Appendix B2 -
San Joaquin Valley Hydrologic Region - GSP Hydrogeologic Conceptual Model Excerpts and Near AEM Profiles

CHOWCHILLA SUBBASIN

Sustainable Groundwater Management Act (SGMA)

Groundwater Sustainability Plan

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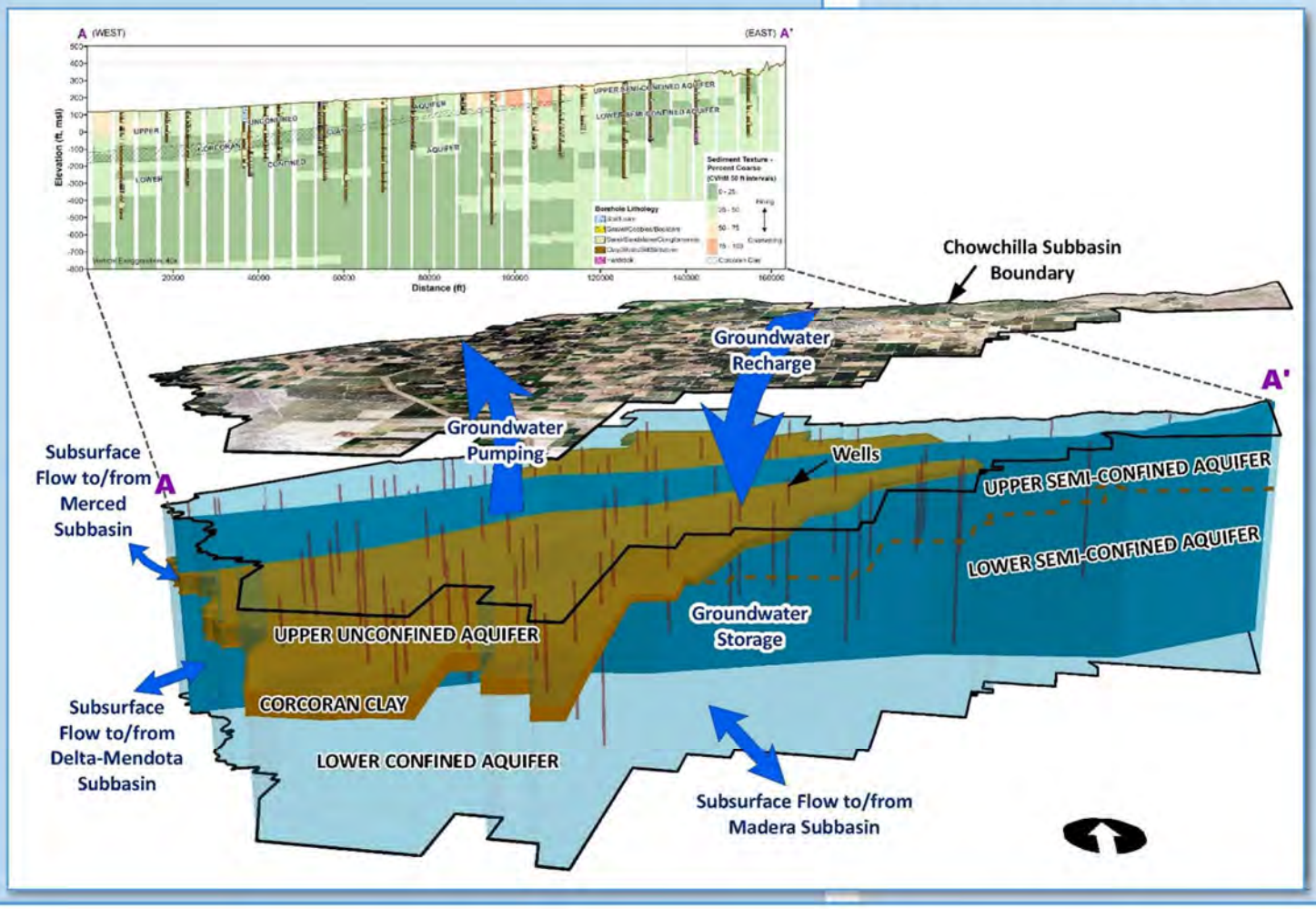


2.2.1.2 Lateral and Vertical Subbasin Boundaries

The Chowchilla Subbasin is bordered by the Madera Subbasin to the east and south, Merced Subbasin to the north, and Delta-Mendota Subbasin to the west (**Figure 2-16**). All Subbasin boundaries are political/agency boundaries across which groundwater flow can and does occur. A basin boundary modification request was approved by DWR in 2016, and the revised boundary is incorporated in this study.

The base of fresh water was evaluated by Page (1973), and was defined in this study as including water with conductivity up to 3,000 umhos/cm. Overall, the base of freshwater was mapped as ranging approximately from elevation -600 to -1,200 feet msl within Chowchilla Subbasin. In general, the shallowest depths to base of fresh water were along the southern boundary of the Subbasin, and the greatest depths were areas located just south of the City of Chowchilla and beneath the Chowchilla River in the central portion of the Subbasin (**Figure 2-17).** This base of fresh water mapped by Page should be considered approximate and might be expected to be slightly shallower, because fresh water is generally considered to have total dissolved solids of less than 1,000 milligrams/liter (mg/L) and conductivity of less than 1,600 umhos/cm. The base of fresh water will be refined over time as more data are collected, including lithologic, geophysical, water level, and water quality data currently being collected as part of the 2019-2020 nested monitoring well program

Maps of the depth to basement rock (**Figure 2-18**) and elevation of basement rock (**Figure 2-19**) show increasing depths (and decreasing elevations) to basement rock from northeast to southwest across the Subbasin. The depths to bedrock range from about 500 feet to greater than 3,500 feet at the southwestern boundary of the Subbasin. In general, the aquifer base is controlled mostly by the base of fresh water provided in **Figure 2-17** except in the far eastern portions of the Subbasin. It should also be recognized that wells drilled and screened below the currently defined base of fresh water likely will still have a hydraulic connection with the overlying fresh water zone and are considered part of the Chowchilla Subbasin.

2.2.1.3 Major Aquifers/Aquitards

Geologic cross-sections are a key element of the HCM required in a GSP under SGMA. Related work completed for this GSP included review of existing literature to extract the available geologic cross-sections and construction of additional new geologic cross-sections based on data compiled for GSP efforts. This section of the GSP (and **Appendix 2.D**) provides a general description of the existing and new cross-sections, and documents the source of available existing geologic cross-sections along with details of how the new cross-sections were developed.

2.2.1.3.1 Existing Geologic Cross-Sections

The geologic cross-sections derived from previous reports are presented in **Appendix 2.D**, and were described in a previous report (DE/LSCE, 2017). Two of these existing cross-sections are described below to provide overall regional context for the stratigraphy of the Subbasin (Mitten, et al.,1970; Page, 1986). The locations of these two existing geologic cross-sections are provided in **Figure 2-20**, and the individual cross-sections are provided in **Figures 2-21 and 2-22**. A summary of the two regional geologic cross-sections is provided below.

Mitten's (1970) cross-section A-A' (**Figure 2-21**) runs west to east across the northern portion of the Chowchilla Subbasin, and extends down to an elevation of -1,400 feet msl. The top of the E-Clay (Corcoran Clay) is present at a depth of approximately 200 feet below ground surface (bgs) on the western edge of the section (with a thickness of about 50 feet) and thins and tapers out near Ash Slough at a depth of about 80 feet bgs. A small deposit of Quaternary floodplain deposits (Qb) is present at the surface on the

western edge of the section, and thin layers of younger Quaternary alluvium (Qya) are present at the surface across the rest of the section. Older Quaternary alluvium (Qoa) underlies the surface deposits, and overlies Tertiary and Quaternary continental deposits (QTc). Undifferentiated Pre-Tertiary and Tertiary marine and continental sedimentary rocks (TpTu) underlie QTc in the eastern portion of the section. Pre-Tertiary basement complex (pTb) is present at the surface along the eastern edge of the section.

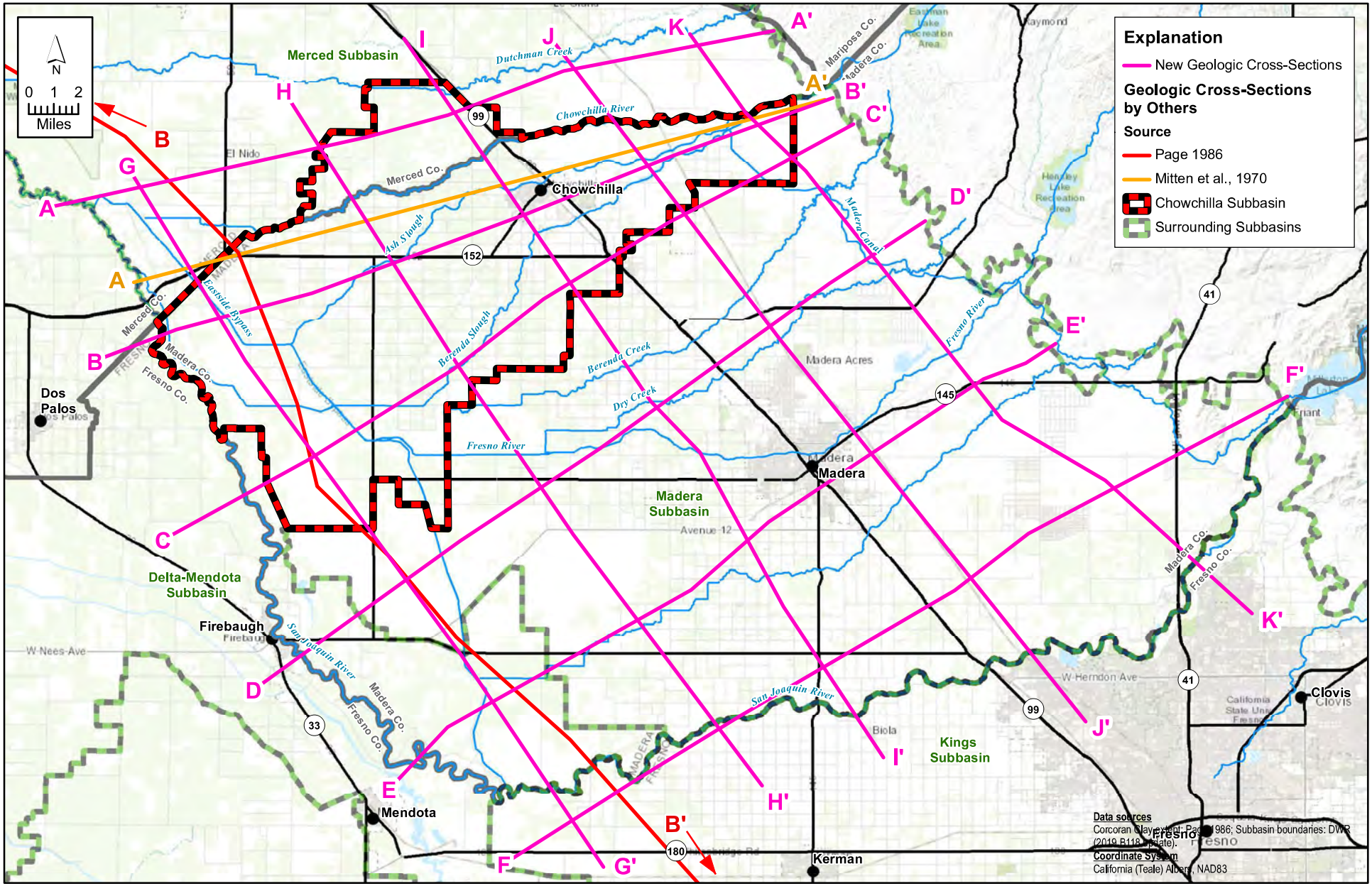
Page (1986) cross-section B-B' (**Figure 2-22**) runs north to south through the western portion of the Chowchilla Subbasin, and extends to a depth of about 9,000 feet bgs. Within the Chowchilla Subbasin, the Corcoran Clay is present throughout, at an approximate elevation of -100 feet msl. Thin deposits of Quaternary floodplain deposits (Qb) are present at the surface, underlain by Quaternary continental rocks and deposits (QTcd). A layer of Tertiary marine rocks and deposits interfinger the QTcd layer. A layer of Pre-Tertiary and Tertiary continental and marine rocks and deposits (i.e., bedrock) underlies these units at elevations ranging from about -2,500 to -3,500 feet msl.

2.2.1.3.2 New Geologic Cross-Sections

New geologic cross-sections were developed during GSP preparation efforts utilizing data collected for the GSP. A location map for new geologic cross-sections is provided in **Figure 2-20**. The new geologic cross-sections include some that do not cross Chowchilla Subbasin, but are included here because they occur within the Model Domain for the Madera-Chowchilla Groundwater-Surface Water Simulation (MCSim) Model developed for Chowchilla Subbasin. The CVHM well log dataset and DWR well log database developed for this project were reviewed to select logs for relatively deep wells that had fairly detailed descriptions of geologic units encountered. Locations for screened well logs were plotted to selected representative well logs at a reasonable spacing along each geologic cross-section line.

New geologic cross-sections A-A', B-B', and C-C' (**Figures 2-23, 2-24, and 2-25**) extend from southwest to northeast across Chowchilla Subbasin towards (perpendicular to) the Sierra Nevada Mountains, with A-A' being furthest north and C-C' being furthest south. Each cross-section generally shows the ground surface, the lithology associated with each well log, the Spring 2014 unconfined groundwater level, the Corcoran Clay (from C2VSim), and the base of fresh water (from Page 1986). The well logs generally range from very close to section lines to one mile of offset from the section line. The cross-sections illustrate the interbedded and variable nature of fine- and coarse-grained sediments both laterally and vertically. There are significant coarse-grained layers to depths of at least 800 feet. However, fine-grained sediments comprise a larger percentage of the subsurface than do coarse-grained sediments overall. Thus, it can be expected that vertical hydraulic conductivity (Kv) values will likely be orders of magnitude lower than horizontal hydraulic conductivity (Kh) values for a given aquifer. Geologic cross-sections A-A', B-B', and C-C' also illustrate the Corcoran Clay extends beneath the western and central portions of the Subbasin, and other clay layers are prominent throughout the Subbasin. New geologic cross-sections D-D', E-E', and F-F' (**Figures 2-26, 2-27, and 2-28**) are included here but not described further as they do not cross Chowchilla Subbasin.

New geologic cross-sections G-G' through K-K' (**Figures 2-29, 2-30, 2-31, 2-32, 2-33**) were constructed parallel to the Sierra Nevada Mountain front starting from the southwestern end of Chowchilla Subbasin and progressing towards the northeast (i.e., cross-section G-G' is furthest from and parallel to the Sierra Nevada Mountain front and K-K' is closest to the mountain front). These geologic cross-sections further demonstrate and confirm the features/characteristics described above for the cross-sections perpendicular the Sierra Nevada Mountains. While it is challenging to reliably correlate coarse-grained units in these cross-sections, they do illustrate well the general distribution of coarse- and fine-grained sediments both laterally and vertically. The textural analysis described in the Groundwater Model



X:\2018\18-017 Chowchilla GSP Development\GIS\Map files\Report Figures\Figure 2-20 Chowchilla Subbasin CrossSection Location Map.mxd

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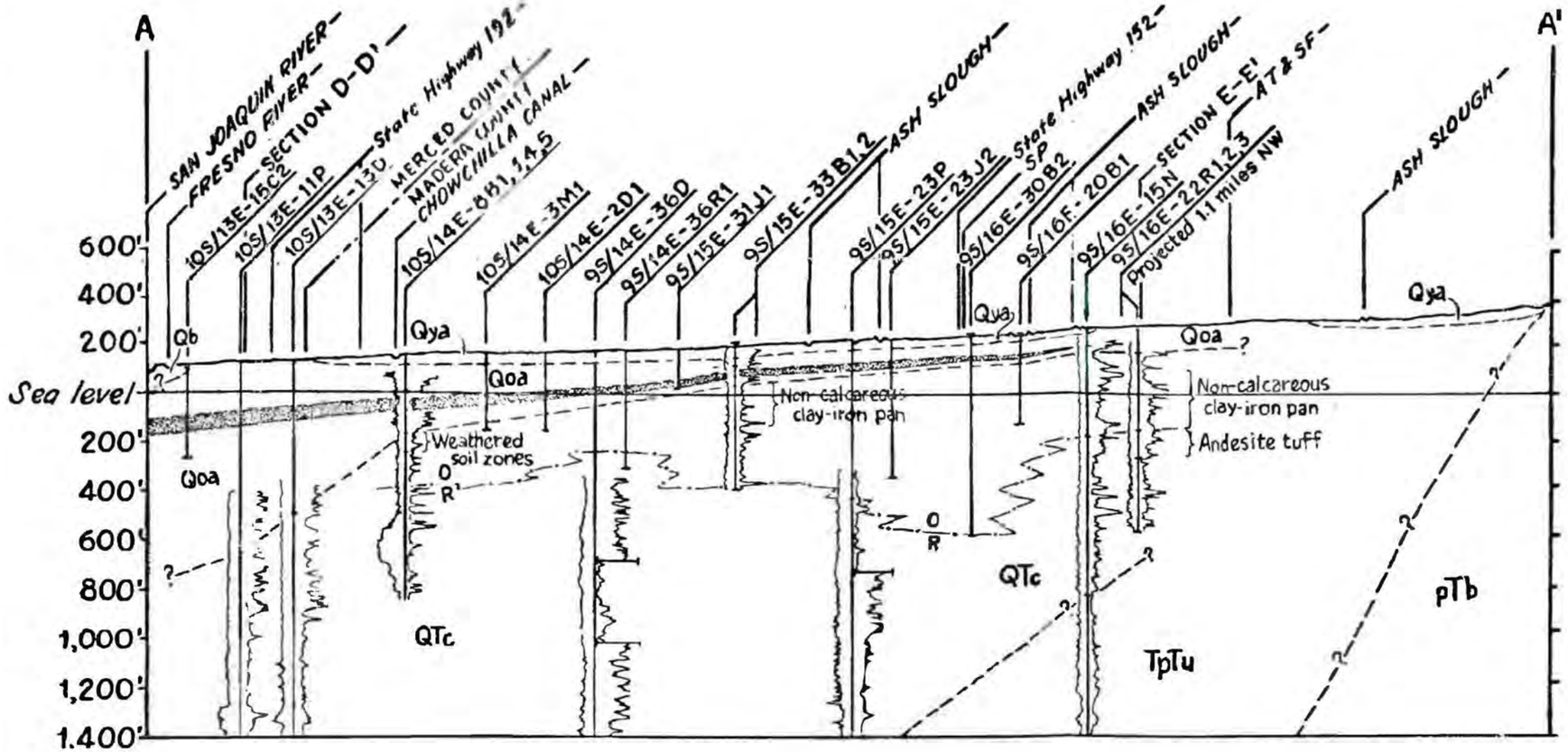
FIGURE 2-20

Geologic Cross-Section Location Map

Chowchilla Subbasin
Groundwater Sustainability Plan



EXPLANATION

UNCONSOLIDATED DEPOSITS

Pleistocene(?) Holocene (?) Holocene	Qb Flood-basin deposits	Qya Younger alluvium	QUATERNARY
	Ql Lacustrine and marsh deposits	Qoa Older alluvium	
Pleistocene(?) Holocene	QTc Continental deposit of Tertiary and Quaternary (?) age		TERTIARY AND QUATERNARY

UNCONFORMITY

CONSOLIDATED ROCKS

TpTu Marine and continental sedimentary rocks, undifferentiated		PLIOCENE-TERTIARY AND TERTIARY
UNCONFORMITY		
pTb Basement complex		PRE-TERTIARY

Contact

Queried where evidence is inconclusive

Contact between oxidized (O) and reduced (R) deposits

E-clay (el)

TOP OF WELL

BOTTOM OF WELL

Well symbol

CHANGE IN RESISTIVITY SCALE

Well with electric log

Horizontal scale same as scale of maps; vertical scale X 26.4. Datum is mean sea level

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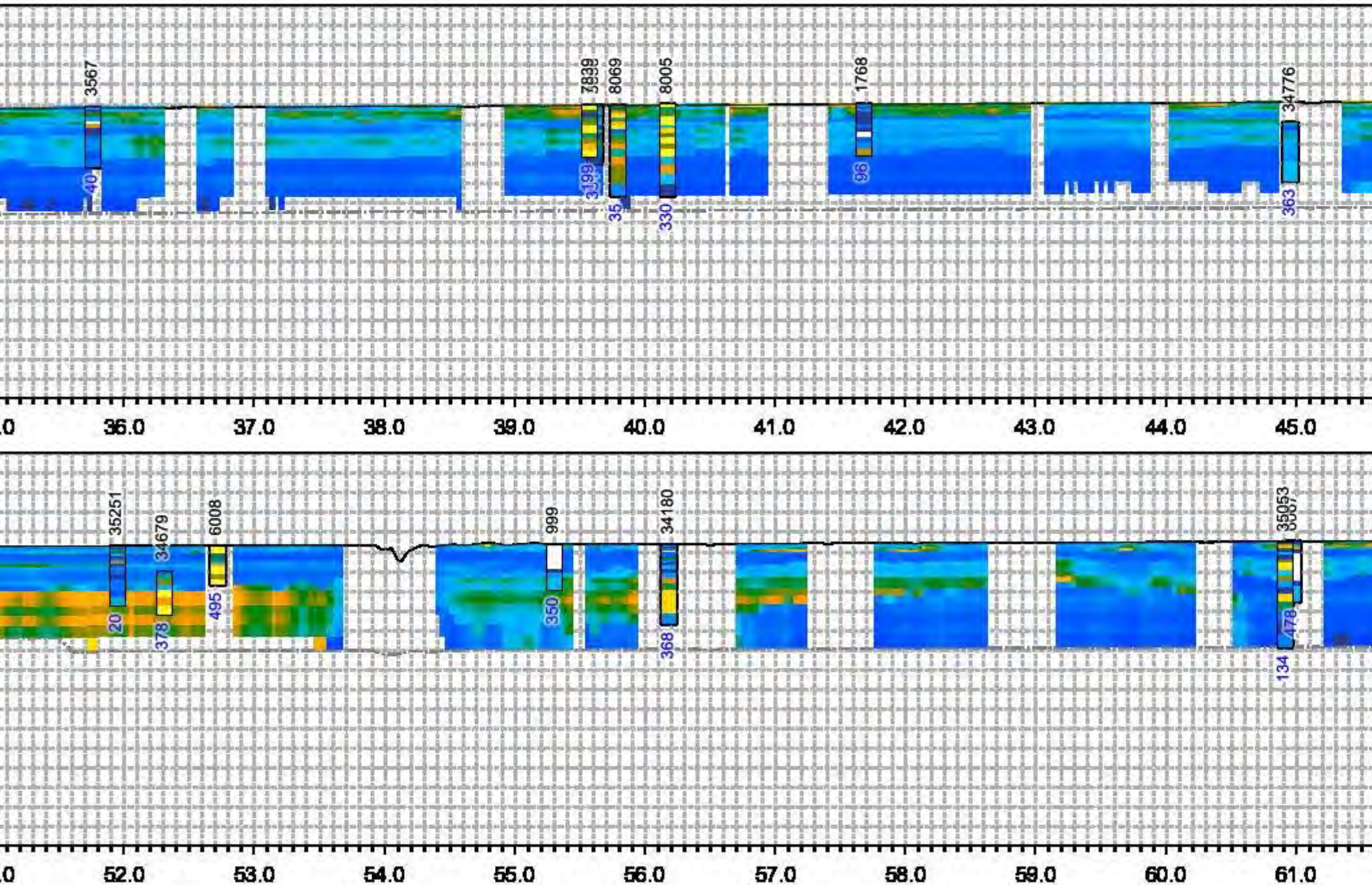
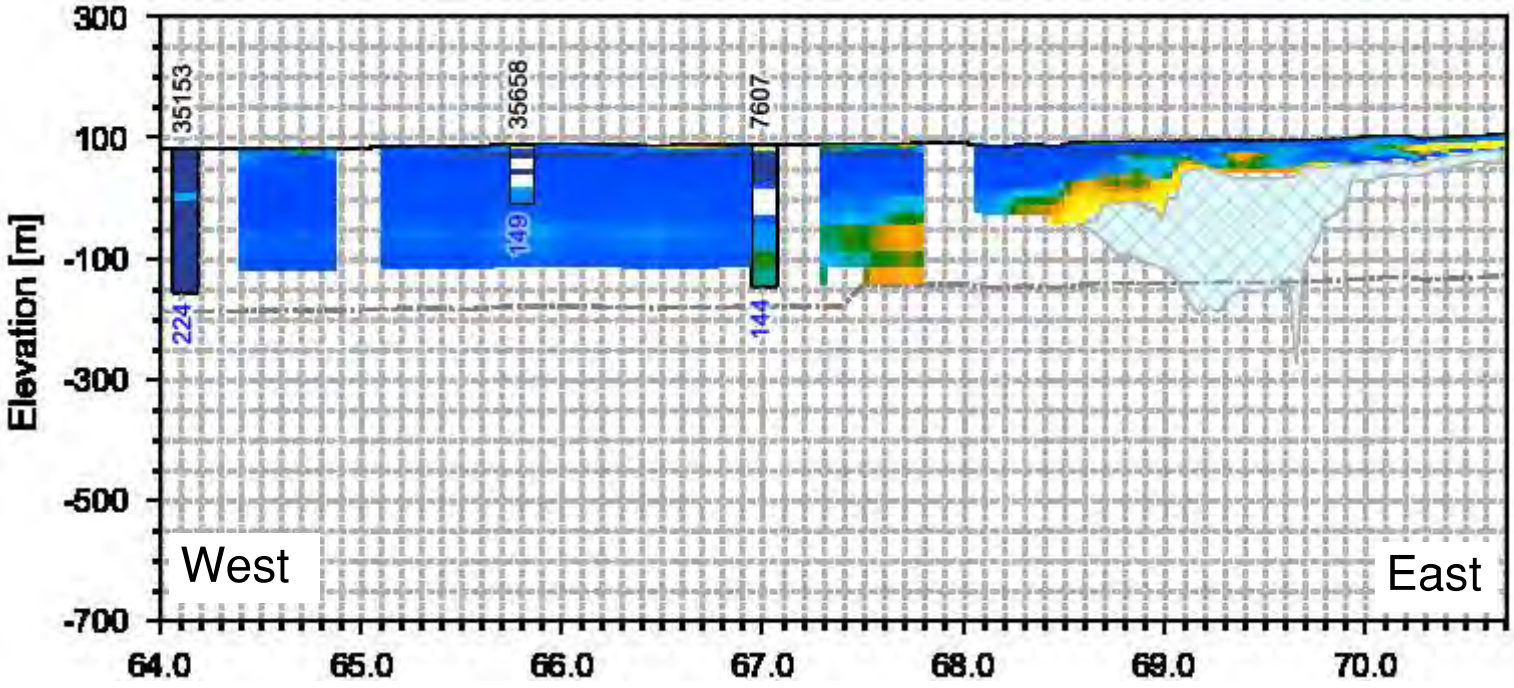
FIGURE 2-21
Geologic Cross-Section: Mitten et al. (1970) Section A-A'

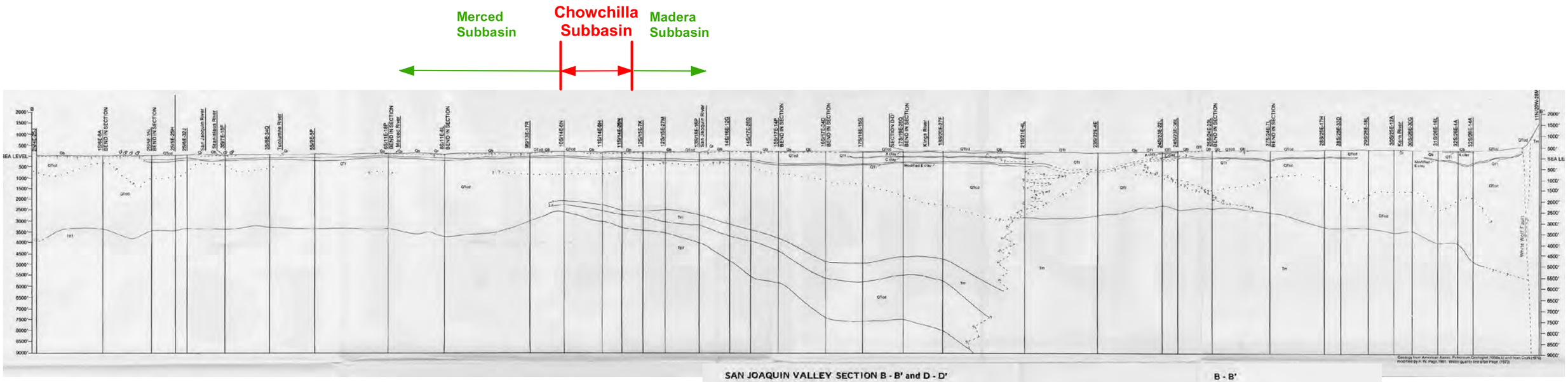
Chowchilla Subbasin
Groundwater Sustainability Plan

A - A' Nearest AEM Log



A - A' Nearest AEM Log





SAN JOAQUIN VALLEY SECTION B - B' and D - D'

