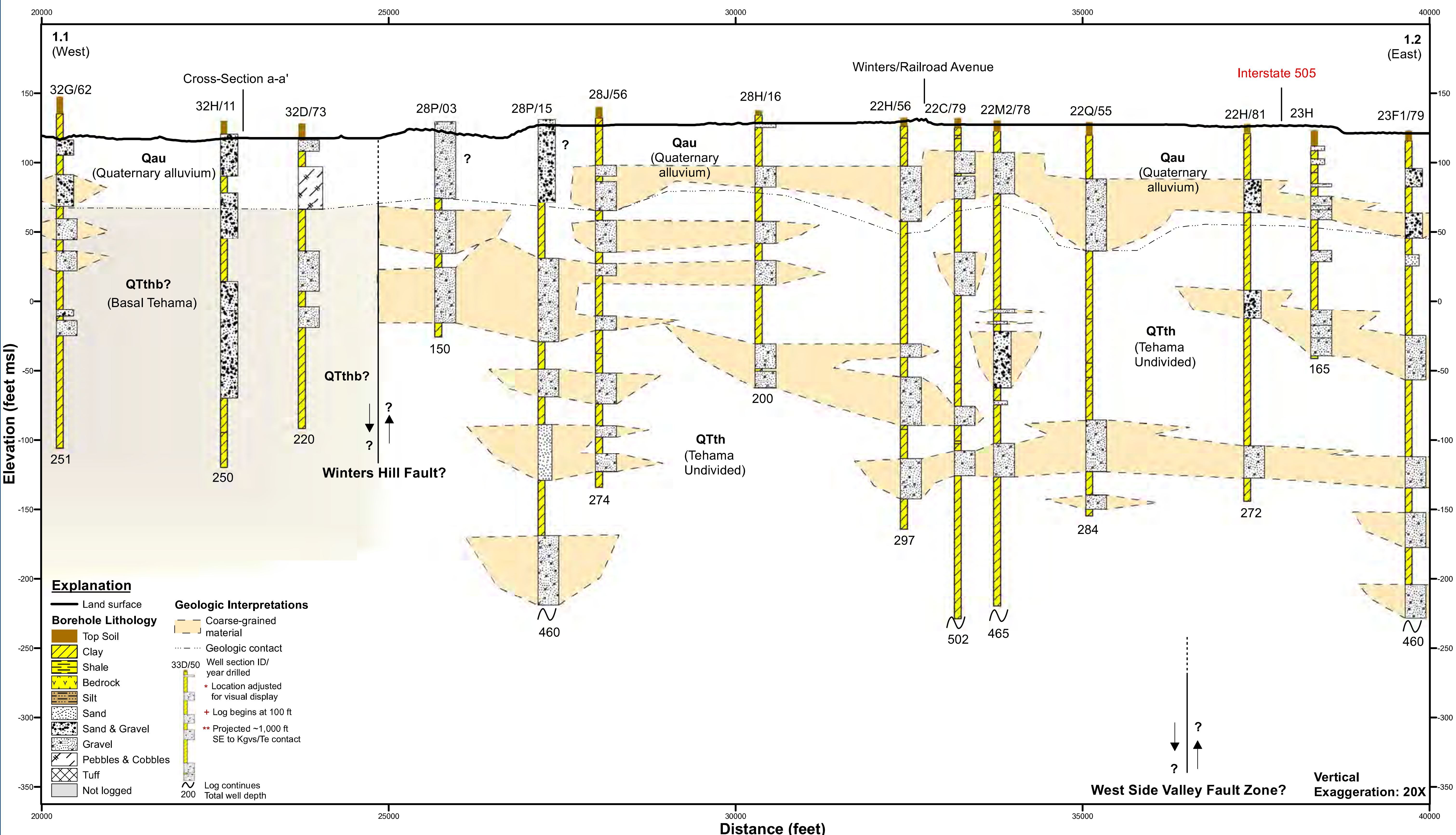
X:\2018\18-037 Solano Subbasin GSP\GIS\Report Map Figures\HCM_GW Conditions TM\Figure 2.21 Solano Subbasin CrossSection 1 -1.1.mxd

LSCE Team

Solano Subbasin Geologic Cross-Section 1-' (Segment 1-1.1)

Figure 2-21a

Groundwater Sustainability Plan
Solano Subbasin



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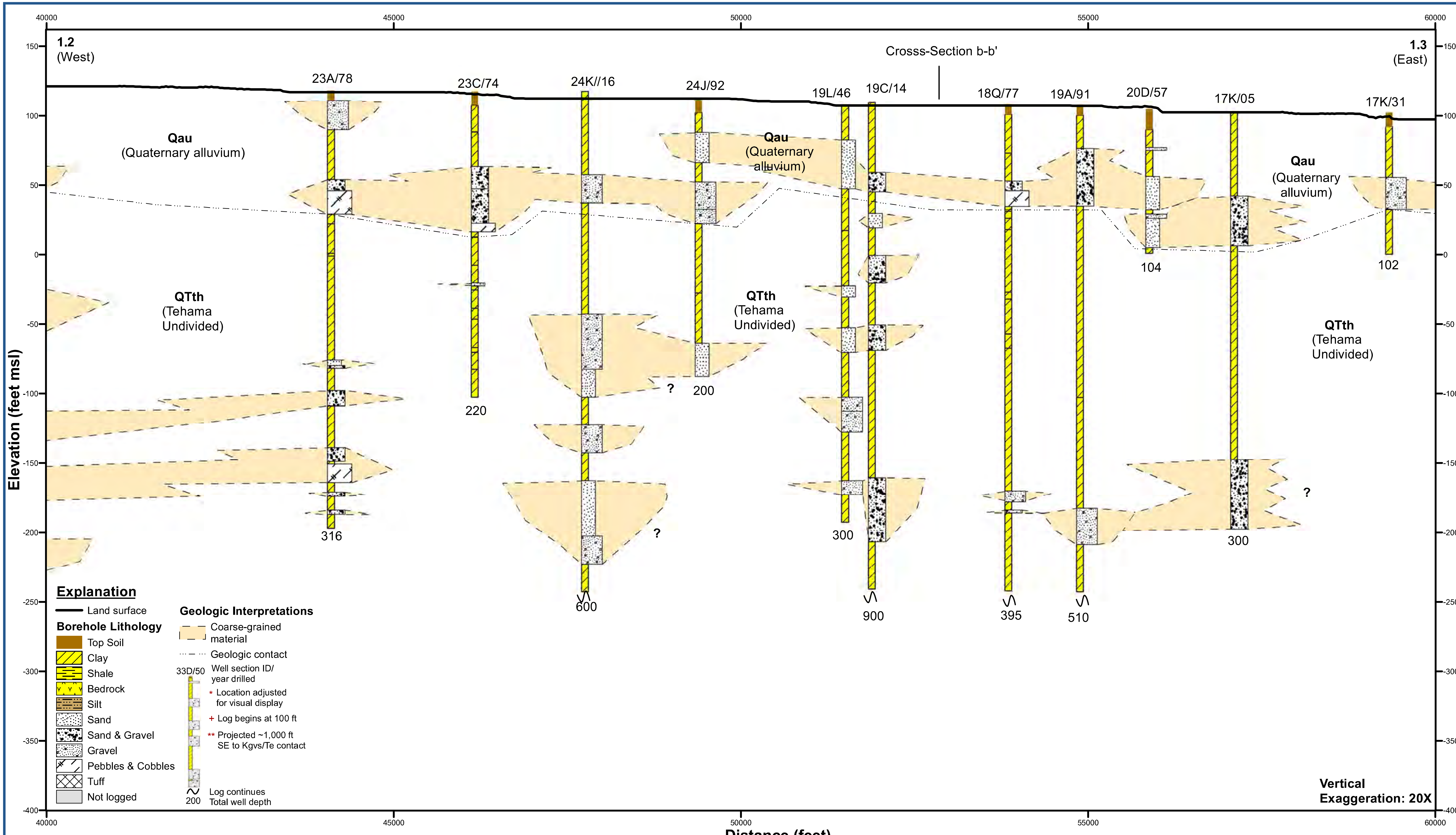
Solano Subbasin Geologic Cross-Section 1-1' (Segment 1.1-1.2)

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-21b



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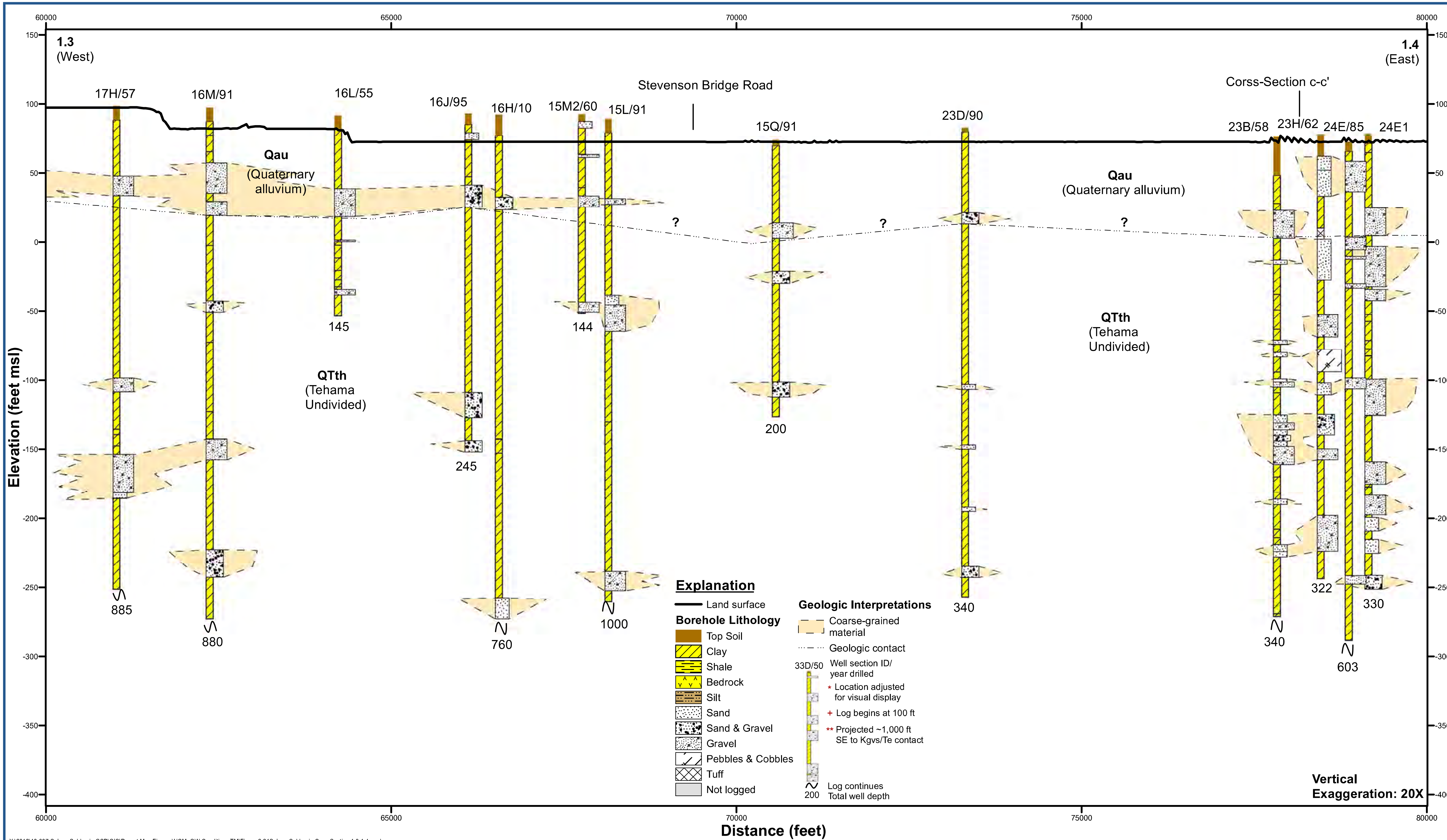
Solano Subbasin Geologic Cross-Section 1-1' (Segment 1.2-1.3)

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-21c



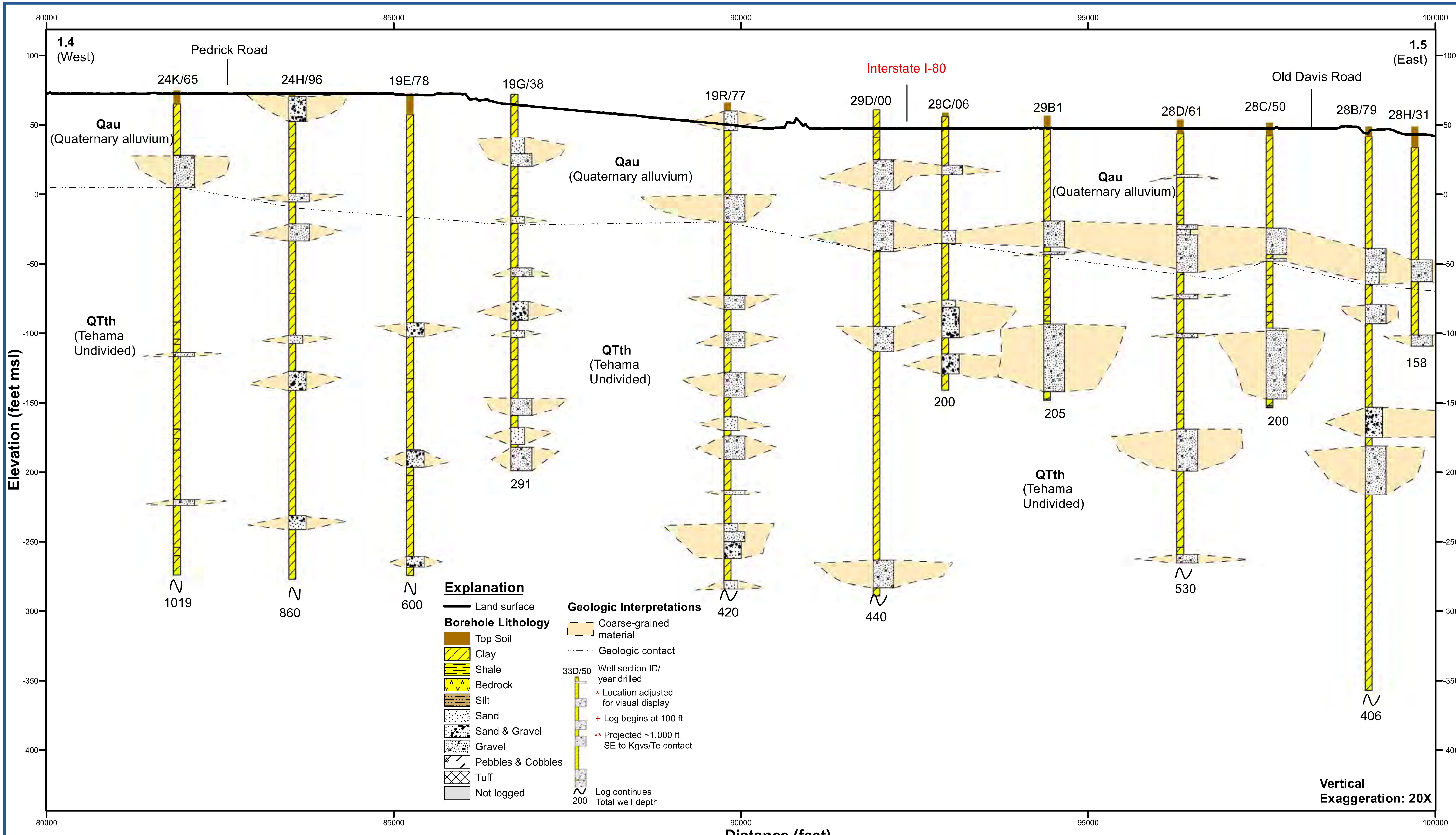
SOLANO SUBBASIN GROUNDWATER SUSTAINABILITY PLAN

LSCE Team

Solano Subbasin Geologic Cross-Section 1-1' (Segment 1.3-1.4)

Figure 2-21d

Groundwater Sustainability Plan
Solano Subbasin



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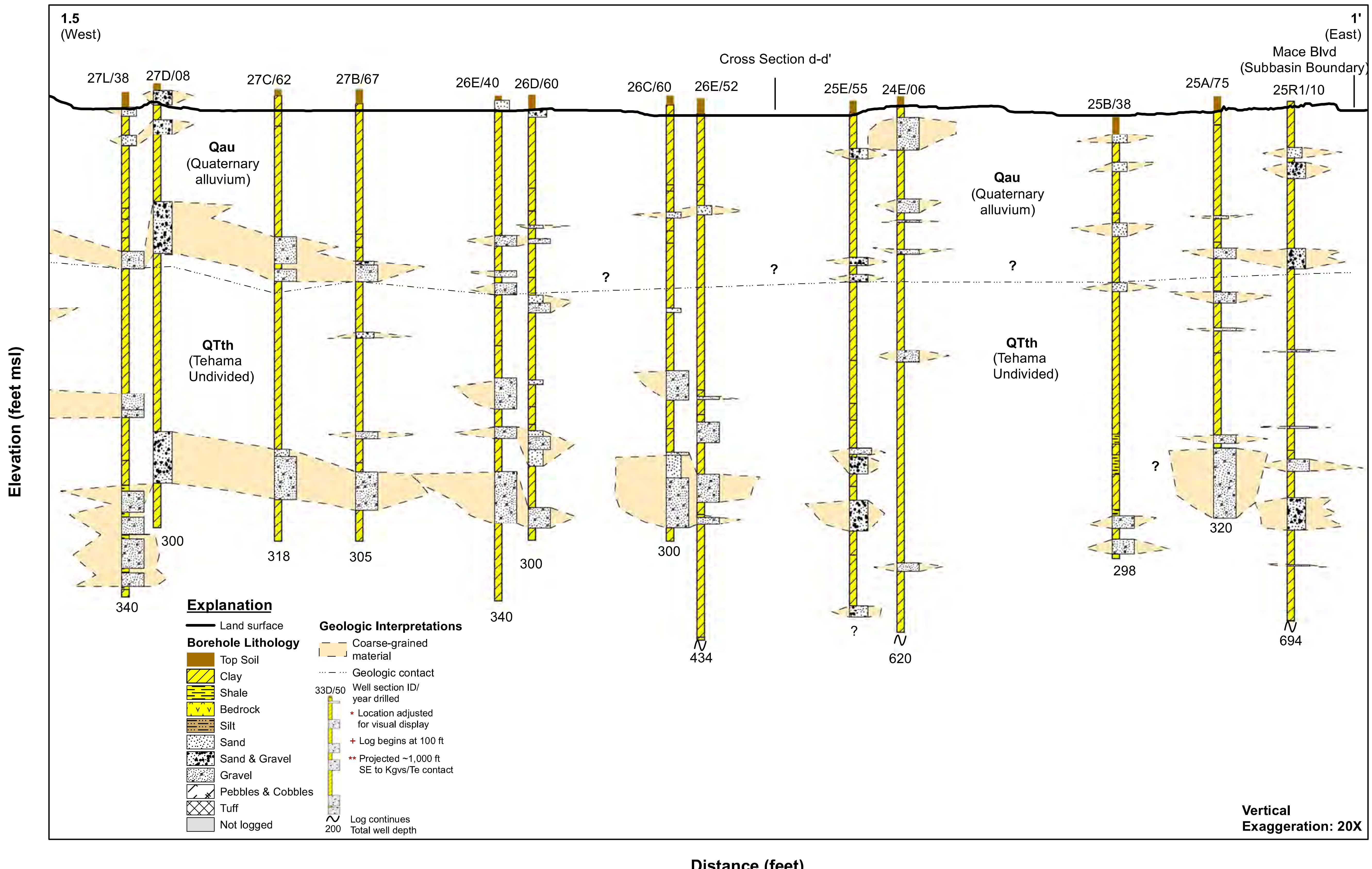
LSCE Team

Solano Subbasin Geologic Cross-Section 1-1' (Segment 1.4-1.5)

Figure 2-21e

Groundwater Sustainability Plan
Solano Subbasin



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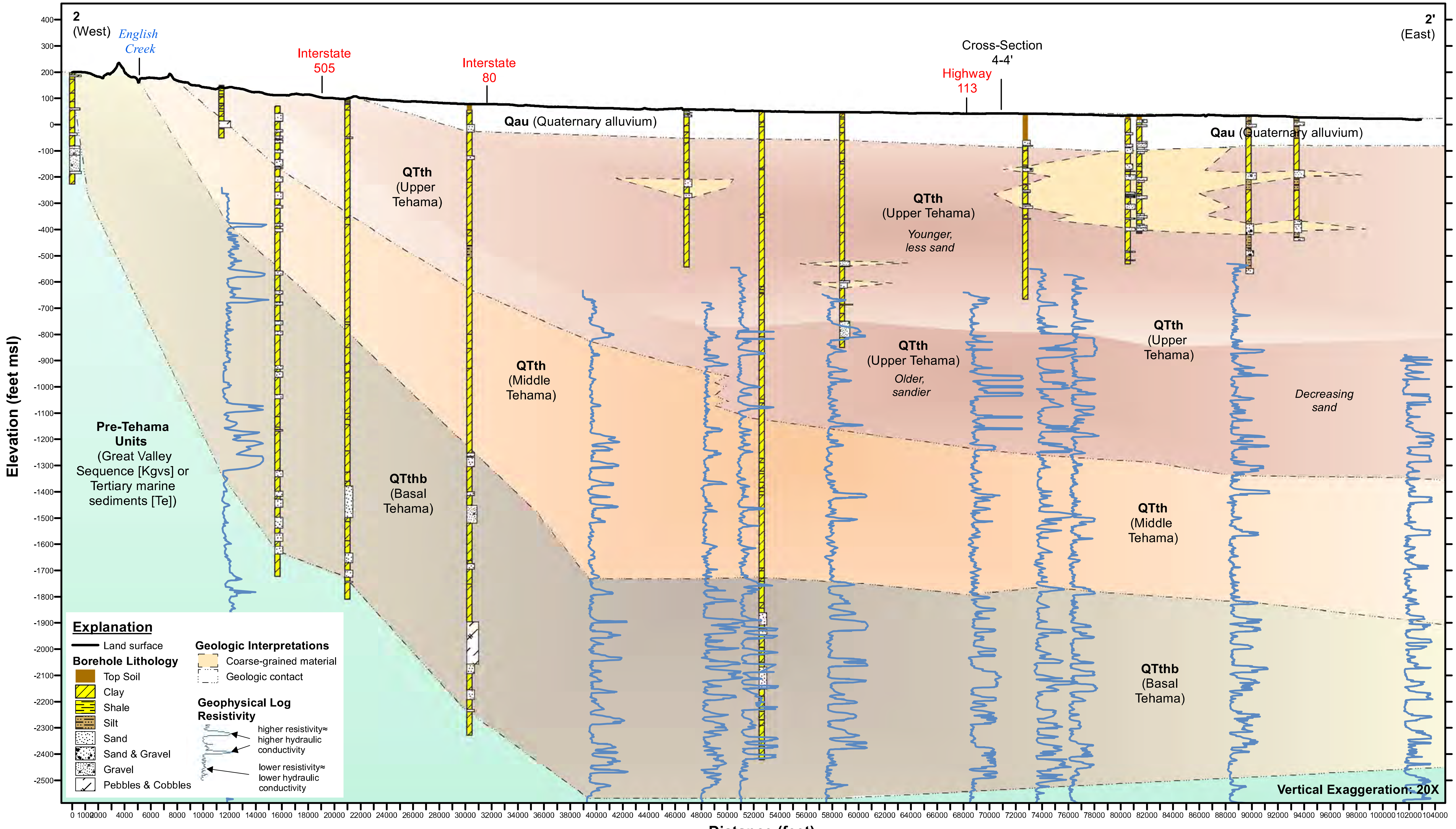
Solano Subbasin Geologic Cross-Section 1-1' (1.5-1')

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-21f



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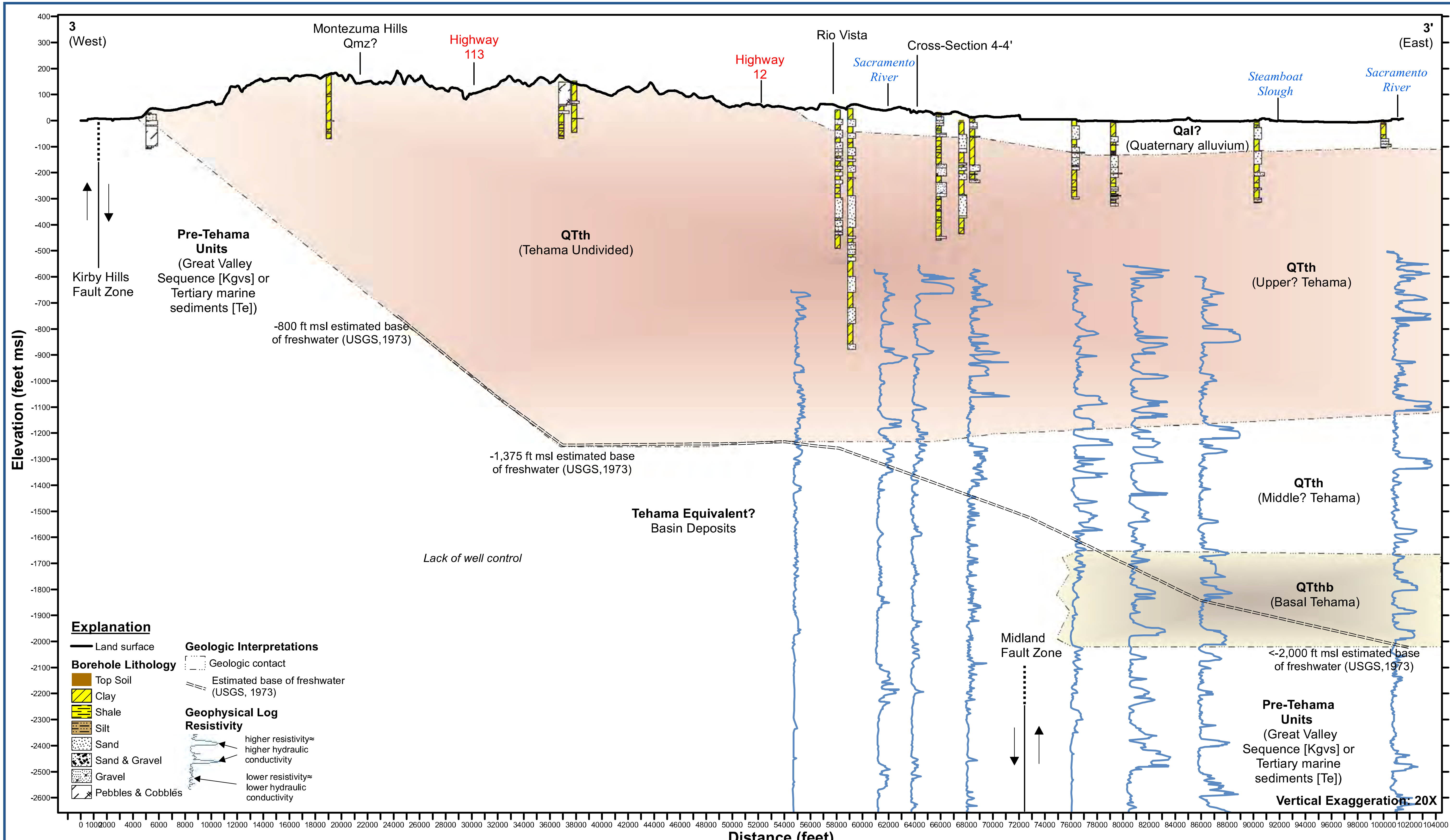
LSCE Team

Solano Subbasin Geologic Cross-Section 2-2'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-22



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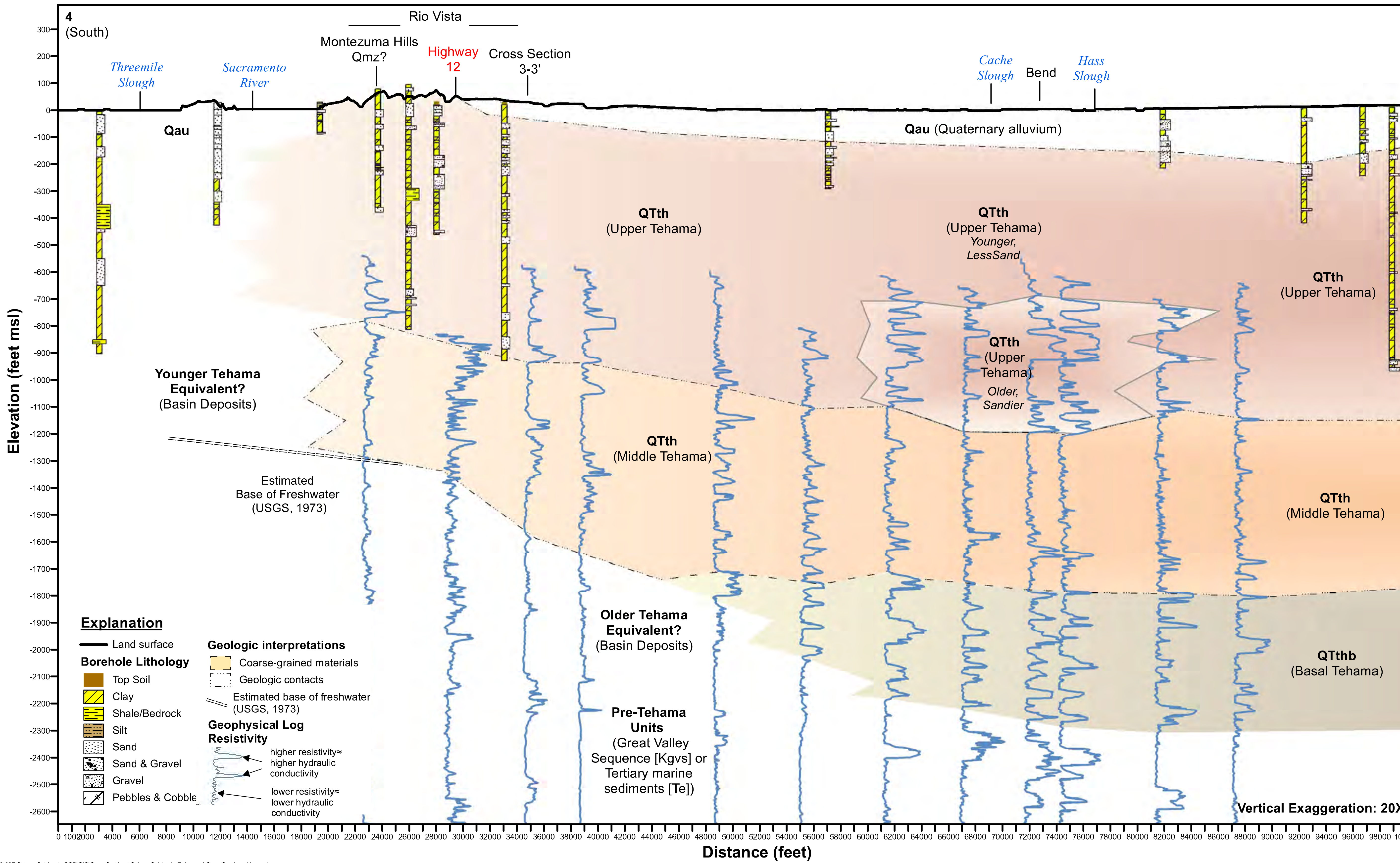
Solano Subbasin Geologic Cross-Section 3-3'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-23



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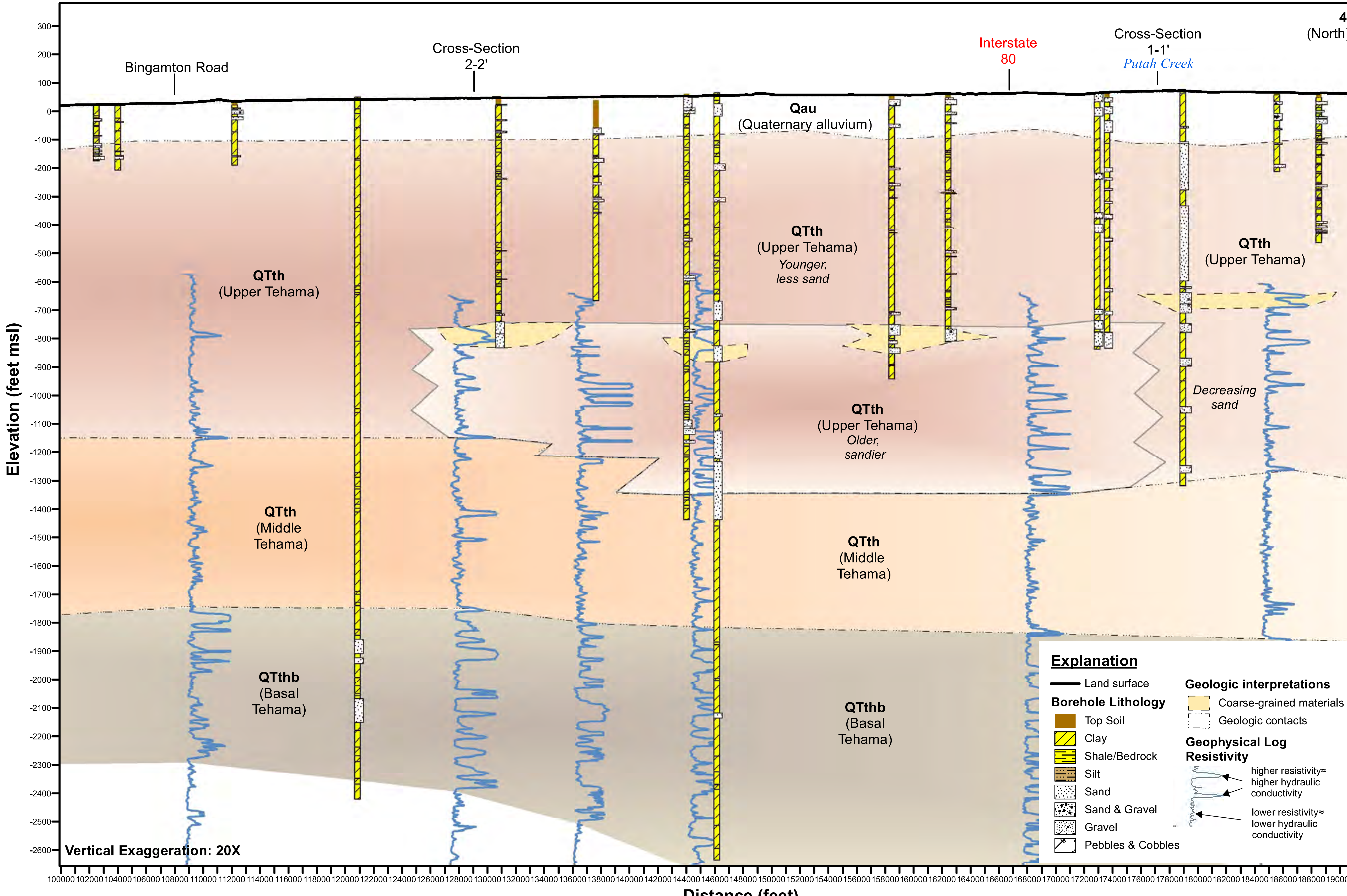
Solano Subbasin Geologic Cross-Section 4-4' (segment 1 of 2)

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-24a



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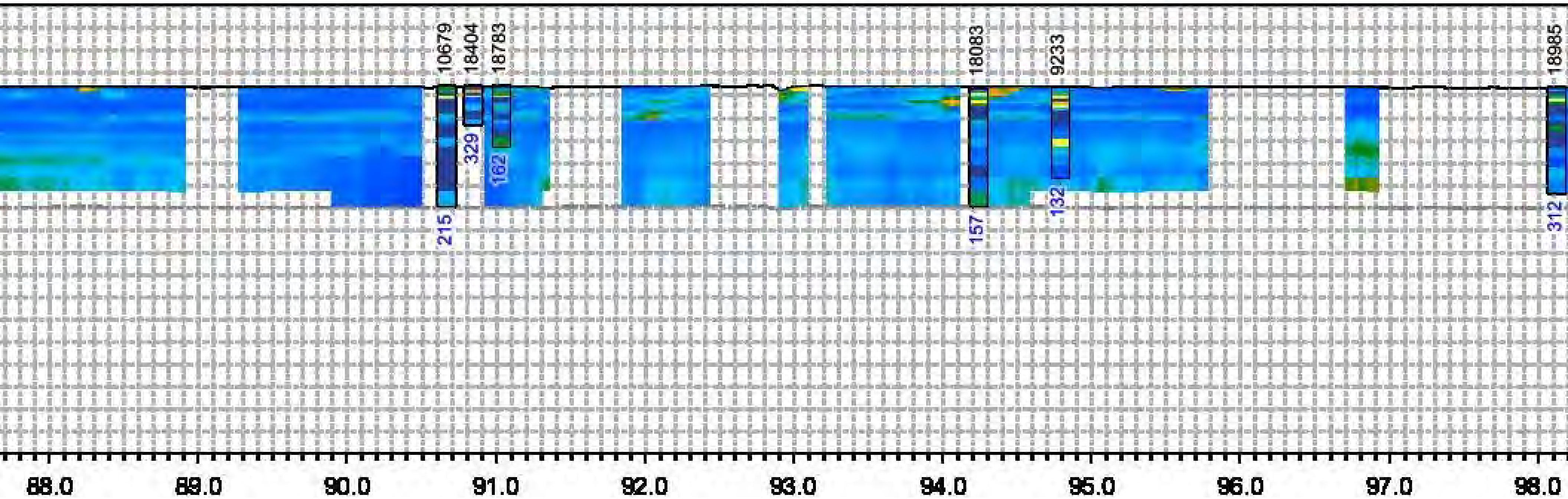
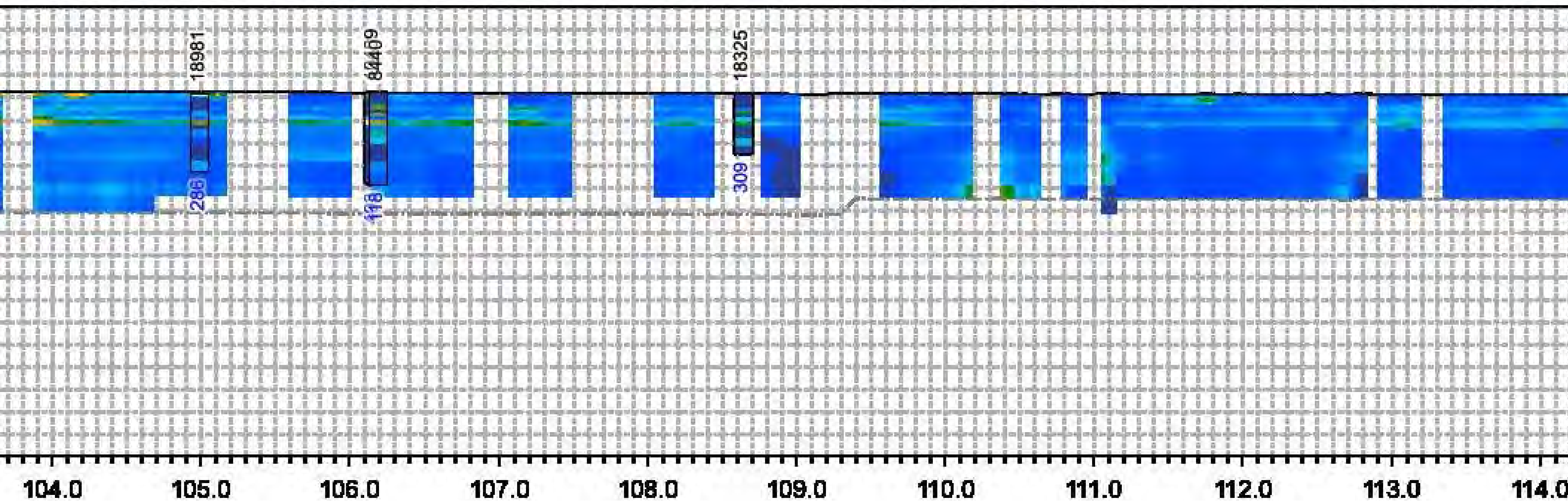
Solano Subbasin Geologic Cross-Section 4-4' (segment 2 of 2)

Groundwater Sustainability Plan
Solano Subbasin

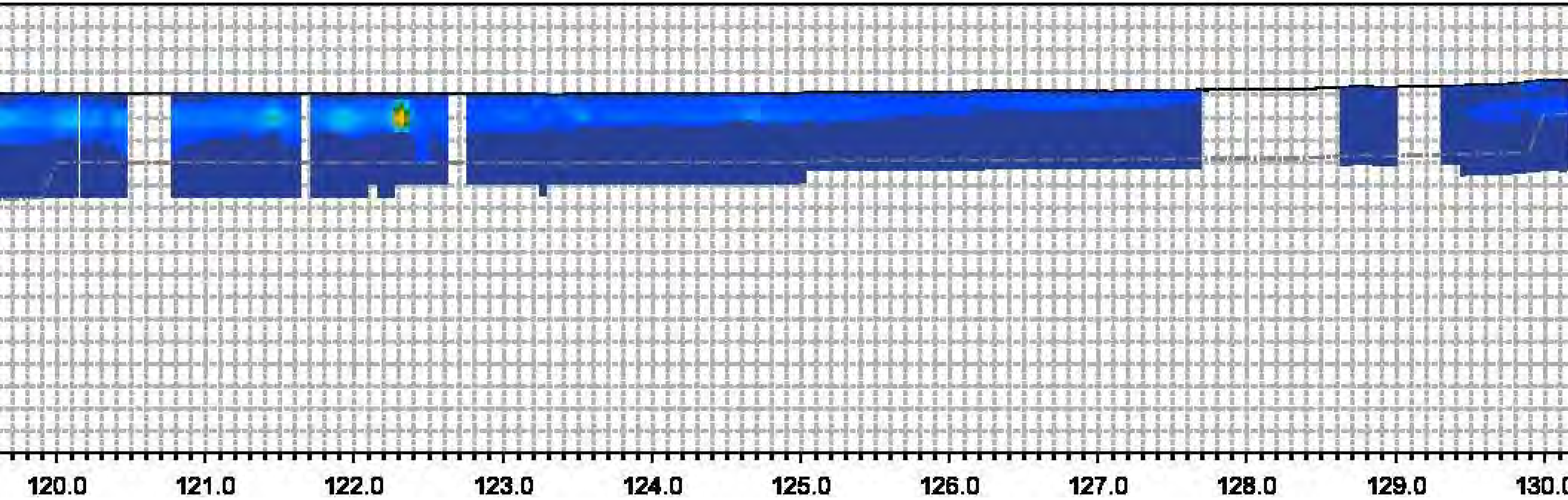
Figure 2-24b

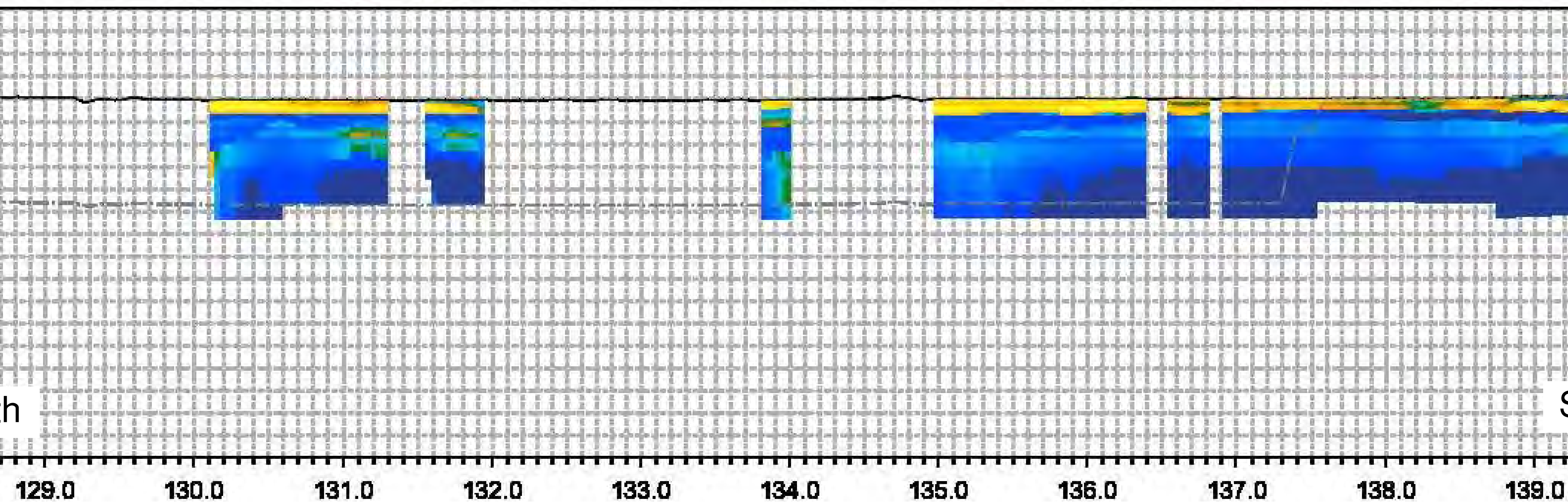
4 - 4' Nearest AEM Log





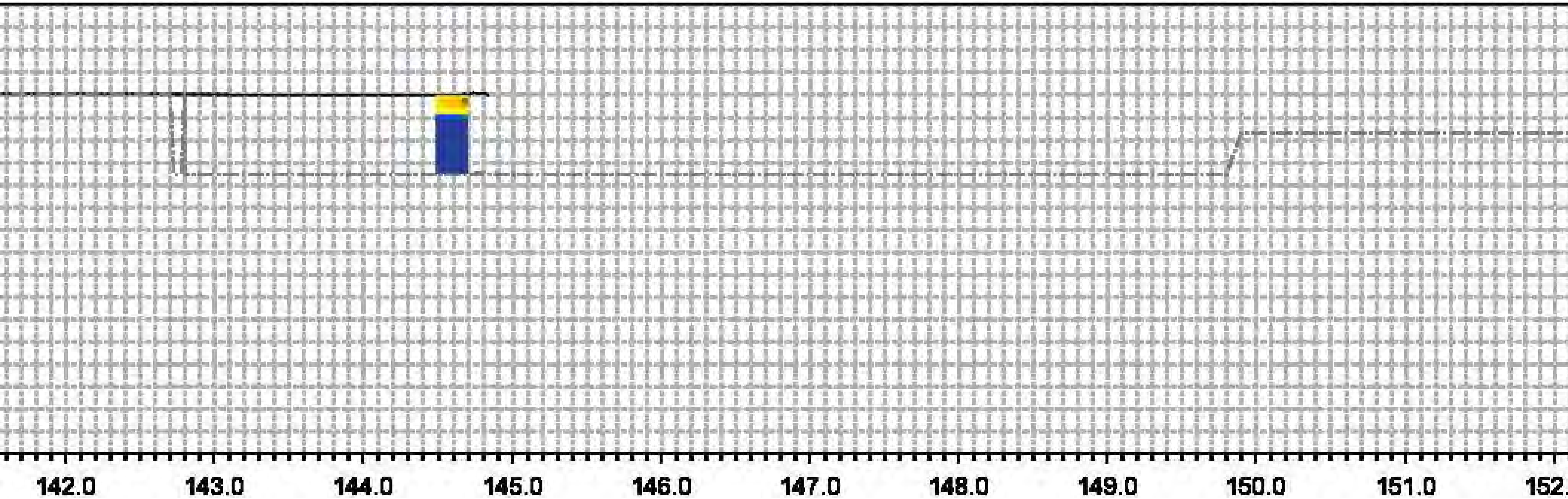
4 - 4' Nearest AEM Log

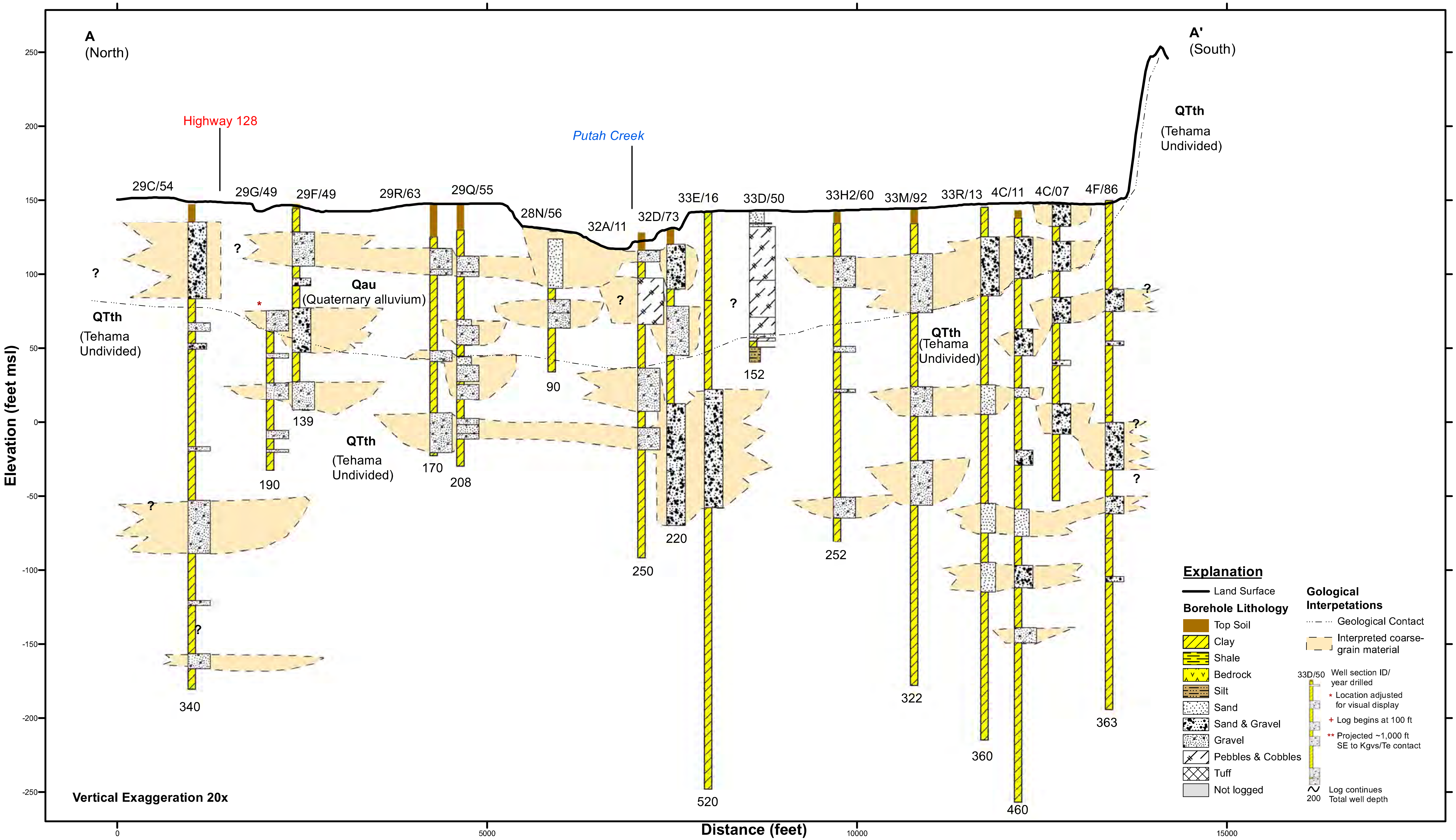




This AEM log is NOT continuous with the previous AEM log.

4 - 4' Nearest AEM Log





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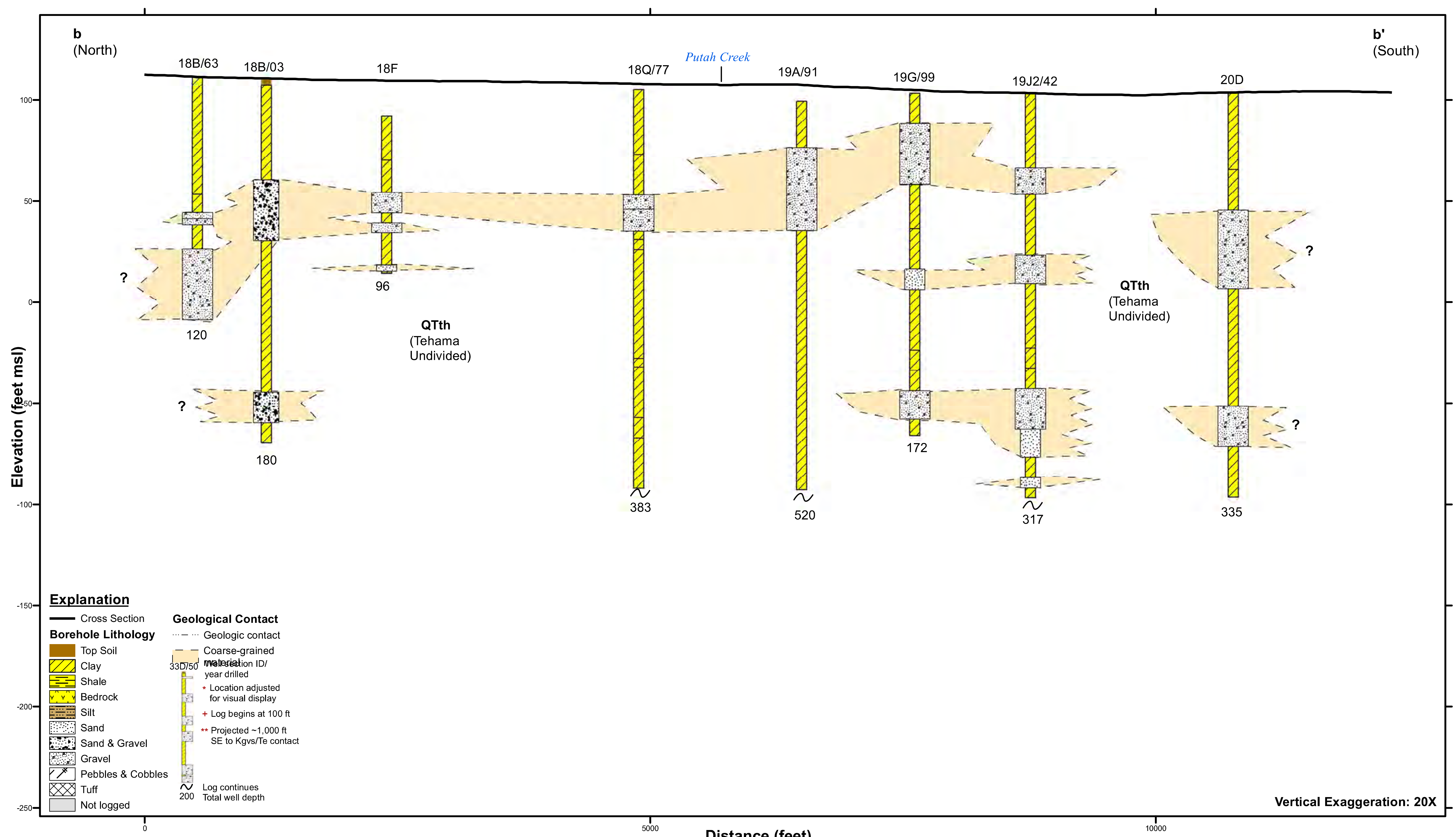
Solano Subbasin Geologic Cross-Section a-a'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-25



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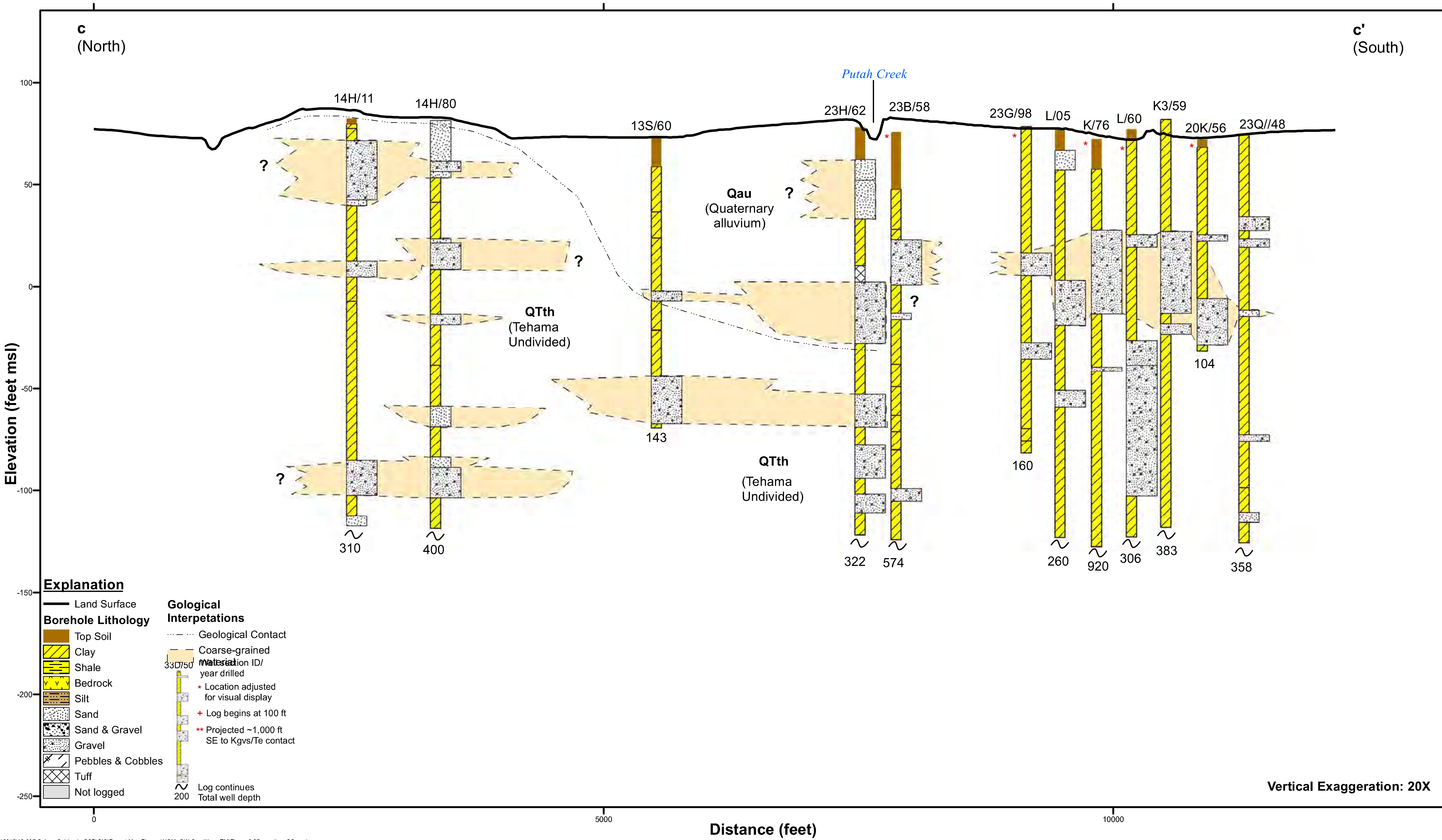
Solano Subbasin Geologic Cross-Section b-b'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-26