		B - B'
Qs	**Sand dunes (Holocene)** Windblown sand and dune sand	Description at left
Qb	**Flood-basin deposits (Holocene)** Clay, silt, and some sand;	Near northern end of section consist of muck, peat, and other organic soils
Qr	**River deposits (Holocene)** Gravel, sand, silt, and minor amounts of clay; deposited along channels, flood plains, and natural levees of main streams.	Description at left
QTl	**Lacustrine and marsh deposits (Pliocene to Holocene)** Clay, silt, and some sand; in subsurface include three widespread clays: A clay (Pleistocene and Holocene?), C clay (Pleistocene); and modified E clay (Pleistocene), includes Corcoran Clay Member of Tulare Formation	Description at left
QTcd	**Continental rocks and deposits (Oligocene to Holocene)** Heterogenerous mix of generally poorly sorted clay, silt, sand, and gravel, some beds of claystone, siltstone, sandstone, and conglomerate...	On this section, principal unit, continental rocks and deposits (Miocene to Holocene); in northern part of section may include continental rocks and deposits (Miocene and Pliocene)–mostly Mehrten Formation or an equivalent, and continental rocks and deposits (Oligocene and Miocene) -mostly Valley Springs Formation or an equivalent. Include continental rocks and deposits (Miocene and Pliocene)--chiefly the Chanac Formation (Miocene) at extreme southern end of section, and the Zilch Formation of informal subsurface usage, which is considered to be the continental equivalent of the Marine Temblor Formation (Oligocene and Miocene)
Tm	**Marine rocks and deposits (Eocene, Oligocene, Miocene, and Pliocene)** Sand, clay, silt, sandstone, shale, mudstone, and siltstone. On these section include marine rocks and deposits of Miocene and Pliocene age only	Description at left
TpT	**Continental and marine rocks and deposits (Pre-Tertiary to Oligocene)** Continental rocks and deposits of clay, shale, sand, sandstone and conglomerate; marine rocks and deposits of clay, shale, sandstone, and conglomerate...	On this section include marine rocks and deposits of Eocene and Oligocene age, also include some Paleocene marine rocks. Include continental rocks and deposits (Eocene to Miocene)-- chiefly Walker Formation (Eocene to Miocene) at depths off the section - greater than 13,000ft, where the Walker Formation underlies Eocene, marine sediments. Include marine rocks (Pre-Tertiary)
pTgm	**Granitic and metamorphic rocks (Pre-Tertiary)** Granitic rocks with some mafic intrusive rocks, and metasedimentary and metavolcanic rocks. Include granitic rocks (Pre-Tertiary) and metamorphic rocks (Pre-Tertiary)	Not present

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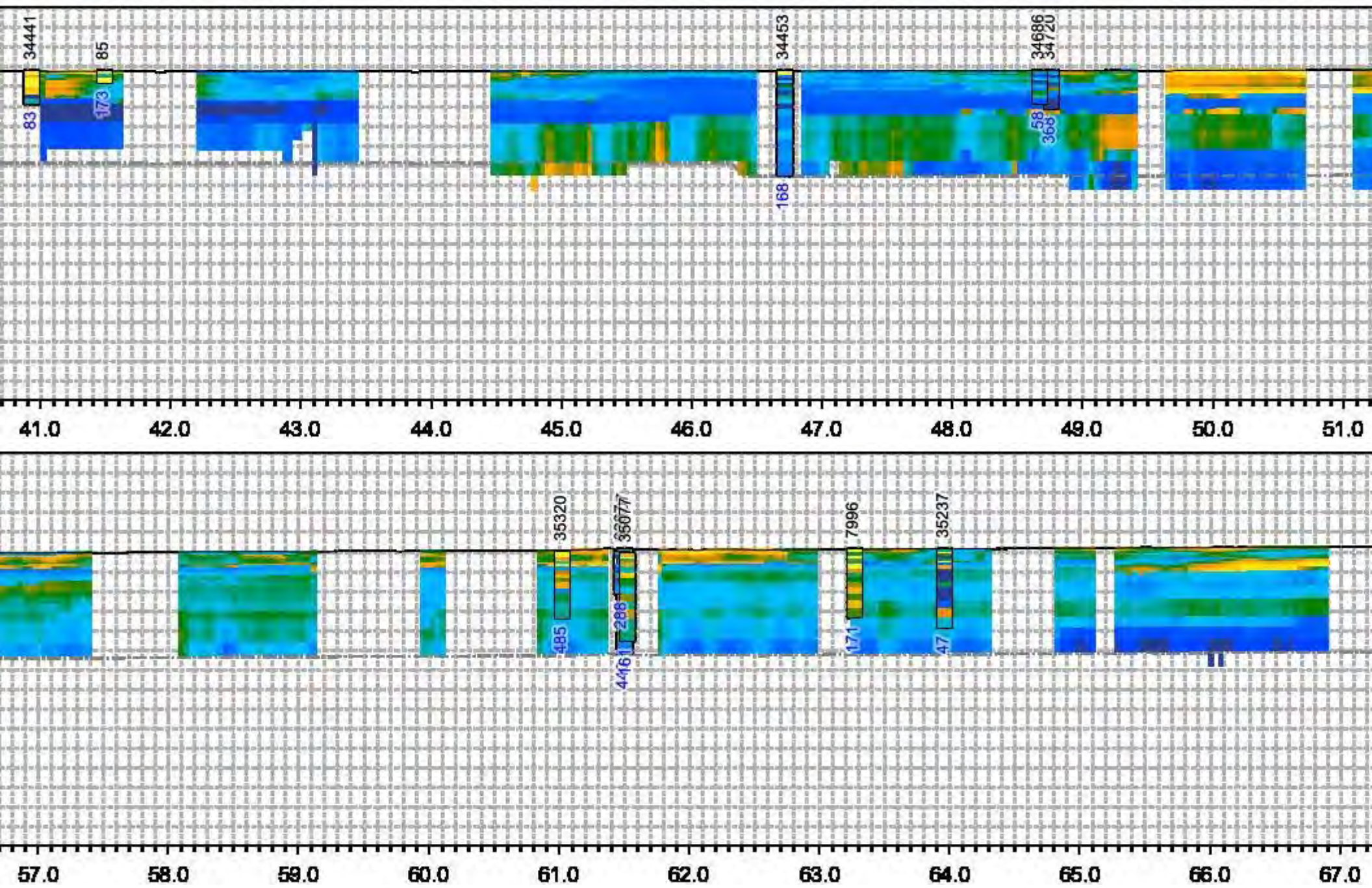
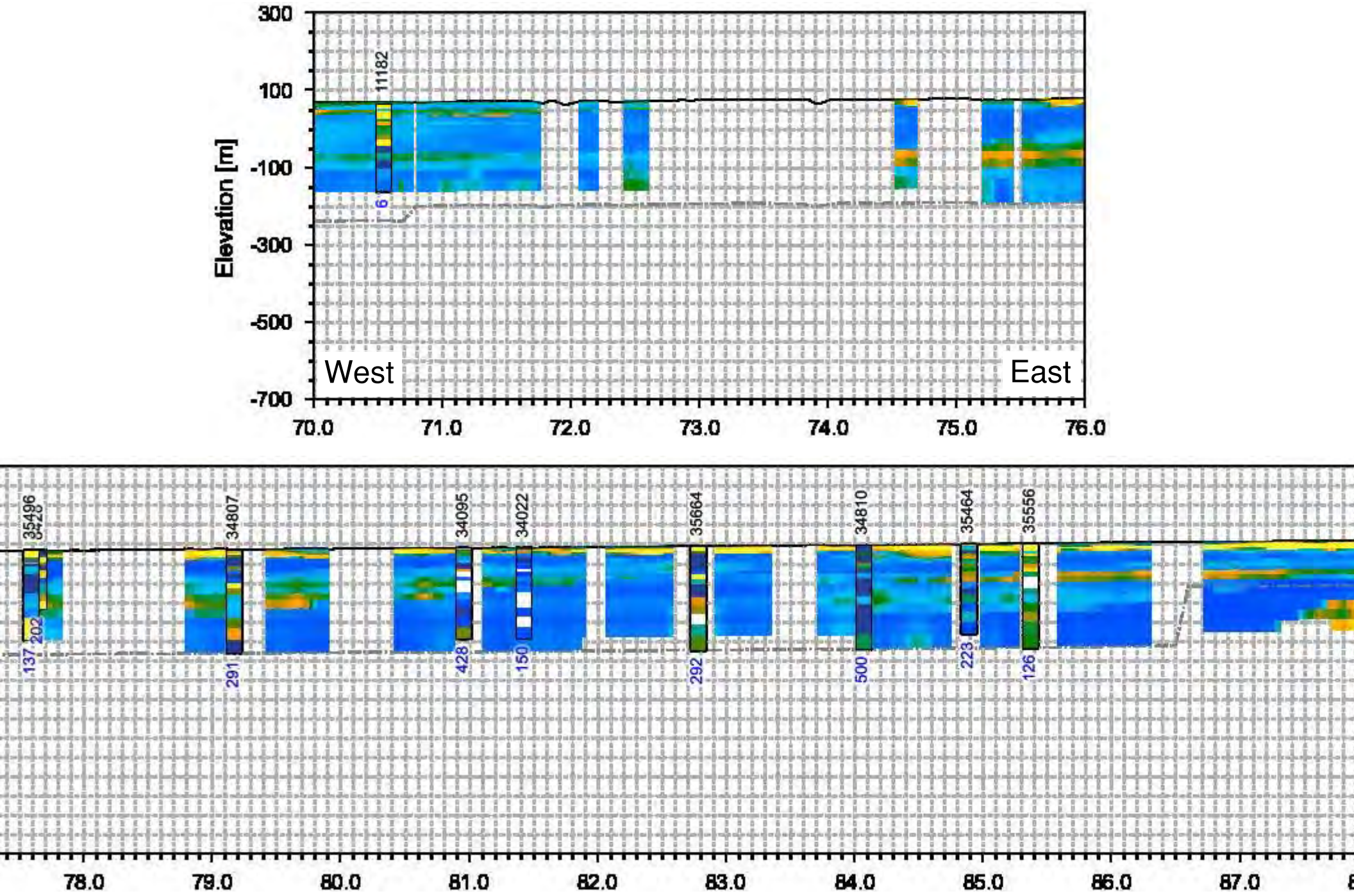
FIGURE 2-22
Geologic Cross-Section:
Page (1986) Section B-B'

Chowchilla Subbasin
Groundwater Sustainability Plan

B - B' Nearest AEM Log



B - B' Nearest AEM Log



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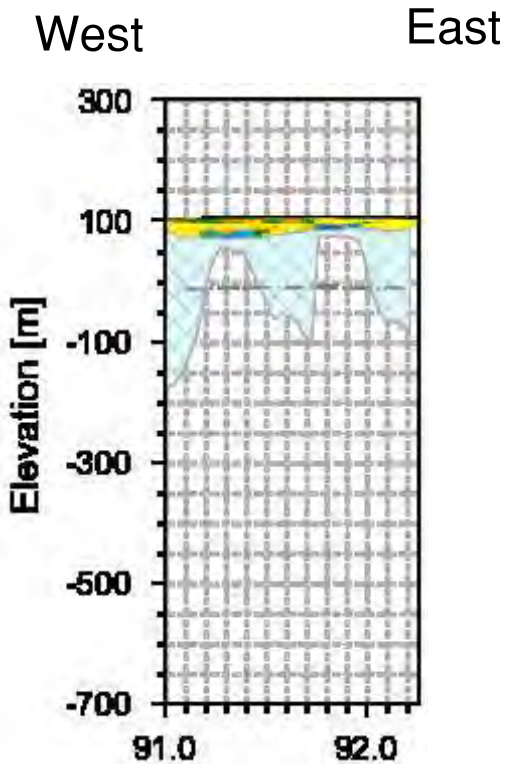

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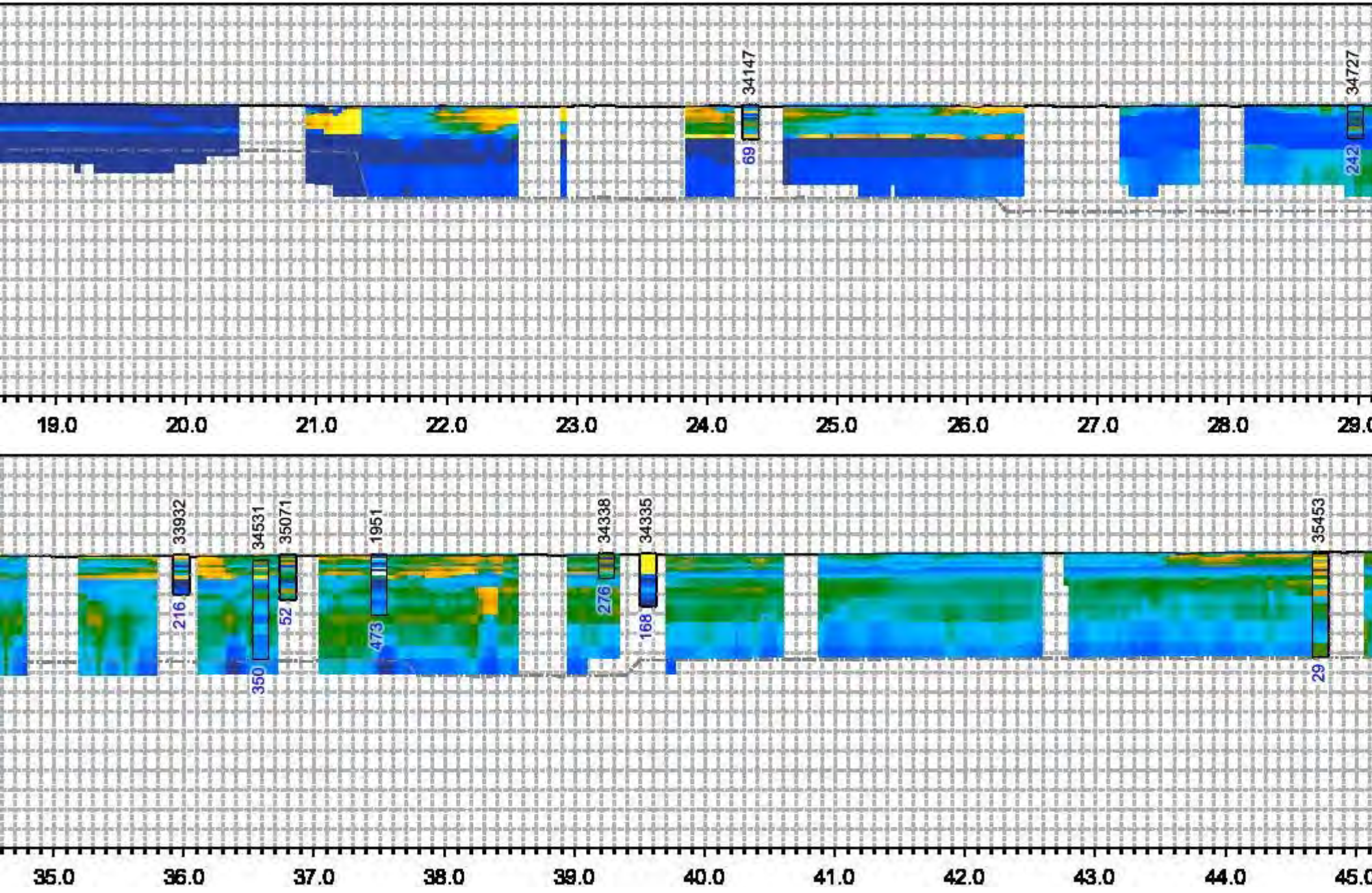

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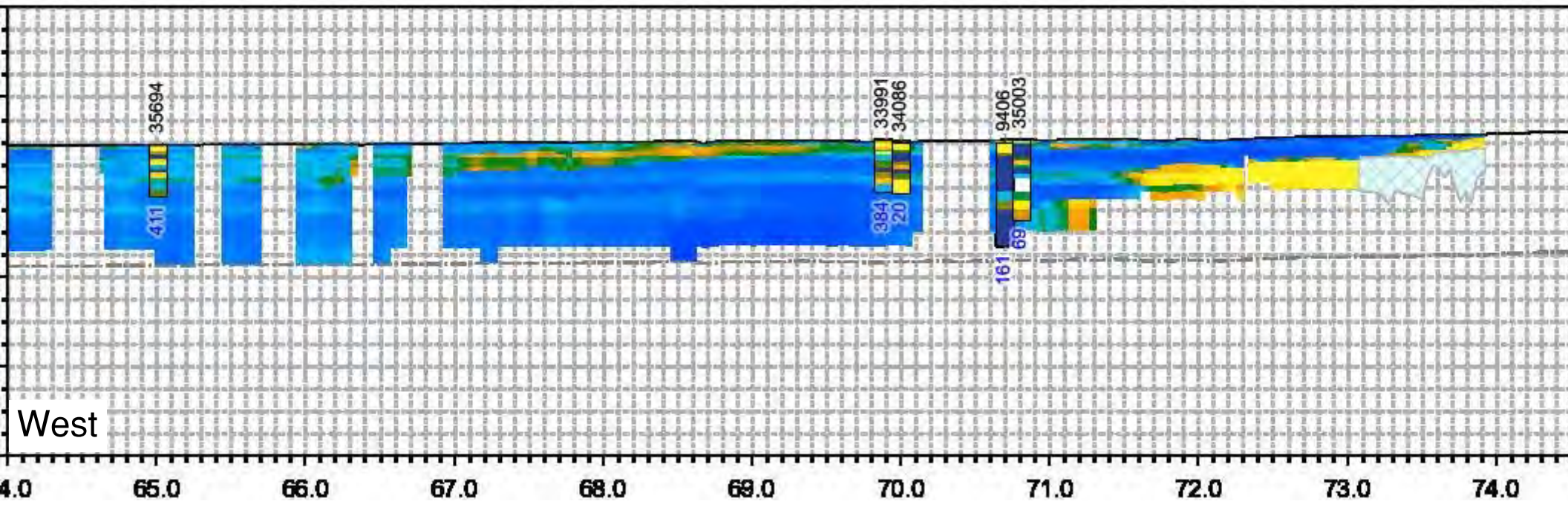

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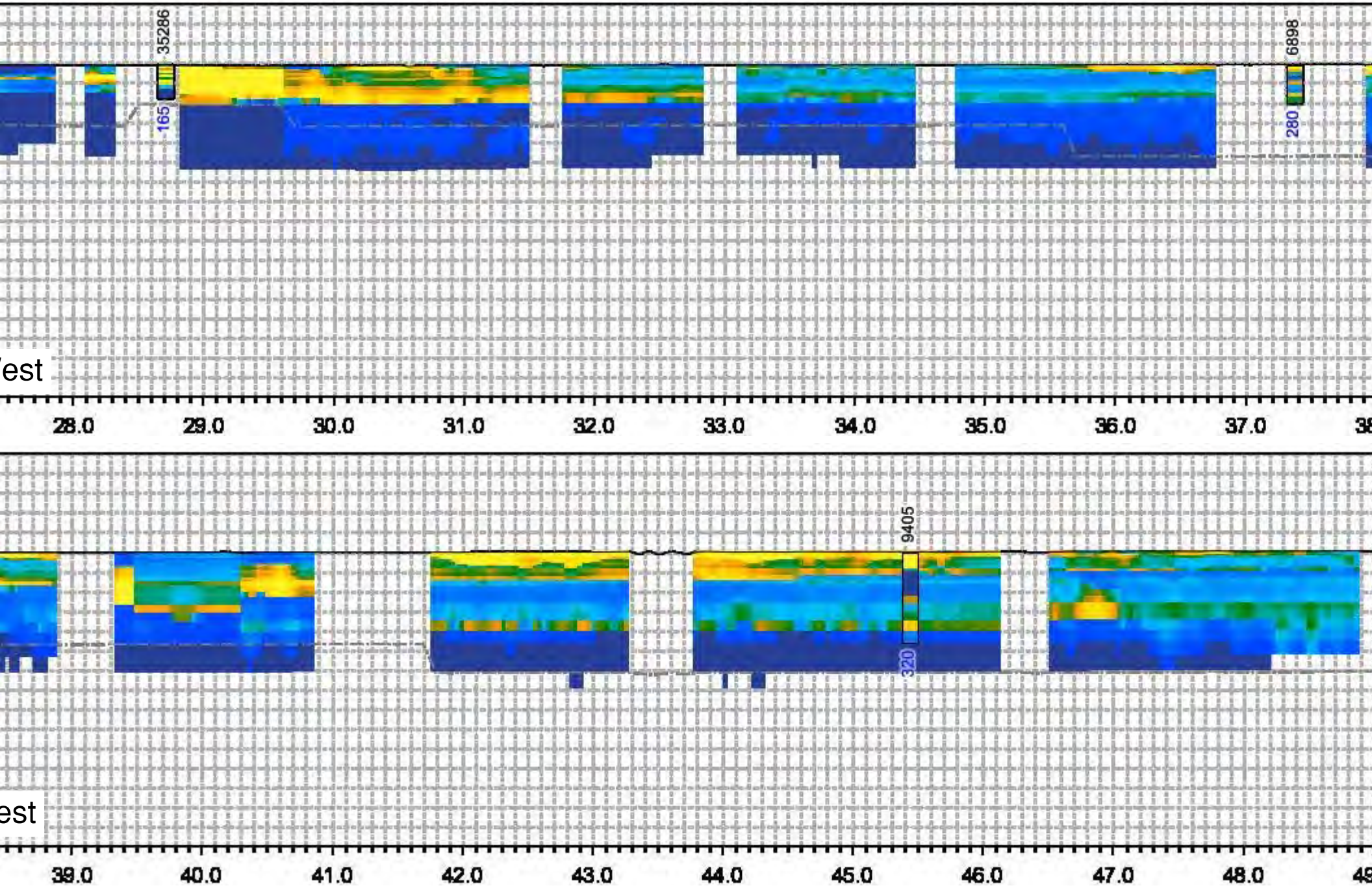

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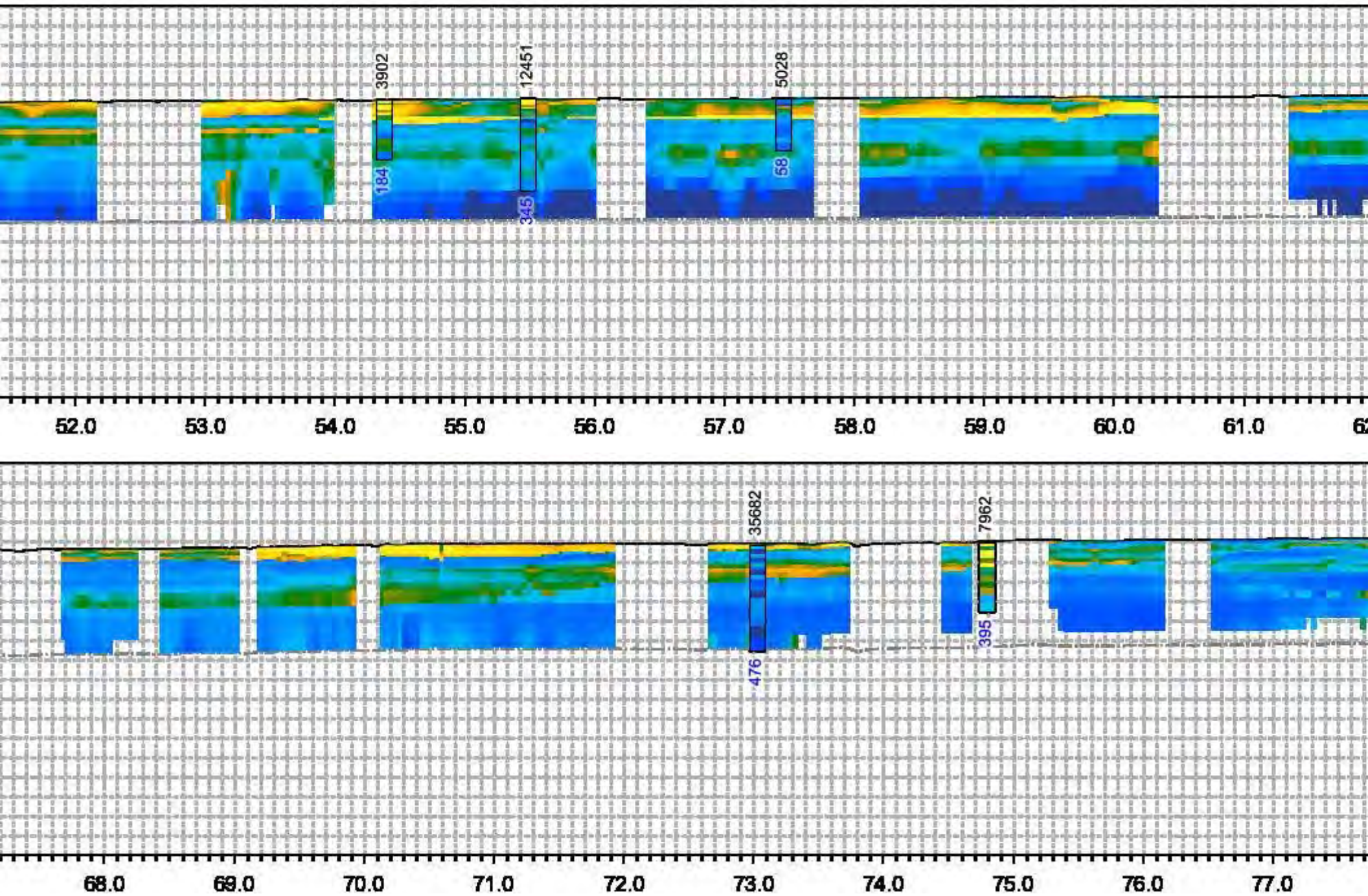

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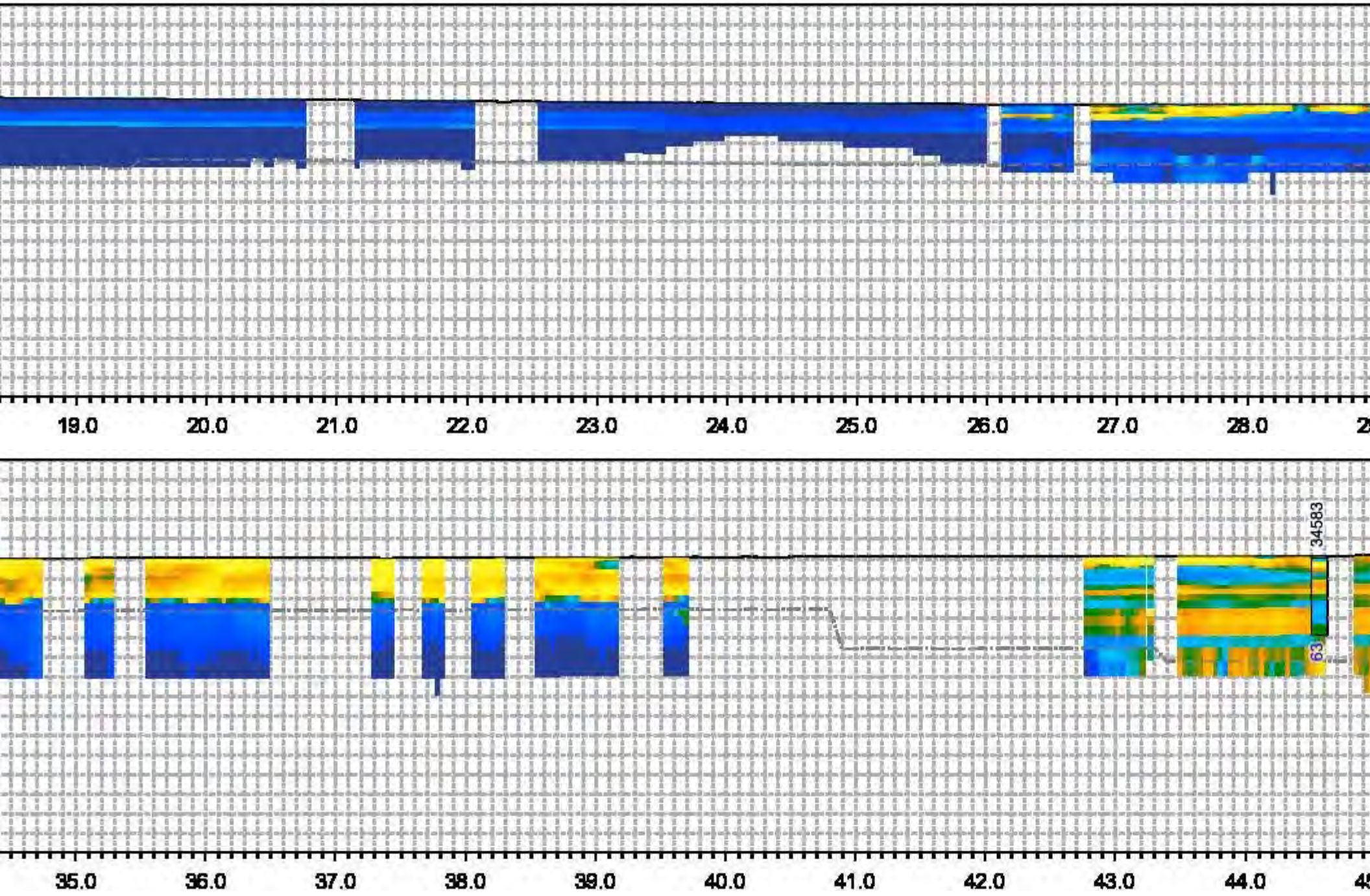