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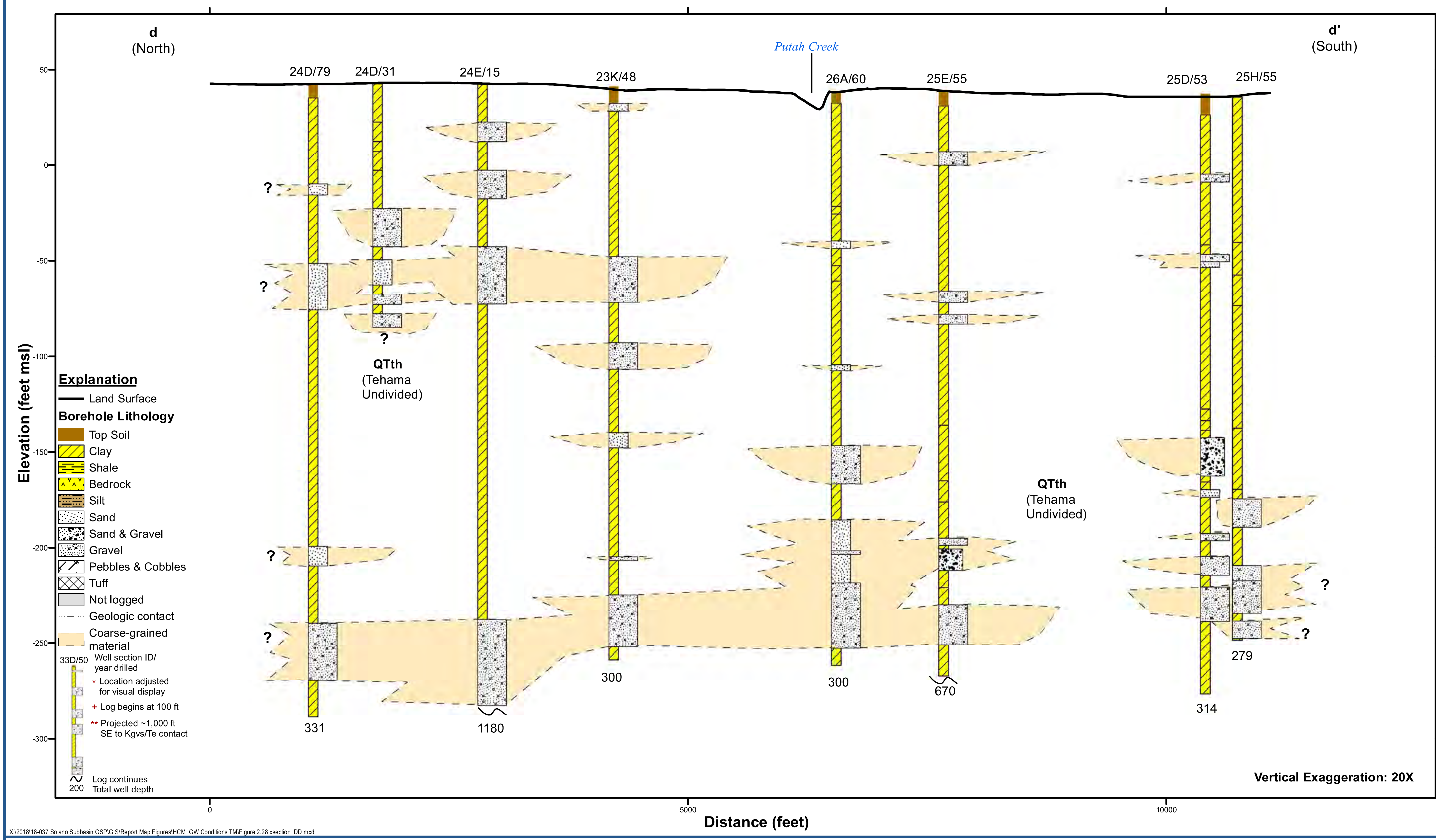
Solano Subbasin Geologic Cross-Section c-c'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-27



Solano Subbasin Geologic Cross-Section d-d'

Groundwater Sustainability Plan
Solano Subbasin

Figure 2-28

10-29-2021

FINAL REPORT

South American Subbasin Groundwater Sustainability Plan

South American SUBBASIN

NDGSA NORTHERN DELTA GROUNDWATER SUSTAINABILITY AGENCY

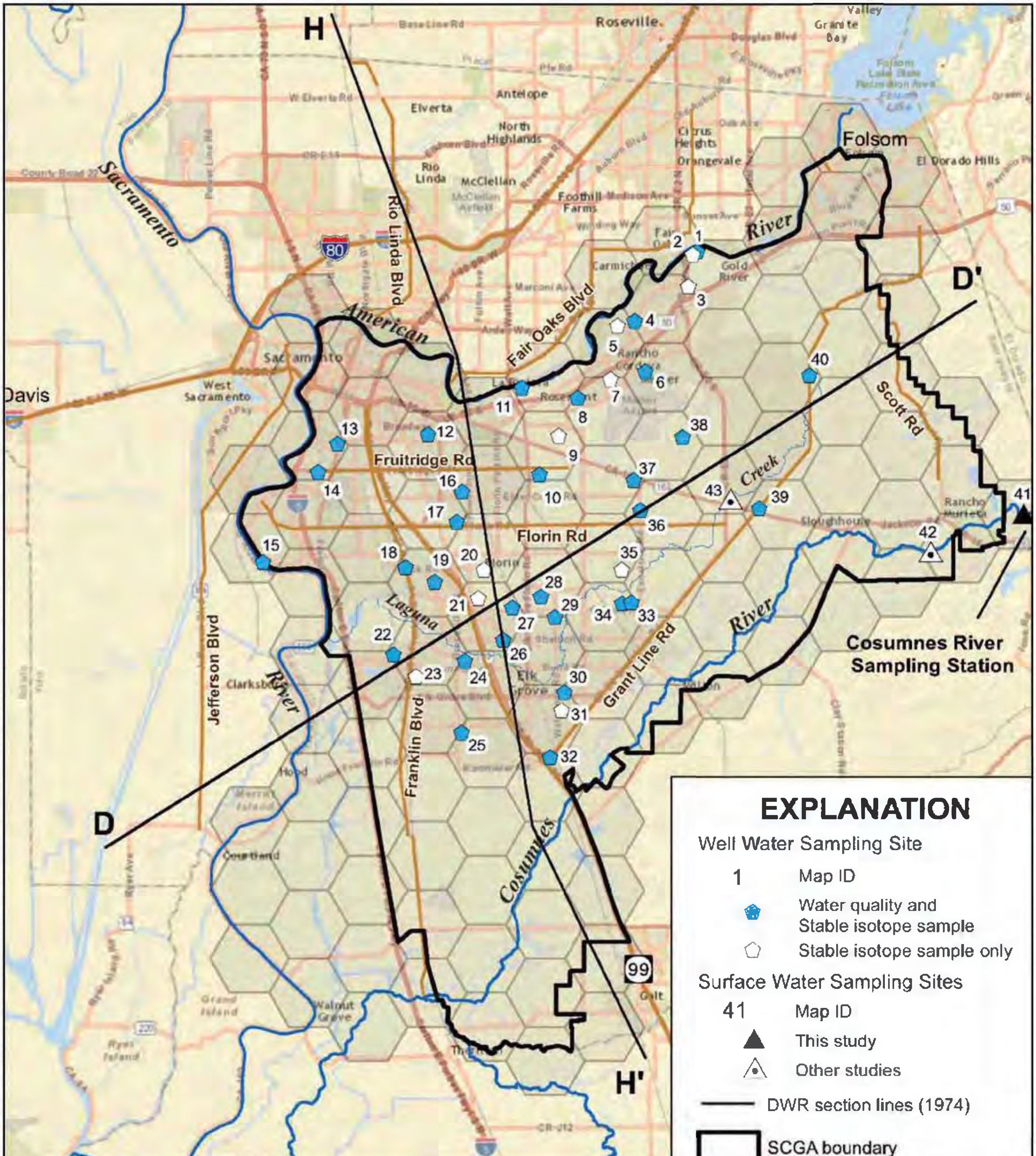
SLOUGHHOUSE Resource Conservation District HERALD | SLOUGHHOUSE | WILTON

SACRAMENTO COUNTY

SCGA Sacramento Central Groundwater Authority

Omochumne - Hartnell Water District Servicing the Community of the Cosumnes River

RECLAMATION DISTRICT 551



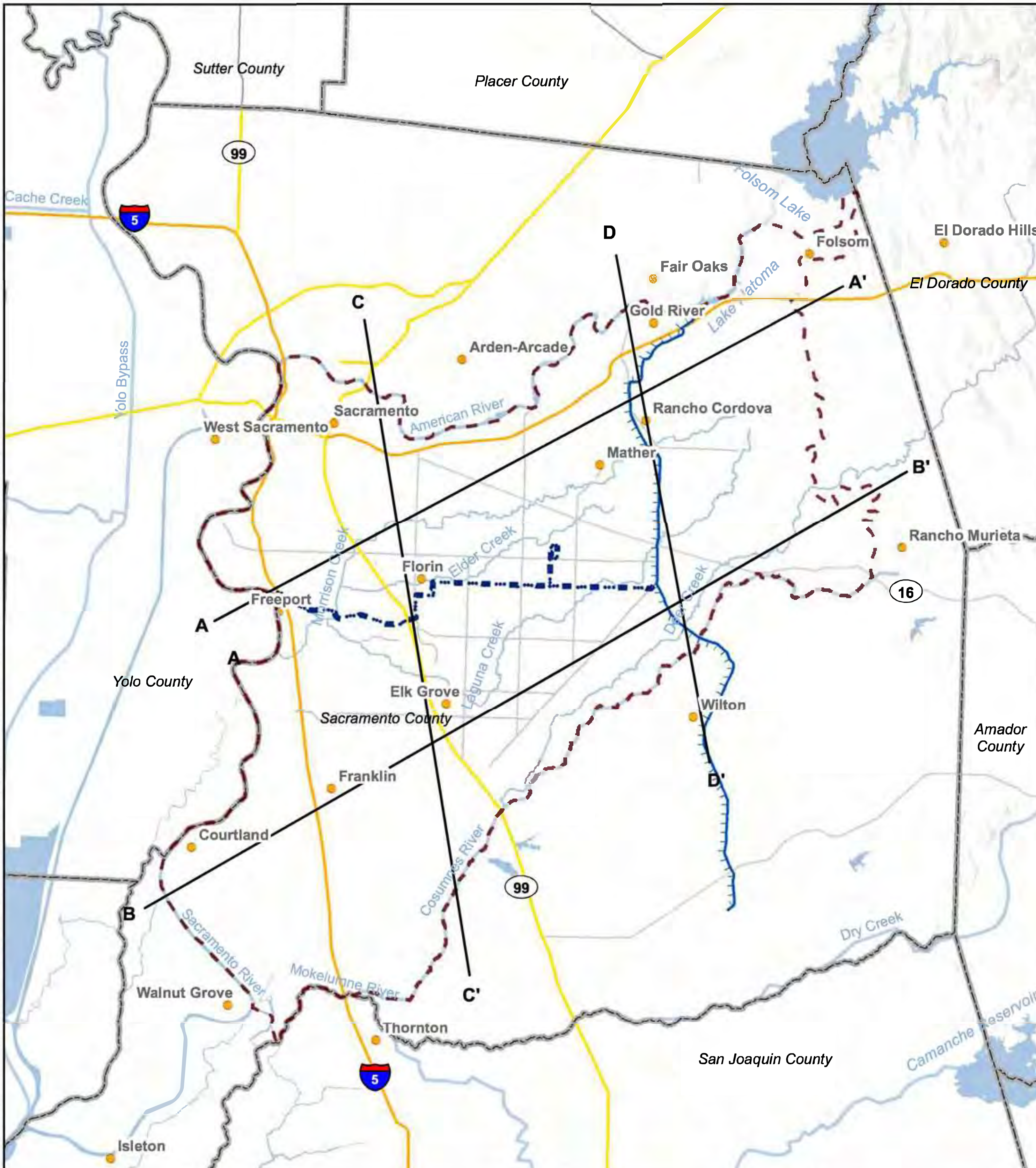
South American Subbasin GSP

Cross Sections and Water Sampling Locations

Figure 2.2-32

Project #: 0011575.00
Map Created: June 2020

Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions. Any reliance upon the map or data contained herein shall be at the users' sole risk. **Data Sources:** Prepared by RMC Water and Environment for the Sacramento Central Groundwater Authority, 2015.



South American Subbasin GSP

CoSANA Model Layer Cross Section Locations

Figure 2.2-33

Legend

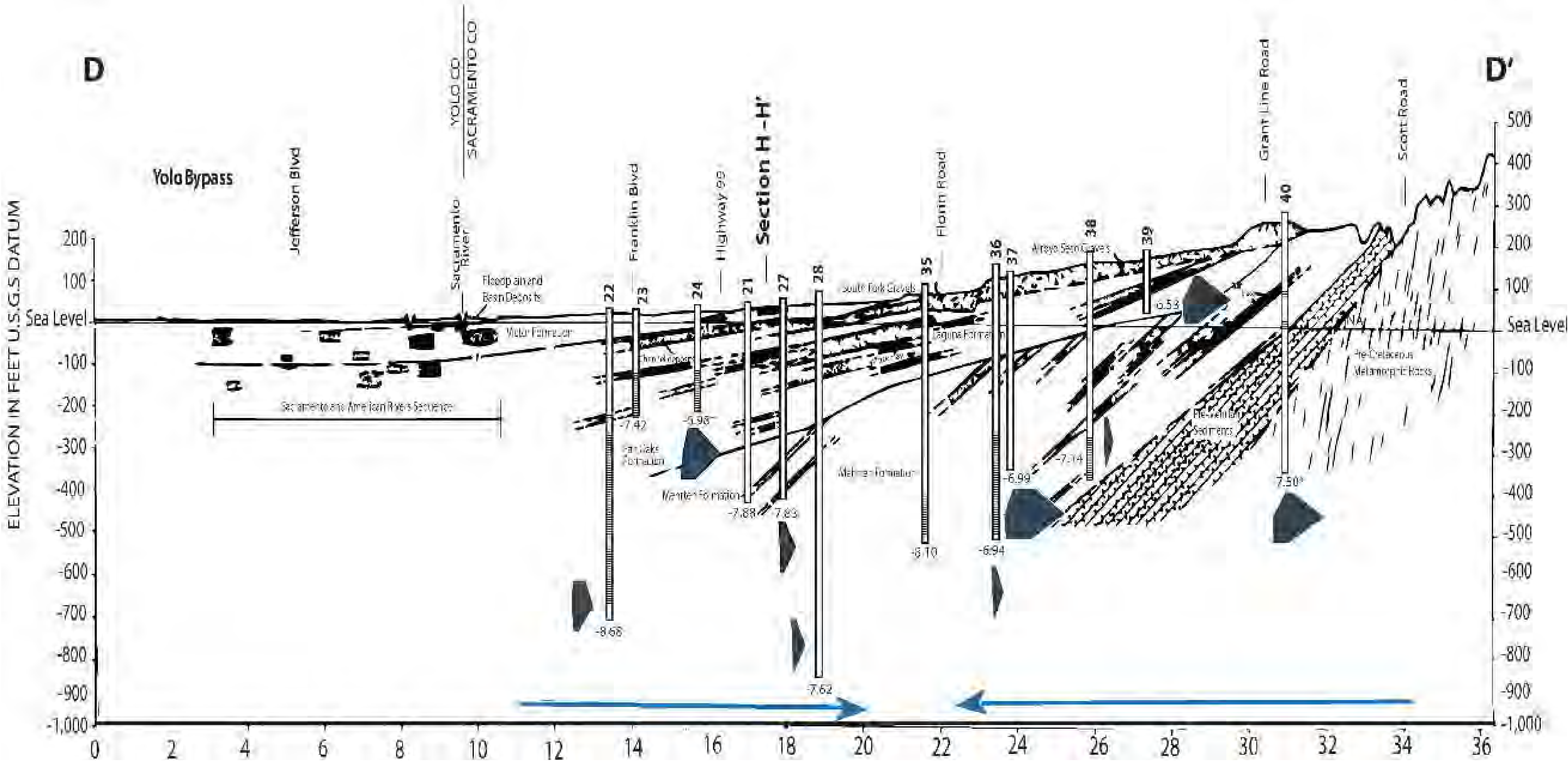
- Cross Section Location
- South American Subbasin
- Cities and Towns
- Rivers and Creeks
- Folsom South Canal
- Freeport Pipeline
- Counties

0 1.25 2.5 5 Miles

N

South American SUBBASIN

Project #: 0011575.00
Map Created: June 2020



South American Subbasin GSP

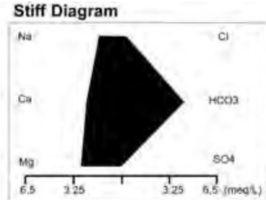
Cross Section D-D'

Figure 2.2-34

Legend

Inferred groundwater direction

Stiff Diagram

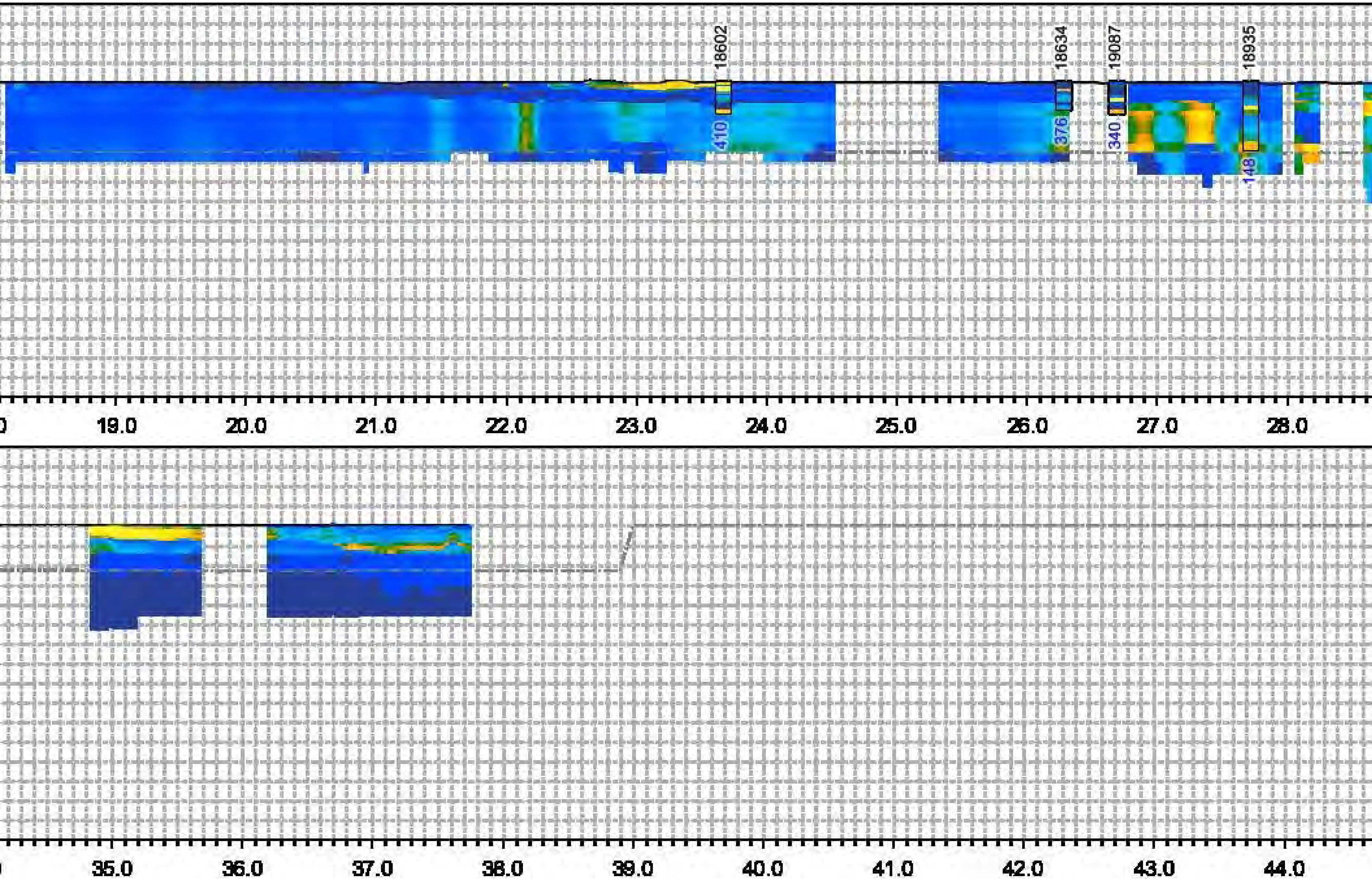


N

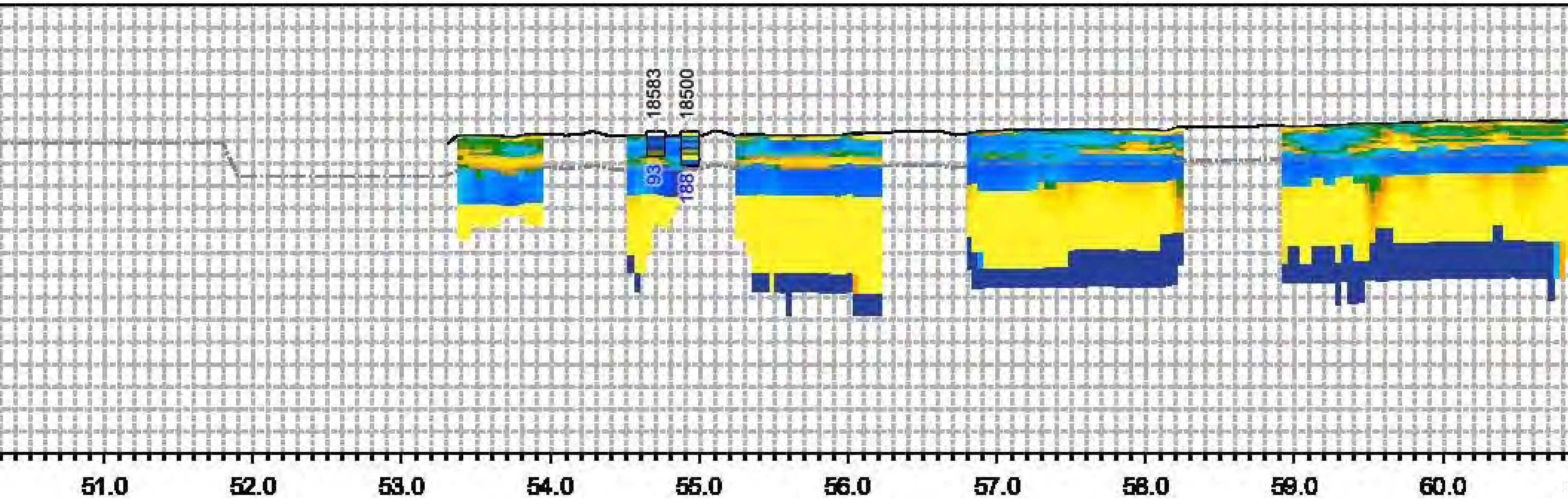
South American SUBBASIN

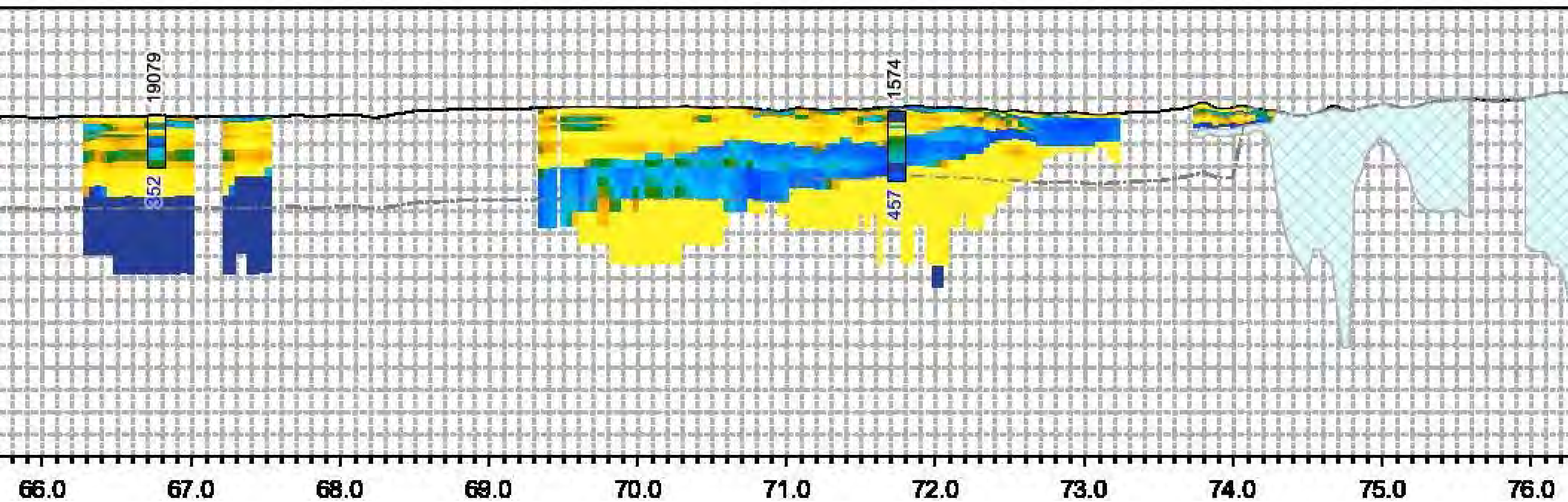
Map Created: October 2021

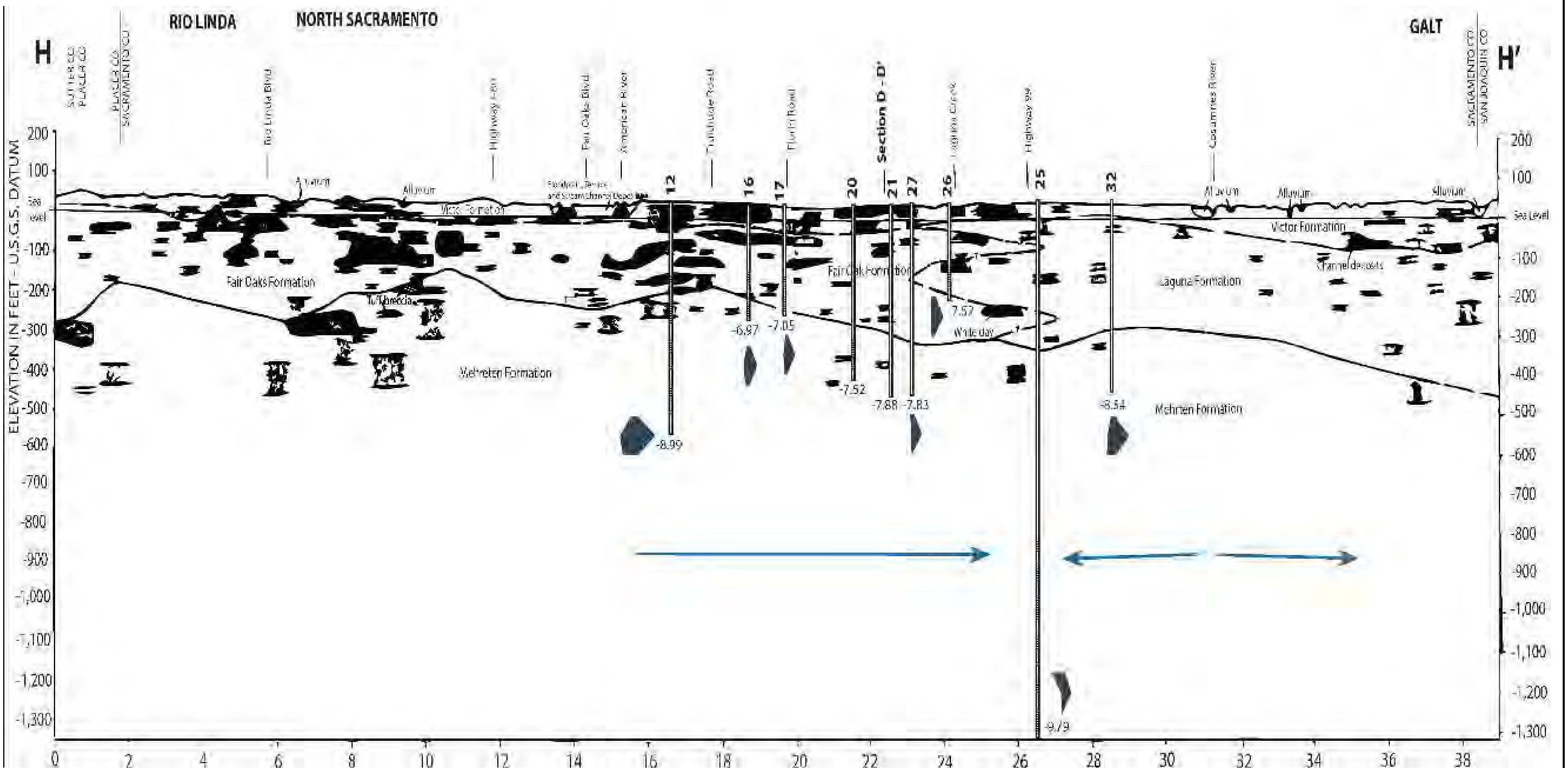
D - D' (Fig 2.2-32) Nearest AEM Log



D - D' (Fig 2.2-32) Nearest AEM Log







South American Subbasin GSP

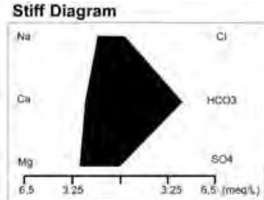
Cross Section H-H'

Figure 2.2-35

Legend

Inferred groundwater direction

Stiff Diagram

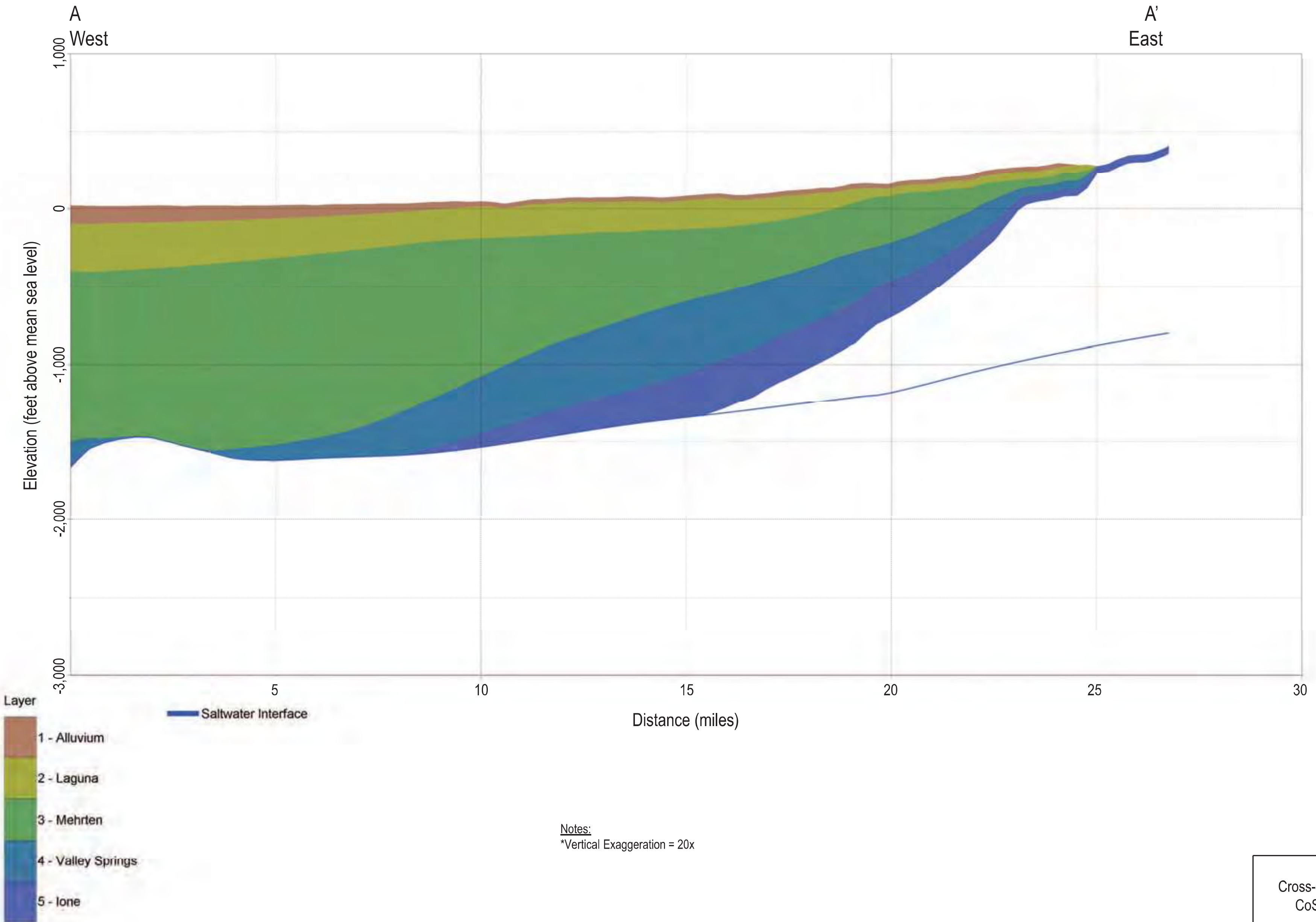


N

South American **SUBBASIN**

Map Created: October 2021

Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions. Any reliance upon the map or data contained herein shall be at the users' sole risk. Adapted from DWR Bulletin No. 118-3, July 1974 **Data Sources:** Prepared by RMC Water and Environment for the Sacramento Central Groundwater Authority, 2015.

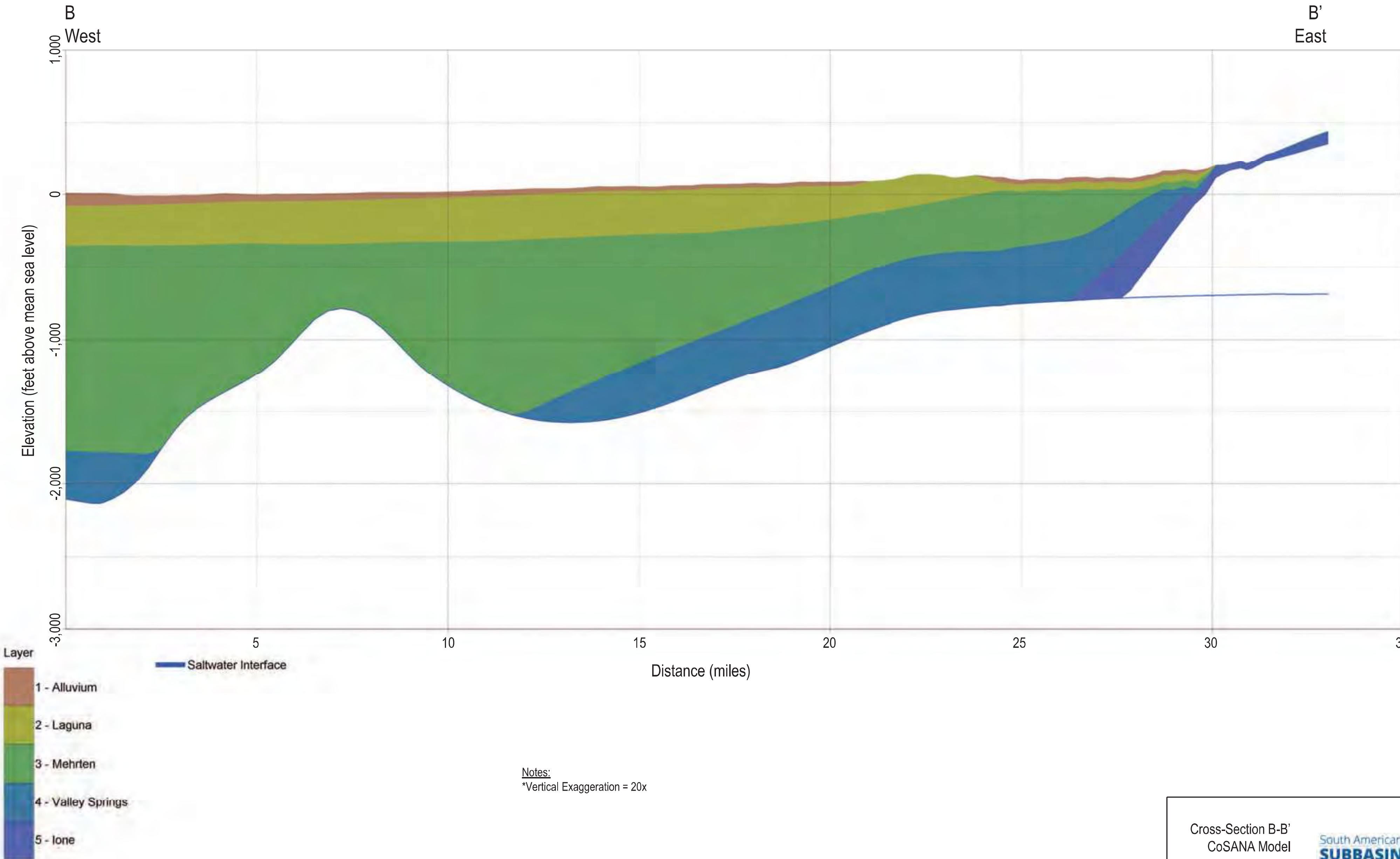


Notes:
*Vertical Exaggeration = 20x

Cross-Section A-A'
CoSANA Model

Figure 2.2-36

South American SUBBASIN

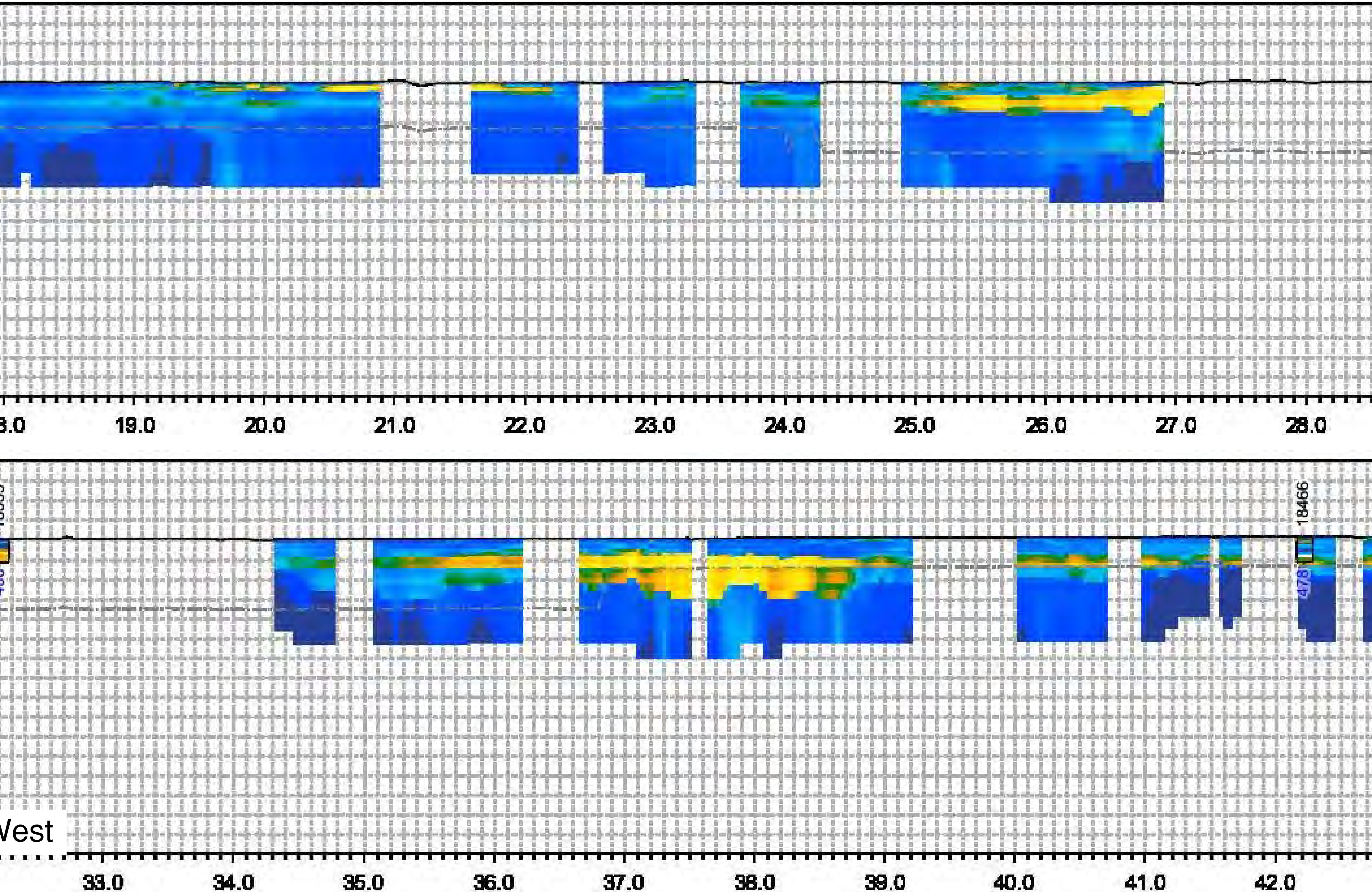


Notes:
*Vertical Exaggeration = 20x

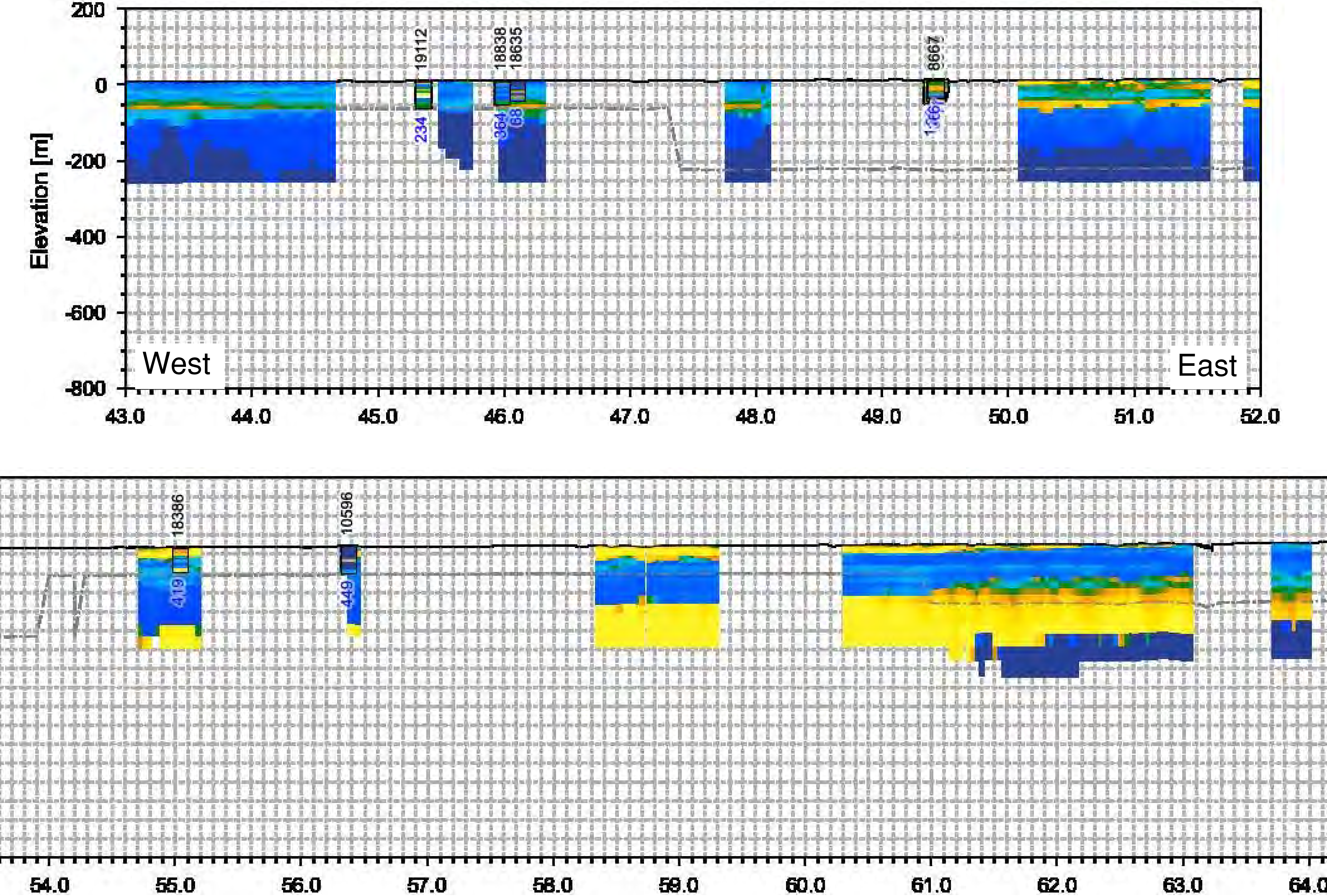
Cross-Section B-B'
CoSANA Model
Figure 2.2-37

South American SUBBASIN

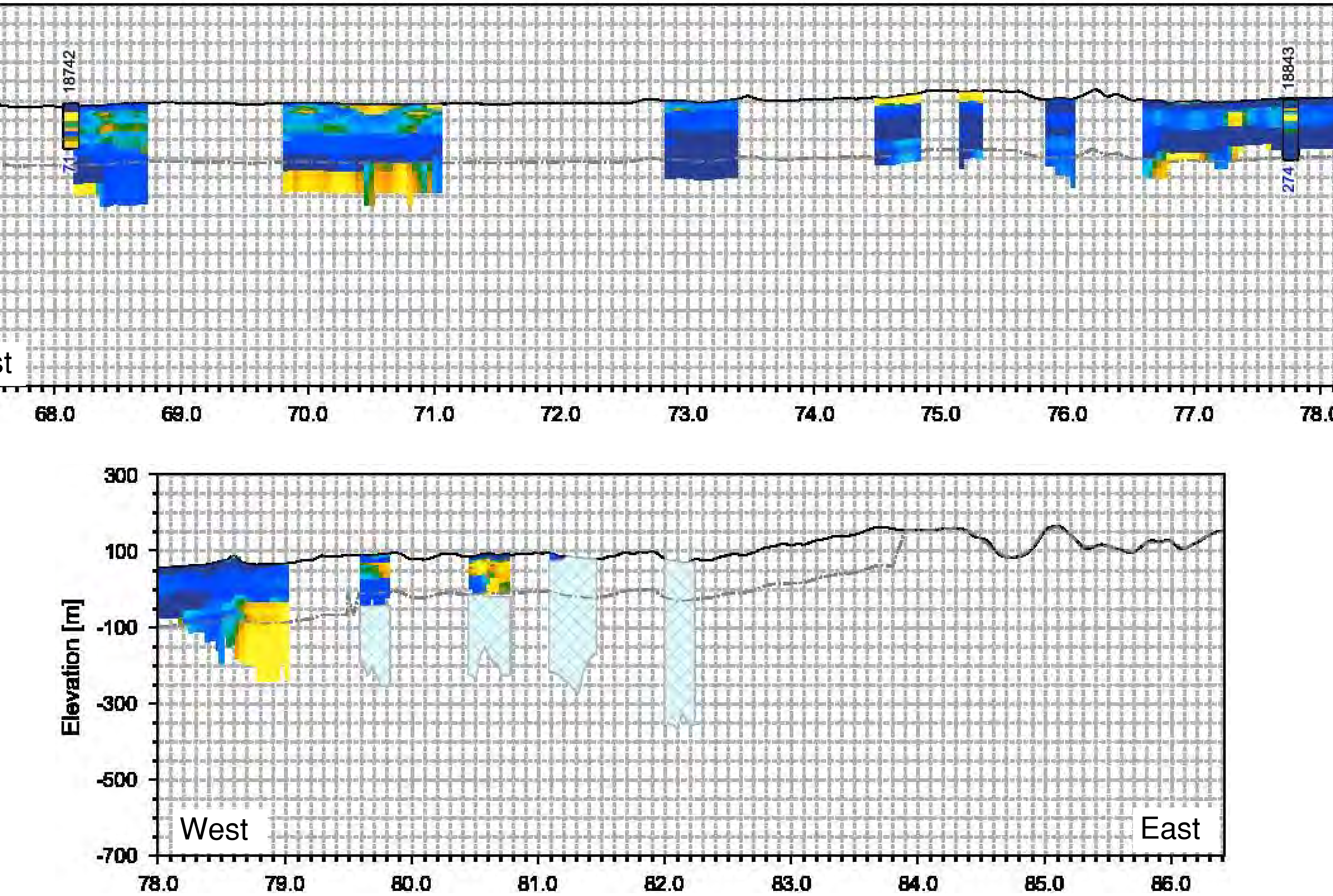
B - B' Nearest AEM Log

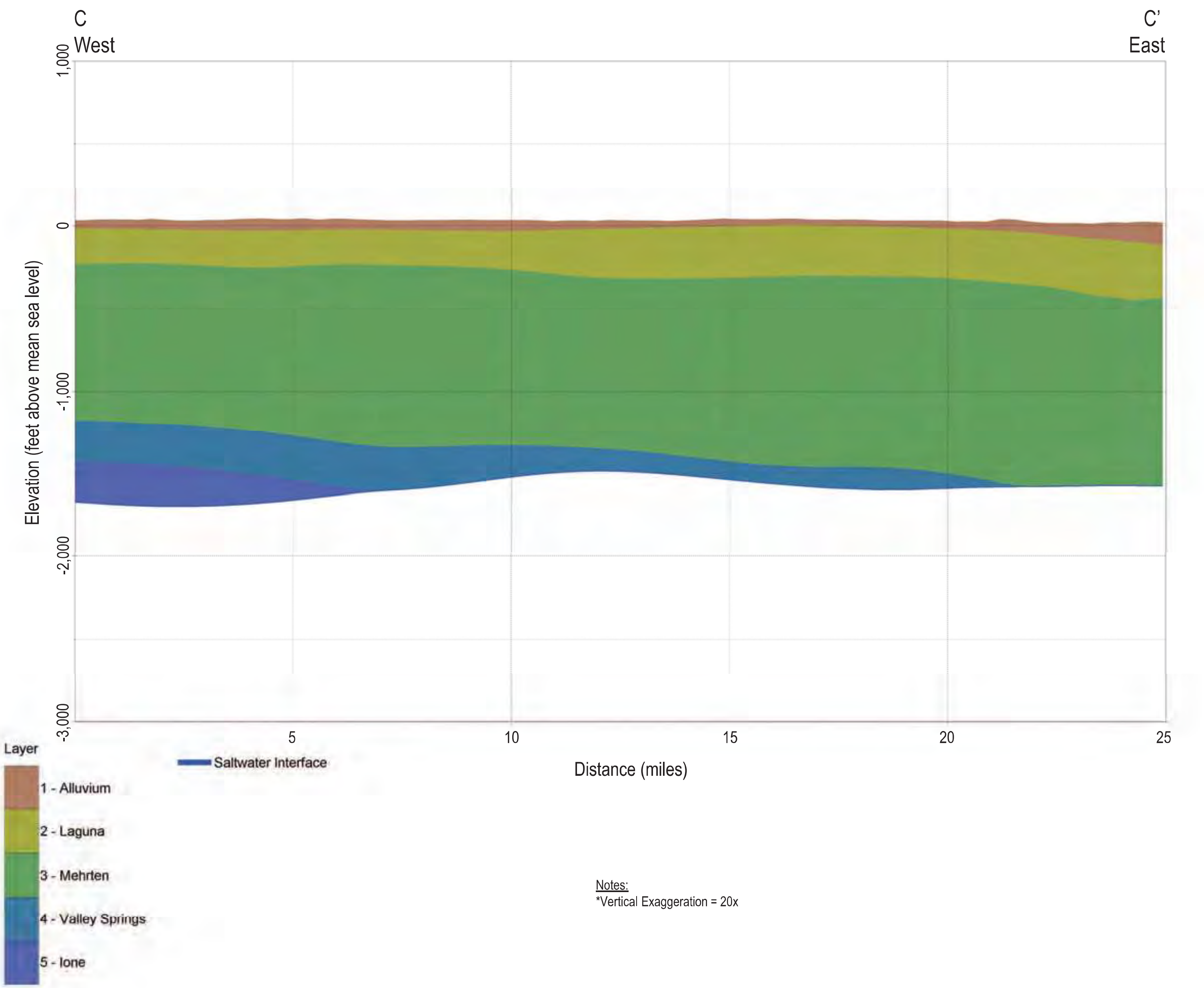


B - B' Nearest AEM Log



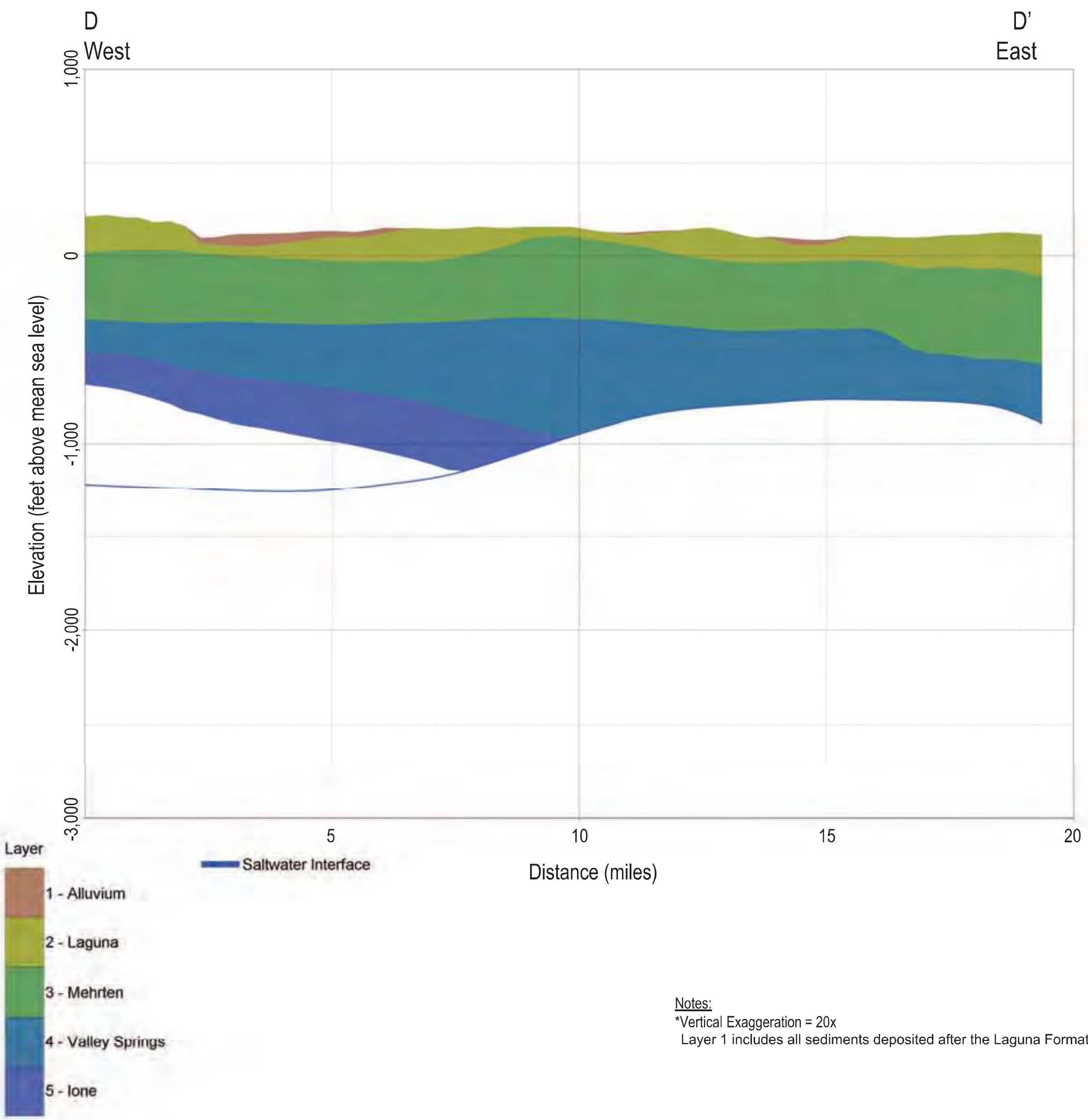
B - B' Nearest AEM Log





Cross-Section C-C'
CoSANA Model
Figure 2.2-38

South American SUBBASIN

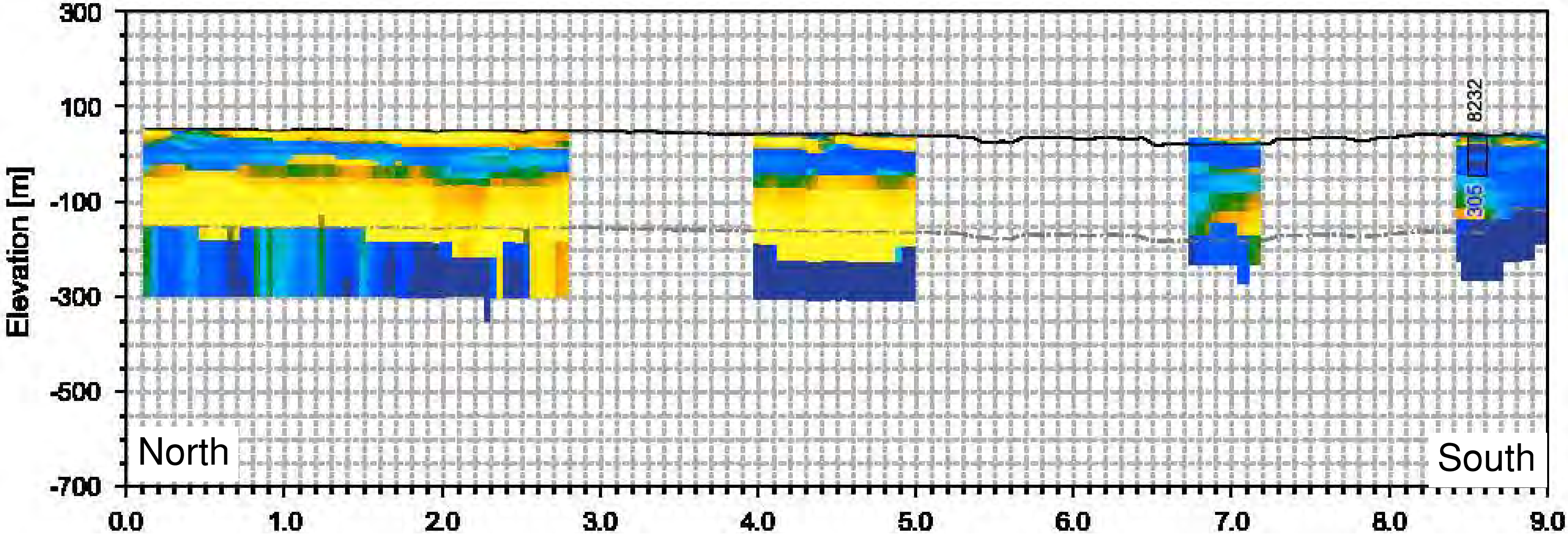


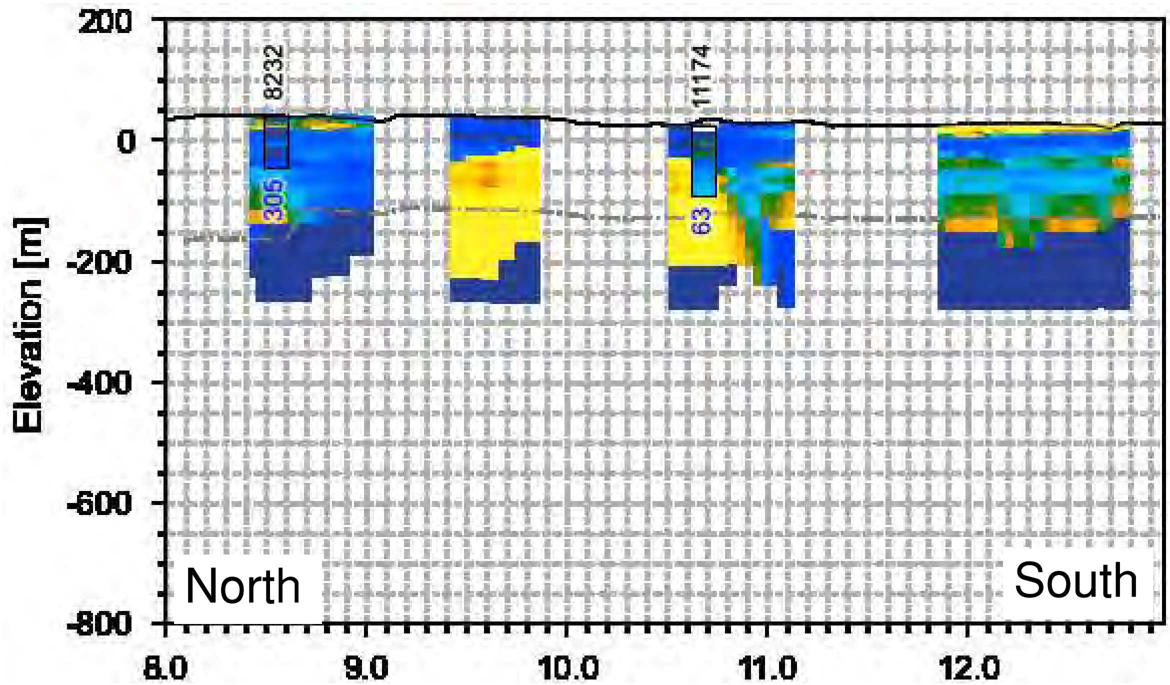
Notes:
*Vertical Exaggeration = 20x
Layer 1 includes all sediments deposited after the Laguna Formation

Cross-Section D-D'
CoSANA Model
Figure 2.2-39

South American SUBBASIN

D - D' (Fig 2.2-33) Nearest AEM Log





influence, but may not substantially limit deeper interbasin flow as evidenced by the Aerojet plume migration into NASb and the flow of water between the SASb and CoSb.