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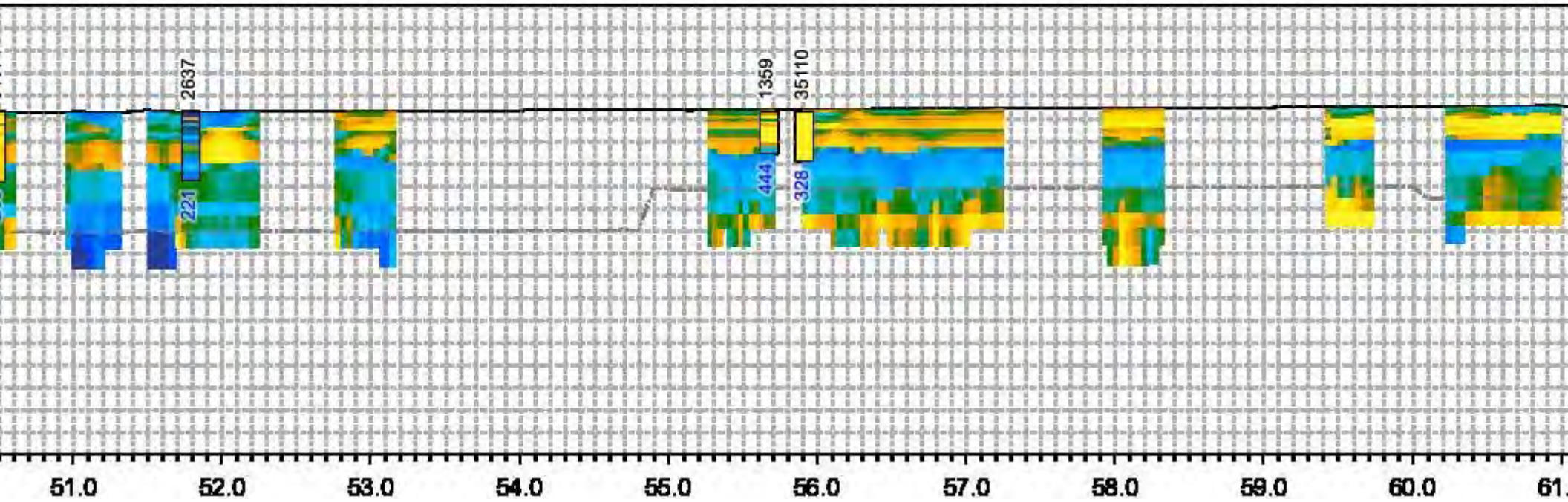

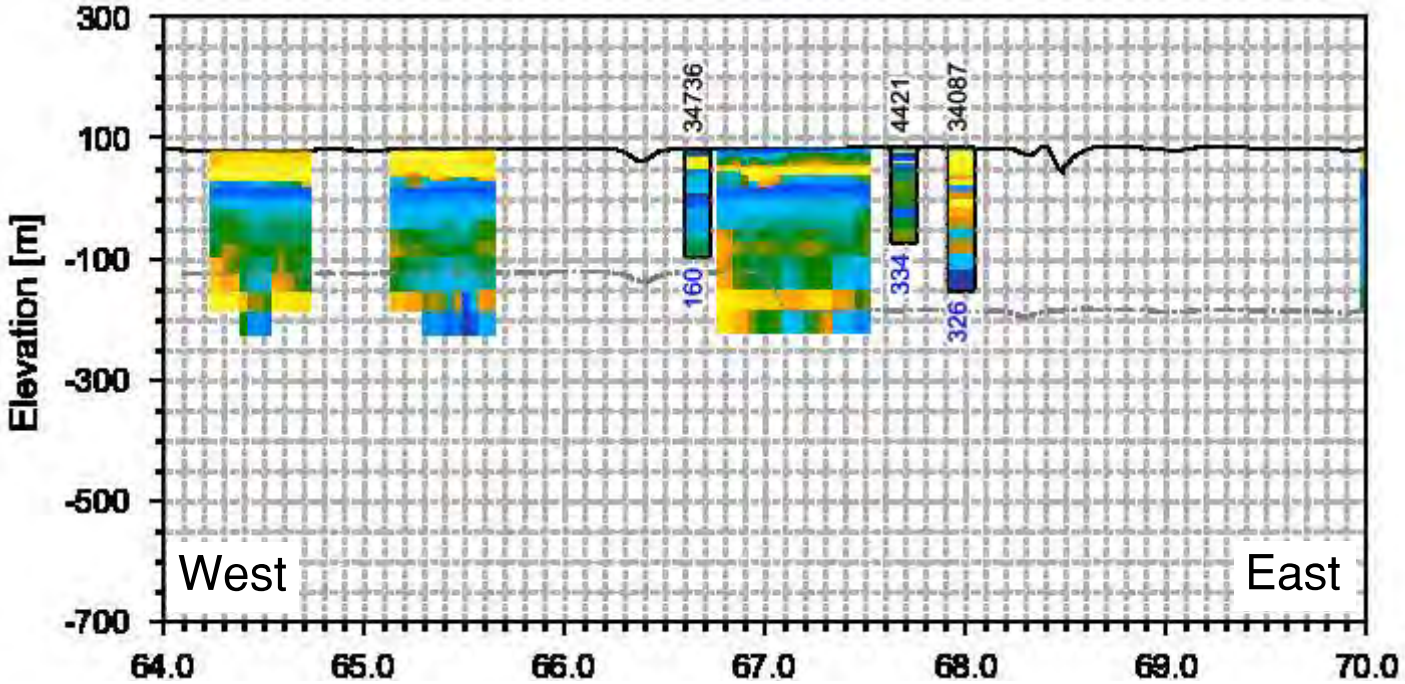

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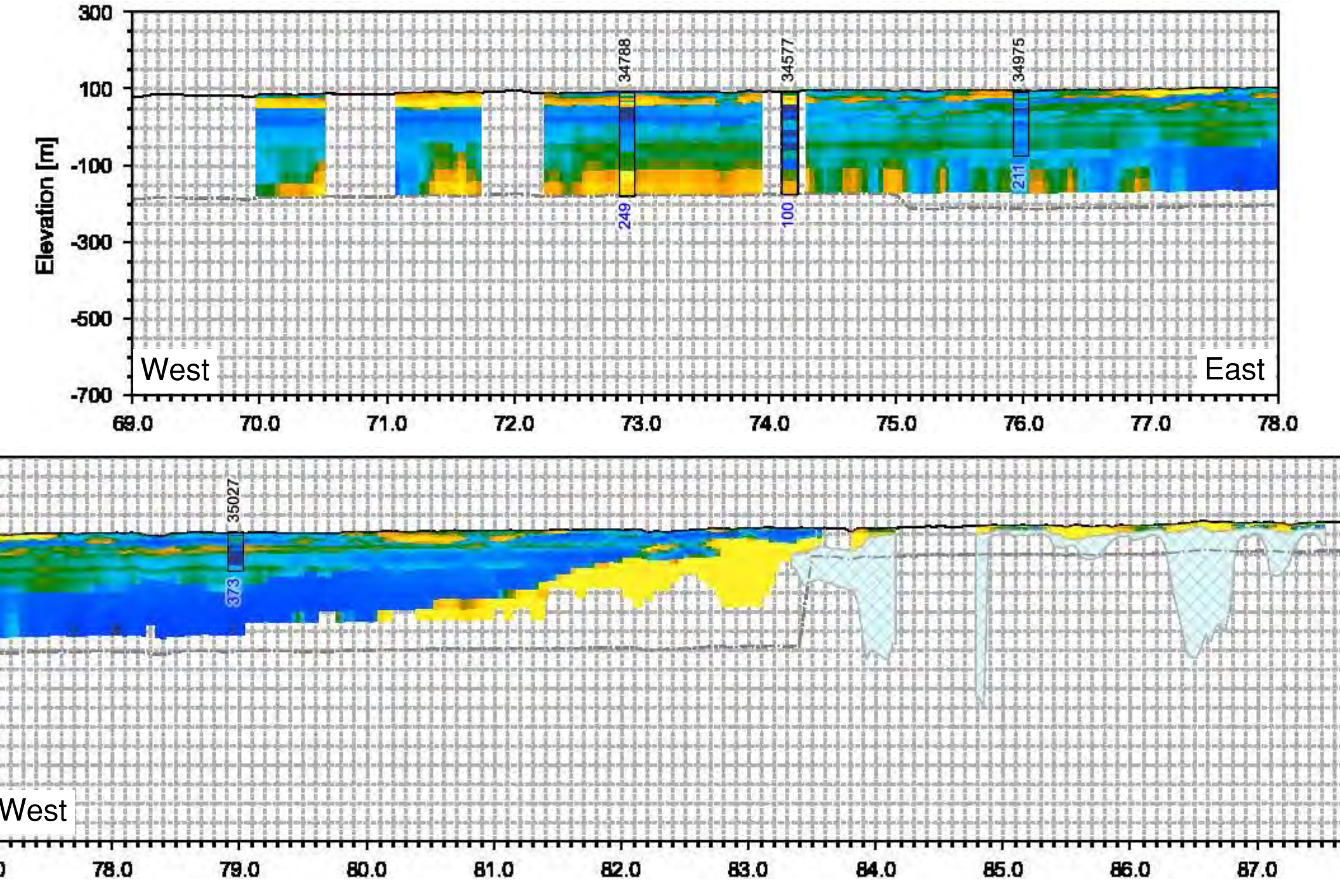

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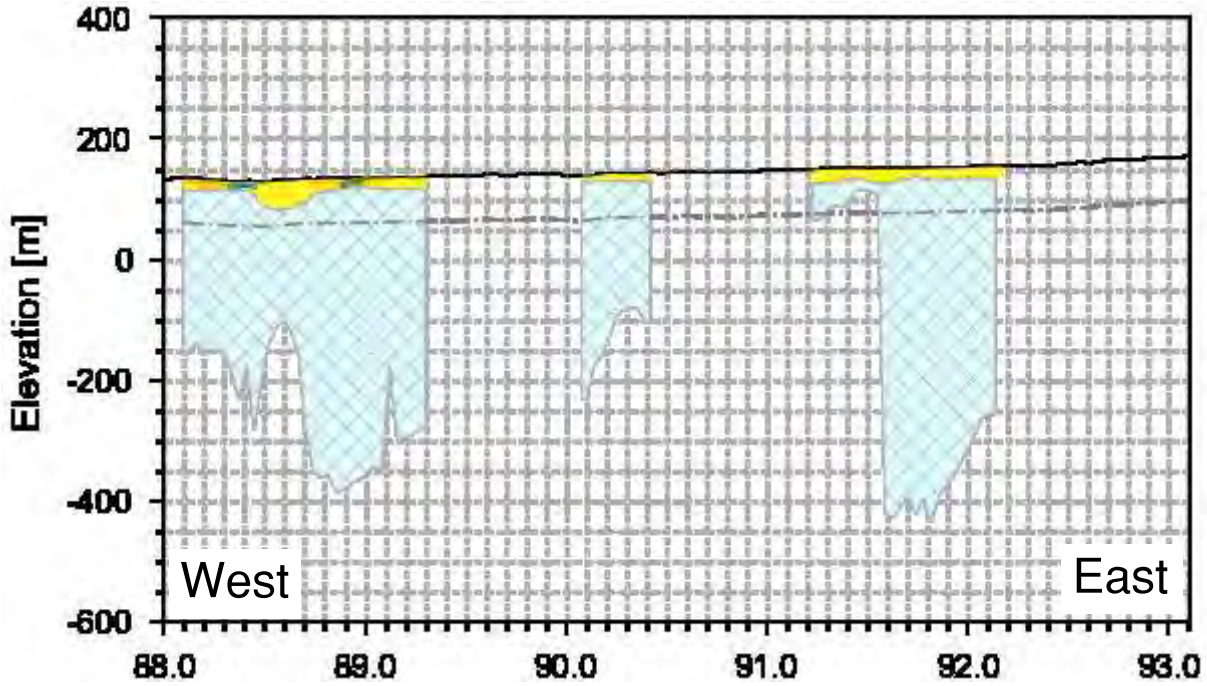

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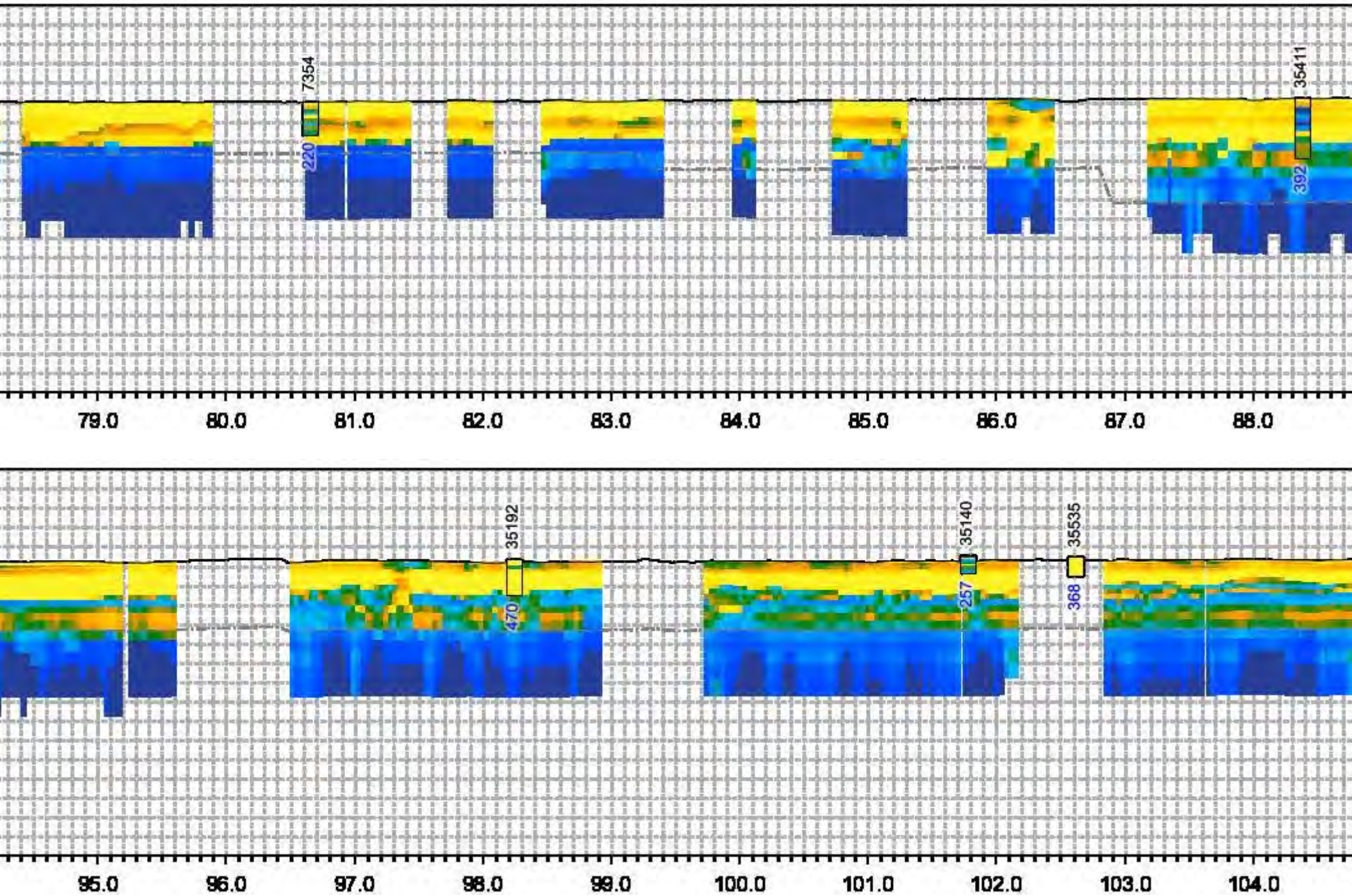

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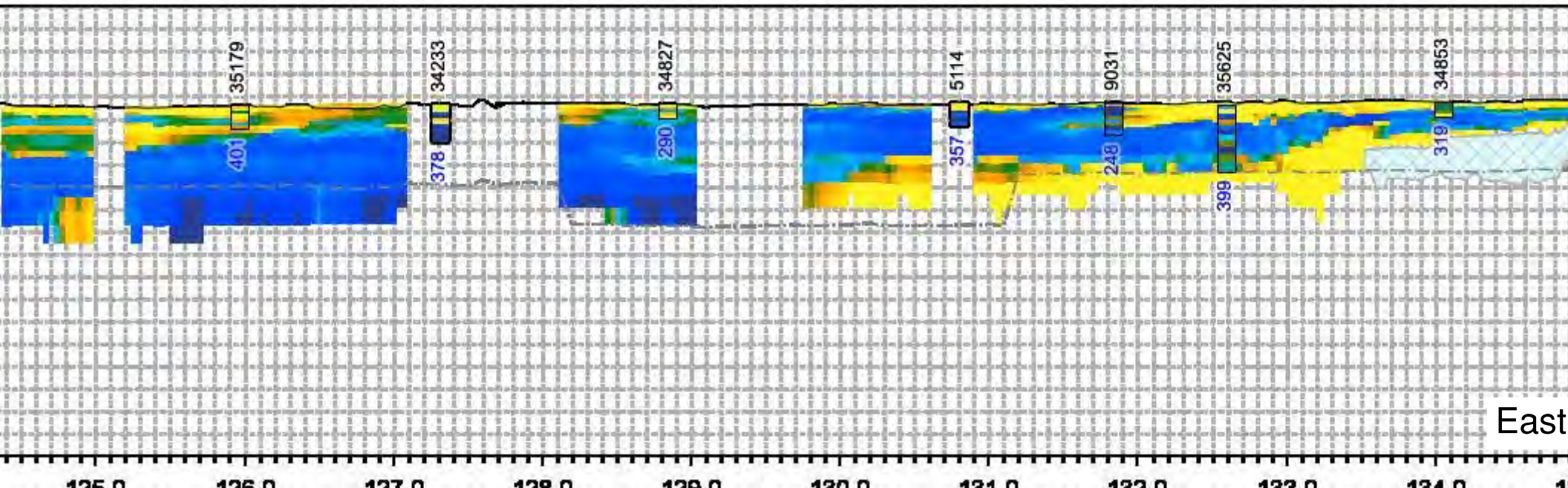

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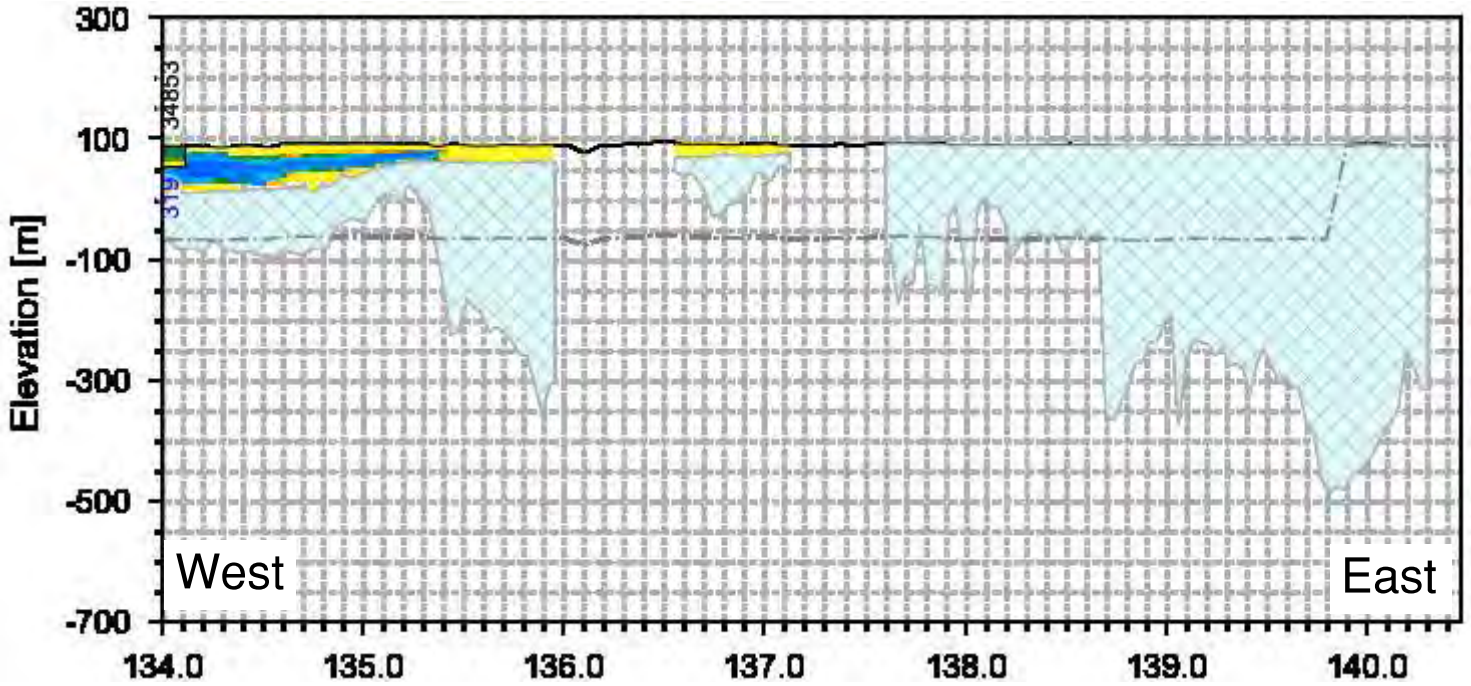

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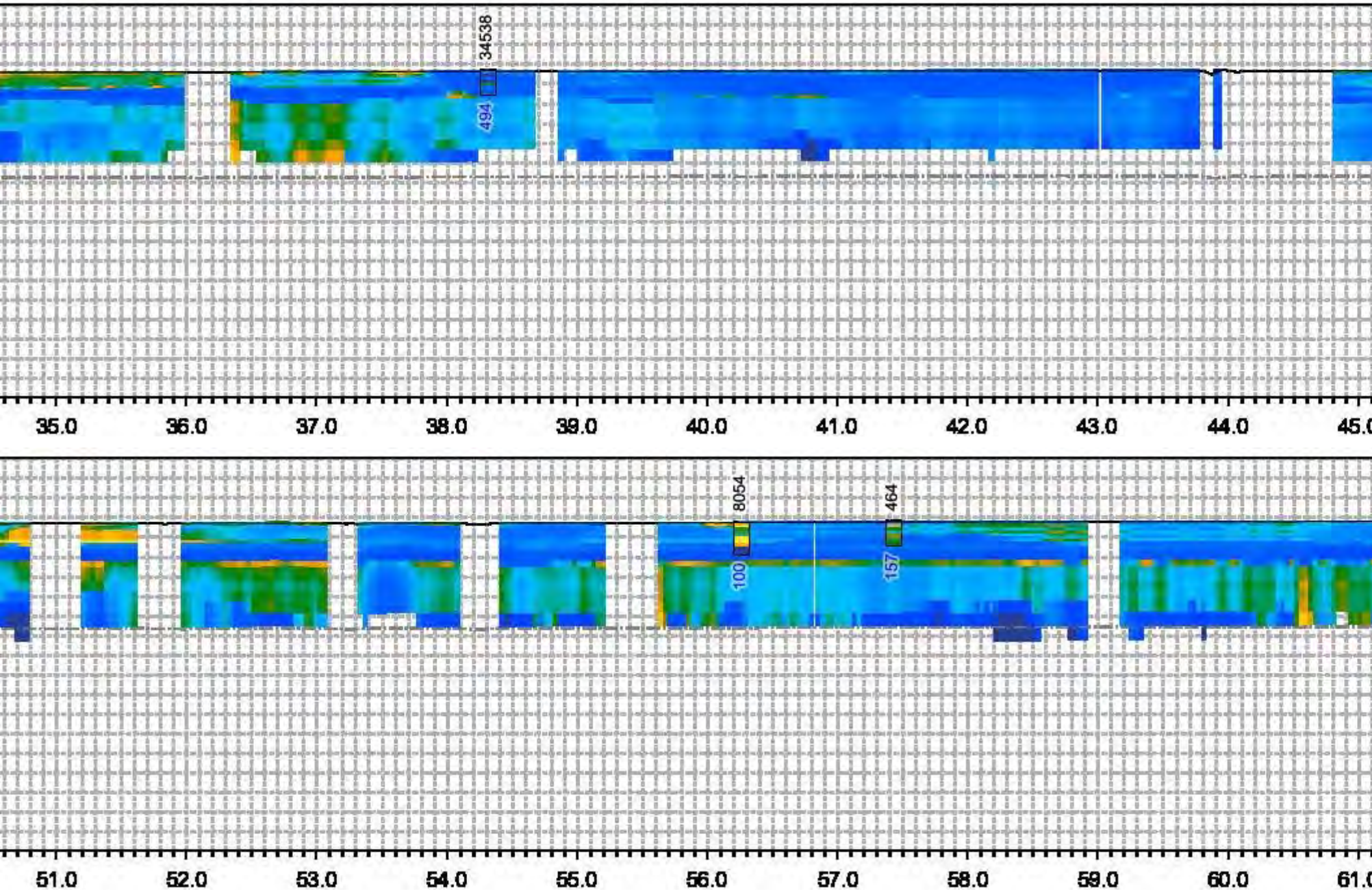

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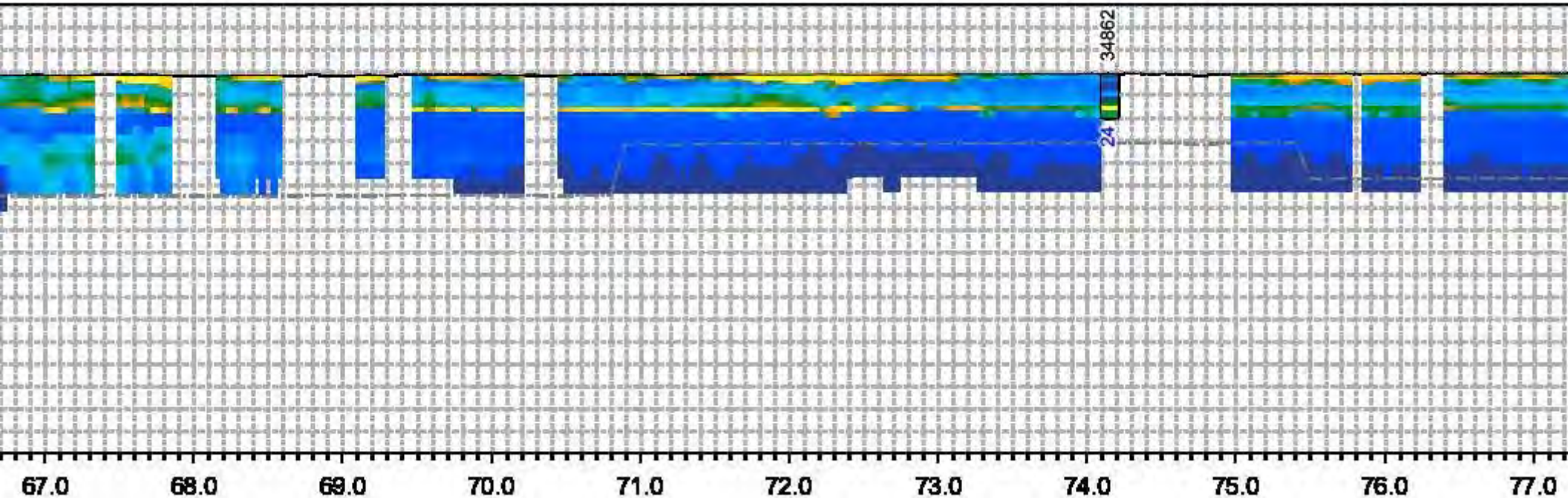

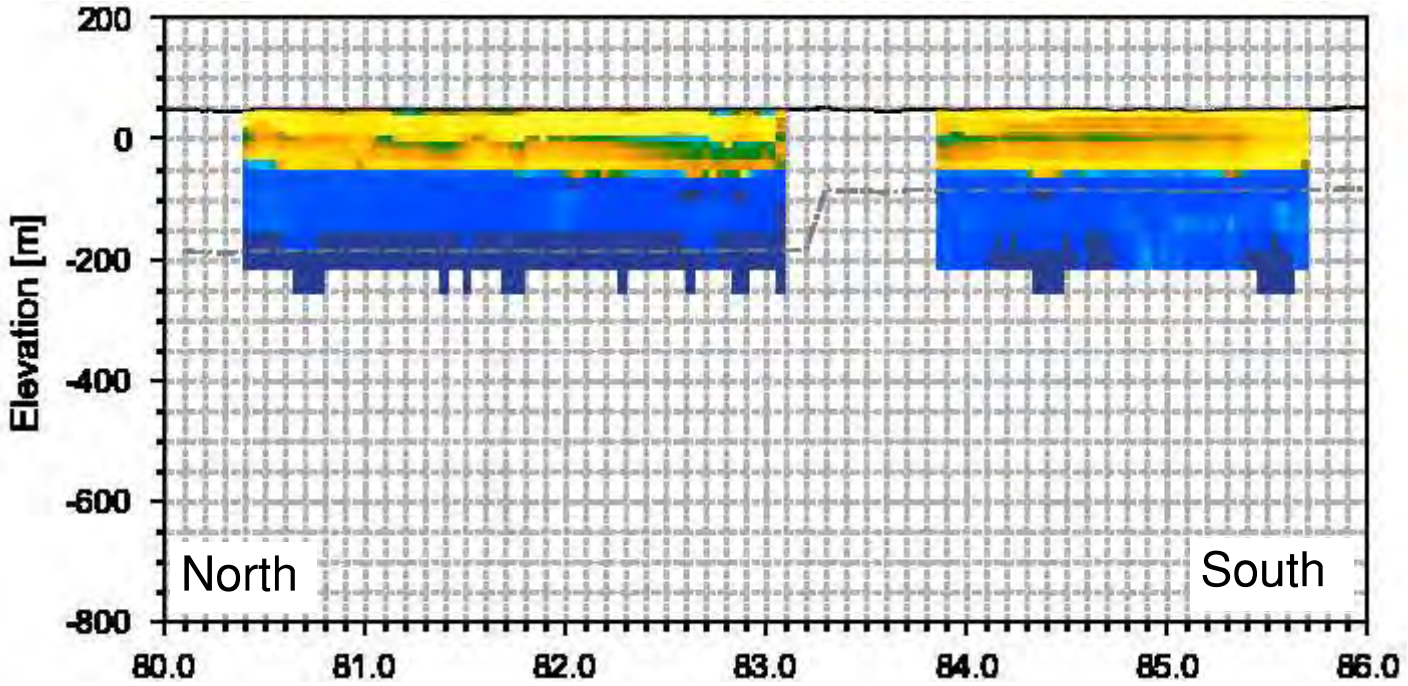

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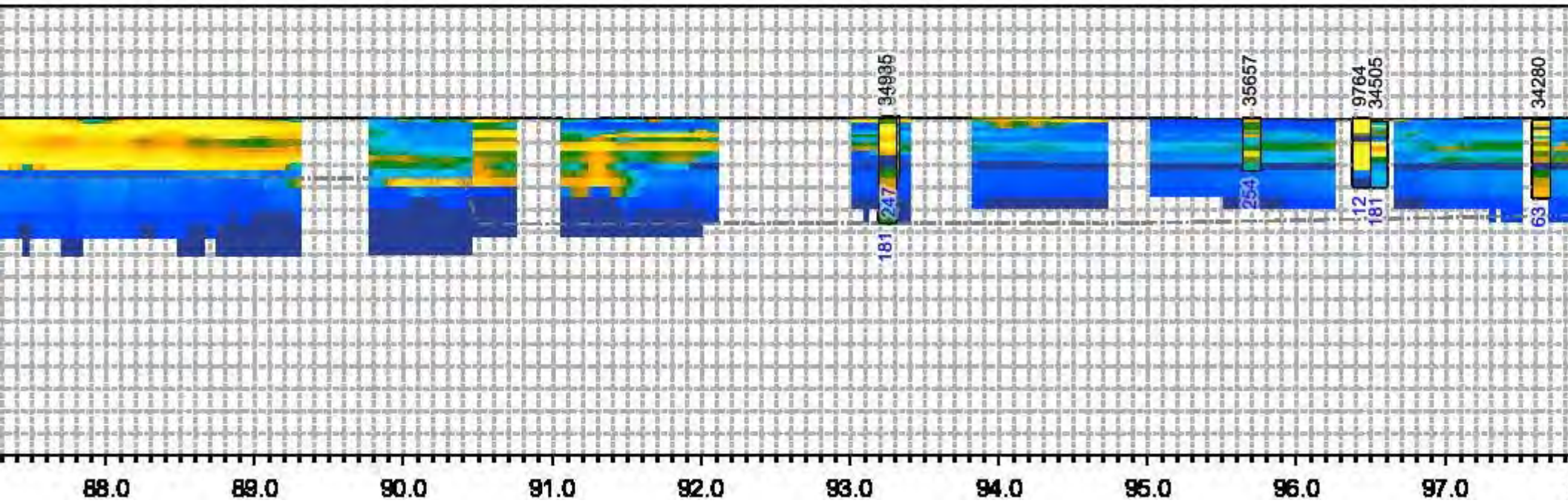