An impermeable bedrock boundary is defined as: “Impermeable bedrock with lower water yielding capacity. These include consolidated rocks of continental and marine origin and crystalline/or metamorphic rock” (DWR, 2003).

2.2.5.2 Boundaries with Neighboring Basins

Boundaries with neighboring subbasins are hydrologic divides as defined above, with a portion of the boundary with the Yolo Subbasin being defined as a political boundary matching the boundary between Yolo and Sacramento Counties which is coincident with the Sacramento River.

2.2.5.3 Bottom of the South American Subbasin

The bottom of the SASb is the shallower of either the base of fresh water or the bottom of the Valley Springs Formation. The base of fresh water is considered the depth at which the specific conductivity of groundwater is 3,000 micromhos per centimeter, which corresponds to a total dissolved solids (TDS) concentration of approximately 2,000 mg/L (Berkstresser, 1973), and is approximately 1400 feet bgs in the central part of SASb.

2.2.6 Principal Aquifers and Aquitards

The SASb is underlain by one principal aquifer, primarily composed of post-Eocene sedimentary deposits. Principal aquifers are defined in the GSP regulations as “aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems.” The aquifer system composing the principal aquifer in the SASb is typically divided into an upper zone and a lower zone. The upper zone is contained in Pleistocene to Quaternary-age sediments including the Modesto, Riverbank, and Laguna Formations, South Fork Gravels and Arroyo Seco Gravels. The lower zone is contained in Miocene to Pliocene-age volcanic sediments, including the Mehrten Formation and portions of the underlying Valley Springs and Ione Formations (DWR, 1974). These zones are partially separated by a discontinuous clay layer in the lower portion of the Laguna Formation that can act as a semi-confining layer for the lower zone of the aquifer (Sacramento Central Groundwater Authority [SCGA], 2012).

2.2.6.1 Upper Zone of the Primary Aquifer

The upper zone of the primary aquifer in the SASb is unconfined that consists of alluvium that extends approximately 200 to 300 feet below the ground surface (SCGA, 2012; DWR, 2003). Quaternary deposits consist of flood basin deposits, dredge tailings, alluvium and stream channel deposits. Pliocene to Pleistocene-age deposits consists of compacted sand, silt and gravel that include the Modesto, Riverbank, Turlock Lake and Laguna Formations, Arroyo Seco Gravels and South Fork Gravels (DWR, 2004; Marchand and Allwardt, 1981). Permeable sand and gravel deposits are typically enclosed by less permeable silt and clay, resulting in a network of tabular water-bearing zones (DWR, 1974). The upper zone groundwater is typically of high quality and is often used for private domestic and/or irrigation wells in SASb (SCGA, 2012).

2.2.6.2 Lower Zone of the Primary Aquifer

The lower zone of the primary aquifer in the SASb primarily consists of volcanic deposits that include the Mehrten Formation and portions of the underlying Valley Springs and Ione formations (DWR, 1974; DWR, 2003). The Mehrten Formation is composed of units of andesitic sand, stream gravel, silt and clay interbedded with tuff-breccia. The andesitic sand and gravel unit is highly permeable and is capable of producing high yields, while the tuff-breccia units are relatively impermeable and act as confining layers. (DWR, 2004). The Valley Springs Formation contains varying amounts of rhyolite ash, vitreous tuff, quartz sand containing glass shards and ashy clays. The Ione Formation is composed of three distinct layers: quartz sandstone, white clay and blue to brown clay (DWR, 1974). The base of freshwater in the lower zone of the aquifer is at an average approximate depth of 1,400 feet below ground surface (bgs), as defined by TDS exceeding 2,000 mg/L. In areas where interference with domestic wells could occur, larger municipal supply wells often target the deeper black sand of the Mehrten Formation where high production rates can be achieved with minimal impacts to domestic wells screened in the upper zone of the aquifer (SCGA, 2012).

2.2.6.3 Hydraulic Conductivity

Hydraulic conductivity is defined as the “measure of the capacity for a rock or soil to transmit water” (DWR, 2003). Hydraulic conductivity within the SASb is variable in the principal aquifer, varying laterally, vertically, and among the two zones of the aquifer. In general, hydraulic conductivities are highest near the margins of the American and Sacramento Rivers, and are lowest near the margins of the Sierra Nevada foothills. In 1978, DWR, in coordination with the U.S. Geological Survey (USGS), mapped average hydraulic conductivity values in a nodal grid pattern throughout the Sacramento Valley, based on available drillers’ logs in sections of the Public Lands Survey System (PLSS) (DWR, 1978). Hydraulic conductivity values ranged from approximately 20 to 260 gallons per day per square foot (2.7 to 35 feet per day [ft/d]) at varying depths up to 550 feet bgs in the approximate SASb area. Average hydraulic conductivities were typically higher in wells assumed to be in the Modesto, Riverbank and Laguna Formation, and were variable in wells assumed to be in the Mehrten Formation. Lower hydraulic conductivities in the Mehrten Formation are observed in the relatively impermeable tuff-breccia units, while higher hydraulic conductivities are observed in the black sand units. (DWR, 1978).

Table 2.3-1 shows the range and average hydraulic conductivity for each layer in the CoSANA model.

Table 2.2-1: Estimated Hydraulic Conductivity (feet per day) for each CoSANA Model Layer

Layer	Minimum	Average	Maximum
1 – Alluvium	2.1	34	108
2 – Laguna	2.2	26	87
3 – Mehrten	0.7	17	50
4 – Valley Springs	0.9	15	42
5 – Ione	0.3	11	38

2.2.6.4 Transmissivity

Transmissivity is defined as an aquifer's "ability to transmit groundwater horizontally through its entire saturated thickness" and is "the product of hydraulic conductivity and aquifer thickness". (DWR, 2003). In 1978, DWR, in coordination with USGS, mapped aquifer transmissivity in post-Eocene deposits for the Sacramento Valley using information from drillers' logs in PLSS sections of the Sacramento Valley (DWR, 1978). Transmissivity values mapped in the SASb area ranged from 10,700 to 26,100 square feet per day. Transmissivity values were highest along the Sacramento River, decreasing toward the Sierra Nevada foothills (DWR, 1978).

Table 2.2-2 shows the range and average transmissivity for each layer included in the CoSANA model.

Table 2.2-2: Estimated Transmissivity (square feet per day) for each CoSANA Model Layer

Layer	Minimum	Average	Maximum
1 – Alluvium	64	1,930	12,955
2 – Laguna	123	5,199	20,770
3 – Mehrten	204	11,303	69,562
4 – Valley Springs	27	2,578	14,984
5 – Ione	0.2	599	3,736

2.2.6.5 Specific Yield and Specific Storage

Specific yield is defined as the "ratio of the volume of water a rock or soil will yield by gravity drainage to the total volume of the rock or soil" (DWR, 2003). Specific yield is a measurement specific to unconfined aquifers, such as the upper zone of the primary aquifer in the SASb. USGS calculated a specific yield for the low plains south of the American River (from a depth of 20 to 200 feet bgs) of 0.07. Calculated specific yields range from 0.054 in flood plain deposits to 0.1 in stream channel deposits (Olmsted and Davis, 1961).

In 1978, DWR, in coordination with USGS, mapped storage coefficient values in post-Eocene deposits for the Sacramento Valley, based on drillers' logs in PLSS sections of the Sacramento Valley (DWR, 1978). Storage coefficient values mapped in the approximate SASb area range from 0.07 to 0.1 (DWR, 1978).

Table 2.2-3 and **Table 2.2-4** show the range and average specific yield and specific storage for each layer included in the CoSANA model. Storage coefficient is the product of specific storage and aquifer thickness.

Table 2.2-3: Estimated Specific Yield (unitless) for each CoSANA Model Layer

Layer	Minimum	Average	Maximum
1 – Alluvium	0.06	0.12	0.24
2 – Laguna	0.07	0.12	0.22
3 – Mehrten	0.07	0.12	0.20
4 – Valley Springs	0.07	0.12	0.21
5 – Ione	0.07	0.10	0.20

Table 2.2-4: Estimated Specific Storage (1/foot) for each CoSANA Model Layer

Layer	Minimum	Average	Maximum
1 – Alluvium	0.000003	0.000039	0.000076
2 – Laguna	0.000002	0.000040	0.000070
3 – Mehrten	0.000002	0.000039	0.000073
4 – Valley Springs	0.000005	0.000038	0.000061
5 – Ione	0.000010	0.000050	0.000078

2.2.7 Natural Water Quality Characterization

According to the 2006 *Central Sacramento County Groundwater Management Plan*, water quality analyses in the aquifer underlying the SASb have generally shown that groundwater in the upper zone of the aquifer is of higher quality than water in the lower zone of the aquifer with the exception of arsenic detections in a few locations (SCGA, 2006). Water in the lower zone of the aquifer typically has higher concentrations of iron, manganese and TDS. At depths below approximately 1,400 feet bgs (variable throughout the subbasin), the TDS exceeds 2,000 mg/L, making the groundwater unsuitable for potable use and not part of the SASb.

Iron concentrations in the potable region of the lower zone of the aquifer have ranged from less than 10 micrograms per liter (µg/L) to 16,000 µg/L, with the majority of wells having an average value of less than 200 µg/L. Manganese concentrations in the potable region of the lower zone of the aquifer range from less than 2 to 1,700 µg/L with the majority of wells having an average value of less than 50 µg/L.

In 2015, RMC Water and Environment prepared the *Sacramento Central Groundwater Authority Recharge Mapping and Field Study Technical Memorandum* for the SCGA that included testing major-ion composition for samples from municipal, park irrigation and domestic water wells throughout the Central Sacramento Groundwater Basin. The test results show that anions were primarily dominated by bicarbonate, and cations were dominated by either calcium, magnesium or sodium. In general, ionic content is relatively low at wells located near the American and Sacramento Rivers. Samples collected more centrally within the study area and from near Laguna Creek show a relative increase in total ionic content (RMC Water and Environment, 2015).

Saline water is present at depths between 1,000 to 2,000 feet (varying throughout the aquifer). The saline water appears to originate from marine deposition as TDS concentrations range between 15,000 to 28,000 mg/L (sea water is typically 34,000 mg/l) and are dominated by a high concentration of sodium and chloride ions (RMC Water and Environment, 2015). **Figure 2.2-40** shows a Piper diagram for select well chemical data throughout the SASb. **Figure 2.2-41** shows the location of these select water wells and provides a Stiff diagram of the chemical data.

SUTTER SUBBASIN

Groundwater Sustainability Plan

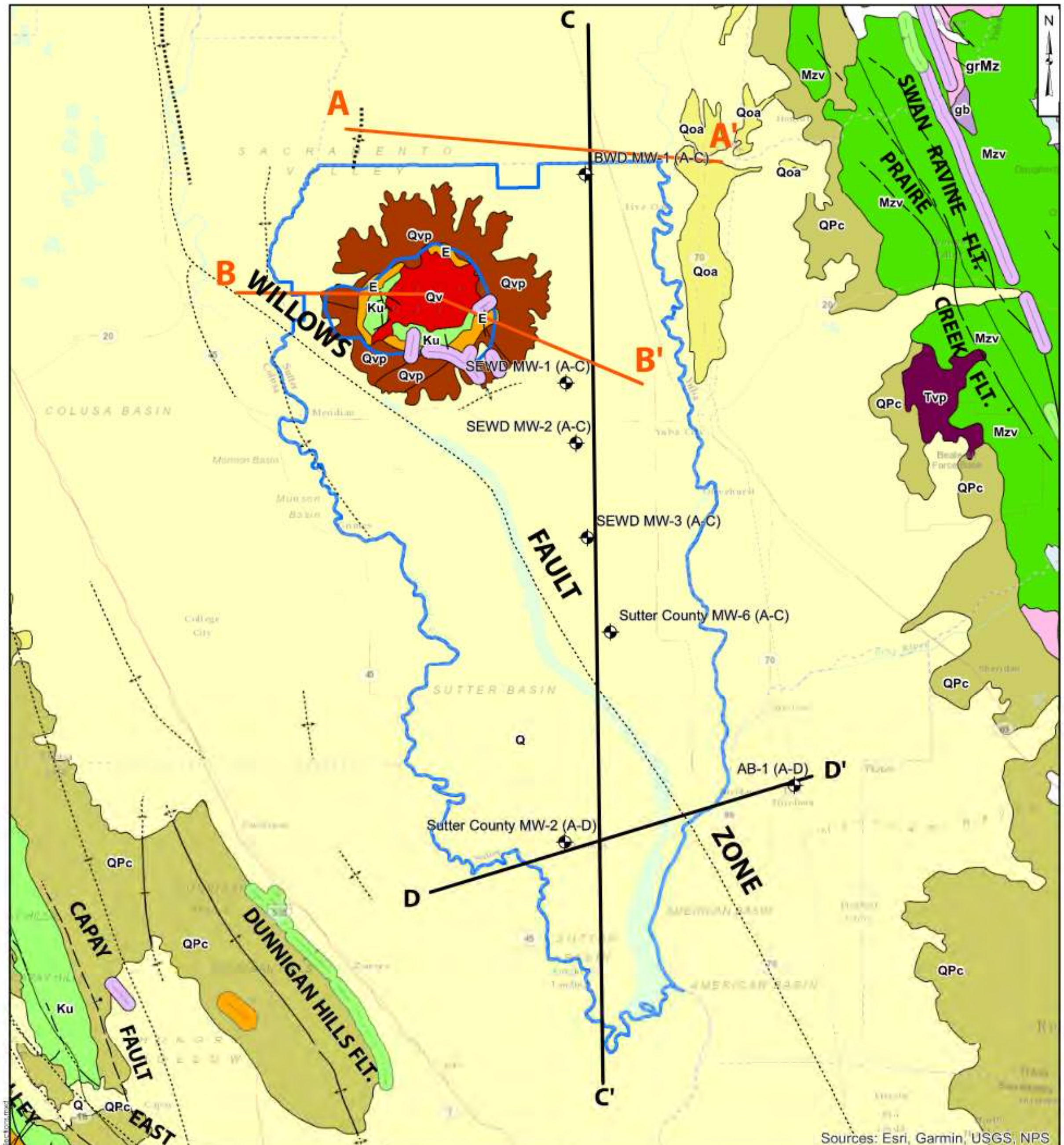
SUTTER COUNTY CALIFORNIA

WOODARD & CURRAN

DEPARTMENT OF WATER RESOURCES STATE OF CALIFORNIA

PROP 1
GOVERNOR EDMUND G. BROWN, JR.
WATER BOND 2014

JANUARY 2022



Notes

1. Legend information provided on the following page
2. Geology data taken from California Department of Conservation.
3. The subbasin boundary reflects the 2018 update of the Bulletin 118 Groundwater Basins
4. Quaternary faults are faults that have been active during the Quaternary Period, while Pre-Quaternary faults have not
5. Location of cross section lines and wells used to construct cross sections from GEI (2016).

approx. = approximately
flt. = fault

5 2.5 0 5 Miles

Cross Section Lines and Well Used

Sutter Subbasin Groundwater Sustainability Plan
Sutter County, California

Geosyntec consultants

Figure 5-6

Project No.: SAC284 May 2021

Figure 5-6. Cross-Section Lines and Well Boring Locations

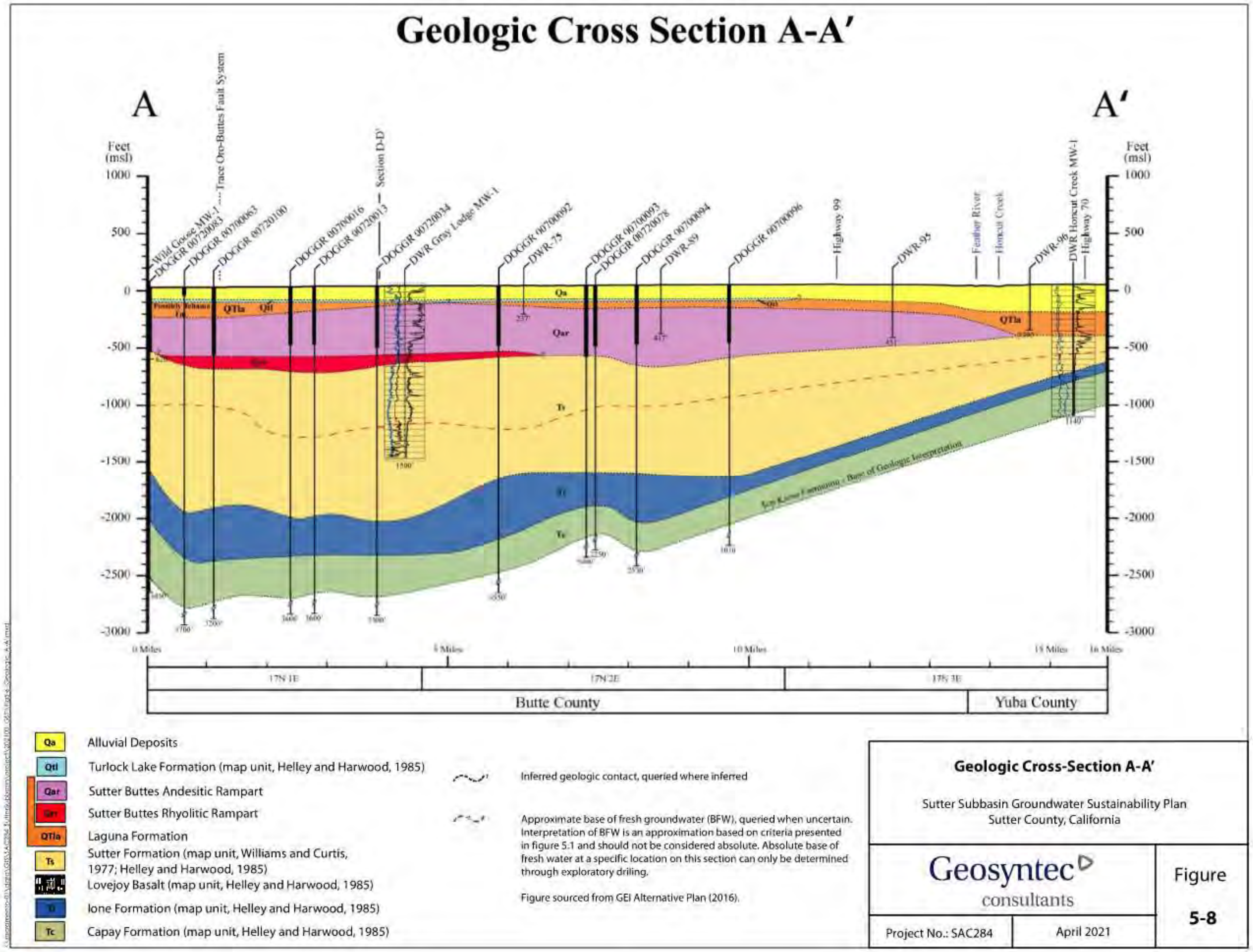


Figure 5-8. Geologic Cross-Section A-A’

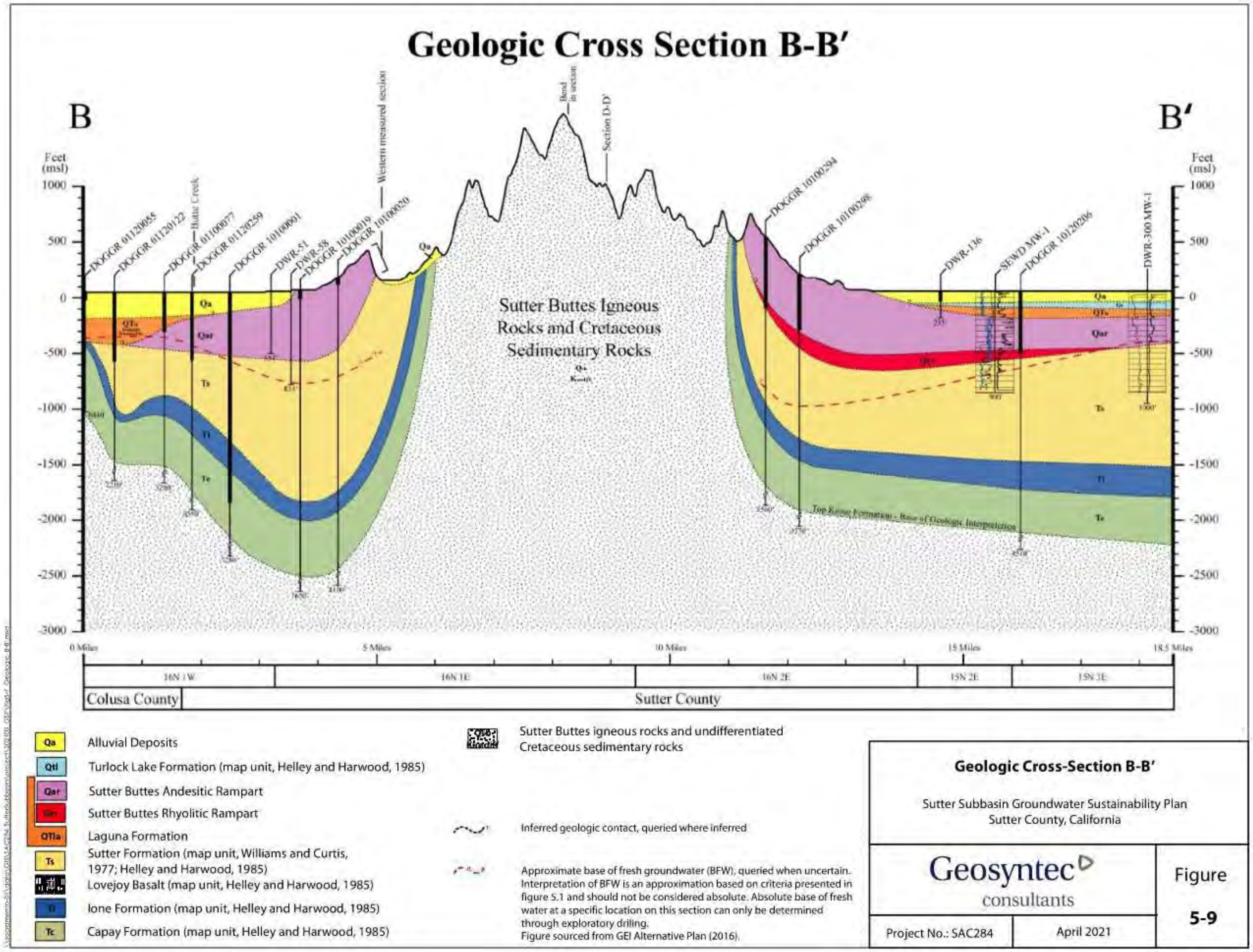
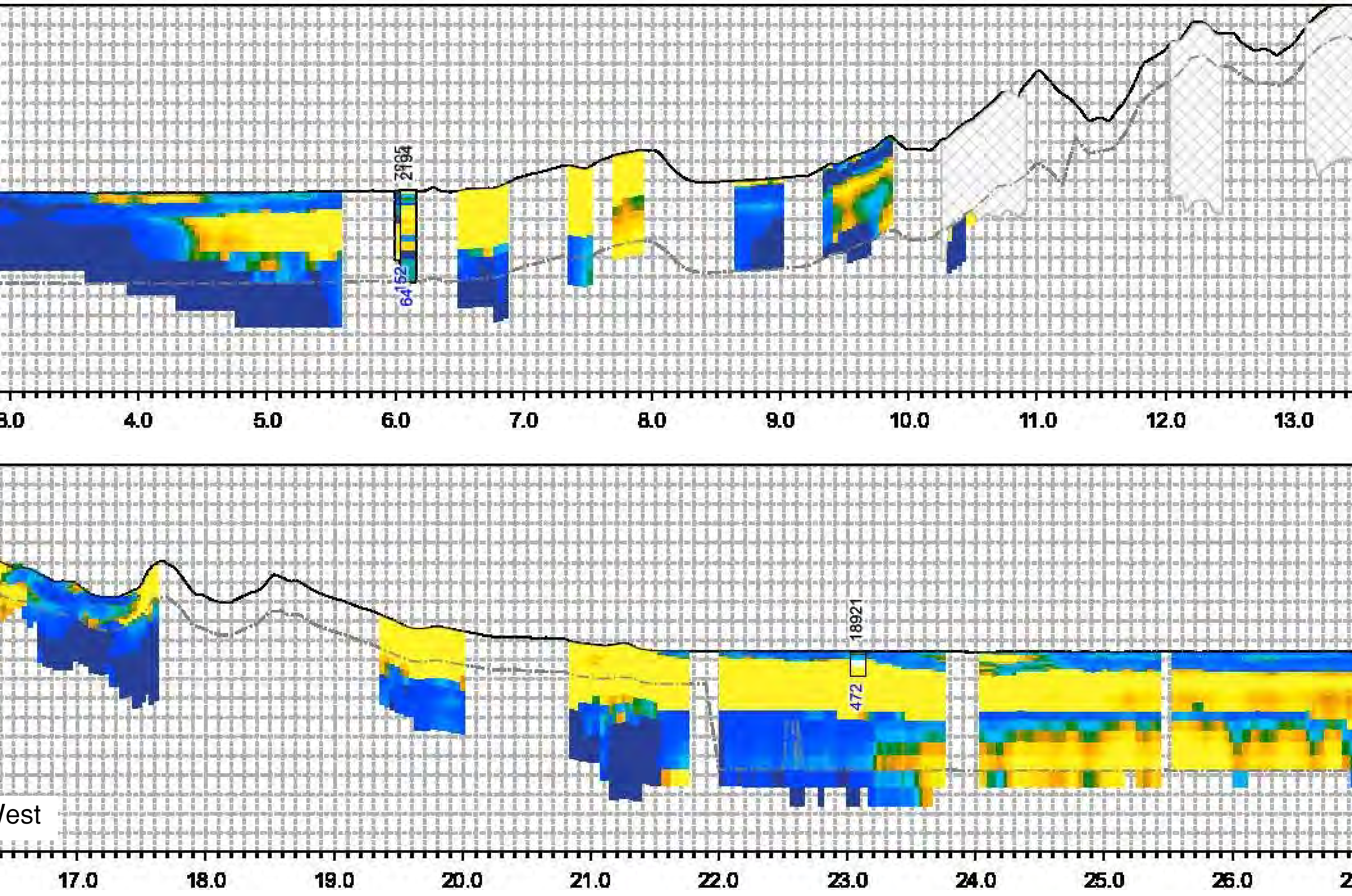


Figure 5-9. Geologic Cross-Section B-B'

B - B' Nearest AEM Log



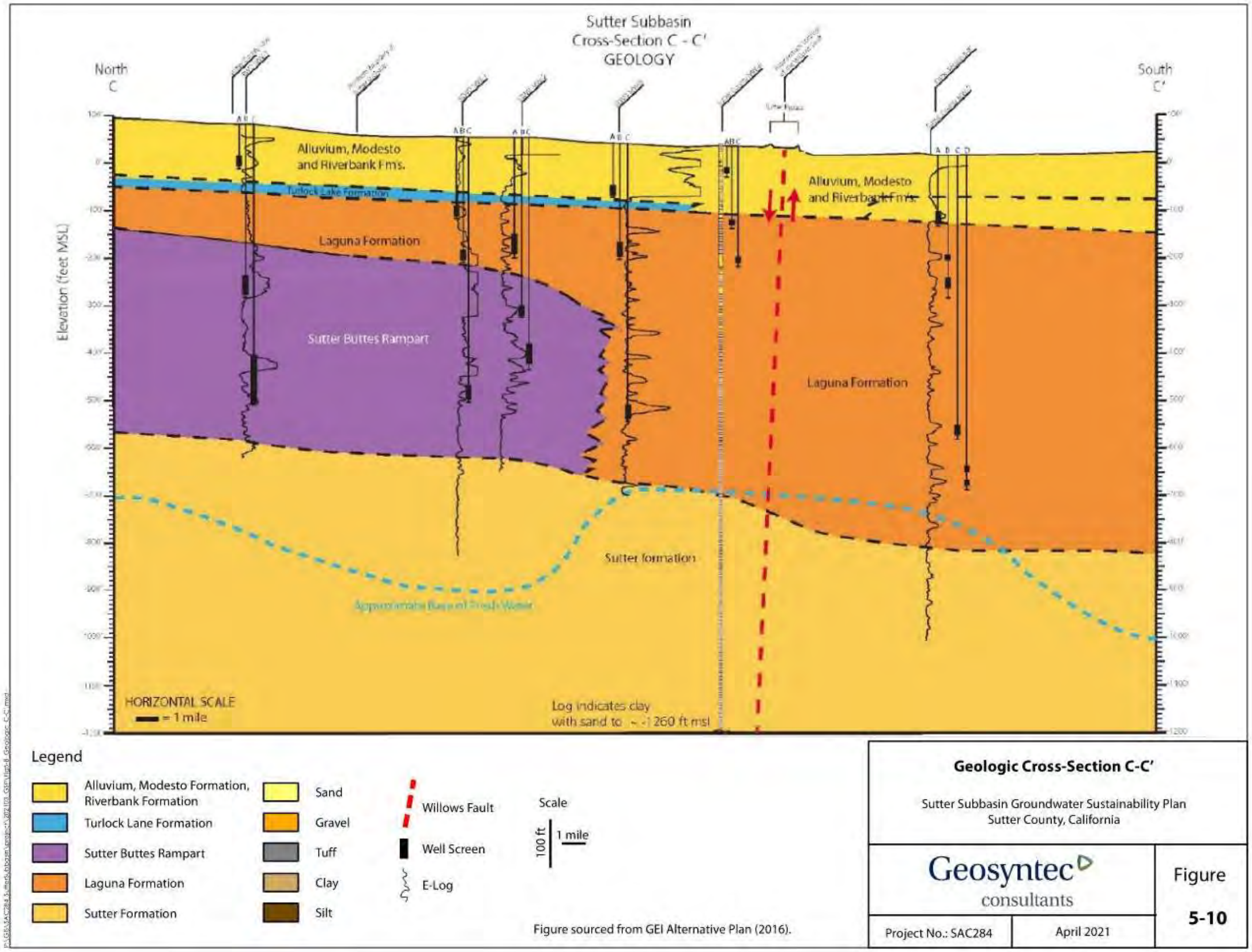
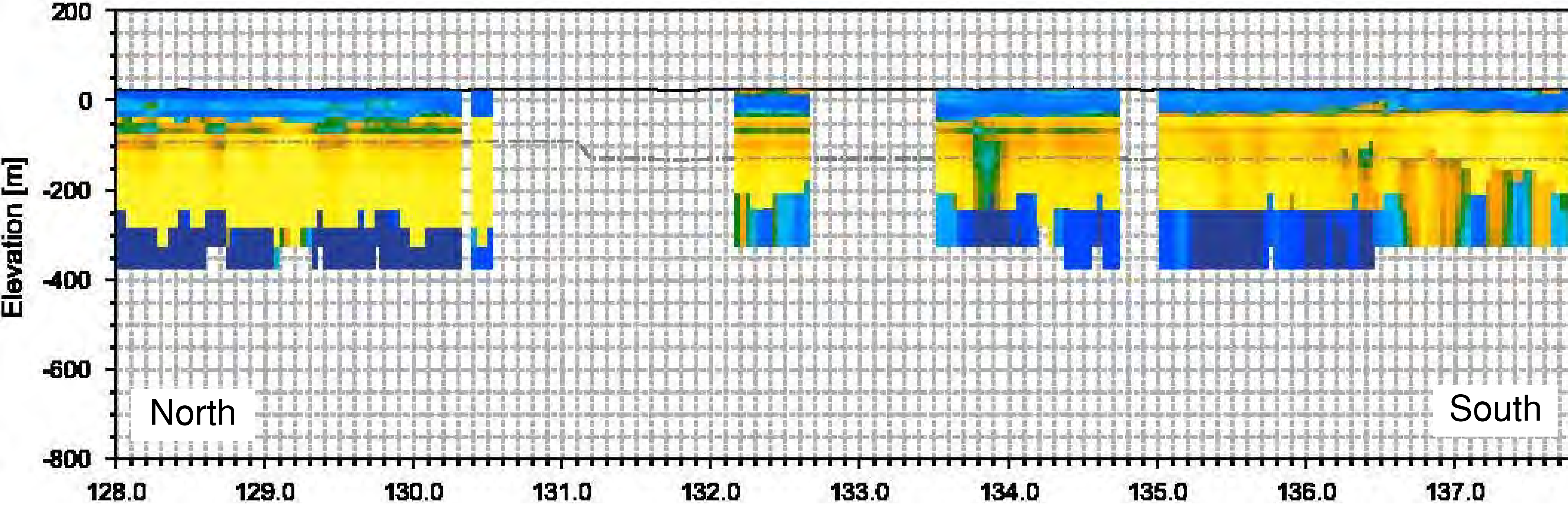
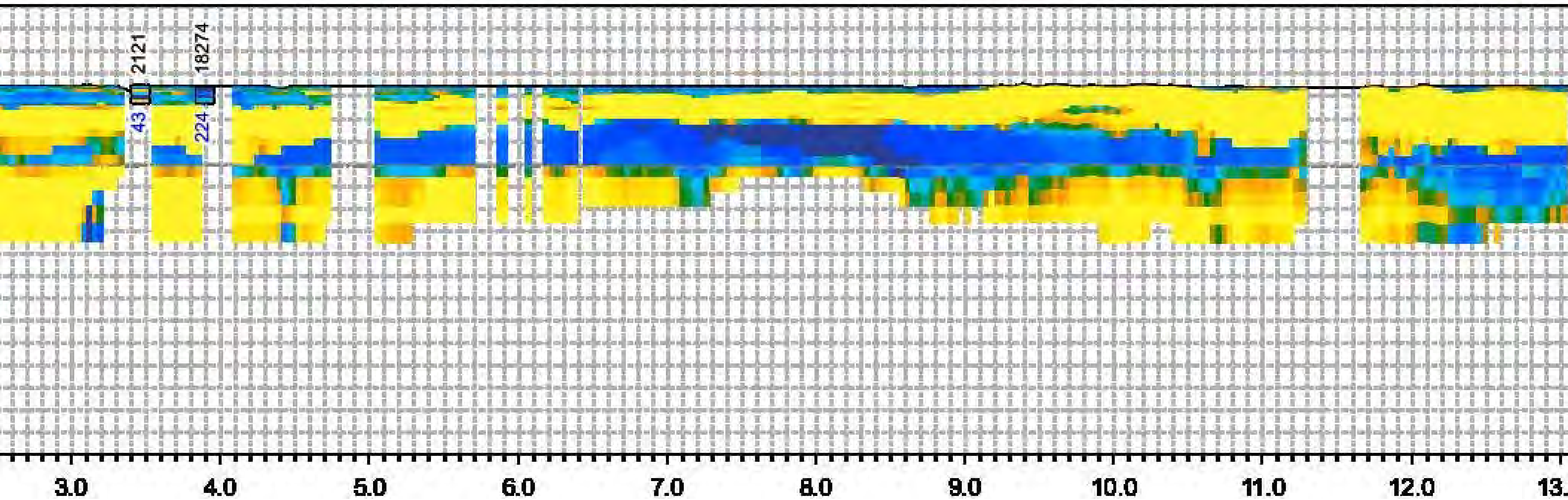


Figure 5-10. Geologic Cross-Section C-C'

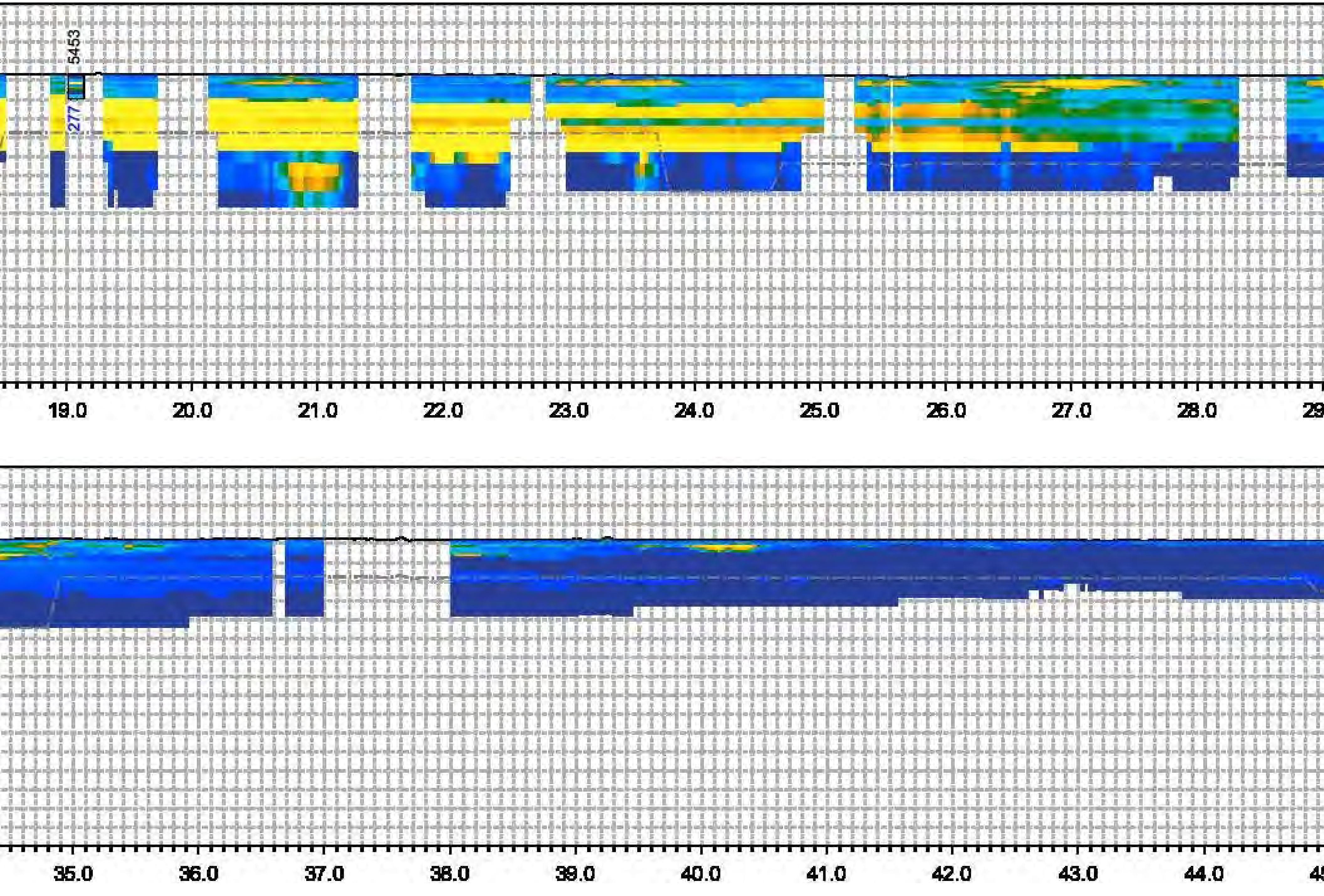
C - C' Nearest AEM Log



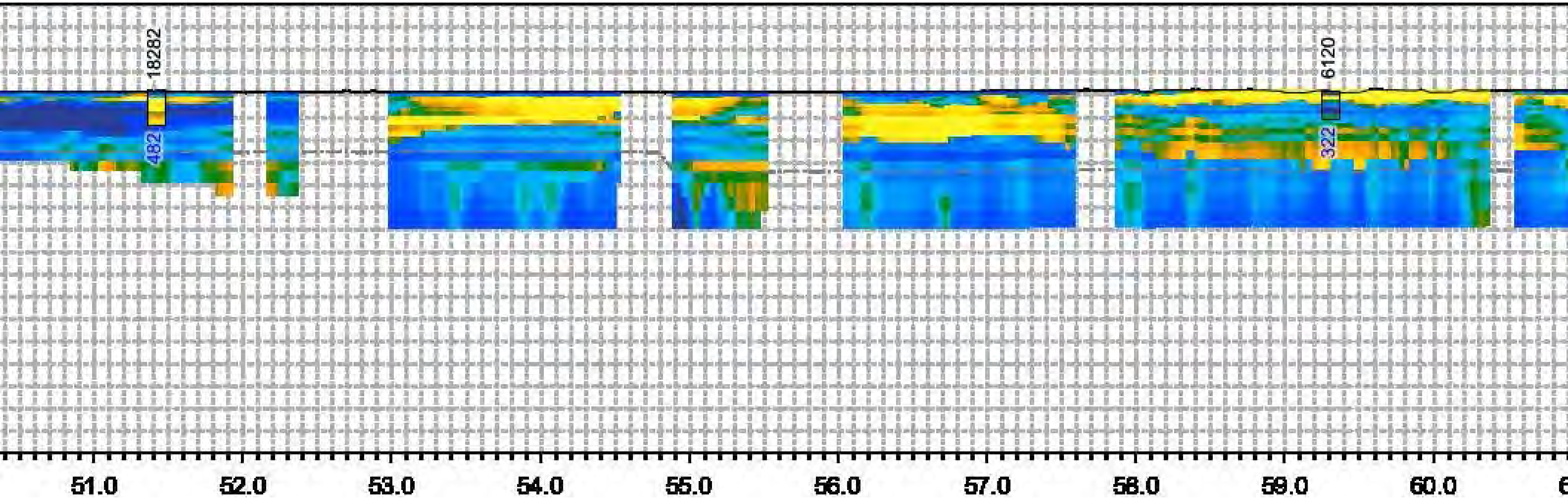


This AEM log is NOT continuous with the previous AEM log.

C - C' Nearest AEM Log



C - C' Nearest AEM Log



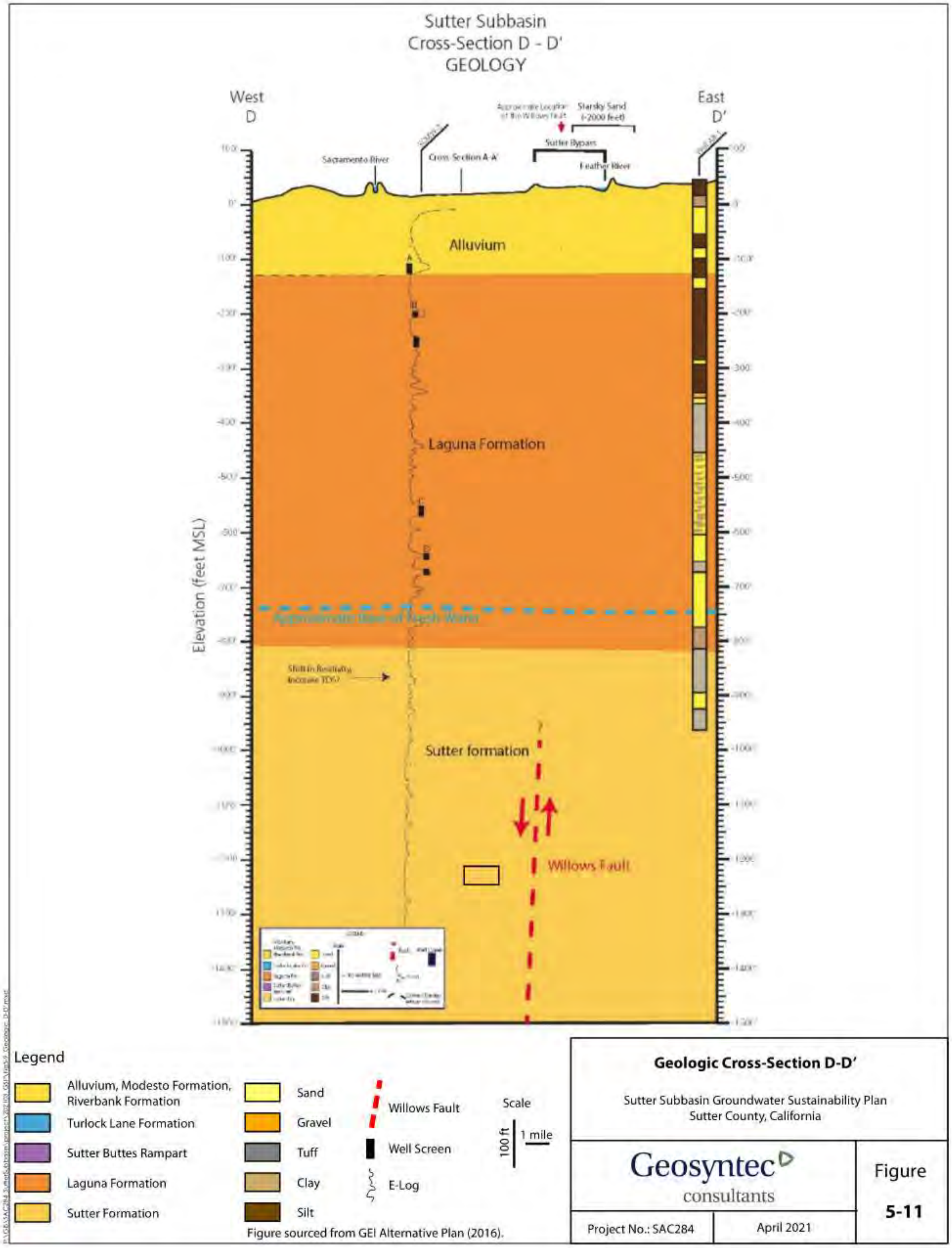


Figure 5-11. Geologic Cross-Section D-D'

5.1.6 Principal Aquifers and Aquitards

As stated in the GSP Regulations, the HCM is to include a description of the principal aquifers and aquitards including the following information:

- Formation names.
- Physical properties of aquifers and aquitards, including the vertical and lateral extent, hydraulic conductivity, and storativity.
- Structural properties of the basin that restrict groundwater flow within the principal aquifers, including information regarding stratigraphic changes, truncation of units, or other features.
- General water quality of the principal aquifers.
- Identification of the primary use or uses of each aquifer, such as domestic, irrigation, or municipal water supply (discussed in **Section 2.1.3.1**).

The following sections provide this information.

5.1.6.1 Formation Names

The Sutter Subbasin groundwater system is comprised of a single principal aquifer composed of the Modesto Formation, Riverbank Formation, Sutter Buttes Rampart, Victor Formation, and Laguna Formation. These formations create various zones with different hydrogeologic properties with both unconfined and semi-confined conditions. This leaky aquifer system has resulted in varied hydraulic connectivity between different depth zones in different areas of the Subbasin.

The Alternative Plan recognized three aquifer zones within the principal aquifer that are designated in this GSP as Aquifer Zones (AZ) 1, 2, and 3. Each of these aquifer zones is separated over portions of the Subbasin by single or multiple layers of silt and clay (or aquitards) that slow the vertical movement of groundwater within the overall aquifer. Geologic units identified within the shallow AZ-1 includes the Modesto Formation and Riverbank Formation. Geologic units identified within the intermediate AZ-2 include the Sutter Buttes Rampart and Laguna Formation. The AZ-2 has been further subdivided into 2A for the area within the Sutter Buttes Rampart and 2B for the area within the Laguna Formation. Units identified within the deep AZ-3 include the Laguna Formation, Sutter Buttes Rampart, and Sutter formation.

5.1.6.2 Aquifer Interactions

Figure 5-12 and **Figure 5-13** provide hydrostratigraphic cross-sections constructed as part of the Alternative Plan that illustrate the vertical and lateral extent of each of the AZs interpreted from the geology, electric log responses, groundwater levels, and water quality. As shown in these cross-sections, the shallow AZ-1 extends from the ground surface to depths ranging from 120 feet to 150 feet bgs at MW-1, nearest the Sutter Buttes in the north, to a depth of about 150 to 200 feet at MW-3, furthest south from the

Sutter Buttes. Although, as discussed below, there are no known aquifer tests conducted in this aquifer, it is believed to be unconfined to semiconfined, a conclusion supported by the response of hydrographs as discussed below.

The intermediate AZ-2 slopes away in a radial pattern from the Sutter Buttes and extends from about 180 to 450 feet bgs, as illustrated in **Figure 5-12** and **Figure 5-13**. The deep AZ-3 extends from about 480 to about 700 feet or more beneath the Subbasin. The low permeability zone between AZ-1 and AZ-2 ranges in thickness from 20 to 60 feet, and the low permeability zone between AZ-2 and AZ-3 ranges in thickness from 30 to 80 feet.

To further assess the interactions between the three aquifer zones, hydrographs for 12 nested monitoring wells (contain multiple separate wells at same location) within the Subbasin were assessed. The locations of these wells are shown in **Figure 5-14**. Nine of these wells (shown as red in **Figure 5-14**) are equipped with pressure transducers and record water levels hourly. The following presents the results of the assessment for the nine wells equipped with pressure transducers going from north to south. The complete hydrographs for each of the nested wells are presented in **Appendix 5-E**. **Figure 5-15** through **Figure 5-23** provide hydrographs for individual years from each of the nine wells with pressure transducers. This smaller scale allows for observations of differences in responses to yearly stresses on the aquifer zones, such as from seasonal pumping, and provides more insight for interactions between the aquifer zones. For each of these hydrographs, AZ-1 wells hydrographs are in green, AZ-2 in blue, and AZ-3 in red. Where a nested well has two screens within the same aquifer zone, the deeper well hydrograph is dashed.

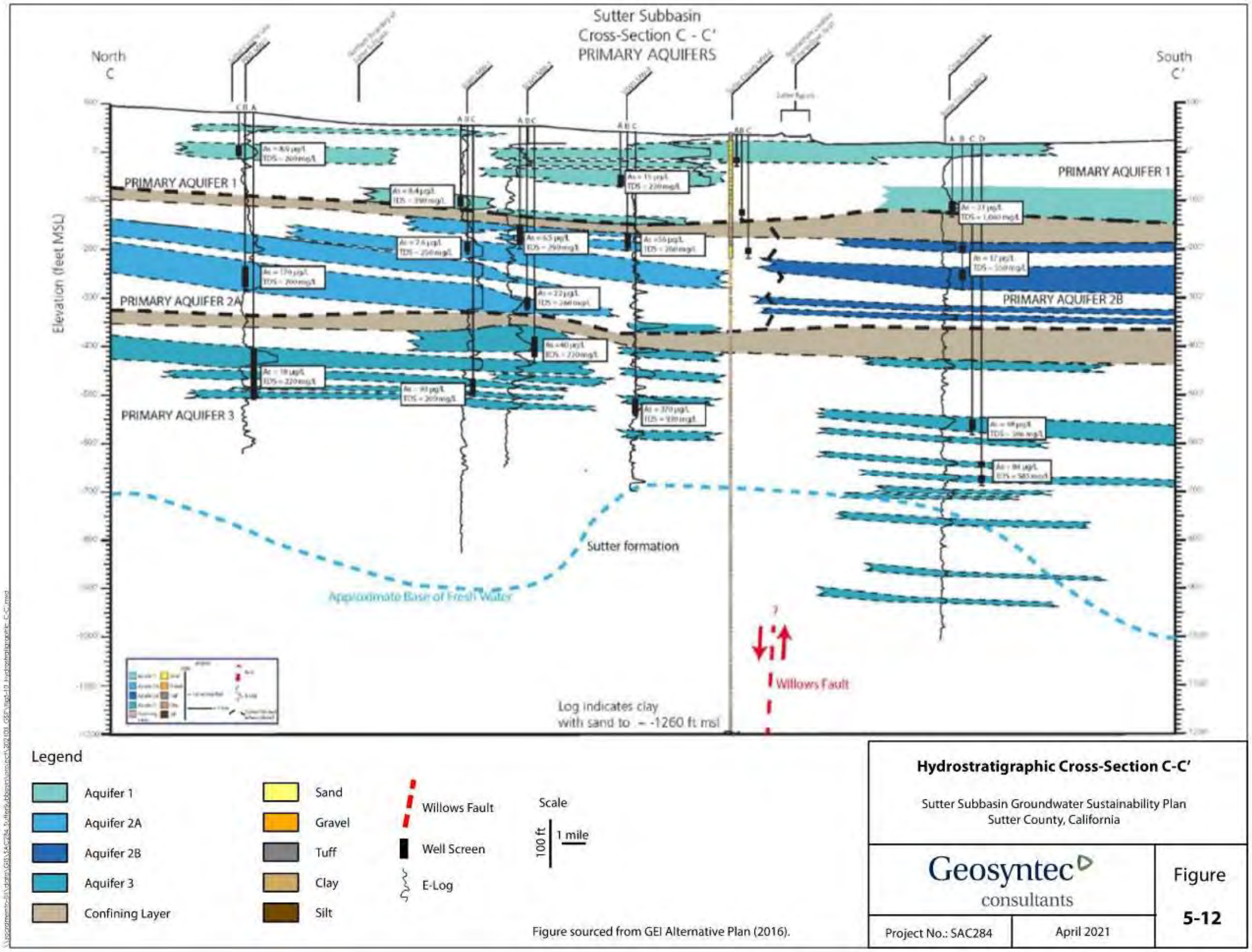


Figure 5-12. Hydrostratigraphic Cross-Section C-C'

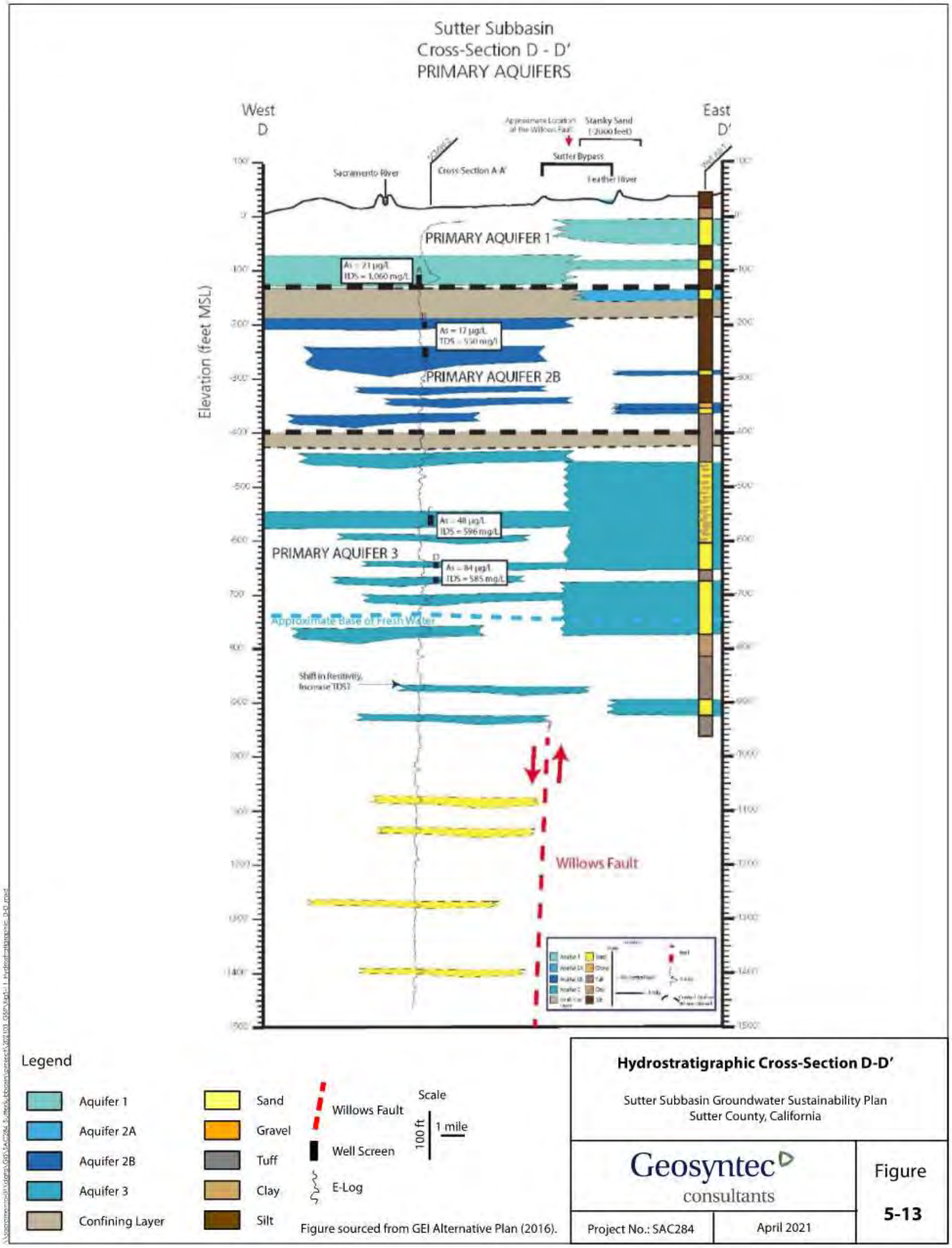
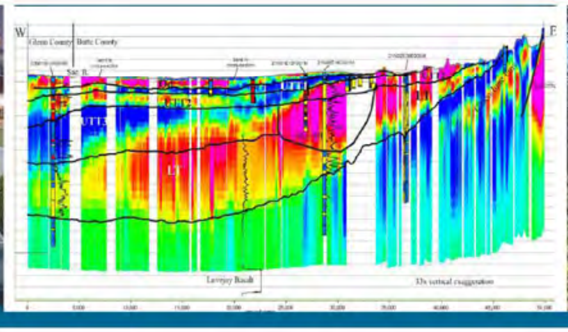