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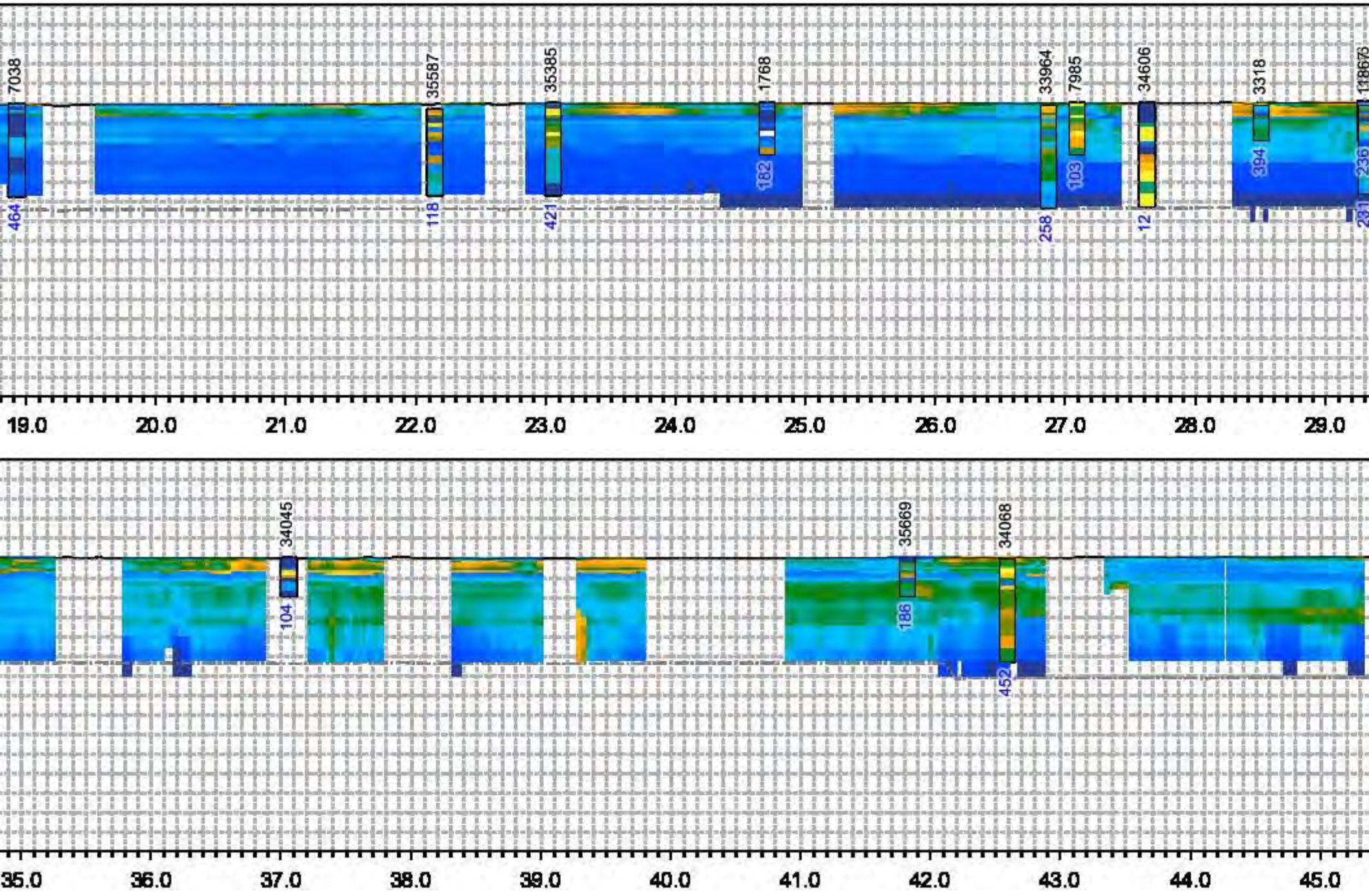

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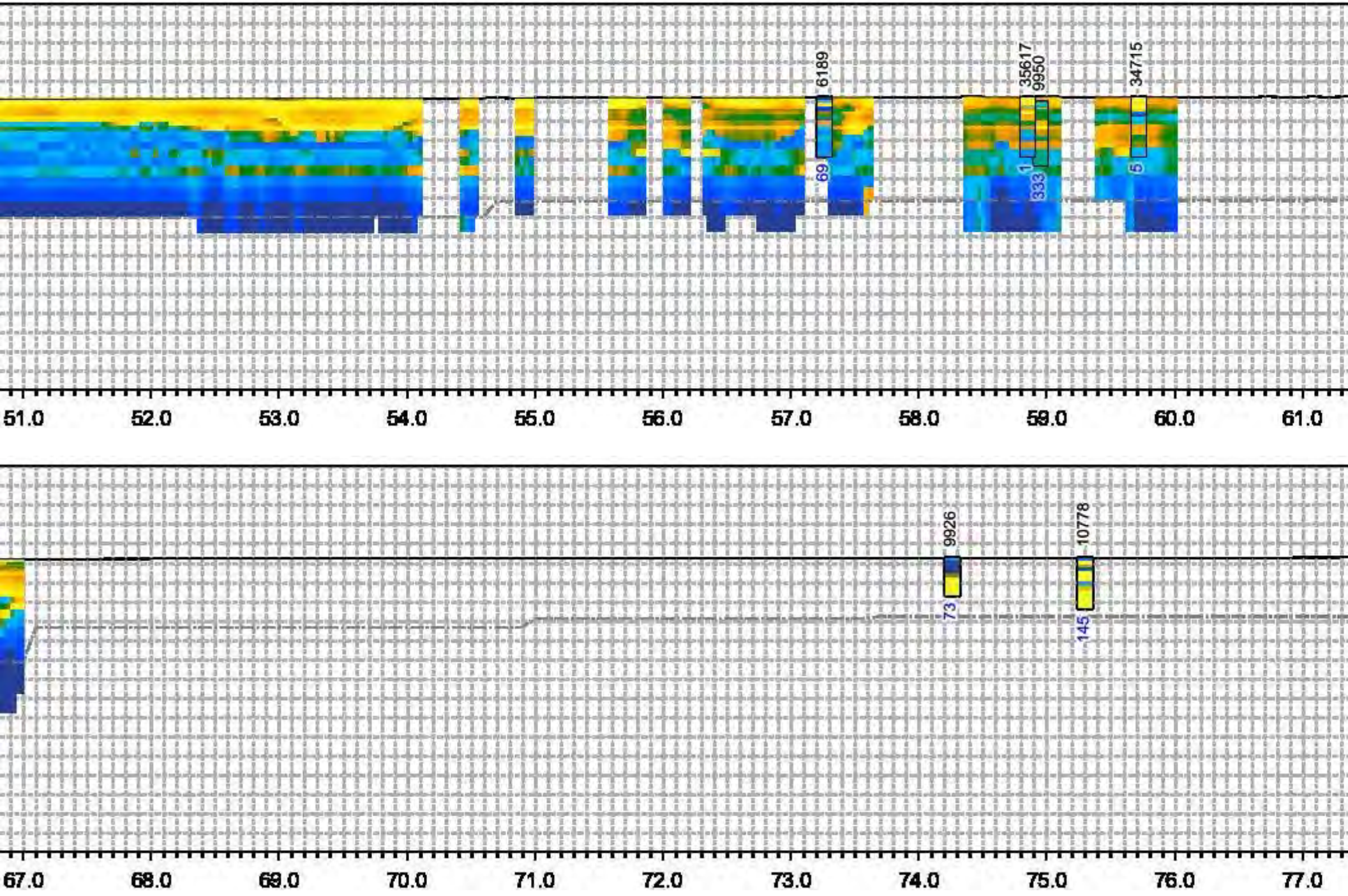

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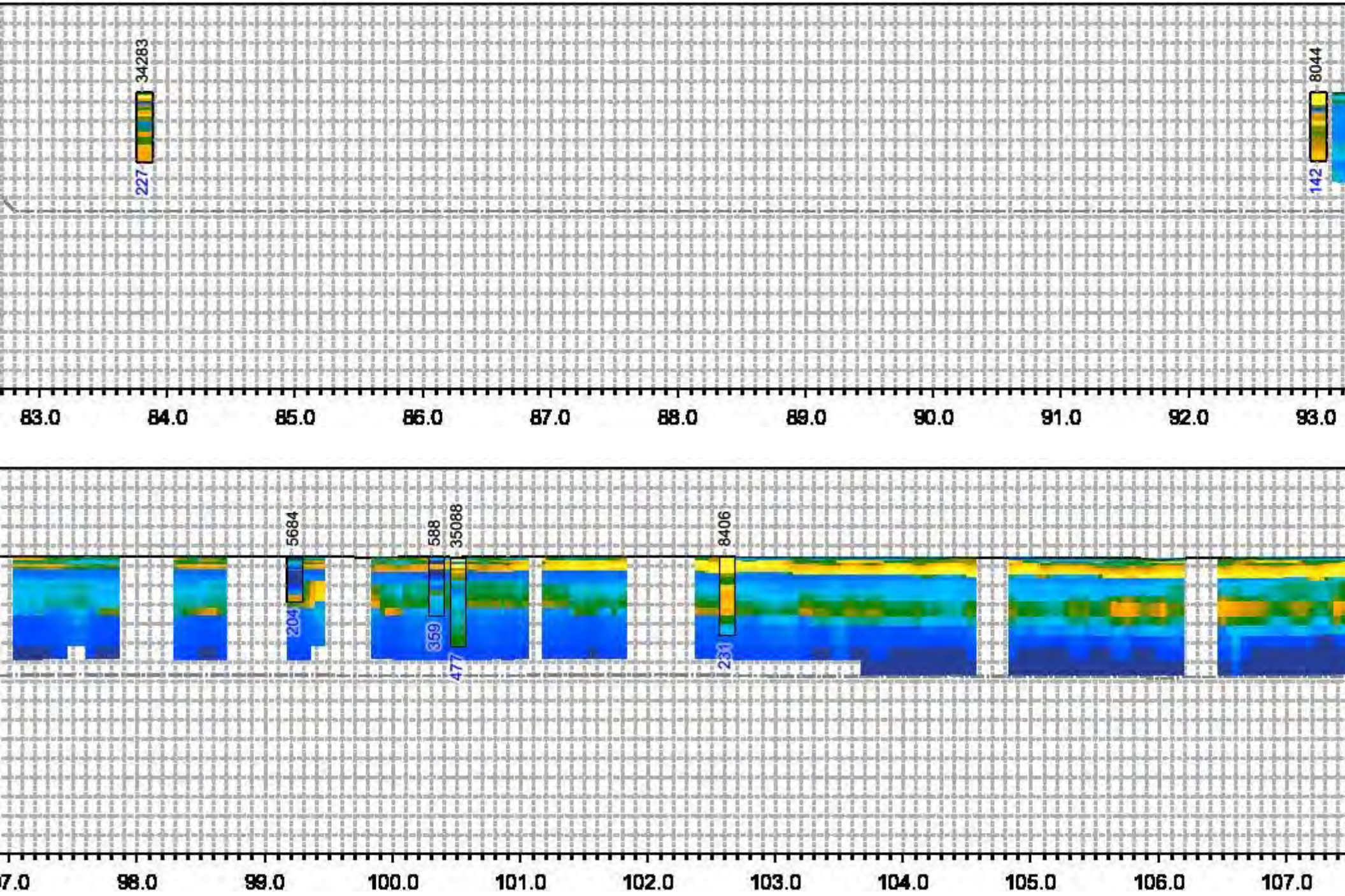

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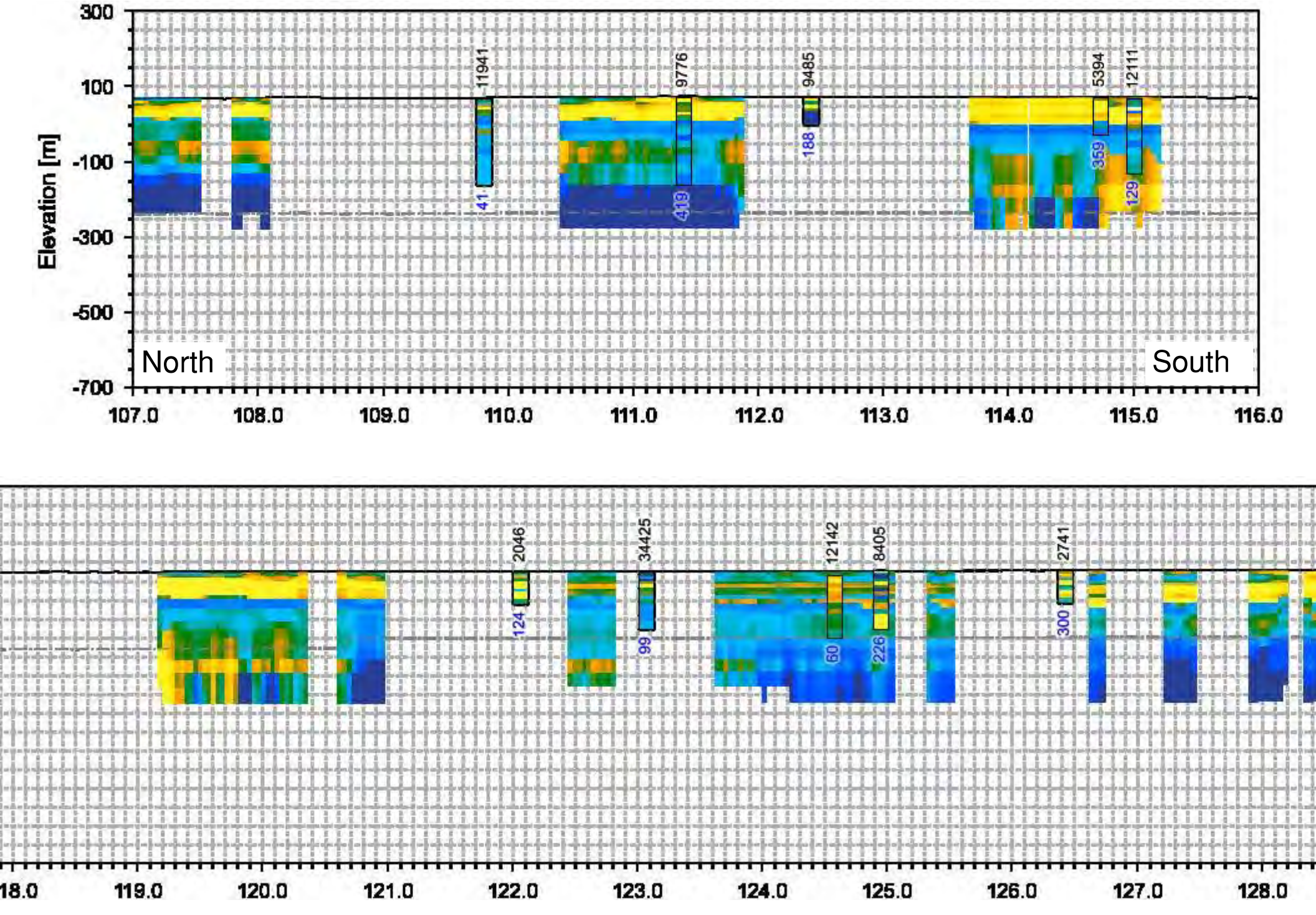

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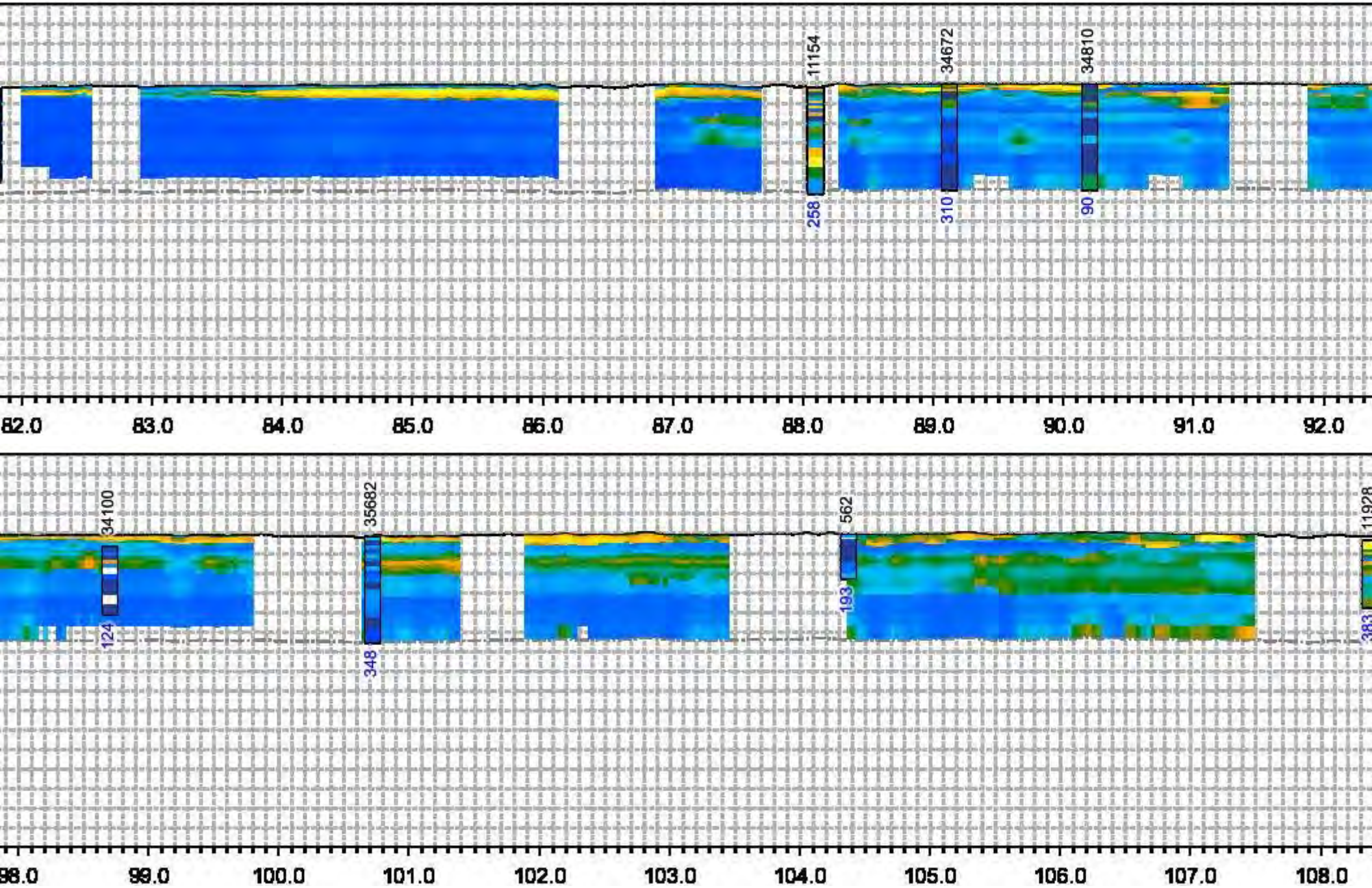

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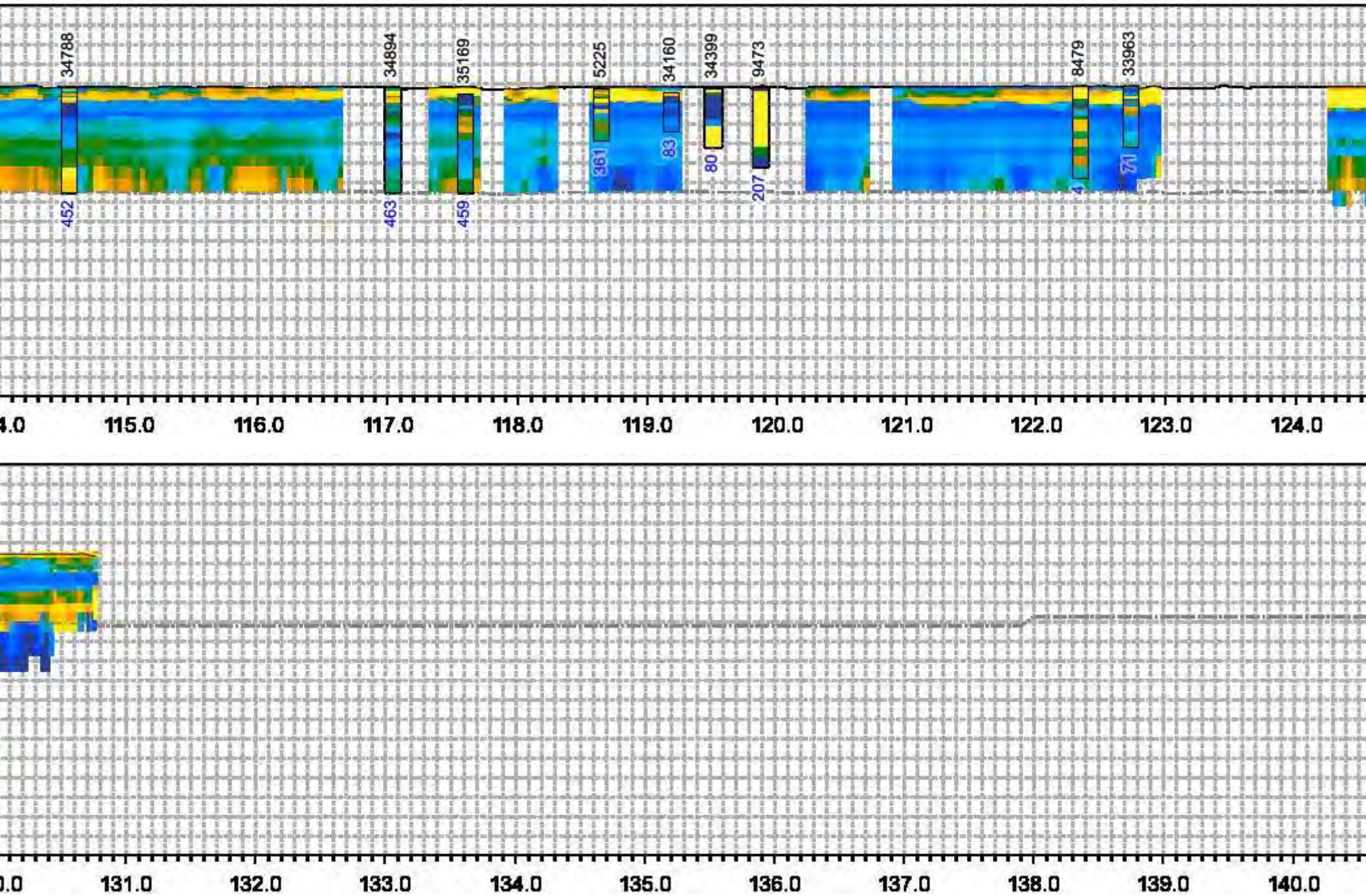
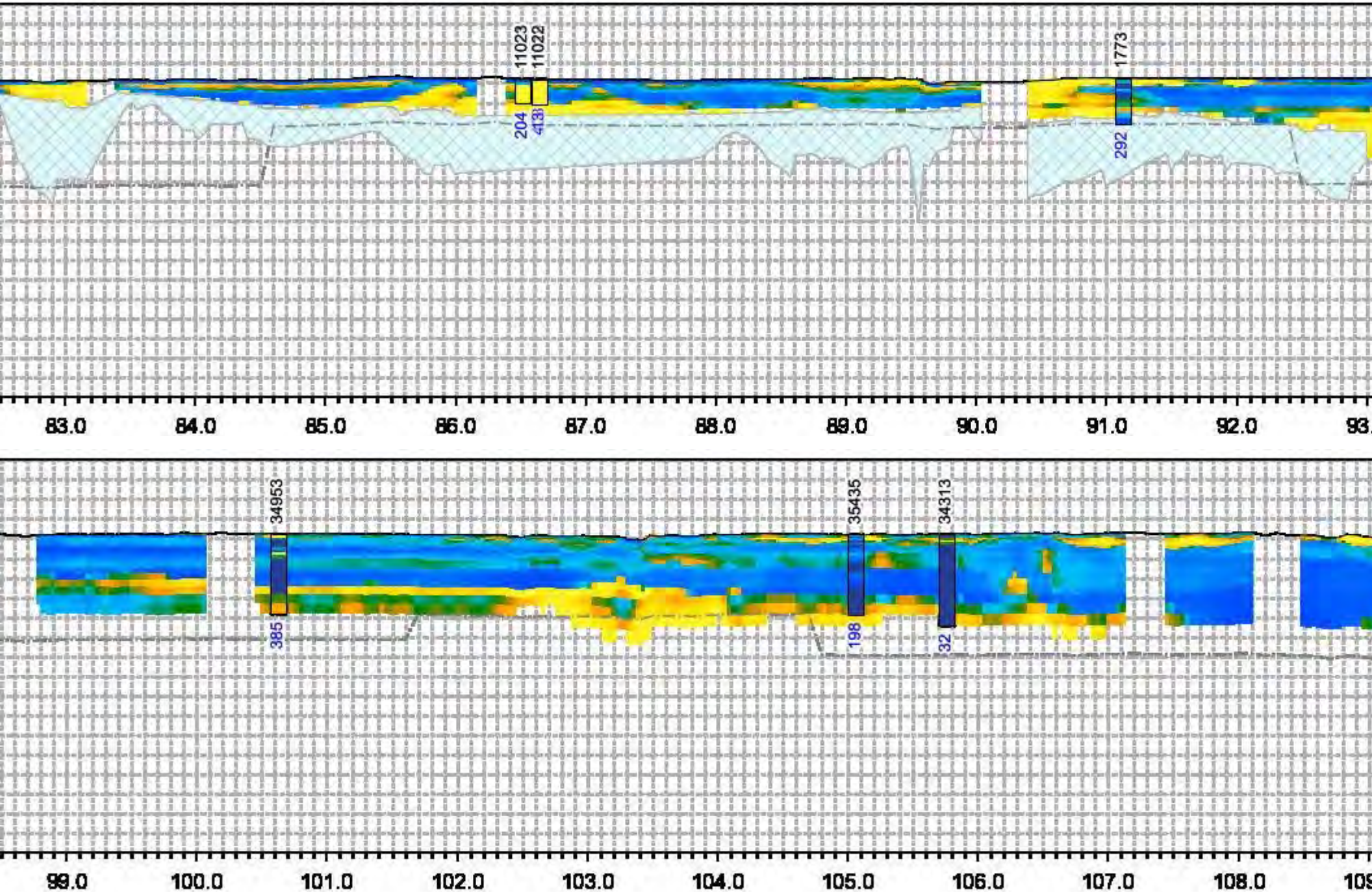


K - K' Nearest AEM Log



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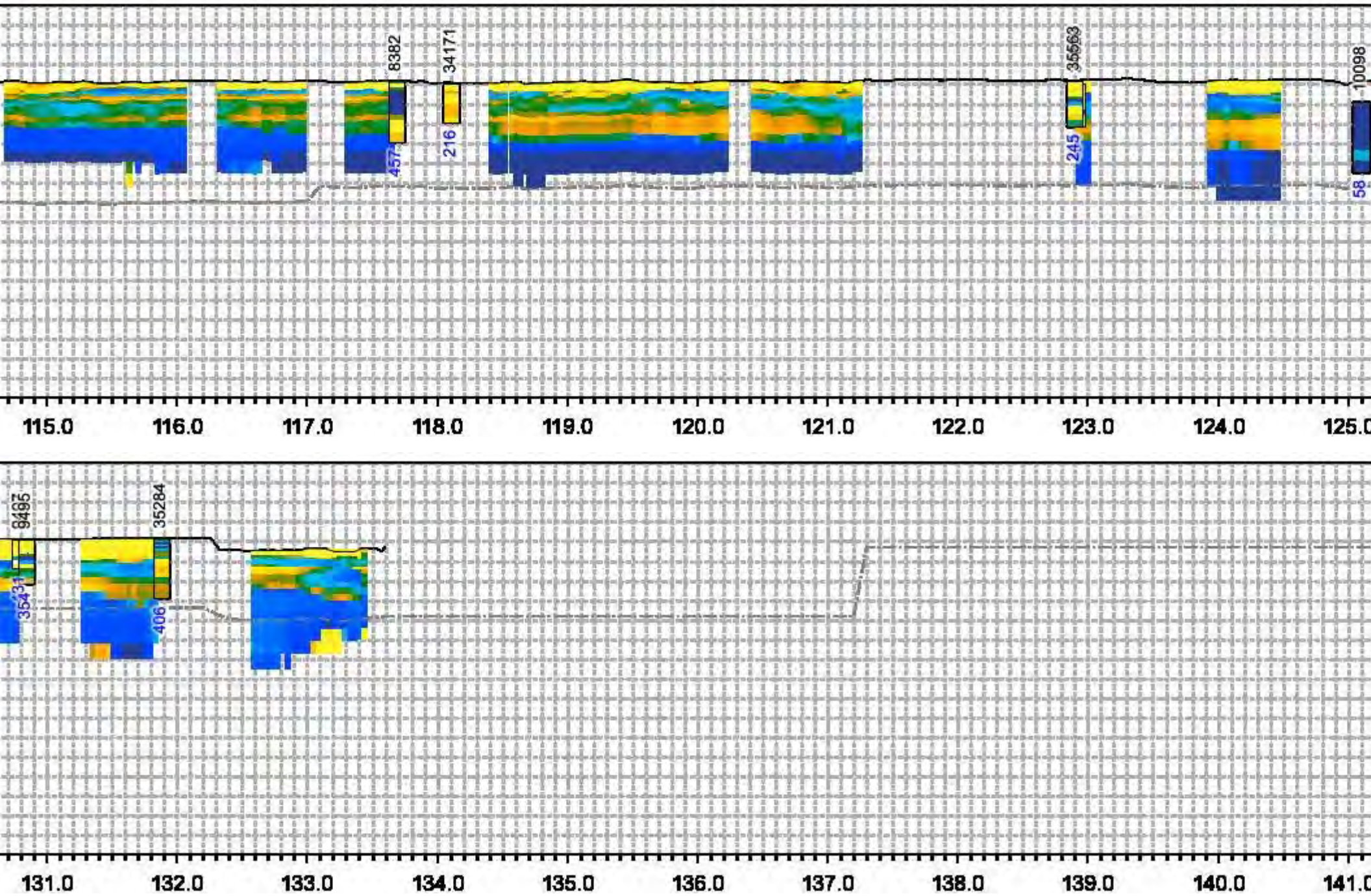
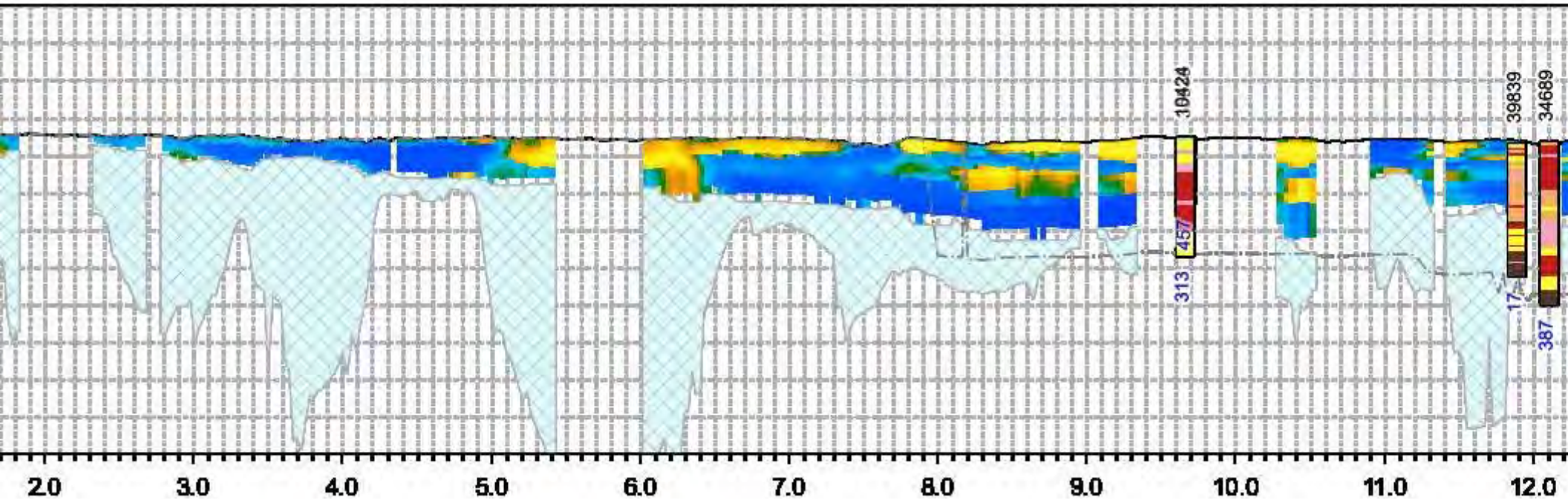


K - K' Nearest AEM Log, South



South AEM Log is NOT continuous with previous log.

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compiled for 295 production wells[26] within the Basin indicate that water supply wells (production wells) are less than 1,720 ft deep, and over 90% are 900 ft deep or less. Hence, most production wells constructed in the Basin are considerably shallower than the bottom of the basin delineated in **Figure HCM-3**.

Table HCM-1. Information used to Define the Bottom of the Basin

Type of Information	Source(s)	Elevation Range (ft msl)	Depth Range (ft bgs)
Depth to Basement Bedrock (**Figure HCM-4**)	Chapman and Bishop, 1995	Basin Foothills: -300 to 400	Basin Foothills: 0 to 930
	DOGGR, 1982	Thornton Area: -10,000 Galt Area: -7,750	Thornton Area: 10,010 Galt Area: 7,780
Base of Fresh Groundwater (**Figure HCM-5**)	Berkstresser, 1973	-1,600 to -800	810 to 1,750
Gas Fields (**Figure HCM-6**)	DOGGR, 1982	Thornton Gas: -3,290 to -2,305	Thornton Gas: 2,315 to 3,300
Deepest Groundwater Extractions from Well Construction Information (**Figure HCM-7**)	Cosumnes Subbasin Data Management System	-1673 to 340	100% of wells < 1,720 feet deep

Note:
(1) Shaded cells indicate estimated values based on approximate ground surface elevation.

8.1.4. Principal Aquifers and Aquitards

In the GSP Regulations (23-California Code of Regulations [CCR] §351), Principal Aquifers are defined as "aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems" (23-CCR §351(aa)). As discussed in more detail below, while multiple water-bearing formations have been identified in the Basin, the available data supports a delineation of a single Principal Aquifer because: (1) the formations within the Basin are all hydraulically-connected; (2) no significant and/or basin-wide continuous barriers to vertical groundwater flow have been identified in borehole data, geophysical survey results, or interpreted from existing cross-sections (**Figure HCM-15**, **Figure HCM-16**, **Figure HCM-17**, and **Figure HCM-18**); (3) the ionic composition of groundwater is generally similar between formations and depths (**Figure HCM-12**); and (4) wells have

[26] Irrigation, domestic, public supply, industrial, commercial, and stock wells with screen, completed well depth, and/or borehole depth information

been constructed throughout the entire Basin and at all formation depths (**Figure HCM-7**).

Formation Names and Occurrence

The Basin is underlain by six hydraulically-connected formations that store and transmit water (**Figure HCM-14**): (1) Younger Alluvium, (2) Older Alluvium –Victor Formation, (3) Older Alluvium – Laguna Formation, (4) Mehrten Formation, (5) Valley Springs Formation, and (6) Ione Formation. These six formations collectively comprise the Principal Aquifer. **Table HCM-2** summarizes the relationships between formation name and geologic age. Formation depths and thicknesses were inferred during cross-sectional development, discussed in more detail in Section 8.2 *Cross Sections* and shown in **Figure HCM-14** through **Figure HCM-18.**

Table HCM-2. Stratigraphic Nomenclature

Aquifer	Formation Name	Geologic Age	Symbol on Surficial Geologic Map (Figure HCM-2)
Principal	Younger Alluvium	Holocene	Qal
	Victor	Pleistocene	Qv
	Laguna	Pliocene	Tl
	Mehrten	Miocene/Pliocene	Tma/Tm
	Valley Springs	Oligocene/Miocene	Tv
	Ione	Eocene	Ti

The **Younger Alluvium** includes recent sediments deposited by the Cosumnes River, Dry Creek, and Deer Creek. The maximum thickness of Younger Alluvium, where it exists, is 100 feet and is comprised of unconsolidated silt, fine- to medium-grained sand, and gravel (DWR, 2003). The sand and gravel deposits are highly permeable and can yield significant quantities of water to wells (DWR, 2003). These deposits also provide important areas for groundwater recharge.

The **Older Alluvium** is comprised mostly of the Victor Formation and underlying Laguna Formation. The **Victor Formation** consists of loose to moderately compacted sand, silt, and gravel with discontinuous clay lenses; the sediment grain size fines to the west and the thickness ranges from 90 to 150 feet (DWR, 1974). The Victor Formation has a relatively higher permeability than the underlying Laguna Formation (DWR, 1974). Evaluation of well-borings indicated the Victor Formation was likely deposited in a shallow body of water (DWR, 1974), and interpretation of electrotelluric sounding (ETS[27]) results indicate predominantly fine-grained, clay deposits at depths that correspond to the approximate interface between the Victor and underlying Laguna formations (**Appendix I**). The Victor Formation approximately extends over the

[27] The ETS method employs a portable receiver that transforms the electrical fields generated by geomagnetically induced currents flowing in subsurface geologic formations into an audible signal, and changes in the signal are correlated to lithologic descriptions in boring or well logs at available control points. The readings are insensitive to nearby power lines and other cultural electrical noise.

western third of the Basin (**Figure HCM-8**), which is consistent with the likely western extent of the clay, based on geophysical survey results. The inferred clay bed therefore is likely not continuous, but where present can impede percolating recharge, support a relatively shallow water table, and result in greater drawdowns as a result of groundwater extractions. The **Laguna Formation** is exposed in the eastern part of the Basin, west of the Victor Formation, and consists of loose to moderately compacted non-volcanic sand, silt, and gravel with discontinuous clay lenses (DWR, 1974). Its thickness ranges from 100 feet in the east to 400 feet in the west, with a westward dip of less than one degree (DWR, 1974). The lithologic characteristics of Laguna and Victor Formations are similar, making it difficult to differentiate between the two based on well boring log data alone. Moreover, their heterogeneous lithologies makes it difficult to correlate these formations between wells. A transition zone occurs between the Laguna Formation and underlying Mehrten Formation where non-volcanic sediments of the Laguna Formation are interbedded with the volcanic sediments of the Mehrten Formation (DWR, 1974). The environment of deposition was similar for both formations, and the transition represents the exposure of the intrusive rocks of the Sierra Nevada batholith.

The **Mehrten Formation** consists of two distinct units: (1) black volcanic sand, silt, and clay layers ("Black Sands"); and, (2) dense tuff breccia (DWR, 1974). The Black Sands are generally five to 20 feet thick, highly permeable, and yield moderate to high quantities of groundwater to wells, whereas the tuff breccia beds act as local confining layers (DWR, 1974). Near the base of the Mehrten Formation is a thick bed of hard gray sandstone (DWR, 1974). In the eastern portion of the Basin, the Mehrten Formation is exposed and is as much as 200 feet thick (Bishop and Chapman, 1975). Formation thickness increases to about 500 feet in the west, and possibly reaching up to 1,200 feet in total thickness beneath the Sacramento-San Joaquin Delta (DWR, 1974).

The **Valley Springs Formation** is of volcanic origin and contains greenish clay members along with volcanic ejecta (DWR, 1974). Its thickness ranges from 75 to 200 feet. The Valley Springs Formation is exposed on the east side of the Basin from Dry Creek northward, and dips gently (1.5 to 2 degrees) to the west (DWR, 1974). In and near its outcrop areas, the formation produces good water quality although yields are low. Where the formation lies below the surface, much of it is deeper than existing well depths. Page (1974) mapped the bottom elevation and thickness of the post-Eocene continental deposits, which corresponds to the bottom of the Valley Springs Formation. Page (1974) reported that the post-Eocene continental deposits (alluvium, Laguna, Mehrten, and Valley Springs) contain most of the fresh groundwater in the valley, and Berkstresser (1973) reported that fresh groundwater is contained almost exclusively in these deposits.

The **Ione Formation** is the oldest freshwater bearing formation in the Basin, but yields from existing wells are generally low (DWR, 1974; DWR, 1978). The Ione Formation is exposed in the eastern part of the Basin and exists at least as far west as the Sacramento River. It is Eocene age, and about 400 feet thick where exposed. The Ione Formation is composed of three distinct members: (1) an uppermost member composed principally of uniformly graded medium to coarse-grained sandstone, (2) a thick bed of white clay, and (3) a thick blue to gray clay (DWR, 1974). The formation dips at about five degrees to the west (DWR, 1974), and therefore these clay beds may form significant barriers to vertical flow in the western

portions of the Basin. In the east, the potential water-bearing zones are found in the uppermost sand and gravels above the clay beds (Jones & Stokes, 2007).

Physical Properties of Aquifers and Aquitards

Groundwater moves through subsurface sediments called **aquifers**, which are comprised primarily of a mixture of coarse-grained beds of sand and gravel. In contrast, fine-grained beds of silt and clay restrict groundwater flow and are called **aquitards**. Due to the depositional history of the Basin, continuous beds of silt or clay do not form Basin-wide aquitards within the current production zones; rather, relatively smaller fine-grained beds locally limit vertical groundwater movement between coarse-grained beds. As such, the Basin is defined as having only one Principal Aquifer.

In general, wells drilled into the Principal Aquifer encounter enough water-bearing sediments to meet overlying domestic, municipal and industrial (M&I), and agricultural demands for water. The Principal Aquifer is comprised of variable lithologies and sediment grain sizes, ranging from gravels and sands, to silts and clays. Hence, its physical aquifer properties (the water transmitting properties, or the aquifer "transmissivity" and "hydraulic conductivity", and the aquifer storage properties, or "storativity") can vary both laterally and with depth. These physical properties can be; (1) measured by conducting and analyzing results from controlled well pumping tests (aquifer tests), or (2) inferred from the specific capacity of wells and the lithology recorded from boreholes.

The available **aquifer test results** for wells located in the Basin are summarized in **Table HCM-3** and shown on **Figure HCM-9**. The limited data indicate that water-bearing sediments in the Basin Plain subarea are more transmissive than the water-bearing sediments in the Basin Foothills subarea. However, nine of the 10 available tests summarized in **Table HCM-3** were conducted on wells located in the eastern portion of the Basin, and additional data collection and analyses are needed to improve characterization of the western portion of the Basin.

Transmissivity and **hydraulic conductivity** represent the capacity of an aquifer to transmit water. Aquifer tests traditionally are the most reliable method to evaluate transmissivity and storativity. Based on the available data (**Table HCM-3**), the transmissivity of water bearing sediments in the Basin Plain subarea is approximately 1,900 square feet per day (ft^2/day). The median transmissivity of water bearing sediments in the Basin Foothills subarea, based on several aquifer tests, is approximately 240 ft^2/day. The transmissivity values correspond to approximate hydraulic conductivities of 16 and 12 feet per day (ft/day), respectively.[28] These results are at the lower end of the hydraulic conductivity range reported from previous numerical models that included the Basin as part of their model domain (0.03 to 1,580 ft/day per [Meirovitz, 2010; Fleckenstein et al., 2006; Faunt, 2009]). Representative hydraulic conductivity values used in the numerical model of the Basin to support GSP development range from about 25 ft/day for the Victor Formation to less than 10 ft/day for the Ione Formation (see Section 10.1

[28] Hydraulic conductivity [ft/d] is approximated by dividing transmissivity [ft^2/day] by the length of well perforations [ft].

Water Budget Methods and Data Sources for a description of the model).

Storativity, or storage coefficient, is the volume of water released from storage per unit decline in water level in the aquifer per unit area of the aquifer and represents its capacity to store water. The generally low storativity values reported for wells located in the Basin Foothills subarea indicate that groundwater is confined by relatively less permeable sediments that overlie the primary water-bearing sediments. Aquifer test results have not included storativity for the Basin Plain subarea, but calibrated values used in the numerical model of the Basin to support GSP development range from 0.07 to 0.18, with a median value of about 0.11 (see Section 10.1 *Water Budget Methods and Data Sources* for a description of the model).

Table HCM-3. Physical Properties based on Aquifer Tests in the Basin

Parameter	Basin Plain	Basin Foothills
Aquifer Tests: Median (Min to Max)		
Horizontal Hydraulic Conductivity (ft/day)	16 (single value)[2]	12 (4 - 31)[1]
Transmissivity (ft^2/day)	1,914 (single value)[2]	236 (95 – 12,200)[1,3]
Storativity (-)	--	0.00034 (0.000021 - 0.014)[1,3]

Abbreviations:
ft/day = feet per day
ft^2/day = feet squared per day
Sources:
(1) Dunn Environmental, 2012a
(2) Dunn Environmental, 2012b
(3) Jones & Stokes, May 2007

Specific capacity is defined as the quantity of water produced by a well per unit drawdown in the well and can be used to infer aquifer transmissivity and hydraulic conductivity. The interpretation of specific capacity values is limited because they represent the productivity of both the well and the aquifer and thus include aspects of well construction and well condition in addition to the water transmitting properties of the aquifer. The specific capacity was calculated for a total of 42 wells in the Basin that had both reported pumping rates and water level drawdown data (**Figure HCM-10**). In general, specific capacity indicates that the transmissivity of the Primary Aquifer decreases from west to east. The specific capacity of Basin Plain subarea wells ranged from 0.3 to 453 gallons per minute per foot (gpm/ft) with a median specific capacity of 54 gpm/ft, which corresponds to a median transmissivity of about 110,000 gallons per day per foot (gpd/ft) or 14,700 square feet per day (ft^2/day) (Driscoll, 1995).

In contrast, the specific capacity of Basin Foothills wells ranged from 0.1 to 2.3 gpm/ft with a median specific capacity of 0.5 gpm/ft, which corresponds to a median transmissivity of about 1,000 gpd/ft or almost 135 ft^2/day. Accordingly, the median specific capacity values suggest that the water transmitting properties of the Principal Aquifer are spatially variable and can vary by a factor of 100 between the Basin Plain to the Basin Foothills subareas.

Lithologic data from well completion reports (WCRs) can characterize relative fractions of coarse-grained

sediment from which to infer the spatial variability in aquifer transmissivity. The lithologic data from 102 WCRs (DWR, 2018a)[29] were combined with similar data from 38 additional WCRs digitized into the Basin Data Management System (DMS) to characterize the spatial distribution of coarse-grained sediment within the Basin. The lithologic descriptions from these 140 WCRs were digitized using numerical codes assigned to the relatively fine- and coarse-grained sediment descriptions (texture) following the classification scheme employed by DWR. Sediments characterized by a relatively high fraction of coarse-grained material (e.g., sands and gravels) are generally indicative of relatively permeable sediments (high hydraulic conductivity). In contrast, sediments characterized by a relatively low fraction of coarse-grained material (e.g., silts and clays) are generally indicative of sediments with relatively low permeability (low hydraulic conductivity).

The fraction of coarse-grained sediment for depth intervals that correspond to the Victor, Laguna and Mehrten Formations are mapped in **Figure HCM-10**. The fraction of coarse-grained sediment shows significant spatial variability across the Basin and with depth. In general, the fraction of coarse-grained sediment, and presumably aquifer hydraulic conductivity, is greatest near the Cosumnes River and Dry Creek and decreases to the west. The fraction of coarse-grained sediment also generally increases with depth. The average fraction of coarse-grained sediment is about 20% in the Victor and Laguna Formations and increases to almost 30% in the Mehrten Formation. The specific capacity results are also mapped in **Figure HCM-10**, and generally support the spatial texture trends whereby the greatest specific capacity values are located near surface water drainages, and specific capacity tends to decrease to the west.

Geophysical data from ETS conducted near the Cosumnes River and Dry Creek indicate subsurface lithology is comprised of alternating sediments characterized as predominantly “fine-grained,” “clay,” and “coarse-grained” intervals of variable thickness. The fine-grained intervals likely include variable mixtures of silt, clayey sand, fine-grained cemented sand, and possibly fine-grained clayey gravel deposits but in relatively small quantities. The clay intervals represent relatively low permeability clay, silty clay, and sandy clay deposits, but may include small quantities of coarse-grained sediment. The coarse-grained intervals include sand, gravel, and possibly small quantities of clayey sand and clayey gravel. The ETS results identified mobile water associated with the predominantly coarse-grained intervals, and the fine-grained and clay intervals impede or restrict percolating recharge. At some locations, the ETS results helped identify potential channel deposits within the coarse-grained intervals based on a signal identifying a very coarse-grained material, or an anomalous thickening of the coarse-grained interval relative to adjacent soundings. Good agreement exists between these channel locations identified by ETS and maps constructed by DWR showing inferred channel deposits based on boring logs (DWR, 1974).

Structural Properties of the Basin that Restrict Groundwater Flow Within the Principal Aquifers

Within a limited portion of the Basin Foothills subarea, exposed metavolcanic basement bedrock outcrops form the Carabas Paleo-Ridge (Chapman and Bishop, 1975) (**Figure HCM-2**). This paleo-ridge was formed pre-Eocene, and sediments were deposited around the paleo-ridge during the following Eocene and Post-Eocene periods (Creely and Force, 2007). Hence, the Ione, Valley Springs, and Mehrten Formations

[29] https://data.cnra.ca.gov/dataset/svsim, accessed 29 July 2019

forming the Principal Aquifer are partially dissected by these paleo-ridge outcrops.

Clay beds at variable depths can partially restrict recharge and vertical groundwater movement, but these clay beds are discontinuous and their effects localized. As discussed above, interpretation of ETS geophysical survey results indicate predominantly fine-grained, clay deposits may extend approximately over the western third of the Basin, but are not likely continuous across the Basin. Where present, these clay beds can impede percolating recharge and support a relatively shallow water table.

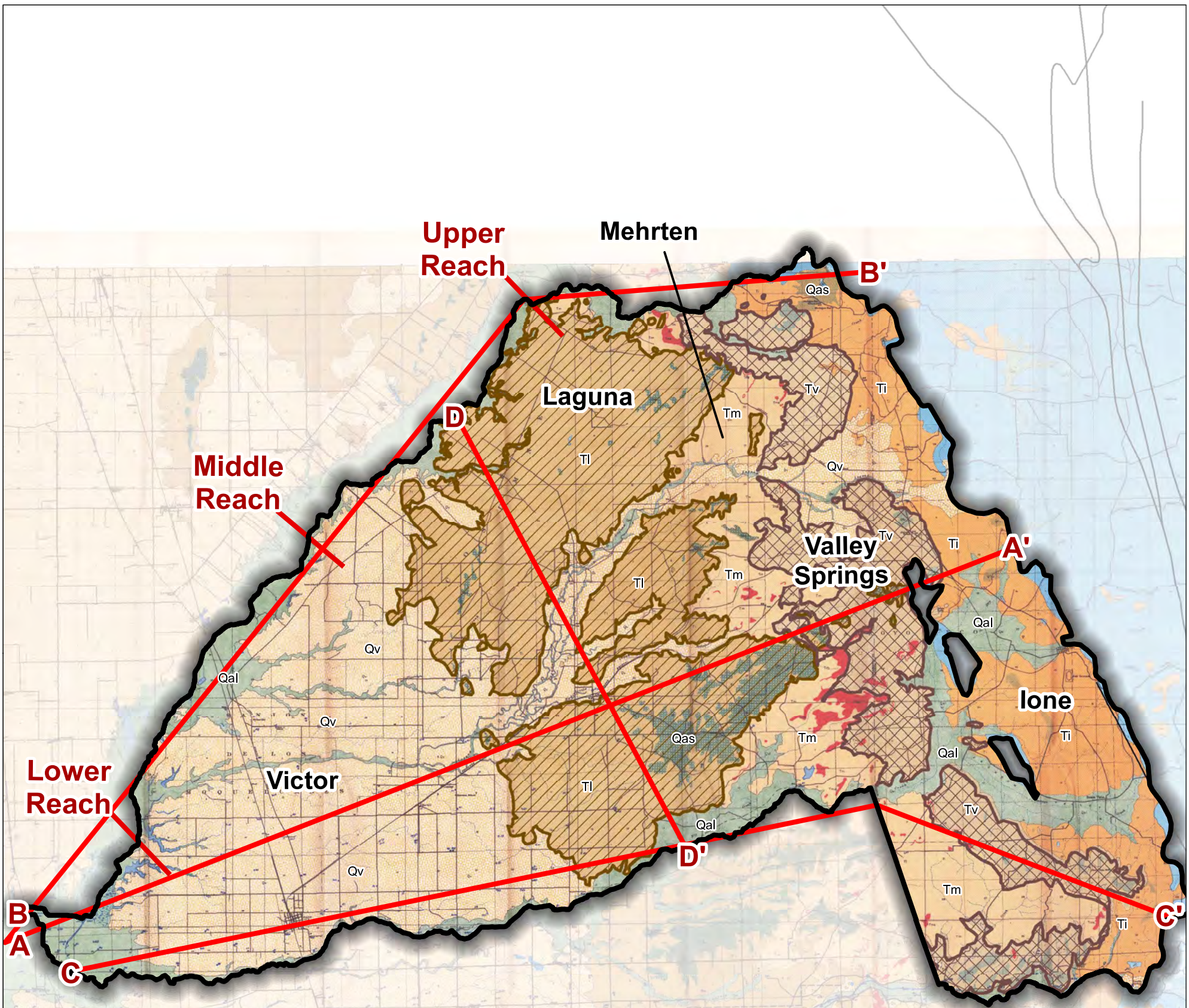
General Water Quality of the Principal Aquifer(s)

General water quality types can be inferred from the ionic composition of water samples, plotted on either a **Piper Diagram** (trilinear diagram) or **Stiff Diagram** which display the relative proportions of cations and anions in water samples. The ionic composition is typically derived from the minerals that the groundwater contacts during its flow downgradient, and in the case of bicarbonate/carbonate anions are further influenced by the partial pressure of carbon dioxide in the atmosphere and soil zone. All water samples considered were from the DMS, and only samples having a charge balance error less than or equal to 10% were plotted in the diagrams.

In a Piper Diagram, the proportions of anions (chloride, sulfate, bicarbonate and carbonate) and cations (calcium, magnesium, potassium, and sodium) are plotted as points in lower triangles and the data points are projected into the central diamond along parallel lines. The Stiff Diagram plotting technique uses parallel horizontal axes extending on each side of a vertical zero axis. Concentrations of cations (sodium, calcium, and magnesium, in milliequivalents per liter [meq/L]), are plotted sequentially on each axis to the left of zero. Similarly, anion concentrations (chloride, bicarbonate, and sulfate) are plotted sequentially on each axis to the right of zero. The resulting points are connected to give an irregular polygonal shape or pattern, which can provide a distinctive method of showing water composition differences and similarities. The width of the pattern is proportional to the sample's total ionic content.

The Piper Diagram presented in **Figure HCM-11** plots water quality samples collected from wells within the Basin between 1995 and 2018 and show that the Basin Plain wells produce mostly mixed-cation bicarbonate waters but some wells produce sodium-bicarbonate waters, as shown by the alignment of symbols from the central, mixed-cation triangle (no dominance) to the apex of the sodium triangle. In contrast, the Basin Foothills wells show more variability in water quality, particularly the anion composition. Half of these wells produce mixed-cation-bicarbonate water while the remaining wells produce mostly sodium-mixed-anion to -sulfate or -chloride water. The Basin Foothills wells also show a linear trend between the mixed cation and sodium triangles.

The Stiff Diagrams presented in **Figure HCM-12** are consistent with the Piper Diagram and show that the ionic composition of groundwater is approximately uniform across the Basin Plain subarea but more variable in the Basin Foothills. Discussions of specific constituents are provided in Section 9.4 *Groundwater Quality Concerns* and address the beneficial uses of variable quality groundwater, including maps showing the spatial distribution of these constituents in well-water samples.



Legend

- Cross Section Location
- Fault
- Cosumnes Subbasin (5-022.16)
- Qal — Alluvium
- Qv — Victor Formation
- Qas — Arroyo Seco gravel
- QTu — Gravel deposits of uncertain age
- Tl — Laguna Formation
- Tma / Tm — Mehrten Formation
- Tv — Valley Springs Formation
- Ti — Ione Formation
- JC — Pre-Cretaceous crystalline rocks

Abbreviations

DWR = California Department of Water Resources
USGS = United States Geological Survey

Notes

1. All locations are approximate.

Sources

1. Basemap is ESRI's ArcGIS Online world topographic map, obtained 3 December 2021.
2. DWR groundwater basins are based on the boundaries defined in California's Groundwater Bulletin 118 - Final Prioritization, dated February 2019.
3. Geology from:
   "Geology and Ground-Water Hydrology of the Mokelumne Area, California" compiled by USGS, 1939. USGS Water-Supply Paper 780.
4. Faults from:
   "Preliminary intergrated geologic map databases for the United States" Western States. Version 1.3. Updated December 2007.compiled by USGS. Open-File Report 2005-1305.