Figure 5-13. Hydrostratigraphic Cross-Section D-D'

Vina Groundwater Subbasin

Groundwater Sustainability Plan

December 2021

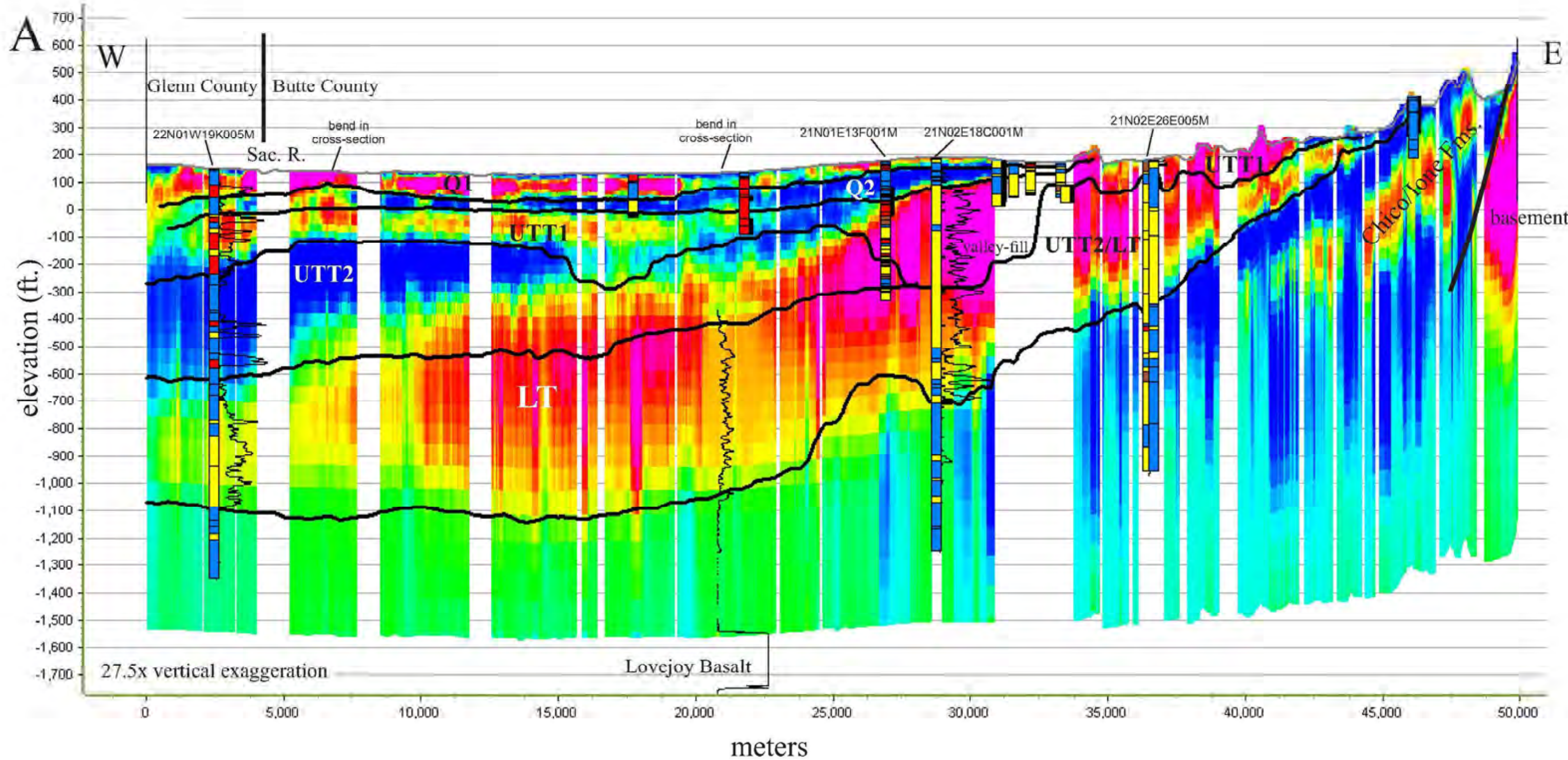


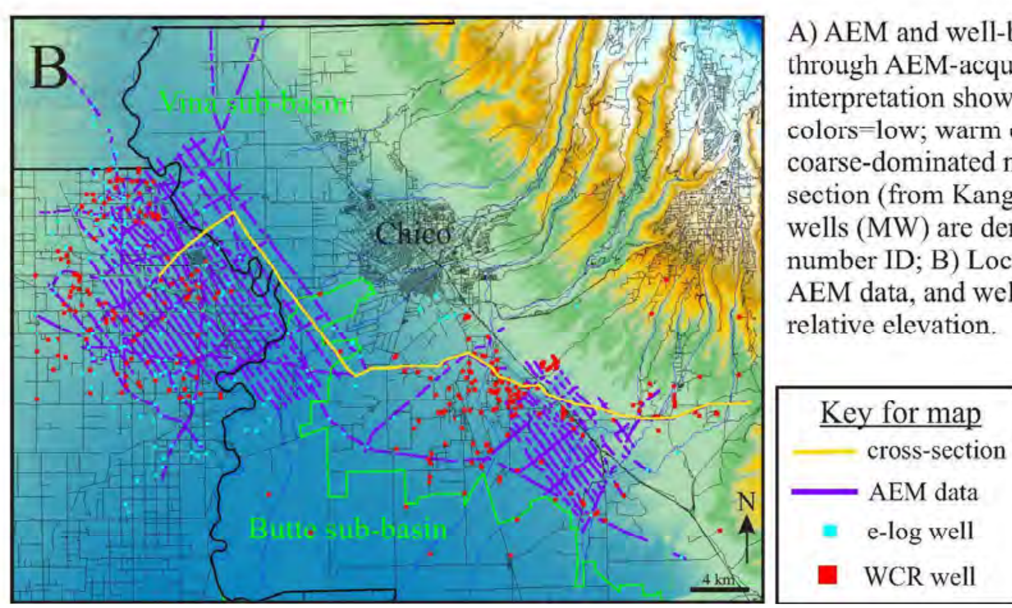
Vina GSA

Rock Creek Reclamation District

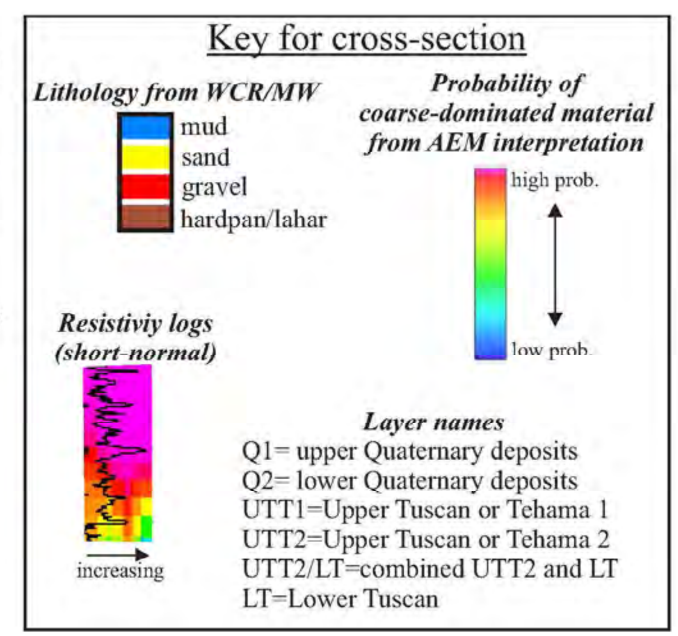
PREPARED FOR

VINA AND ROCK CREEK RECLAMATION DISTRICT GROUNDWATER SUSTAINABILITY AGENCIES





A) AEM and well-based hydrogeologic layering through AEM-acquired data areas. AEM interpretation shows probability (cold colors=low; warm colors=high) of encountering coarse-dominated material along the cross-section (from Kang et al., in prep.). Monitoring wells (MW) are denoted by the State's well number ID; B) Location map of cross-section, AEM data, and well data. Background colors are relative elevation.



Vina Subbasin East-West AEM Cross-Section
Vina Groundwater Subbasin GSP

Project No.: SAC282 | December 2021

Figure **2-9A**

2.1.8 Principal Aquifers and Aquitards

2.1.8.1 Overview

The Vina Subbasin groundwater system is comprised of a single principal aquifer composed of the Quaternary Deposits (Q1, Q2), Upper Tuscan/Tehama (UTT1 and UTT2) and Lower Tuscan units creating various aquifer zones with different hydrogeologic properties and both unconfined and semi-confined conditions. This leaky aquifer system has varied hydraulic connectivity between different depth zones in different areas of the Vina Subbasin. Due the localized variation of vertical connectivity, this is identified as a data gap.

Characteristics of the groundwater system vary from the northeast to the southwest as the Tuscan Formation materials become more reworked and less consolidated with distance from their geologic source. The characteristics of the aquifer system also vary in the vicinity of the Sacramento River, Butte Creek, and the base of the eastern foothills as different processes deposited materials that make up the aquifer system at depth.

The degree of connectivity between various zones in the aquifer system are evident in some areas based on hydrographs, pumping tests, and water level measurements. Hydrographs from nested wells show slight vertical gradients in the subsurface (Section 1.2.2.2). A pump test in the northeastern area of the Vina Subbasin (at monitoring well 23N01W03H02-04) demonstrated that in some cases low-permeability lahar units caused different discrete aquifer zones to be hydraulically disconnected while in other cases the lahar layers functioned as a leaky aquitard, allowing a delayed hydraulic connection between aquifer zones (Appendix E of Brown and Caldwell, 2013).

In the central area of the valley near the Sacramento River, thick fine-dominated layers of the UTT2 separate coarser-dominated materials of the UTT1 from the coarse-dominated zone of the Lower Tuscan (Figure 2-9A). Yet a pump test in the area (on M&T Ranch) demonstrated hydraulic connectivity between these zones and significant storage in the aquitard of the UTT2 separating them (Appendix E of Brown and Caldwell, 2013). A pump test in the vicinity of Rancho Esquon demonstrated hydraulic connectivity between an intermediate and deeper aquifer zone of the Lower Tuscan unit with 100 feet or more of low permeability fines separating them. However, in the same monitoring well no connectivity was observed between the shallower aquifer zone of the UTT1 (80 to 150 feet bgs) and the Lower Tuscan unit’s intermediate zones where 100 feet of low-permeability fines separated them (Appendix E of Brown and Caldwell, 2013).

Due to the variance in hydraulic connectivity between zones in different areas of the Vina Subbasin and between different depths, a single principal aquifer is defined. In most cases, patterns of groundwater levels in nested wells suggest some degree of connectivity. DWR defines “principal aquifers” under SGMA as the “aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems” (Cal. Code of Regs., title 23, § 351(aa)).

There are no known structural properties (i.e., faults) that significantly restrict groundwater flow within the Vina Subbasin within the portion of the aquifer that stores, transmits, and yields significant quantities of water.

YSGA
Yolo Subbasin Groundwater Agency
YOLOGROUNDWATER.ORG

Yolo Subbasin Groundwater Agency
2022 Groundwater Sustainability Plan
Yolo County, CA




Yolo Subbasin Groundwater Agency
34274 State Highway 16, Woodland CA 95695

2.1.2.1.2 Physical Subbasin Boundaries

The western boundary of the Yolo Subbasin abuts the Coast Range which is comprised of Upper Cretaceous marine sedimentary and metasedimentary rocks (Ku), including sandstone, shale, and conglomerate (Jennings 1977). The consolidated nature of these rock limits infiltration of precipitation, which produces runoff that flows eastward into the Yolo Subbasin. As such, higher groundwater levels are present along the western boundary of the Subbasin, which produces a general easterly direction of groundwater flow. The Capay Hills are a north-south trending ridge of marine rocks (Ku) near the northwestern corner that isolate Capay Valley from the main part of Yolo Subbasin. As such, Capay Valley is a small tributary groundwater body to the Yolo Subbasin.

2.1.2.2 Vertical Subbasin Boundaries – Bottom of the Subbasin

The bottom of the Yolo Subbasin has been defined by the base of fresh groundwater as shown by **Figure 2-2** (LSCE 2004). The base of fresh groundwater was defined as specific conductance measurements less than 3,000 micromhos per centimeter (µmhos/cm) (Olmsted and Davis 1961). The deepest area of fresh groundwater is located in the southernmost part of the Subbasin at an elevation of below -3,000 feet mean-sea-level (msl). The depths are somewhat less at more than -2,500 feet msl in a broad, north-trending area beneath the cities of Davis and Woodland that extend further north toward the community of Zamora. A narrow north-trending trough with a bottom elevation of -2,500 feet msl is present on the east side of the city of Winters and extends northward toward the town of Esparto. These north-trending features area consistent with the structural fabric of the Sacramento Valley. Bottom elevations increase quickly on the west side of the narrow trough to greater than -1,000 feet msl while bottom elevations increase more gradually elsewhere in the Subbasin. Bottom elevations vary between -1,500 and -2,000 feet msl along the eastern boundary of the Subbasin and between -1,000 and -2,000 along the northern boundary.

The base of fresh groundwater is several hundred feet above the base of the post-Eocene continental deposits, which are generally equivalent to the base of the Tehama Formation (Page 1974).

2.1.3 Principal Aquifers and Aquitards

An aquifer is a body of rock or sediment that is sufficiently porous and permeable to store, transmit, and yield significant quantities of groundwater to wells and springs. An aquitard is a confining bed or formation composed of rock or sediment that retards but does not prevent the flow of water to or from an adjacent aquifer. It does not readily yield water to wells or springs but stores groundwater. The hydrogeology of the Yolo Subbasin was described in *Groundwater Monitoring Program, Data Management System, and Update of Groundwater Conditions in the Yolo County Area* (YCFWCD, 2004), and the following sections are essentially quoting that text.

The report divided the aquifer system, consisting of alluvium and the upper Tehama Formation, into three zones: shallow, intermediate, and deep zones, which are described below. The three zones were delineated by LSCE through "rough correlation of geologic units and on water well completion depths" (LSCE 2004).

2.1.3.1 Shallow Zone

The shallow zone extends from the surface to a depth of about 220 feet below ground surface (bgs) and consists predominantly of alluvium as well as the upper portion of the Tehama Formation. The deposits consist of thick sand and gravel deposits within a mile or 2 of the major sediment sources of Cache and Putah creeks. The coarse beds appear to thin laterally from the present stream channels with thinner distributary channel, and sheet flood sand deposits occurring under the more distal alluvial plains.

Well yields can be relatively high where thick channel deposits are encountered with yields of several hundred to 1,500 gallons per minute (gpm). Specific capacities range up to 100 gpm per foot of drawdown or greater in this setting. More modest production (e.g., up to 500 gpm yields) likely results from wells constructed in thin sands that are more distant from stream channels and have lower specific capacities. Wells completed in even just a few thin sand beds produce sufficient quantities for domestic use. In the Capay Valley, more information about the aquifer conditions is needed. There are many wells in this area with total depths of less than 100 feet. For additional information, see Section 4.11.2 – Plan to Address Data Gaps.

2.1.3.2 Intermediate Zone

The intermediate zone extends from depths of about 220 to 600 feet bgs and occurs exclusively within the upper Tehama Formation. These deposits are believed to be largely alluvial plains with distributary channel and sheet flood sands interbedded in silts and clays. These deposits are believed to be slightly more consolidated than the shallow zone, although the coarser beds may remain loose.

Well yields appear to be high for eastern areas with ranges of 500 to 1,000 gpm where thick sands are encountered. Wells yields in the western alluvial plain area appear to be lower and range from about 100 to 500 gpm where thick sands are encountered. In this area, a higher percentage of test holes may not encounter sufficient sand to provide desired production well yields. Specific capacities for wells completed in the intermediate zone are comparatively lower than those for the shallow zone. Intermediate zone wells in the western alluvial plain likely have poor to low yields due to the lack of sand beds, in comparison to wells in the eastern alluvial plain. However, thick sand beds are less prevalent in the intermediate zone than the shallow zone.

2.1.3.3 Deep Zone

The deep zone extends from depths of about 600 to 1,500 feet bgs and encompasses the deeper upper Tehama Formation (Els, Elus, D sands, and F sands). These sands sequences are believed to be of central fluvial origin in eastern Yolo County.

Well yields appear to be high in the eastern area where thick or numerous sand beds or sand sequences are encountered. Well yields of 1,000 to 3,000 gpm are not uncommon. However, if sand sequences with low sand content are encountered, supply wells may not be feasible. Specific capacities for deep zone wells completed in thick sand sequences appear to be about 20 to

30 gpm/foot. The deeper (below -1,500 feet elevation) lower Tehama Formation is not utilized by water wells in the County.

2.1.3.4 Aquifer Properties

The aquifer properties summarized in the following section provide input parameters to the YSGA Model and form the basis of understanding of how water is stored in and flows throughout the Subbasin. A finite element numerical model was established for the Yolo Subbasin in 2006 by WRIME (now called RMC Water and Environment) using the Integrated Groundwater Surface-Water Model (IGSM). As detailed in **Table 2-1**, the aquifer system was represented by three layers which generally correspond to alluvium in the shallow zone (#1), upper Tehama Formation or intermediate and deep zones (#2) and the lower Tehama Formation or deepest zone (#3).

Table 2-1. Summary of Aquifer Parameters Data in the Yolo Subbasin IGSM (WRIME 2006).

Zone (Layer)	Location/General Area	Transmissivity feet^2/day	Hydraulic Conductivity feet/day	Storage Coefficient unitless
Shallow (1)	Yolo County	3,000 to 46,000		7.3E-02
	RD 108	26,000 to 52,000	13 to 67	8.0E-02 to 9.0E-02
	RD108, RD 787, RD730, Yolo-Zamora WD	26,000 to 65,000	64	6.0E-02 to 1.2E-01
	Yolo-Zamora WD	9,000 to 26,000	48	7.0E-02 to 9.0E-02
	Woodland	10,000 to 105,000		3.1E-02
	Cache Creek above Moore's Siphon	25,000 to 260,000		
	Knights Landing Ridge Drainage District	26,000 to 52,000	21	6.0E-02 to 1.1E-01
Intermediate & Deep (2)	Dunnigan WD	5,600 to 13,000		9.0E-04 to 2.3E-03
	Yolo County			6.5E-02 to 7.2E-02
	RD108, RD 787, RD730, Yolo-Zamora WD	26,000 to 65,000	19 to 119	6.0E-02 to 1.2E-01
	Yolo-Zamora WD	9,000 to 26,000	41 to 118	7.0E-02 to 9.0E-02
	Davis	4,000 to 18,000		
	Capay Valley	9,000 to 10,000		
	Cache Creek below Moore's Siphon	1,000 to 18,000	400	
	Knights Landing Ridge Drainage District	26,000 to 52,000	21 to 139	6.0E-02 to 1.1E-01
Yolo County IGSM				
1	Model-wide		8 to 38	5.0E-02 to 9.0E-02
2	Model-wide		4 to 20	5.0E-02
3	Model-wide		1 to 20	5.0E-02

Similarly, RMC Water and Environment (formerly WRIME) utilized IGSM for a 5-layer simulation of groundwater flow in the Capay Valley (RMC 2016), *see* **Table 2-2**. Layers 1 and 2 in Capay Valley represent the shallow zone, while layers 3 and 4 represent the intermediate and deep zone, and layer 5 is the deepest zone. The aquifer parameters for the Capay Valley used in the YSGA model come from **Table 2-2.**

Tables 2-1 and 2-2 summarize the available aquifer properties from these various agencies and/or the two models. As defined by Heath (1983), aquifer properties include:

- Hydraulic Conductivity (K): Volume of water that will move through material during a unit amount of time under a unit gradient through a unit area. Units are typically gallons per day per square foot or feet per day.
- Transmissivity (T): Capacity of material to transmit water and is equal to the product of hydraulic conductivity and thickness. Units are typically gallons per day per foot or square feet per day.
- Storage Coefficient (S): Volume of water that is released from or takes into storage per unit surface area per unit change in water level (head). No units.
- Specific Yield (SY): Amount of water that will drain from material under the influence of gravity. Unit is % volume.

Table 2-2. Summary of Aquifer Parameters in the Capay Valley IGSM (RMC 2016).

Yolo Subbasin Zone (Equivalent IGSM Layer)	Capay Valley Layer	Hydraulic Conductivity feet/day	Storage Coefficient unitless	Specific Yield
Shallow (1)	1	25 to 50	1E-02	15%
	2	10	1E-02	10%
Intermediate & Deep (2)	3	1	8E-03	8%
	4	4	8E-03	8%
(3)	5	2	5E-03	5%

Figure 2-3 indicates that the aquifer system is comprised of mostly sand with some gravel in the intermediate and deep zone. The IGSM values were similar to agency values for the shallow zone but were somewhat less for the intermediate and deep zone, and the Capay Valley model values were less than the County model.

Finer-grained layers (silt and clay) undoubtedly exist with the Subbasin and the respective hydraulic properties would be notably less than the coarse-grained layers (gravel and sand). However, wells are not typically installed (screens) in the fine-grained layers so hydraulic properties have not been measured directly.

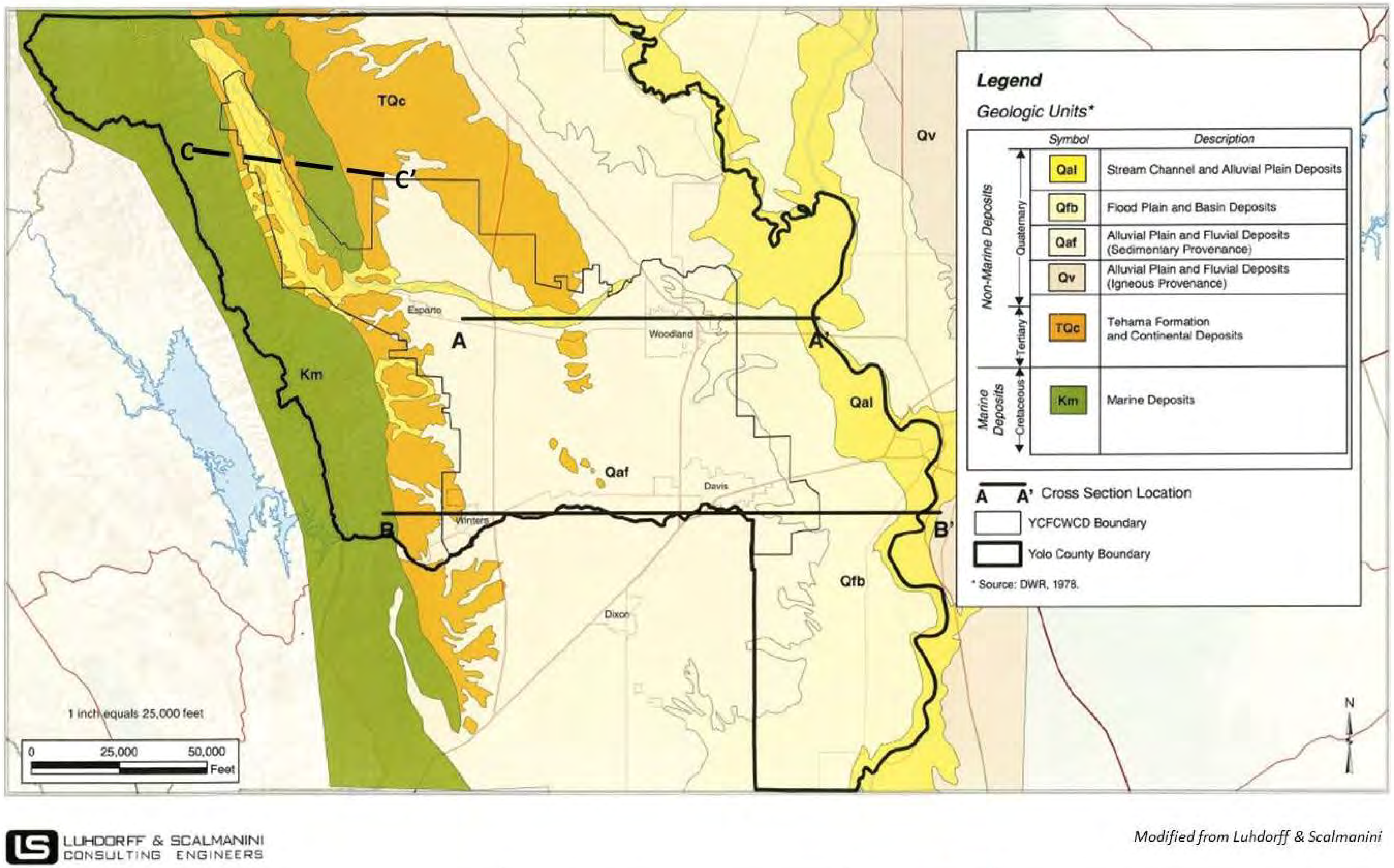
Groundwater within the Subbasin occurs under water table or unconfined conditions in the shallow zone and possibly semi-confined conditions with increasing depth.

2.1.4 Topography

The topography of the Yolo Subbasin is presented in **Figure 2-4** and is based on the U.S. Geological Survey (USGS) National Elevation Dataset[17]. Detailed topographic information can be obtained from 25, 7.5-minute maps, as listed below, plus a tangential portion of the Glascock Mountain map.

Glascock Mtn	Rumsey	Wildwood School	Dunnigan	Kirkville		
	Guinda	Bird Valley	Zamora	Eldorado Bend	Knights Landing	Verona
	Brooks	Esparto	Madison	Woodland	Grays Bend	Taylor Monument
		Monticello Dam	Winter	Merritt	Davis	West Sacramento
					Saxon	Clarksburg
					Liberty Island	Courtland

[17] Viewable at https://apps.nationalmap.gov/viewer/



Yolo Subbasin Groundwater Agency	GEI Consultants	
Yolo County, California		

Figure 2-6. Location Map for Geologic Cross Sections.

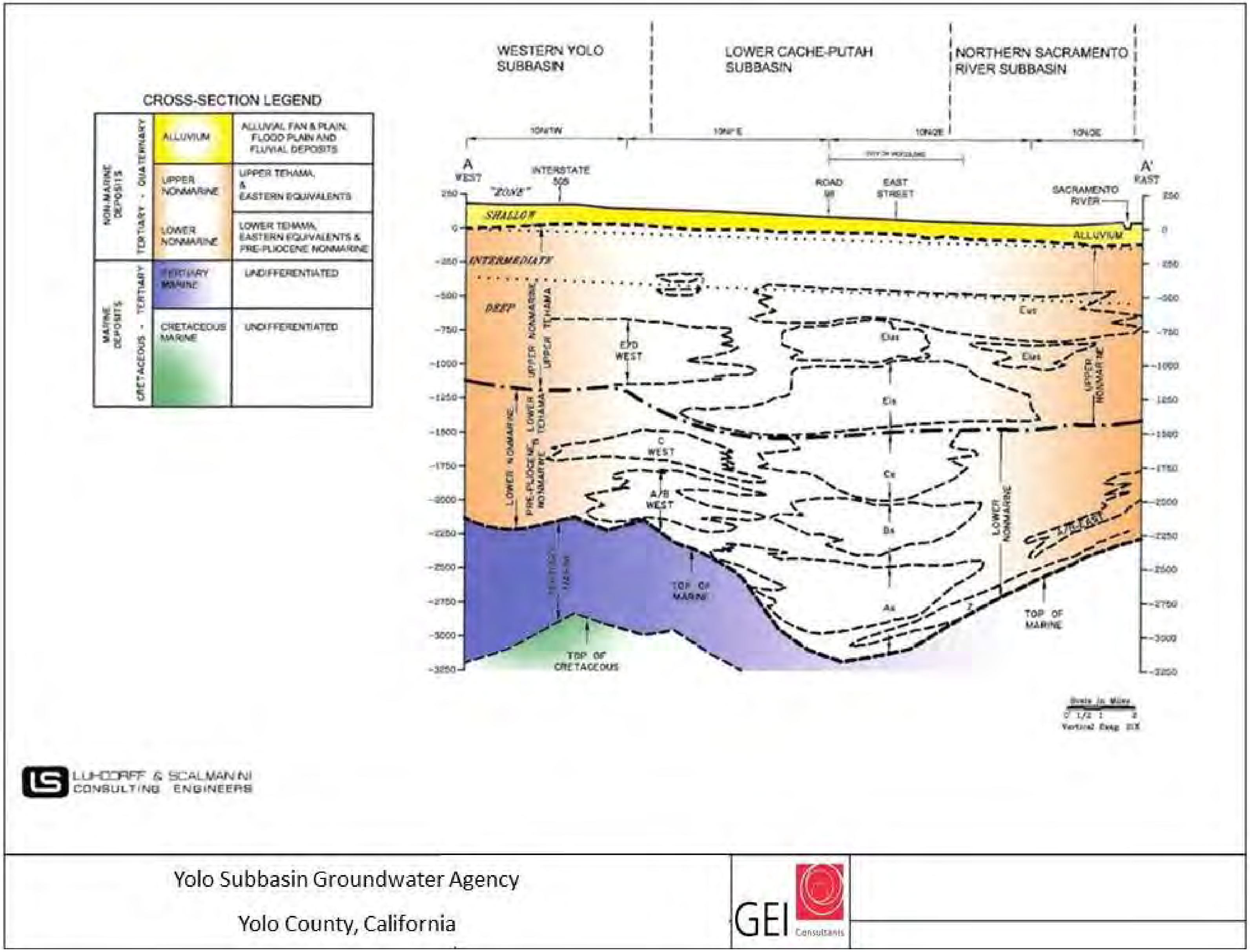
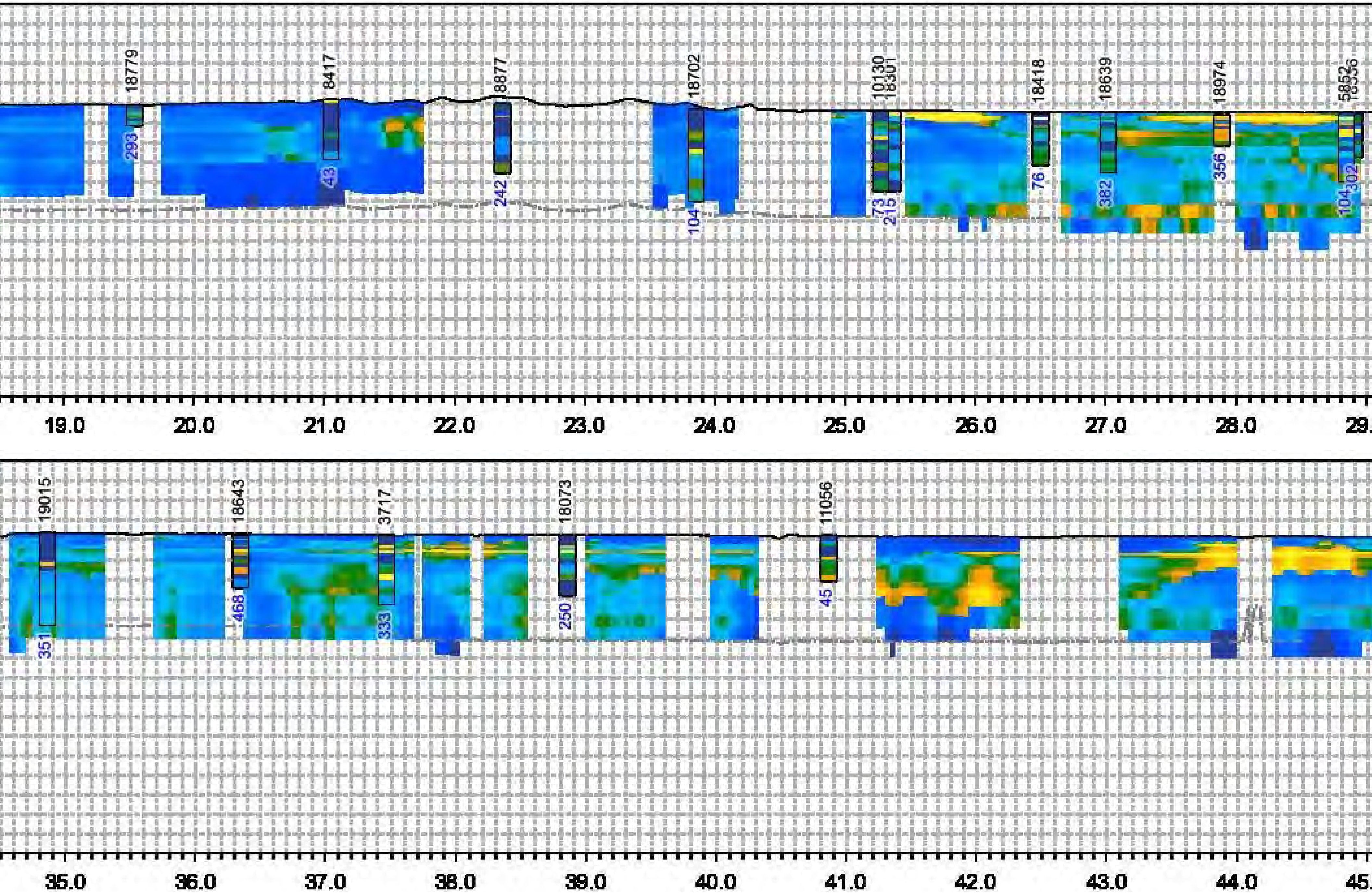


Figure 2-7. Geologic Cross Section A-A'.

A - A' Nearest AEM Log



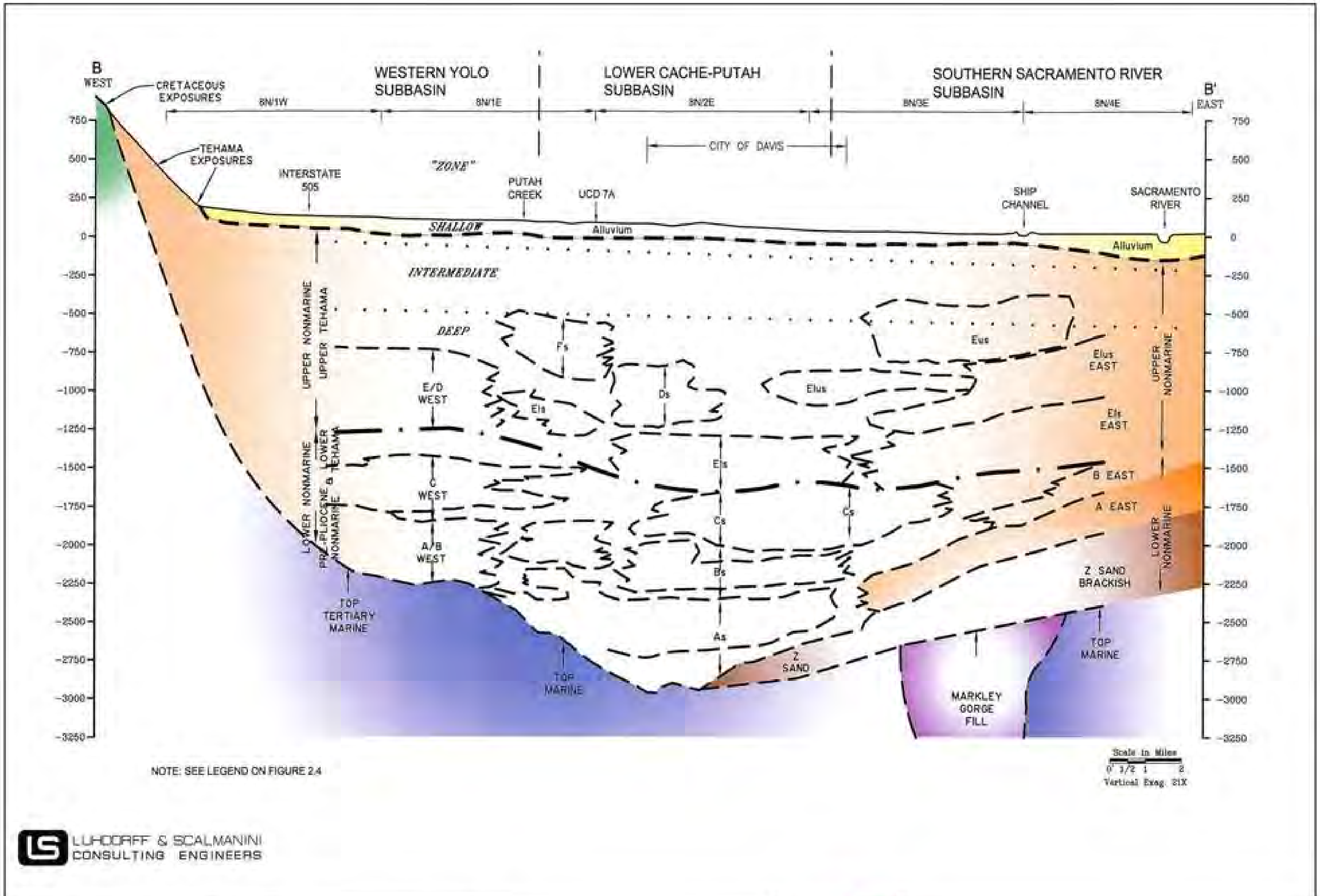


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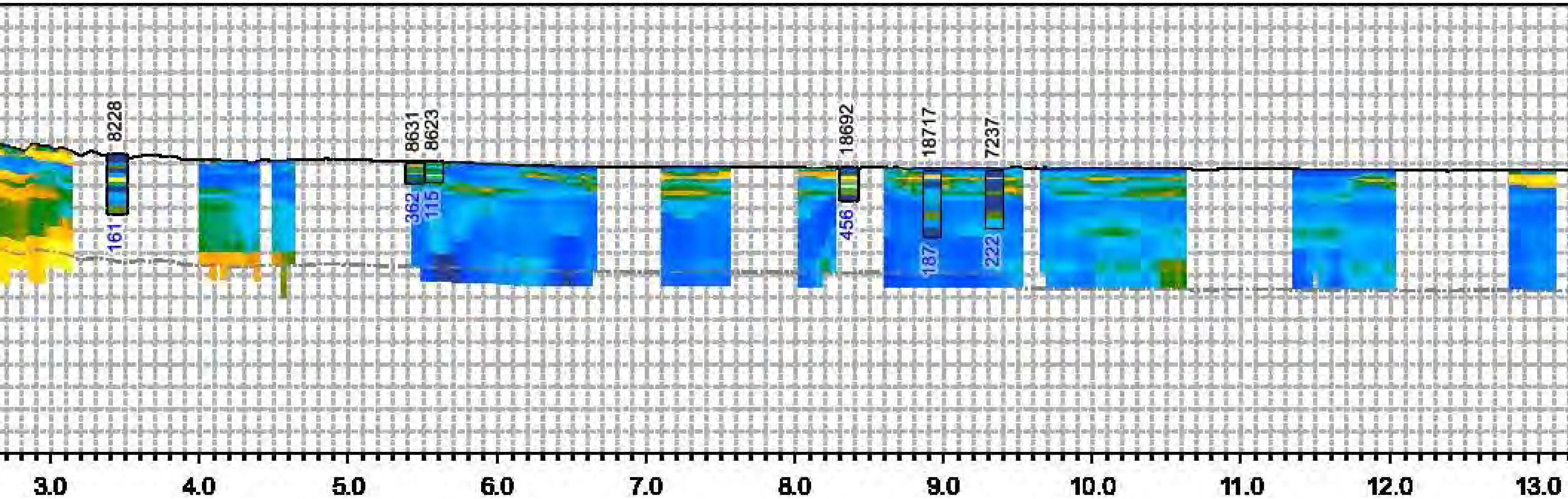
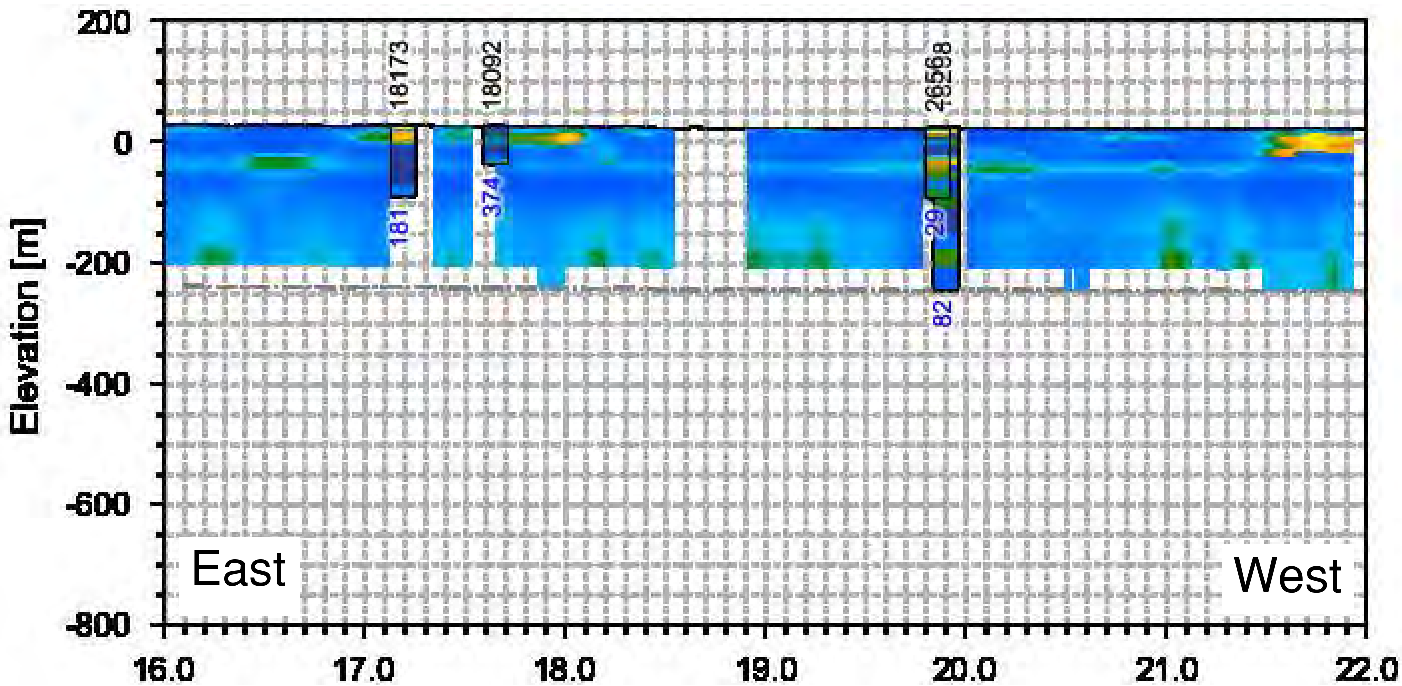
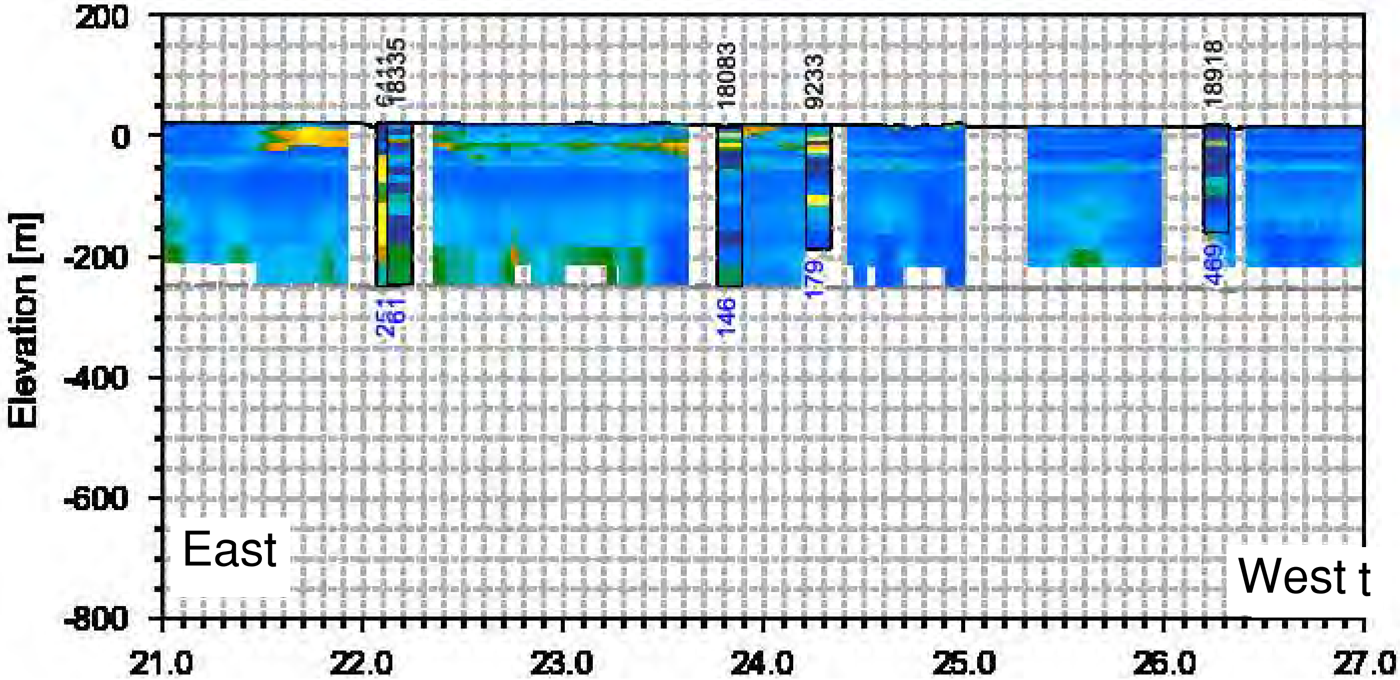
Figure 2-8. Geologic Cross section B-B'.

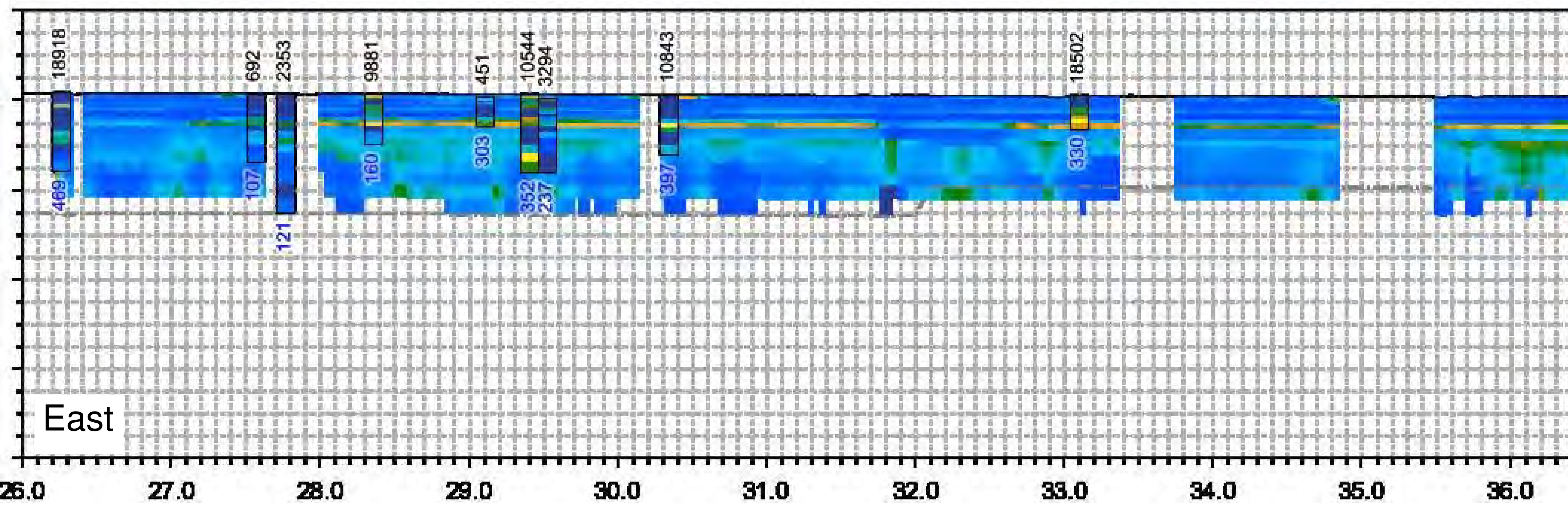
B - B' Nearest AEM Log



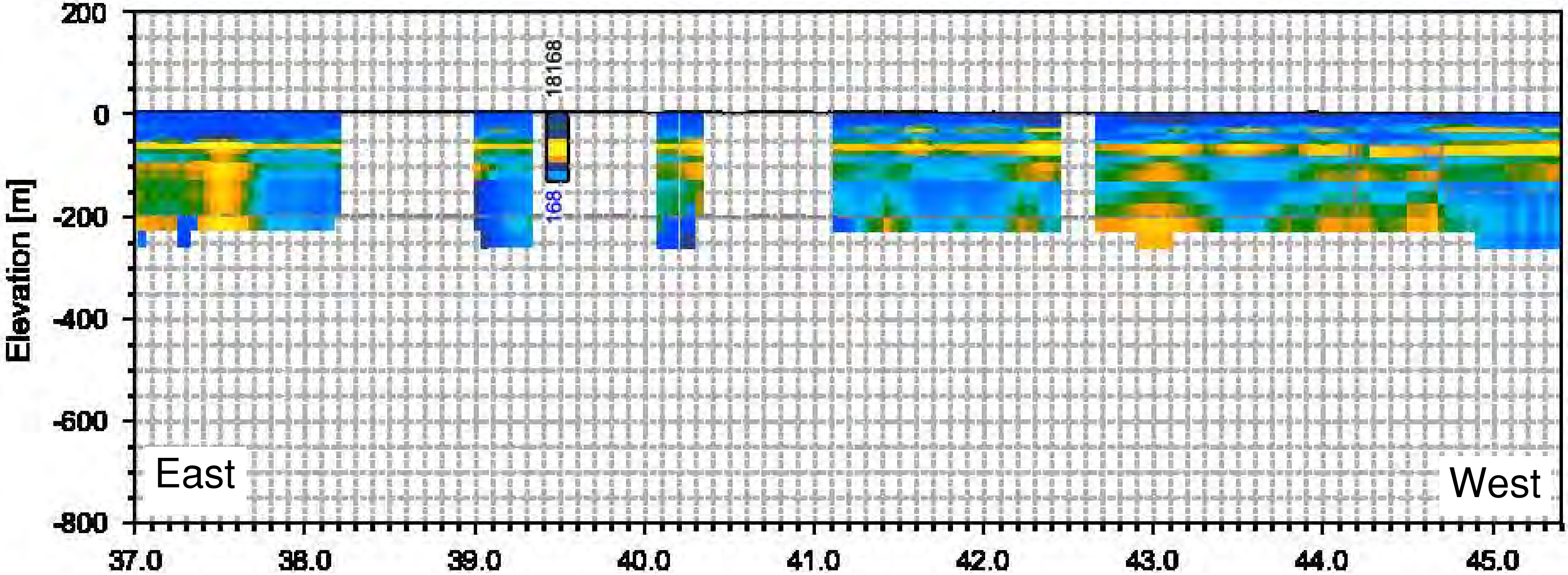


B - B' Nearest AEM Log





B - B' Nearest AEM Log



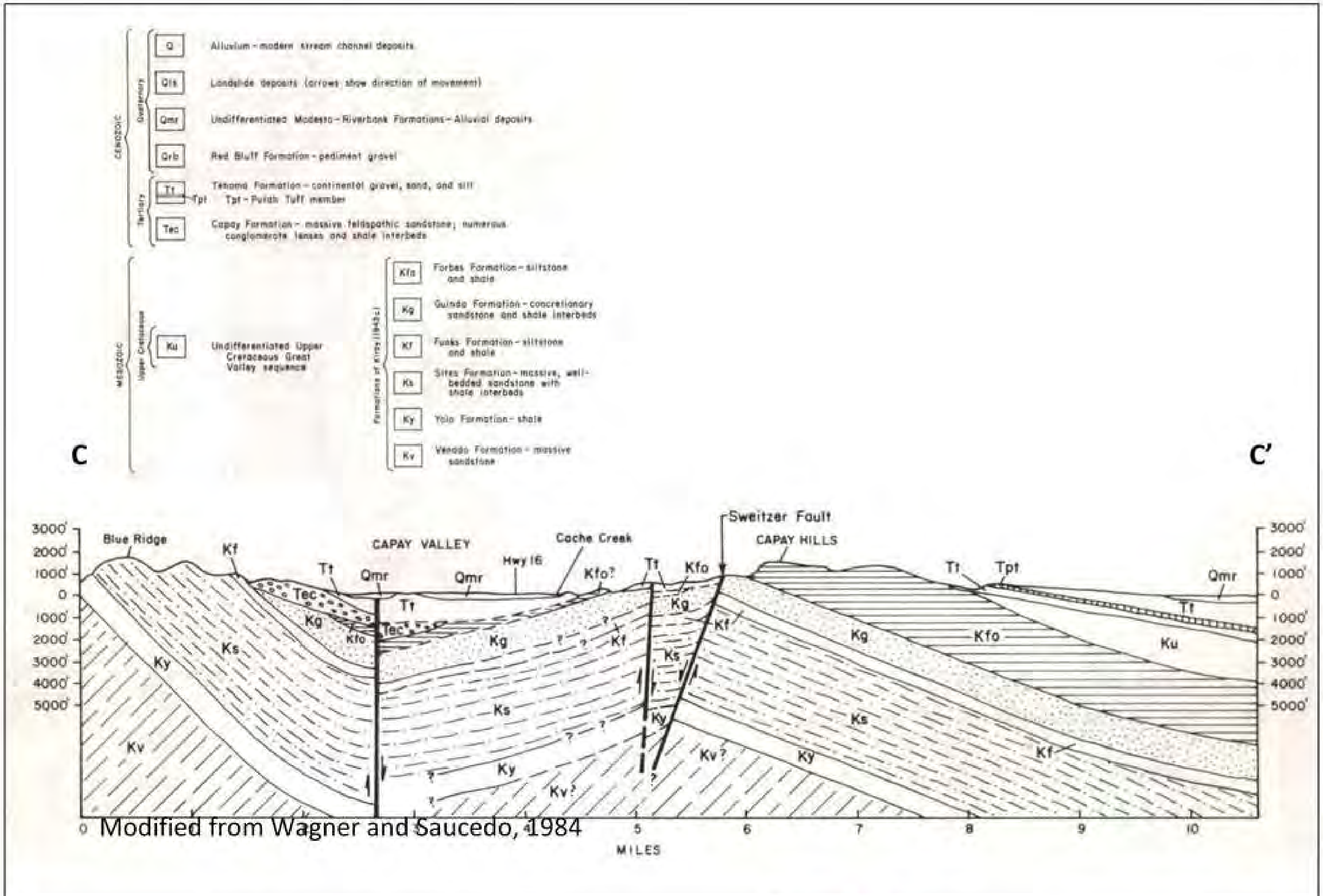


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Figure 2-9. Geologic Cross section C-C'.

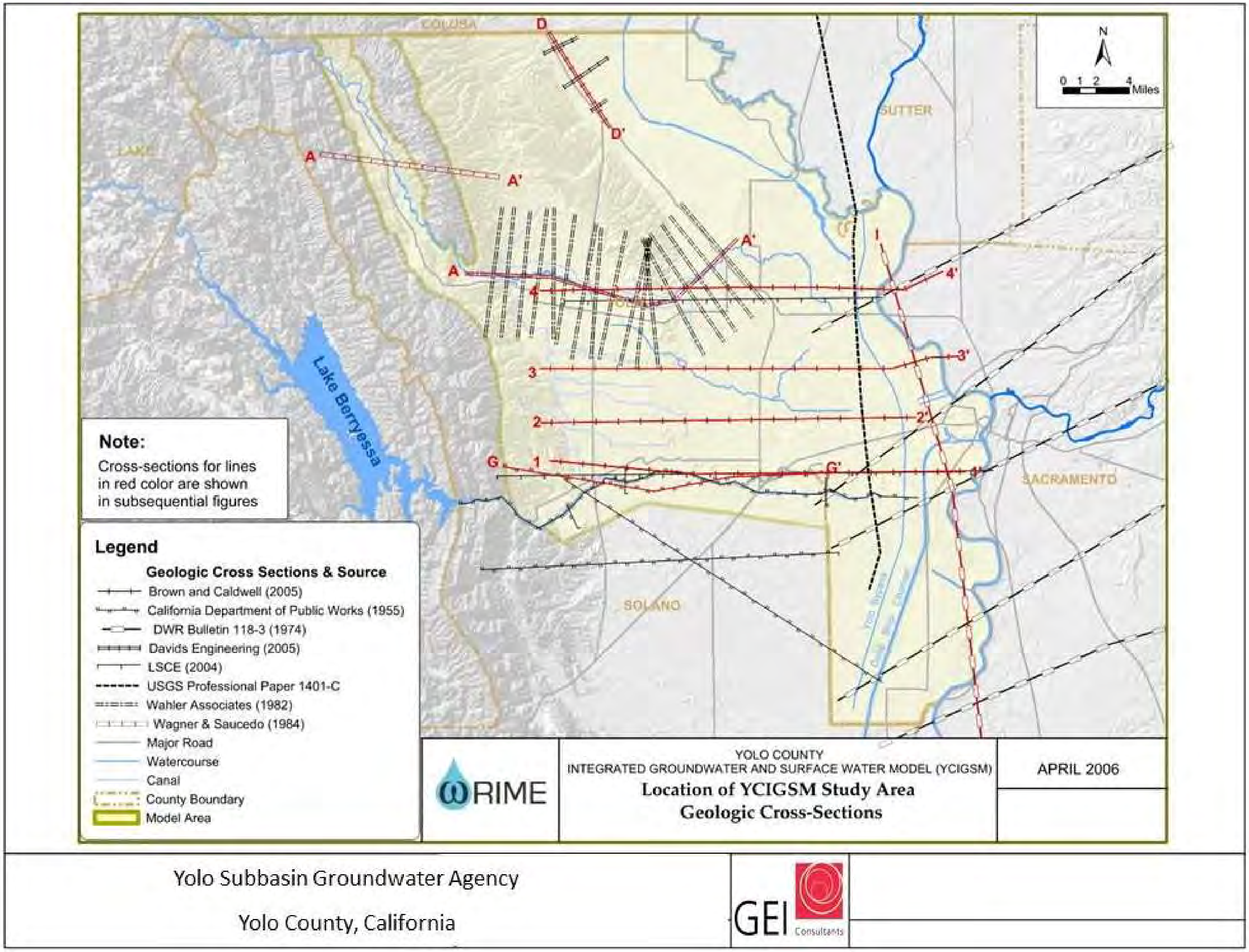

Figure 2-10. Geologic Cross Sections evaluated in Yolo County Integrated Groundwater and Surface Water Model.