N

0 3 6

(Scale in Miles)

Surficial Geology and Cross-Section Locations

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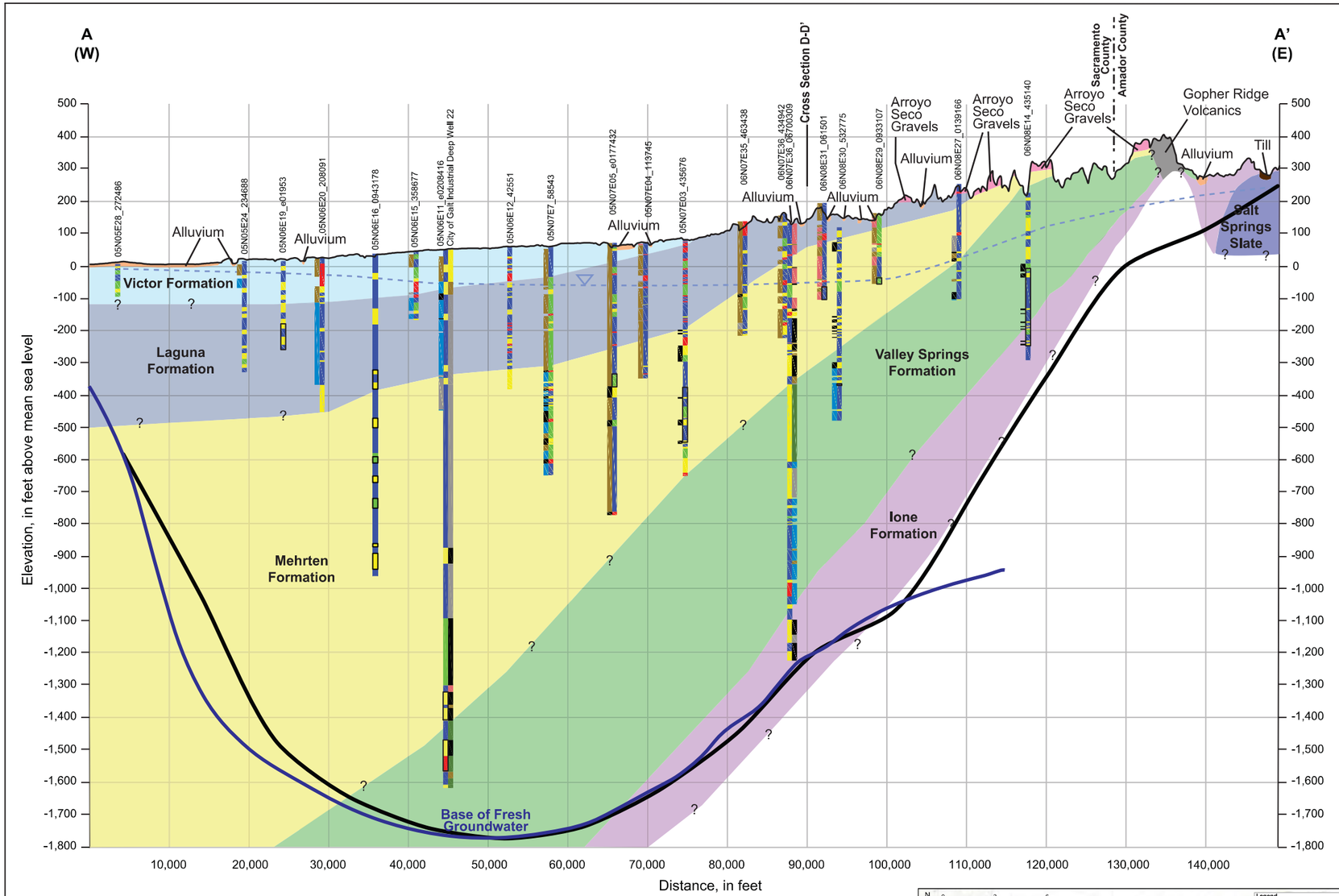
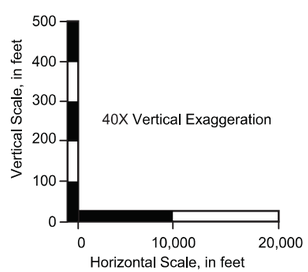
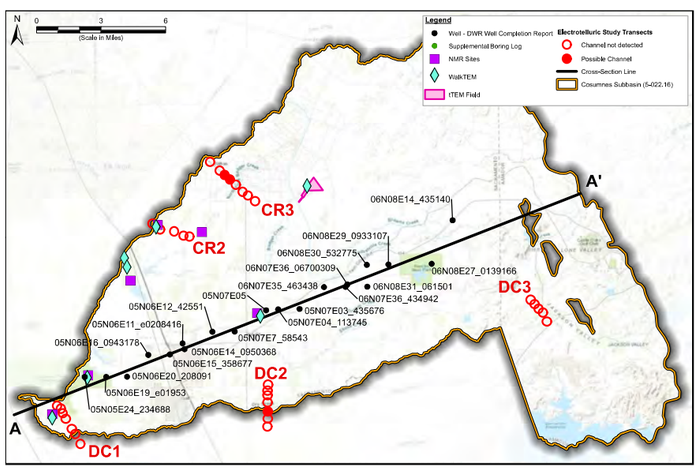
Figure HCM-14

Path: X:\B80081_Cosumnes\Maps\GSP\Final Draft\Fig_HCM-14_Surficial Geology.mxd







Legend:

Wells

Well Identification
DWR Well Completion Report Number
Section
Range
Township

06N08E14_435140

Lithology - Derived from Well Logs

Generalized Texture
- Fine-Grained Materials (i.e., clay, silt)
- Fine Sand
- Sand
- Gravel
- Volcanic
- Well Screen

Color
- Gray
- Brown/Tan
- Black
- Blue
- Red
- Green
- White
- Yellow

Selected Subsurface Geologic Units (See Note 2)

- Alluvium
- Undifferentiated Victor Formation
- Laguna Formation
- Mehrten Formation
- Valley Springs Formation
- Ione Formation
- Salt Springs Slate
- Gopher Ridge Volcanics
- Arroyo Seco Gravels
- Base of Fresh Groundwater (Berkstresser, 1973)
- Basin Bottom
- Groundwater Elevation - Fall 2018

Abbreviations:

DWR = California Department of Water Resources
USGS = United States Geological Survey

Sources:

1. USGS 10-Meter Digital Elevation Model (https://viewer.nationalmap.gov/basic/).
2. Dawson T, 2009, Preliminary Geologic Map of the Lodi 30' x 60' Quadrangle, California. California Geological Survey.
3. Holland PJ, 2016, Preliminary Geologic Map of the Irish Hill 7.5' Quadrangle, Amador County, California. Version 1.0. California Geological Survey.
4. DWR, 1974, Evaluation of Ground Water Resources: Sacramento County. Bulletin No. 118-3, July 1974 (Reprinted April 1980).
5. Piper AM, Gale HS, Thomas HE, Robinson TW, 1939, "Geology and Ground-Water Hydrology of the Mokelumne Area, California." USGS Water-Supply Paper 780.
6. Berkstresser, 1973, "Base of Fresh Ground Water in the Sacramento Valley and Sacramento-San Joaquin Delta, California." USGS WRI 40-73.
7. Page RW, 1974, Base and thickness of the post-Eocene continental deposits in the Sacramento Valley, California, USGS WRI 45-73.
8. Chapman RH and Bishop CC, 1975, Geophysical Investigations in the Ione Area, Amador, Sacramento, and Calaveras Counties, California, California Division of Mines and Geology Special Report 117.

Notes:

1. Well identification based on Public Land Survey System.
2. Subsurface geologic units based on DWR (1974) cross-section F-F', surficial geologic maps (Dawson, 2009; Holland, 2016; Piper and others, 1939), contours representing the top of Ione Formation (Page 1974), contours representing the top of basement bedrock (Chapman and Bishop, 1975), and informed by lithology derived from DWR Well Completion Report records. Contacts are queried where uncertain.
3. Wells shown on cross-section are located within 1 mile of cross-section line.
4. Groundwater elevation is based on groundwater elevation contours for Fall 2018, as mapped on Figure GWC-2.
5. Basin bottom is based on depth to bottom of the Basin as mapped on Figure HCM-3.

Geologic Cross-Section A - A'

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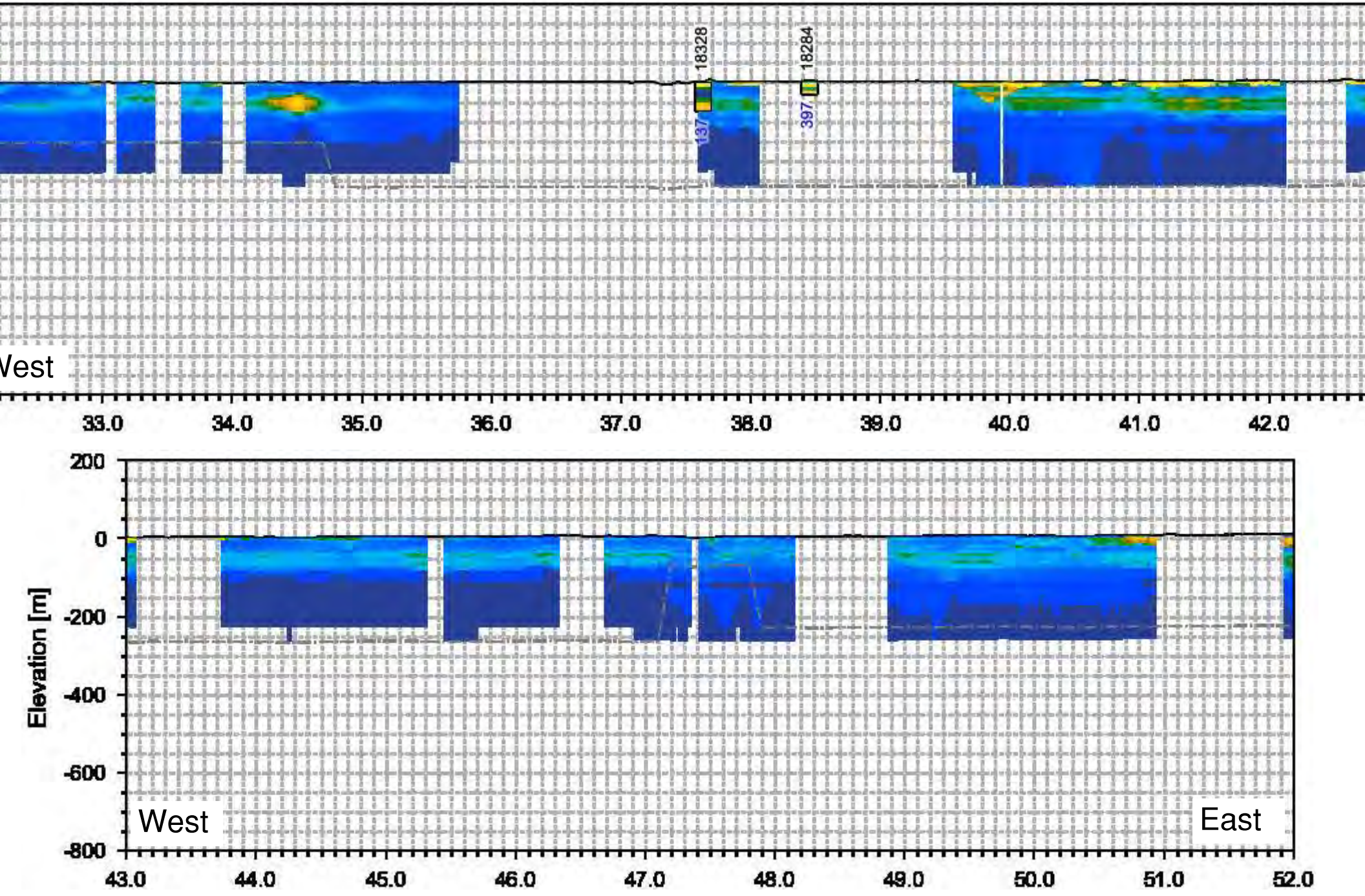
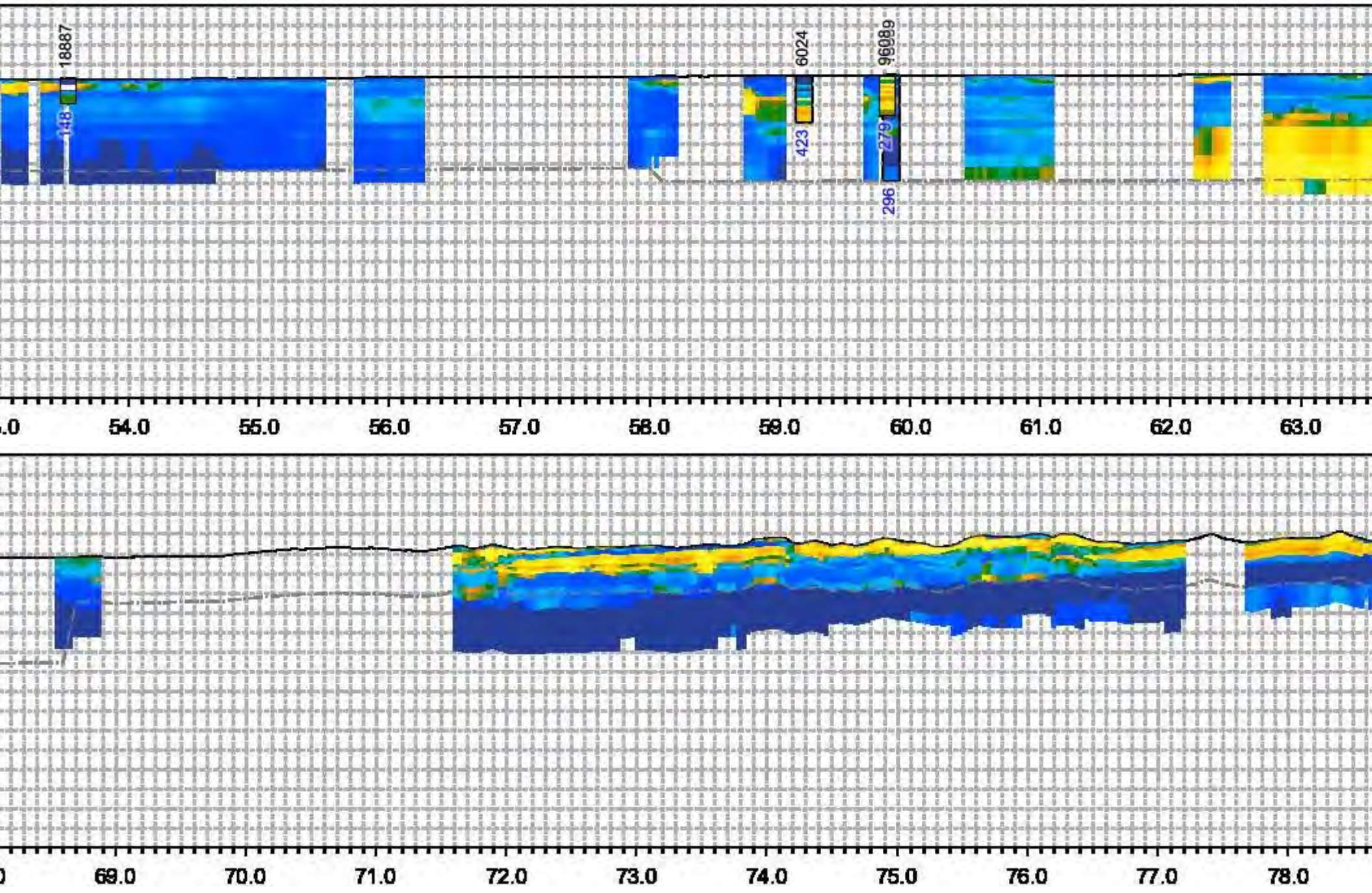
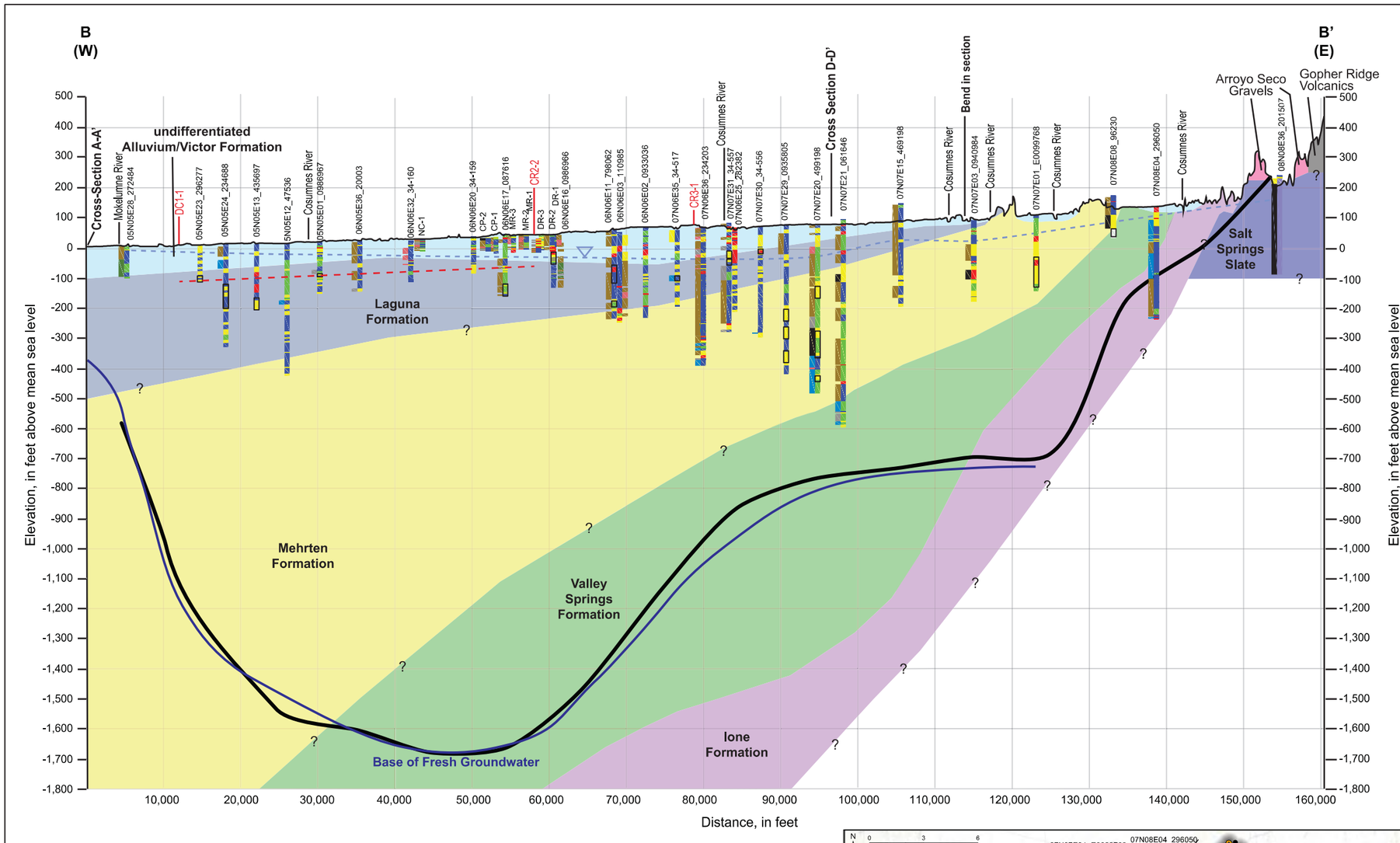
Figure HCM-15

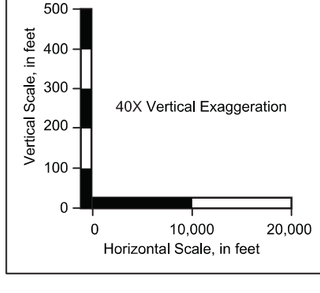
A - A' Nearest AEM Log

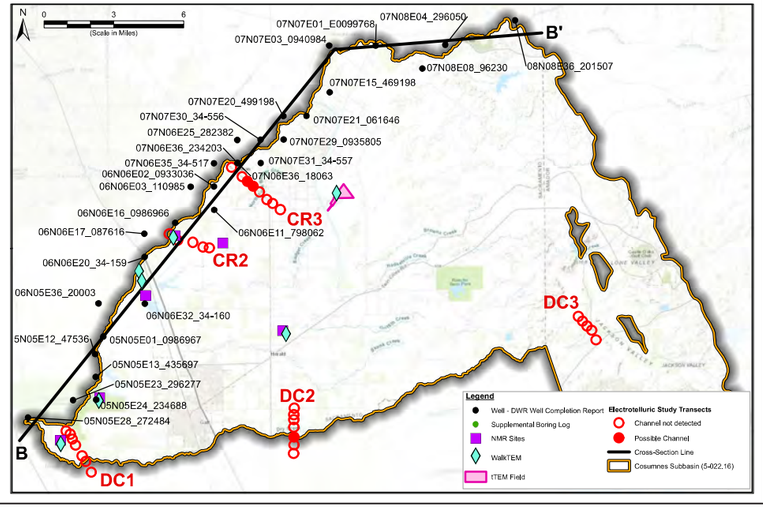


A - A' Nearest AEM Log









Legend:

Wells

- Well Identification
- DWR Well Completion Report Number
- Section
- Range
- Township

(07N07E15_469198)

Other

- CR3-1 — Electrotelluric Survey Transect Identification

Lithology - Derived from Well Logs

Generalized Texture

- Fine-Grained Materials (i.e., clay, silt)
- Fine sand
- Sand
- Gravel
- Volcanic
- Slate
- Well Screen

Color

- Gray
- Brown/Tan
- Black
- Blue
- Red
- Green
- White
- Yellow

Selected Subsurface Geologic Units (See Note 2)

- Undifferentiated Alluvium/Victor Formation
- Laguna Formation
- Mehrten Formation
- Valley Springs Formation
- Ione Formation
- Salt Springs Slate
- Gopher Ridge Volcanics
- Arroyo Seco Gravels
- Base of Fresh Groundwater (Berkstresser, 1973)
- Top of Clay Interval inferred from Electrotelluric Survey (ETS, See Note 4)
- Basin Bottom
- Groundwater Elevation - Fall 2018

Abbreviations:

DWR = California Department of Water Resources
USGS = United States Geological Survey

Sources:

1. USGS 10-Meter Digital Elevation Model (https://viewer.nationalmap.gov/basic/).
2. Dawson T, 2009, Preliminary Geologic Map of the Lodi 30' x 60' Quadrangle, California. California Geological Survey.
3. Holland PJ, 2016, Preliminary Geologic Map of the Irish Hill 7.5' Quadrangle, Amador County, California. Version 1.0. California Geological Survey.
4. DWR, 1974, Evaluation of Ground Water Resources: Sacramento County. Bulletin No. 118-3, July 1974 (Reprinted April 1980).
5. Piper AM, Gale HS, Thomas HE, Robinson TW, 1939, "Geology and Ground-Water Hydrology of the Mokelumne Area, California." USGS Water-Supply Paper 780.
6. Berkstresser, 1973, "Base of Fresh Ground Water in the Sacramento Valley and Sacramento-San Joaquin Delta, California." USGS WRI 40-73.
7. Page RW, 1974, Base and thickness of the post-Eocene continental deposits in the Sacramento Valley, California, USGS WRI 45-73.
8. Chapman RH and Bishop CC, 1975, Geophysical Investigations in the Ione Area, Amador, Sacramento, and Calaveras Counties, California, California Division of Mines and Geology Special Report 117.
9. Meirovitz CD, 2010, Influence of American River Incised Valley Fill on Sacramento County Hydrogeology. Master's Thesis. University of California, Davis.
10. Geoconsultants, Inc., 2020, Hydrogeologic Study using Electrotelluric Transects Cosumnes Groundwater Subbasin Sacramento, San Joaquin, and Amador Counties, California.

Notes:

1. Well identification based on Public Land Survey System.
2. Subsurface geologic units based on DWR (1974) cross-section intersections, surficial geologic maps (Dawson, 2009; Holland, 2016; Piper and others, 1939), contours representing the top of Ione Formation (Page 1974), contours representing the top of basement bedrock (Chapman and Bishop, 1975), and informed by lithology derived from DWR Well Completion Report records. Contacts are queried where uncertain.
3. Wells shown on cross-section are located within 1 mile of cross-section line.
4. Electrotelluric Survey (Geoconsultants, Inc., 2020) is included as Appendix I.
5. Groundwater elevation is based on groundwater elevation contours for Fall 2018, as mapped on Figure GWC-2.
6. Basin bottom is based on depth to bottom of the Basin as mapped on Figure HCM-3.

Geologic Cross-Section B - B'

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Figure HCM-16

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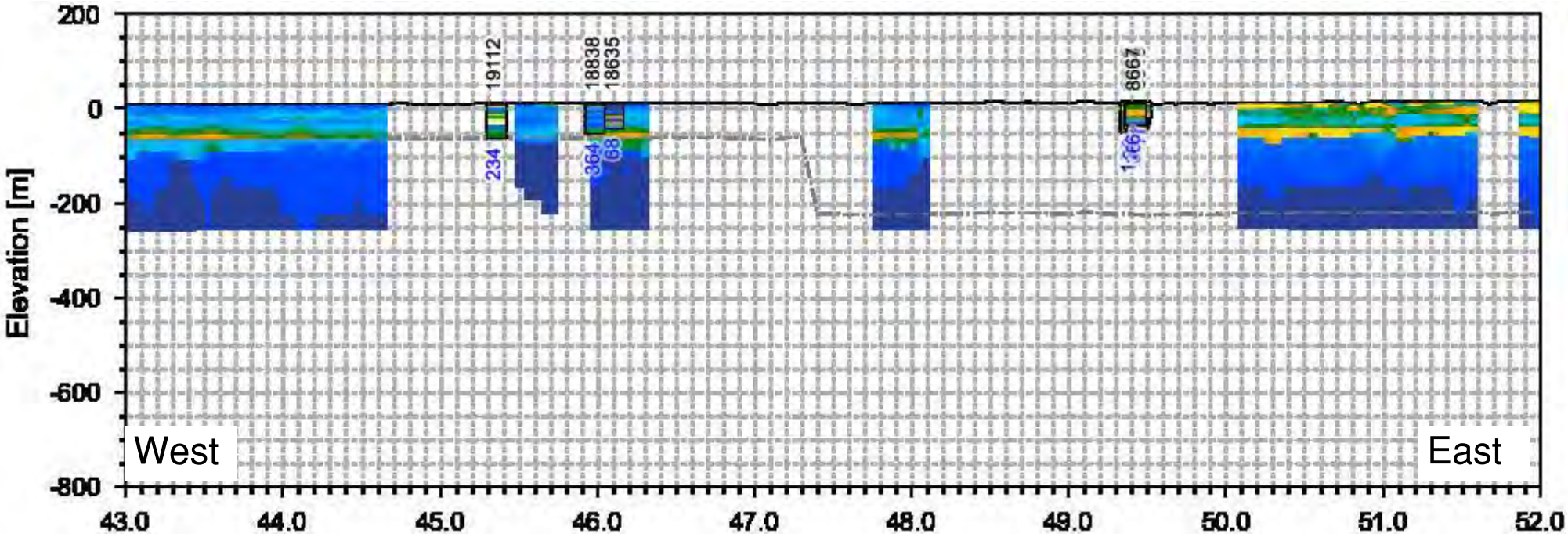
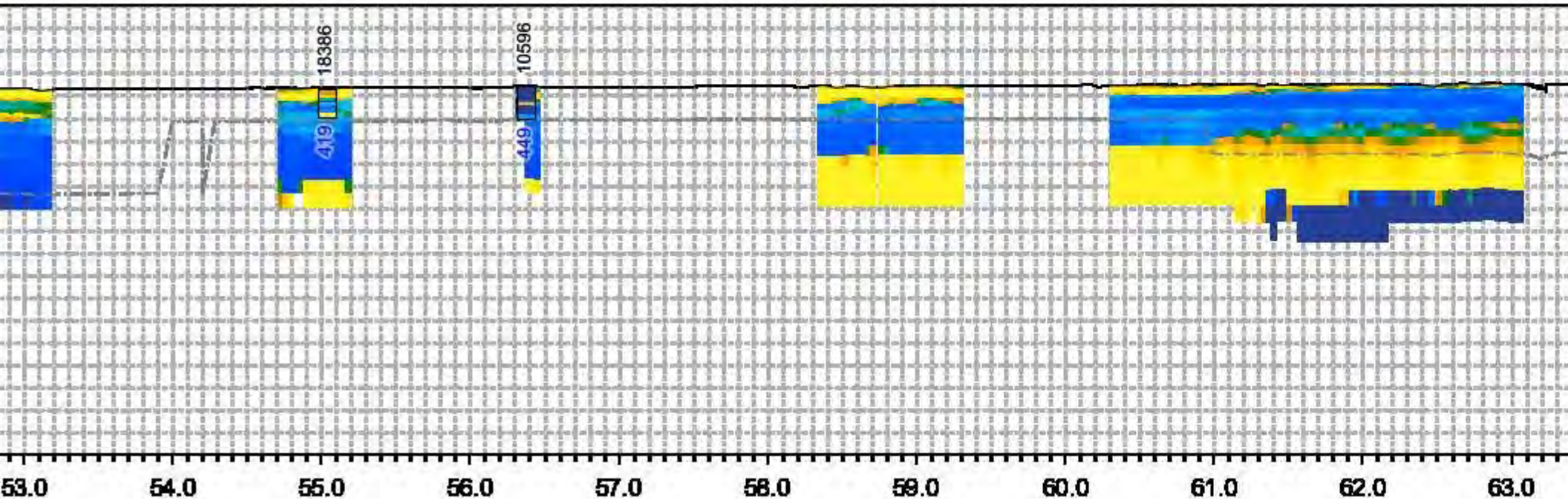
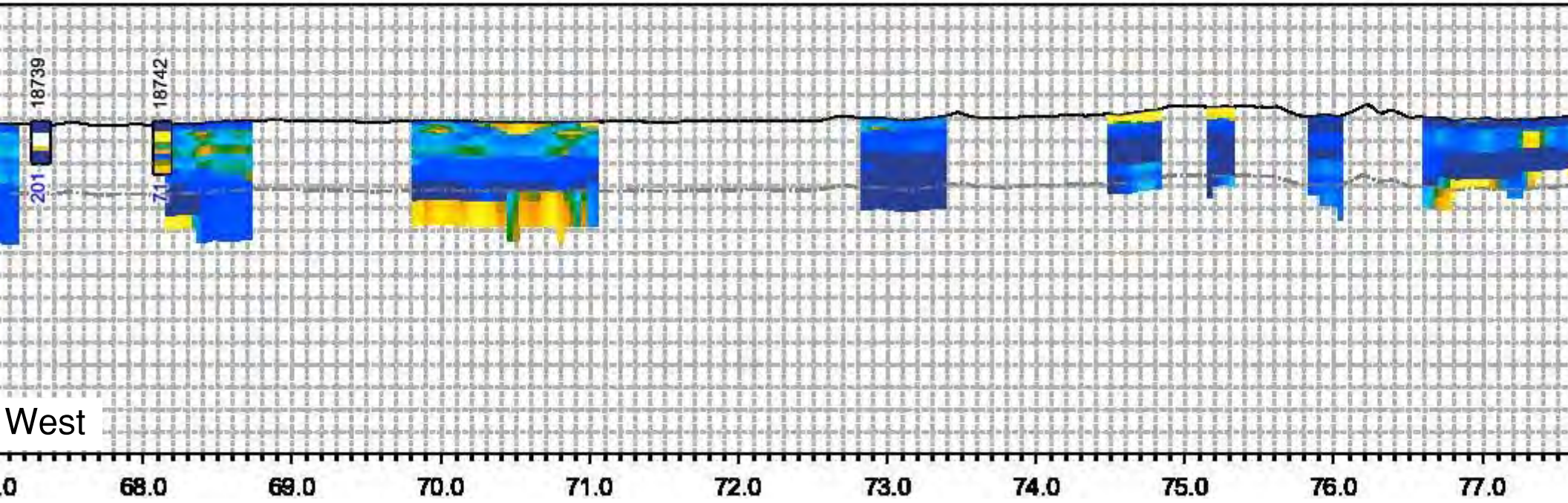
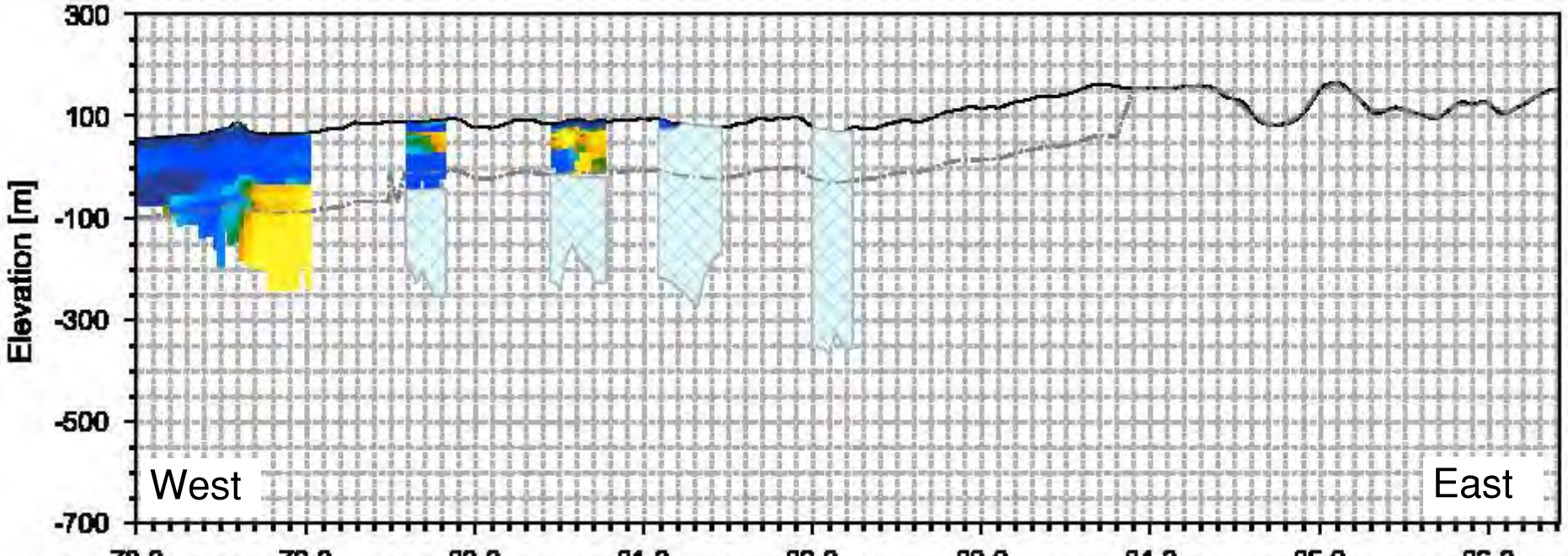
B - B' Nearest AEM Log

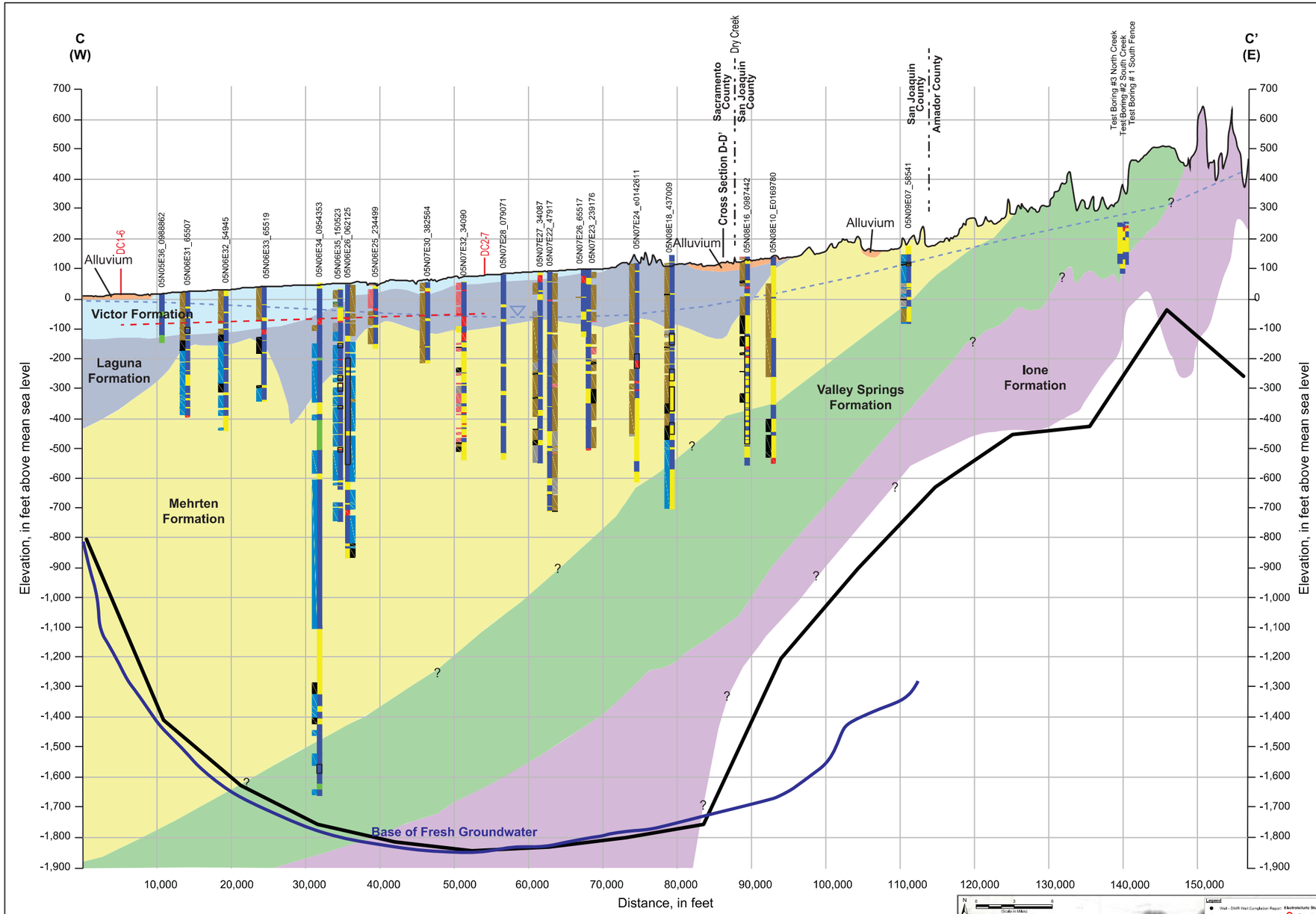


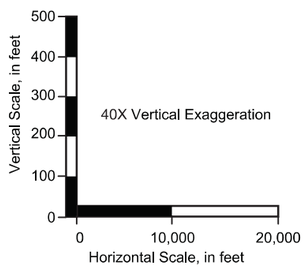


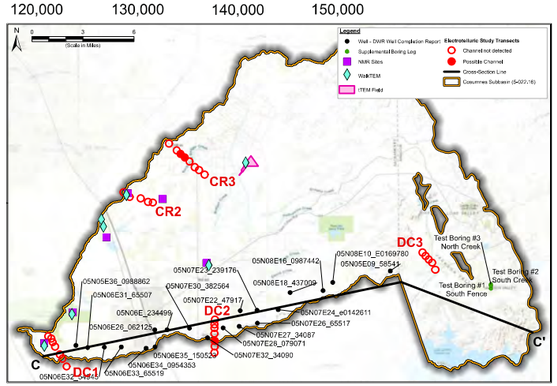
B - B' Nearest AEM Log











Legend:

Wells

- Well Identification
- DWR Well Completion Report Number
- Section
- Range
- Township

(05N07E30_382564)

Other

- DC1-6 — Electrotelluric Survey Transect Identification

Lithology - Derived from Well Logs

Generalized Texture

- Fine-Grained Materials (i.e., clay, silt)
- Fine Sand
- Sand
- Gravel
- Volcanic
- Well Screen

Color

- Gray
- Brown/Tan
- Black
- Blue
- Red
- Green
- White
- Yellow

Selected Subsurface Geologic Units (See Note 2)

- Alluvium
- Undifferentiated Victor Formation
- Laguna Formation
- Mehrten Formation
- Valley Springs Formation
- Ione Formation
- Arroyo Seco Gravels
- Base of Fresh Groundwater (Berkstresser, 1973)
- Basin Bottom
- Groundwater Elevation - Fall 2018

Abbreviations:

DWR = California Department of Water Resources
USGS = United States Geological Survey

Sources:

1. USGS 10-Meter Digital Elevation Model (https://viewer.nationalmap.gov/basic/).
2. Dawson T, 2009, Preliminary Geologic Map of the Lodi 30' x 60' Quadrangle, California. California Geological Survey.
3. Holland PJ, 2016, Preliminary Geologic Map of the Irish Hill 7.5' Quadrangle, Amador County, California. Version 1.0. California Geological Survey.
4. DWR, 1974, Evaluation of Ground Water Resources: Sacramento County. Bulletin No. 118-3, July 1974 (Reprinted April 1980).
5. Piper AM, Gale HS, Thomas HE, Robinson TW, 1939, "Geology and Ground-Water Hydrology of the Mokelumne Area, California." USGS Water-Supply Paper 780.
6. Berkstresser, 1973, "Base of Fresh Ground Water in the Sacramento Valley and Sacramento-San Joaquin Delta, California." USGS WRI 40-73.
7. Page RW, 1974, Base and thickness of the post-Eocene continental deposits in the Sacramento Valley, California, USGS WRI 45-73.
8. Chapman RH and Bishop CC, 1975, Geophysical Investigations in the Ione Area, Amador, Sacramento, and Calaveras Counties, California, California Division of Mines and Geology Special Report 117.
9. Geoconsultants, Inc., 2020, Hydrogeologic Study using Electrotelluric Transects Cosumnes Groundwater Subbasin Sacramento, San Joaquin, and Amador Counties, California.

Notes:

1. Well identification based on Public Land Survey System.
2. Subsurface geologic units based on DWR (1974) cross-section intersections, surficial geologic maps (Dawson, 2009; Holland, 2016; Piper and others, 1939), contours representing the top of Ione Formation (Page 1974), contours representing the top of basement bedrock (Chapman and Bishop, 1975), and informed by lithology derived from DWR Well Completion Report records. Contacts are queried where uncertain.
3. Wells shown on cross-section are located within 1 mile of cross-section line; supplemental boring logs are located within 2 miles of cross-section line.
4. Electrotelluric Survey (Geoconsultants, Inc., 2020) is included as Appendix I.
5. Groundwater elevation is based on groiundwater elevation contours for Fall 2018, as mapped on Figure GWC-2.
6. Basin bottom is based on depth to bottom of the Basin as mapped in Figure HCM-3.

Geologic Cross-Section C - C'

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Cosumnes Subbasin
December 2021
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Figure HCM-17

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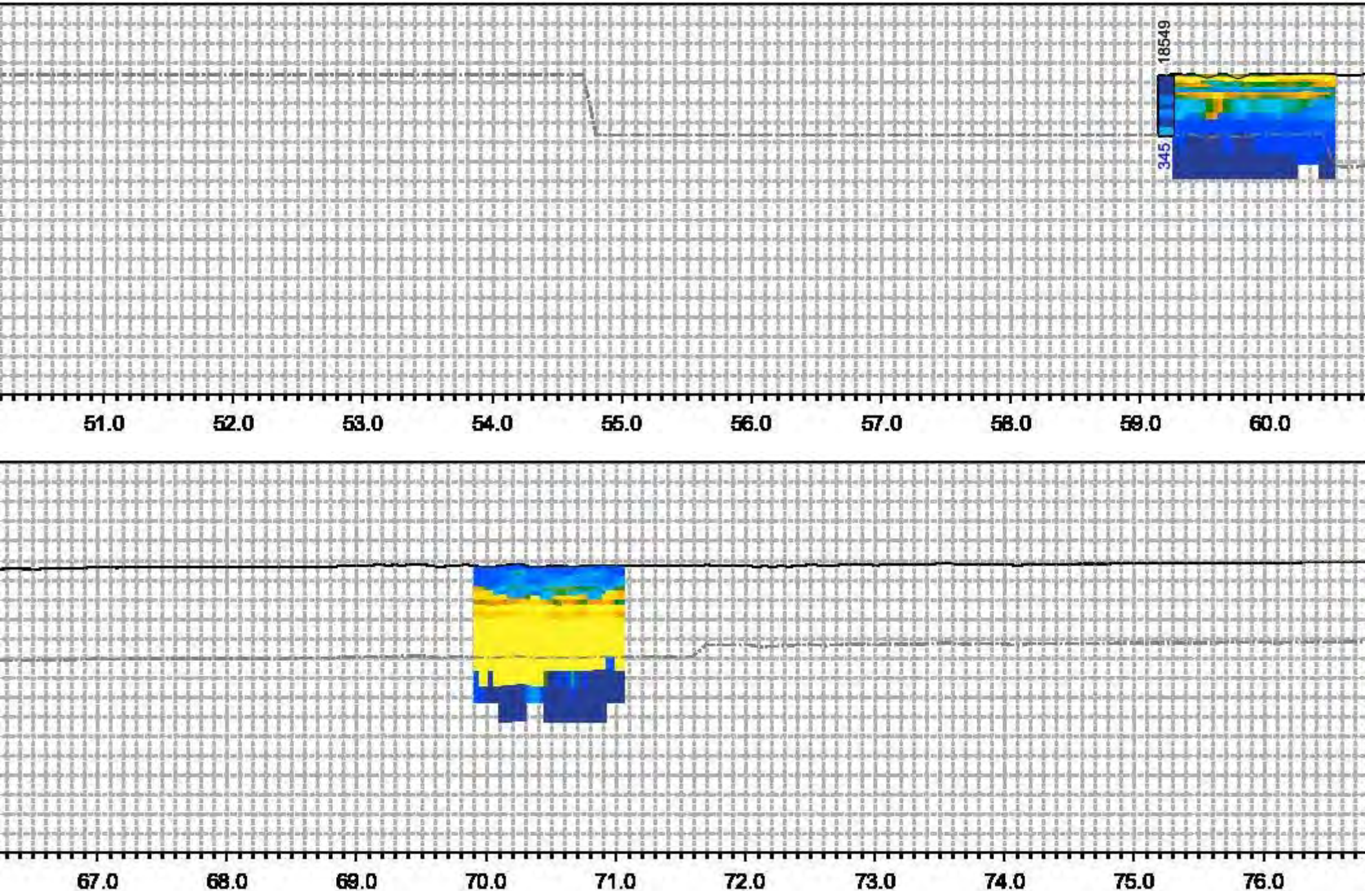
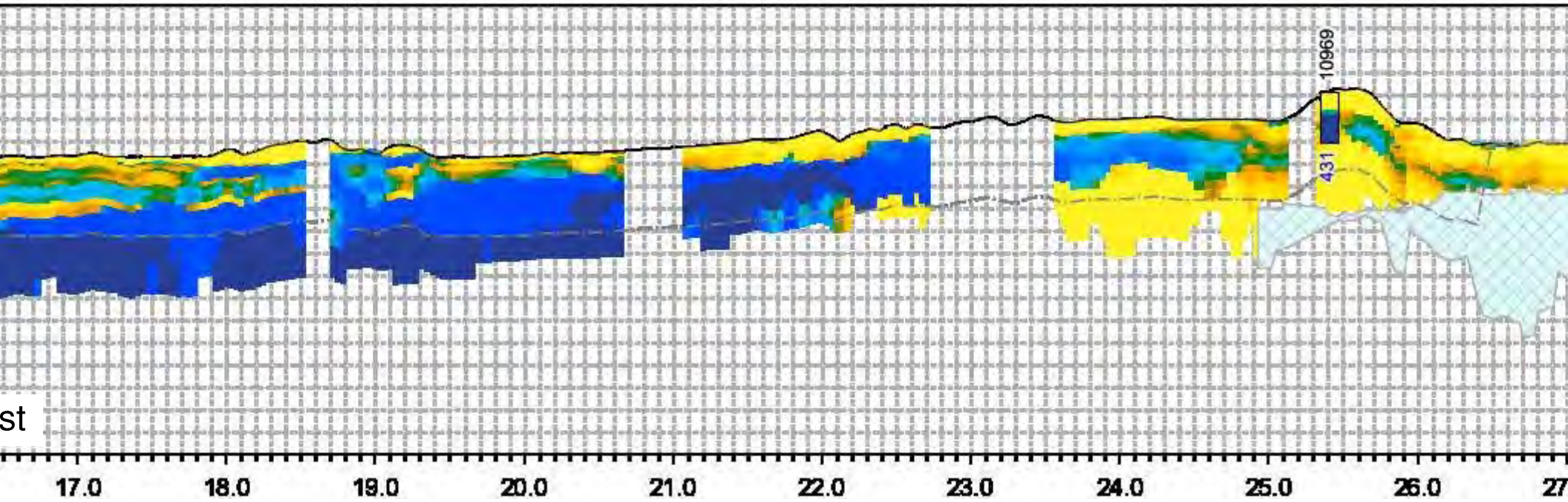
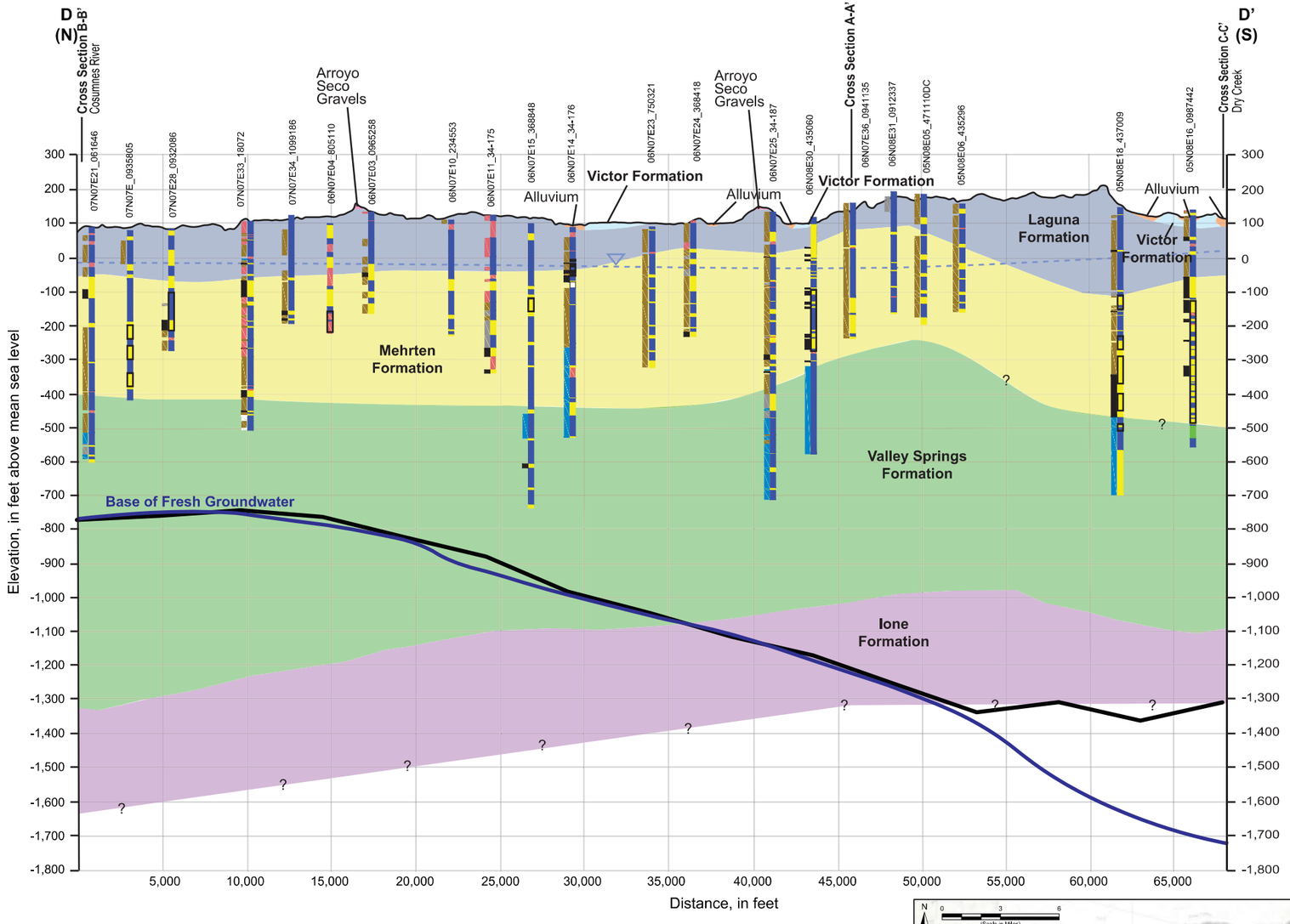
C - C' Nearest AEM Log

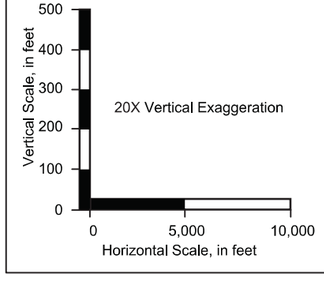


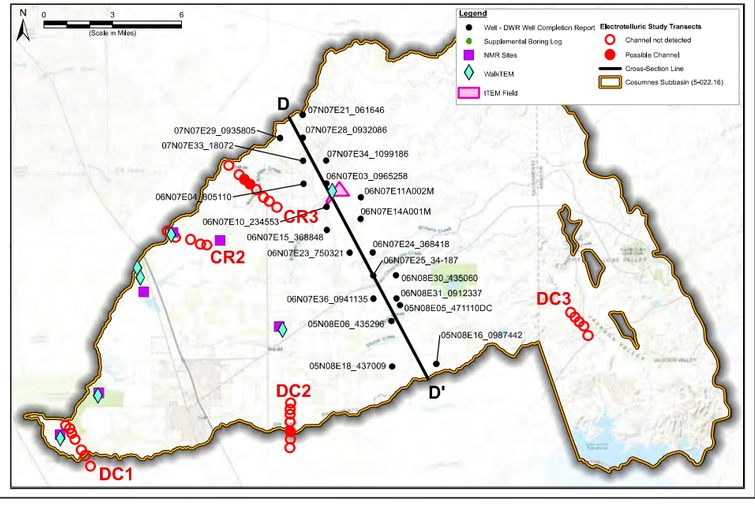
C - C' Nearest AEM Log, South West



South West AEM Log is NOT continuous with previous log.







Legend:

Wells

Well Identification
DWR Well Completion Report Number
Section
Range
Township

06N08E14_435140

Lithology - Derived from Well Logs

Generalized Texture
- Fine-Grained Materials (i.e., clay, silt)
- Fine Sand
- Sand
- Gravel
- Volcanic
- Well Screen

Color
- Gray
- Brown/Tan
- Black
- Blue
- Red
- Green
- White
- Yellow

Selected Subsurface Geologic Units (See Note 2)

- Alluvium
- Undifferentiated Victor Formation
- Laguna Formation
- Mehrten Formation
- Valley Springs Formation
- Ione Formation
- Arroyo Seco Gravels
- Base of Fresh Groundwater (Berkstresser, 1973)
- Basin Bottom
- Groundwater Elevation - Fall 2018

Abbreviations:

DWR = California Department of Water Resources
USGS = United States Geological Survey

Sources:

1. USGS 10-Meter Digital Elevation Model (https://viewer.nationalmap.gov/basic/).
2. Dawson T, 2009, Preliminary Geologic Map of the Lodi 30' x 60' Quadrangle, California. California Geological Survey.
3. Holland PJ, 2016, Preliminary Geologic Map of the Irish Hill 7.5' Quadrangle, Amador County, California. Version 1.0. California Geological Survey.
4. DWR, 1974, Evaluation of Ground Water Resources: Sacramento County. Bulletin No. 118-3, July 1974 (Reprinted April 1980).
5. Piper AM, Gale HS, Thomas HE, Robinson TW, 1939, "Geology and Ground-Water Hydrology of the Mokelumne Area, California." USGS Water-Supply Paper 780.
6. Berkstresser, 1973, "Base of Fresh Ground Water in the Sacramento Valley and Sacramento-San Joaquin Delta, California." USGS WRI 40-73.
7. Page RW, 1974, Base and thickness of the post-Eocene continental deposits in the Sacramento Valley, California, USGS WRI 45-73.
8. Chapman RH and Bishop CC, 1975, Geophysical Investigations in the Ione Area, Amador, Sacramento, and Calaveras Counties, California, California Division of Mines and Geology Special Report 117.

Notes:

1. Well identification based on Public Land Survey System.
2. Subsurface geologic units based on DWR (1974) cross-section G-G', surficial geologic maps (Dawson, 2009; Holland, 2016; Piper and others, 1939), contours representing the top of Ione Formation (Page 1974), and informed by lithology derived from DWR Well Completion Report records. Contacts are queried where uncertain.
3. Wells shown on cross-section are located within 1 mile of cross-section line.
4. Groundwater elevation is based on groundwater elevation contours for Fall 2018, as mapped on Figure GWC-2.
5. Basin bottom is based on depth to bottom of the Basin as mapped on Figure HCM-3.

Geologic Cross-Section D - D'

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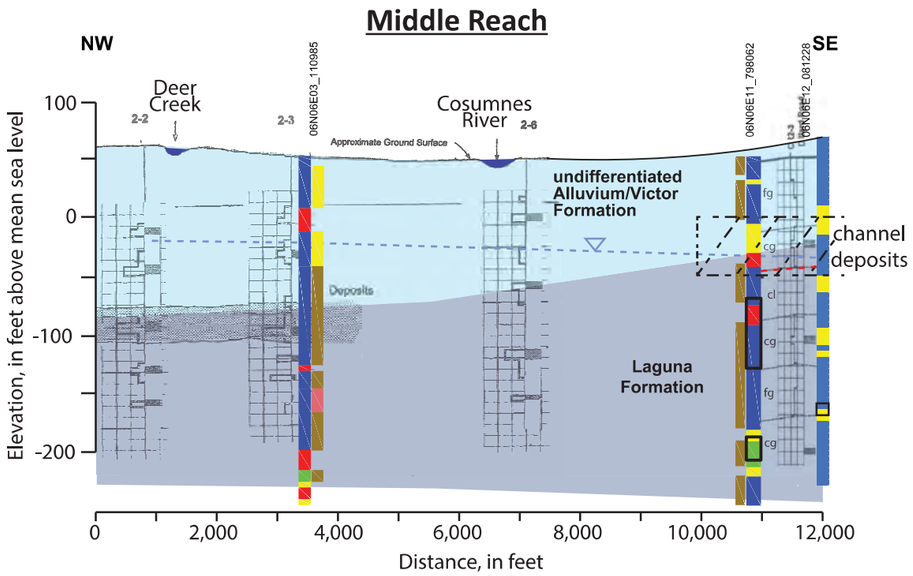
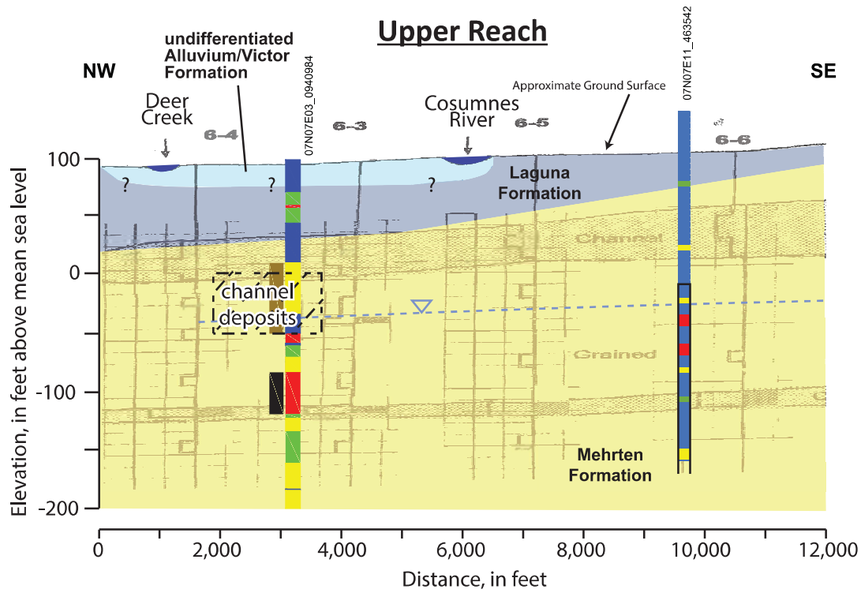
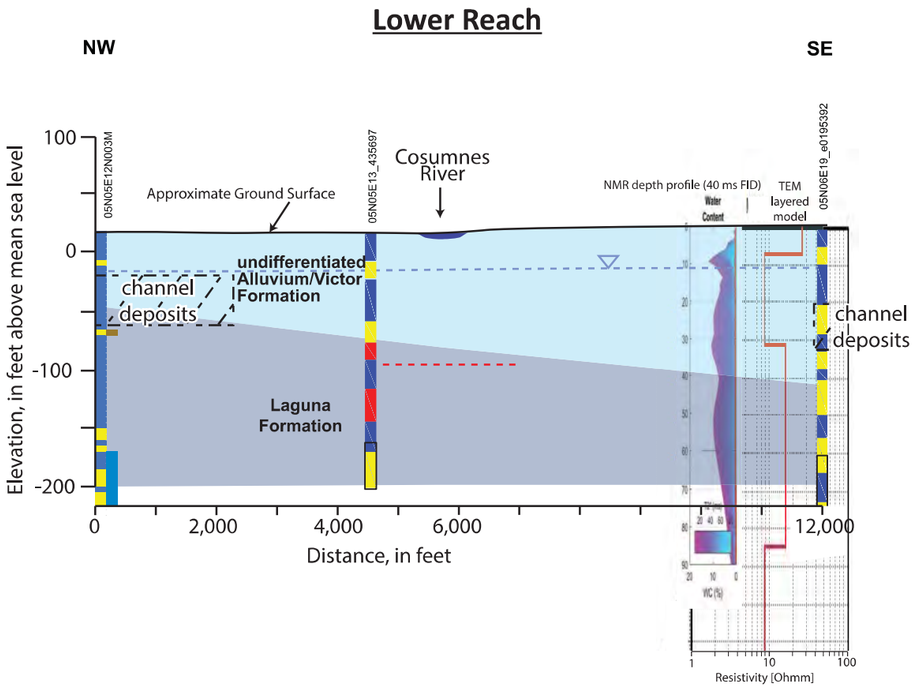
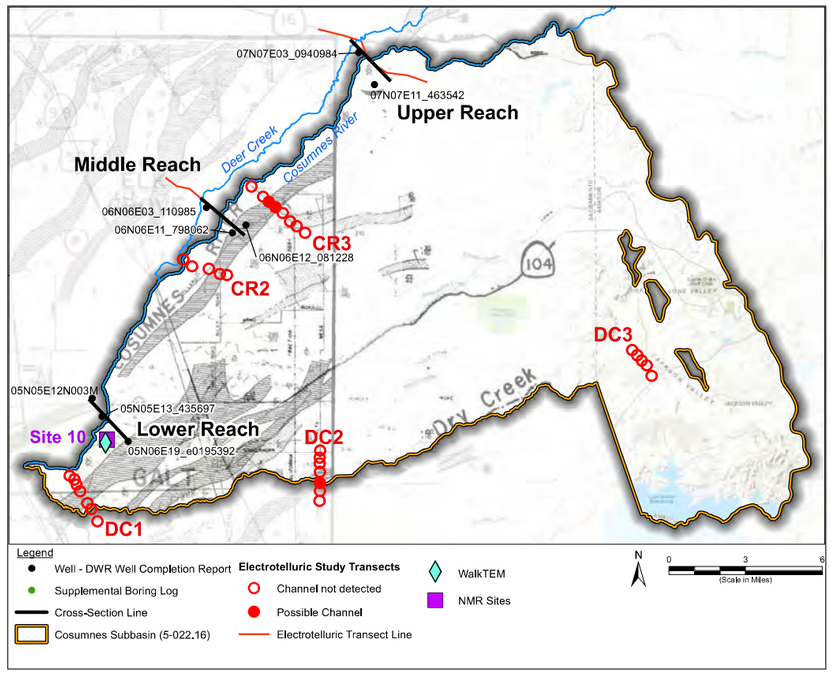
Cosumnes Subbasin
December 2021
B80081.00

Figure HCM-18



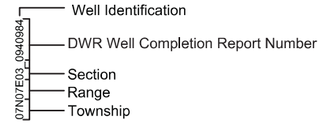






Legend:

Wells



Lithology - Derived from Well Logs

Generalized Texture

- Fine-Grained Materials (i.e., clay, silt)
- Fine Sand
- Sand
- Gravel
- Well Screen

Color

- Brown/Tan
- Black
- Blue
- Red
- Yellow

Selected Subsurface Geologic Units (See Note 6)

- Undifferentiated Alluvium/Victor Formation
- Laguna Formation
- Mehrten Formation
- Groundwater Elevation - Fall 2018
- Top of Clay Interval inferred from Electrotelluric Survey (ETS, See Note 3)

Abbreviations:

DWR = California Department of Water Resources
NMR = Nuclear Magnetic Resonance
TEM = Transient Electro Magnetics
USGS = United States Geological Survey

Sources:

1. USGS 10-Meter Digital Elevation Model (https://viewer.nationalmap.gov/basic/).
2. Geoconsultants, Inc., 2016, Geological and Geophysical Survey for Proposed Basin Boundary Adjustment Sloughhouse Resource Conservation District Sacramento County, California. Prepared for Jay Schneider Vice-Chairman Sloughhouse Resource Conservation District, dated March 2016.
3. DWR, 1974, Evaluation of Ground Water Resources: Sacramento County. Bulletin No. 118-3, July 1974 (Reprinted April 1980).
4. Piper AM, Gale HS, Thomas HE, Robinson TW, 1939, "Geology and Ground-Water Hydrology of the Mokelumne Area, California." USGS Water-Supply Paper 780.
5. Dawson T, 2009, Preliminary Geologic Map of the Lodi 30' x 60' Quadrangle, California. California Geological Survey.
6. Geoconsultants, Inc., 2020, Hydrogeologic Study using Electrotelluric Transects Cosumnes Groundwater Subbasin Sacramento, San Joaquin, and Amador Counties, California.
7. Vista Clara Inc., 2021, Surface NMR Survey Cosumnes River Basin.
8. Ramboll, 2021, TEM Geophysical Investigations Cosumnes tTEM & WalkTEM Surveys.

Notes:

1. Middle reach cross section falls along Electrotelluric Transect 2 (Geoconsultants, Inc., 2016). Electrotelluric Survey Transect CR2-3 (Geoconsultants, Inc., 2020) is projected onto middle reach cross section.
2. Upper reach cross section falls along Electrotelluric Transect 6 (Geoconsultants, Inc., 2016).
3. Groundwater elevation is based on depth to groundwater contours for Fall 2018, as mapped on Figure GWC-4.
4. Channel deposit extents and approximate elevations inferred from Figure 3 and Figure 5 in DWR, 1974.
5. Well identification based on Public Land Survey System.
6. Subsurface geologic units based on DWR (1974) cross-section intersections, surficial geologic maps (Dawson, 2009; Piper and others, 1939), and informed by lithology derived from DWR Well Completion Report records. Contacts are queried where uncertain.
7. Electrotelluric Survey (Geoconsultants, Inc., 2020), NMR (Vista Clara Inc., 2021), and WalkTEM (Ramboll, 2021) are included as Appendix I.

Cosumnes River Focused Cross Sections

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Cosumnes Subbasin
December 2021
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Figure HCM-19

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Delta-Mendota Groundwater Subbasin

Groundwater Sustainability Plan: Revised Common Chapter

Prepared by:

WOODARD &CURRAN

August 2019; Revised June 2022

4.1.6 Definable Bottom of Basin

In the San Joaquin Valley, the bottom of the Delta-Mendota Subbasin is defined as the interface of saline water of marine origin (base of fresh water) within the uppermost beds of the Tulare Formation. The Tulare Formation is characterized by blue and green fine-grained rocks and principally composed of fine-grained silty sands, silt, and clay (Foss and Blaisdell 1968). The Tulare Formation is predominantly marine in origin and is considered late Pliocene and possibly early Pleistocene in age. This formation is the upper shaley part of the Pliocene sequence. The top of the Tulare Formation is generally encountered around -2,000 feet mean sea level throughout the Delta-Mendota Subbasin. As agreed upon by the Delta-Mendota Subbasin GSP Groups, the base of freshwater is specifically defined by an electrical conductivity of 3,000 micromhos per centimeter at 25 °C, as presented by Page (1973). If and when significant use of water beyond the defined bottom takes place, the definition of the bottom will be revised appropriately.

4.1.7 Principal Aquifers and Aquitards

DWR's Groundwater Glossary defines an aquifer as "a body of rock or sediment that is sufficiently porous and permeable to store, transmit, and yield significant or economic quantities of groundwater to wells, and springs". There are two primary aquifers within the Delta-Mendota Subbasin: a semi-confined aquifer above the Corcoran Clay and a confined aquifer below the Corcoran Clay, with the Corcoran Clay acting as the principal aquitard within the Delta-Mendota Subbasin. **Figure CC-24** shows the locations of the representative cross-sections for the Delta-Mendota Subbasin, where **Figure CC-25** through **Figure CC-30** show the hydrostratigraphy of the representative cross-sections.

While the two-aquifer system described above is generally true across the Delta-Mendota Subbasin, there are portions of the Subbasin where the Corcoran Clay does not exist (predominantly along the western margin of the Subbasin) and hydrogeology is generally controlled by localized interfingering clays, and/or where local hydrostratigraphy results in shallow groundwater conditions that differ, to some extent, from that seen in the Subbasin as a whole. Additionally, in the southern portion of the Subbasin in the Mendota, Aliso and Tranquillity areas, there are A and C Clay layers in addition to the Corcoran Clay that inhibit vertical groundwater flow. However, while there are localized complexities throughout the Subbasin, the Corcoran Clay (or E Clay) extends through much of the Delta-Mendota Subbasin, generally creating a two-aquifer system.

Principal Aquifers

In the Delta-Mendota Subbasin, there are two primary aquifers composed of alluvial deposits separated by the Corcoran Clay (KDSA, 2015): a semi-confined Upper Aquifer (generally the ground surface to the top of the Corcoran Clay), and a confined Lower Aquifer starting at the bottom of the Corcoran Clay to the base of fresh water. However, as previously described, the localized presence of the A and C Clay layers in the southern portion of the Subbasin, the absence of the Corcoran Clay at the western margin of the Subbasin, and/or local hydrostratigraphy result in differing shallow groundwater conditions and/or perched groundwater conditions in some portions of the Subbasin. See the individual GSPs for more detailed descriptions of hydrostratigraphy in the respective Plan areas.

Upper Aquifer

The Upper Aquifer is represented by materials extending from the upper groundwater table to the top of the Corcoran Clay. The Upper Aquifer includes shallow geologic units of younger and older alluvium and upper parts of the Tulare Formation. Sediments within the upper Tulare Formation have variable sources, and subdivision of units can be distinguished between eastern and western sourced materials. Alluvial fan materials above the Corcoran Clay in the Delta-Mendota Subbasin are generally more extensive than older alluvial fan deposits within the Tulare Formation below the Corcoran Clay. As shown in Figure CC-31 by the depth to the top of the Corcoran Clay, the Upper Aquifer extends to depths ranging between approximately 150 feet and greater than 350 feet. Other notable mapped clay units also exist within the upper part of the Tulare Formation in the Delta-Mendota Subbasin, including the A and C Clay members of the Tulare Formation and a white clay mapped by Hotchkiss and Balding (1971).

Lower Aquifer

The Lower Aquifer is the portion of the Tulare Formation that is confined beneath the Corcoran Clay, extending downward to the underlying San Joaquin Formation and the interface of saline water of marine origin within its uppermost beds. The Lower Aquifer is generally characterized by groundwater that tends to be dominantly sodium-sulfate type, which is often of better quality than the Upper Aquifer (Davis et al., 1957; Hotchkiss and Balding, 1971). Exceptions to this quality do exist in the Subbasin, particularly in the southwestern portion of the Subbasin. Because of its relatively shallow depth within the Delta-Mendota Subbasin and lower salinity in areas when compared to other groundwater resources, the Lower Aquifer is heavily utilized as a source of groundwater for agricultural and drinking water uses within the Subbasin.

The base of the Lower Aquifer generally decreases from south to north, changing in depth from about 1,100 to 1,200 feet deep in the south to about 600 feet to the north. Depth to the top of the Corcoran Clay ranges from less than 100 feet on the west near Interstate 5 (I-5) to more than 500 feet in the area near Tranquillity. The Corcoran Clay pinches out or is above the water level near the California Aqueduct in the western part of the Subbasin, where the Upper and Lower Aquifers merge into interfingered layers of sand, gravel, and clay.

Corcoran Clay

The Corcoran Clay, as a regional aquitard, is a notable hydrogeologic feature throughout most of the Delta-Mendota Subbasin, impeding vertical flow between the Upper and Lower Aquifers. The Corcoran Clay is present at varying depths across most of the Central Valley floor (**Figure CC-31** and **Figure CC-33**). The depths to the top of the Corcoran Clay ranges between approximately 100 and 500 feet below the ground surface throughout most of the Subbasin, with a general spatial pattern of deepening to the south and east. In the far southeastern area of the Subbasin, in the vicinity of Mendota and Tranquillity, the top of the Corcoran Clay is at depths of greater than 350 feet (**Figure CC-31**). The thickness of the Corcoran Clay, which likely influences the degree of hydraulic separation between the Upper and Lower Aquifers, is greater than 50 feet across most of the Delta-Mendota Subbasin with thicknesses of more than 75 feet in central Subbasin areas in the vicinity of Los Banos and Dos Palos, and 140 feet in the eastern portions of the Subbasin. The Corcoran Clay appears thinner in areas north of Patterson, between Patterson and Gustine, and also in the vicinity of Tranquillity to the south (**Figure CC-33**). Along the westernmost portions of the Delta-Mendota Subbasin, the Corcoran Clay layer is generally non-existent or it exists as Corcoran-equivalent clays (clays existing at the same approximate depth but not part of the mapped aquitard).

Aquifer Properties

The following subsections include discussion of generalized aquifer properties within the Delta-Mendota Subbasin. These include hydraulic conductivity, transmissivity, specific yield and specific storage.

DWR defines hydraulic conductivity as the "measure of a rock or sediment's ability to transmit water" and transmissivity as the "aquifer's ability to transmit groundwater through its entire saturated thickness" (DWR, 2003). High hydraulic conductivity values correlate with areas of transmissive groundwater conditions with transmissivity generally equaling hydraulic conductivity times the saturated thickness of the formation. Storage of water within the aquifer system can be quantified in terms of the specific yield for unconfined groundwater flow and the storage coefficient for confined flow, respectively (Faunt et al., 2009). Specific yield represents gravity-driven dewatering of shallow, unconfined sediments at a declining water table, but also accommodates a rising water table. The specific yield is dimensionless and represents the volume of water released from or taken into storage per unit head change per unit area of the water table. Specific yield is a function of porosity and specific retention of the sediments in the zone of water-table fluctuation.

Where the aquifer system is confined, storage change is governed by the storage coefficient, which is the product of the thickness of the confined-flow system and its specific storage. The specific storage is the sum of two component specific storages – the fluid (water) specific storage and the matrix (skeletal) specific storage, which are governed by the compressibility of the water and skeleton, respectively (Jacob, 1940). Specific storage has units of 1 over length and represents the volume of water released from or taken into storage in a confined flow system per unit change in head per unit volume of the confined flow system (Faunt et al., 2009). Therefore, the storage coefficient of a confined flow system is dimensionless and, similar to specific yield, represents the volume of water released from or taken into storage per unit head change.

Hydraulic Conductivity

Figure CC-34 shows the saturated C-horizon hydraulic conductivity of surficial soils within the Delta-Mendota Subbasin based on the National Resource Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO). Soil survey data for counties within the Subbasin were combined using the weighted harmonic mean of these representative layers to depict the saturated hydraulic conductivity of the C-horizon for each soil map unit. The soil profile represented by these data is variable but commonly extends to a depth of six or more feet.

Floodplain deposits are evident as soils with relatively low hydraulic conductivity (less than 0.5 feet per day [ft/day]) blanket much of the Central Valley Floor, although localized areas of soils with higher hydraulic conductivity are present in association with modern and ancient surface waterways and alluvial fan features (**Figure CC-34**). Coarse soils of distributary alluvial fan sediments deposited by Del Puerto Creek, Orestimba Creek, Los Banos Creek, Ortigalita Creek, and Little Panoche Creek, in addition to other ephemeral northeasterly creek flows off the Coast Ranges, are notably apparent as areas of soils of high hydraulic conductivity located along active and inactive stream channels extending eastward from the fan apex areas along the Valley Floor margins to the current alignment of the San Joaquin River in the valley axis. Additionally, soils in areas adjacent to the active channel of the San Joaquin River also exhibit high hydraulic conductivities, including values of greater than 4 ft/day which are particularly apparent in an area north of Mendota. Soils of similarly high hydraulic conductivity trending as linear features in a general northwest-southeast alignment to the north of Dos Palos and Los Banos are likely the result of historical depositional processes and paleochannels associated with the San Joaquin River (**Figure CC-34**). In areas peripheral to the Central Valley floor, soils tend to be characterized by relatively low hydraulic conductivity, although soils of somewhat higher hydraulic conductivity

associated with distinct geologic units are mapped across much of the peripheral area to the west of Patterson and Gustine and also in localized bands associated with surface water courses.

Transmissivity

Transmissivity varies greatly above the Corcoran Clay, within the Corcoran Clay, and below the Corcoran Clay within the Delta-Mendota Subbasin, with transmissivities in the confined Lower Aquifer generally being larger than those in the semi-confined Upper Aquifer. Based on testing conducted at multiple locations within both the Upper and Lower Aquifers of the Delta-Mendota Subbasin, average transmissivities in the Subbasin are approximately 109,000 gallons per day per square foot (gpd/ft^2) (KDSA, 1997b).

Specific Yield

DWR defines specific yield as the "amount of water that would drain freely from rocks or sediments due to gravity and describes the proportion of groundwater that could actually be available for extraction" (DWR, 2003). Specific yield is a measurement specific to unconfined aquifers.

The estimated specific yield of the Delta-Mendota Subbasin is 0.118 (DWR, 2006). Within the southern portion of the Delta-Mendota Subbasin, specific yield ranges from 0.2 to 0.3 (Belitz et al., 1993). Specific yield estimates for the Delta-Mendota Subbasin are fairly limited in literature since the Upper Aquifer above the Corcoran Clay is semi-confined and the Lower Aquifer below the Corcoran Clay is confined. Therefore, specific yield values only characterize the shallow, unconfined groundwater within the Subbasin.

Specific Storage

Values for specific storage were extracted from the Central Valley Hydrologic Model 2 (CVHM2), which is currently under development by the United States Geological Survey (USGS) and includes refinements for the Delta-Mendota Subbasin. Specific storage varies above, within, and below the Corcoran Clay with CVMH2. Above the Corcoran Clay, specific storage ranges from 1.34×10^{-6} to 6.46×10^{-2} $meters^{-1}$ (m^{-1}) with average values ranging from 6.16×10^{-3} to 1.97×10^{-2} m^{-1}. Specific storage within the Corcoran Clay is considerably smaller than above the Corcoran Clay, ranging between 1.41×10^{-6} and 2.35×10^{-6} m^{-1} and average values between 1.96×10^{-6} and 2.02×10^{-6} m^{-1}. Below the Corcoran Clay, specific storage is comparable to within the Corcoran Clay with overall ranges the same as within the Corcoran Clay and average values ranging from 1.86×10^{-6} to 2.01×10^{-6} m^{-1}. Therefore, specific storage is greatest within the semi-confined aquifer overlying the Corcoran Clay layer, with considerably smaller specific storage values within the low permeability Corcoran Clay and confined aquifer underlying the Corcoran Clay layer.

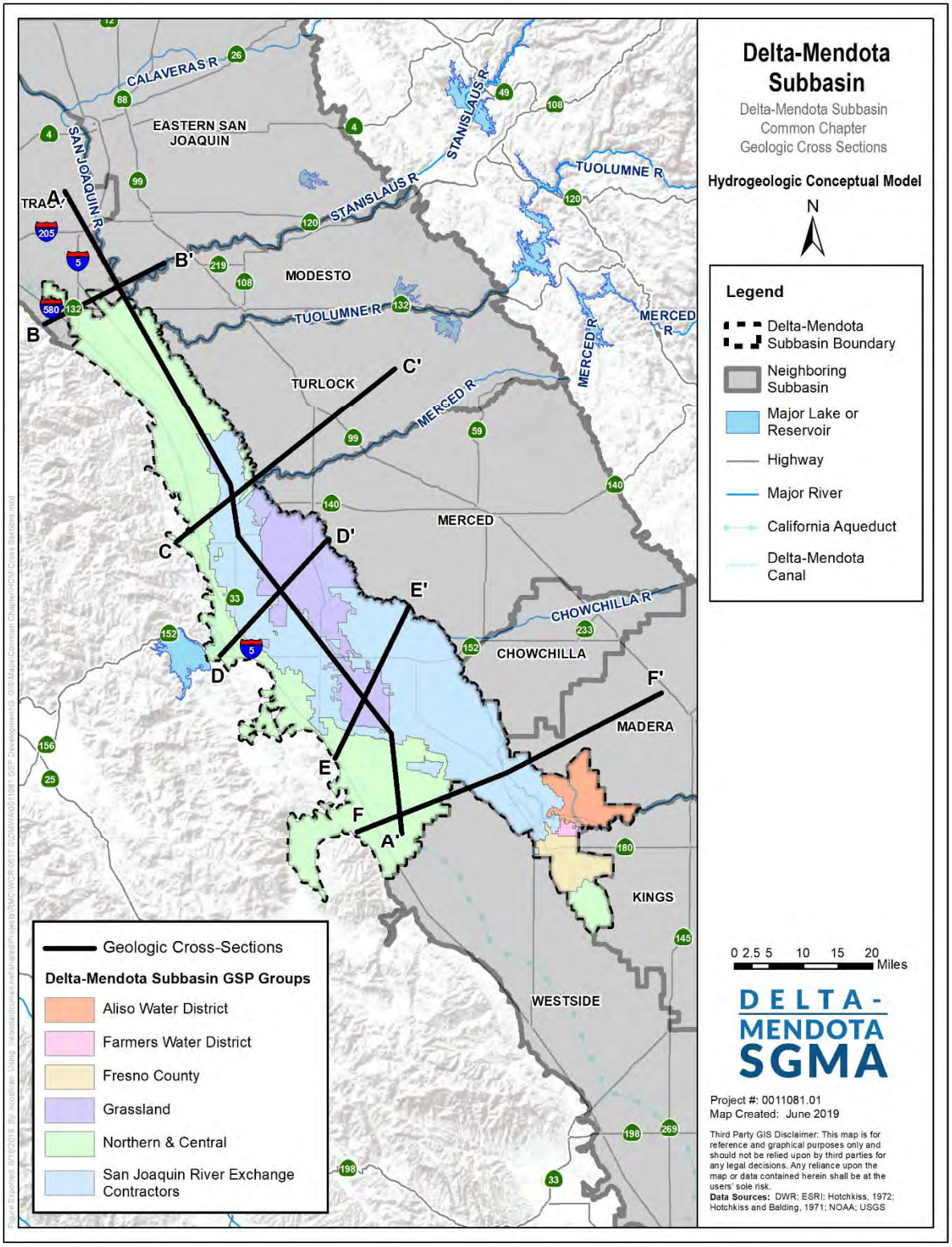


Figure CC-24: Representative Cross-Sections

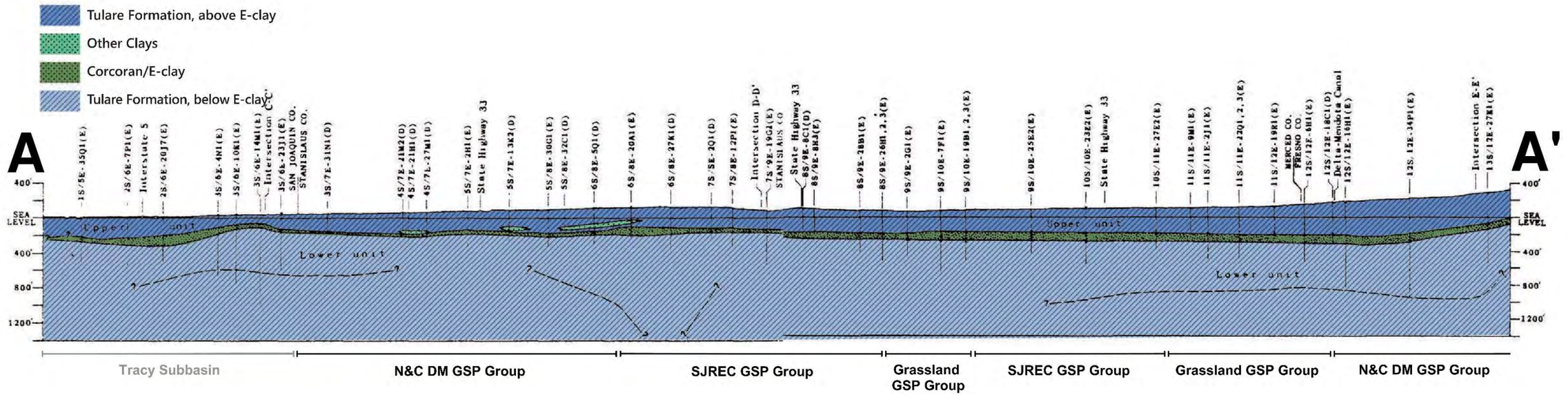
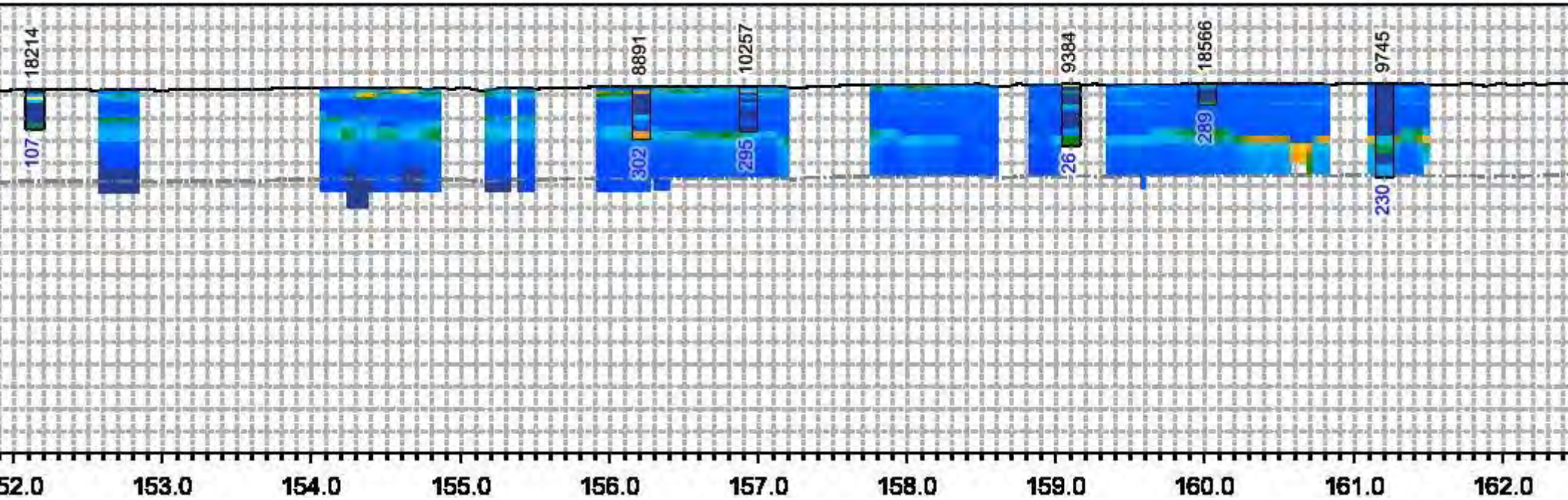
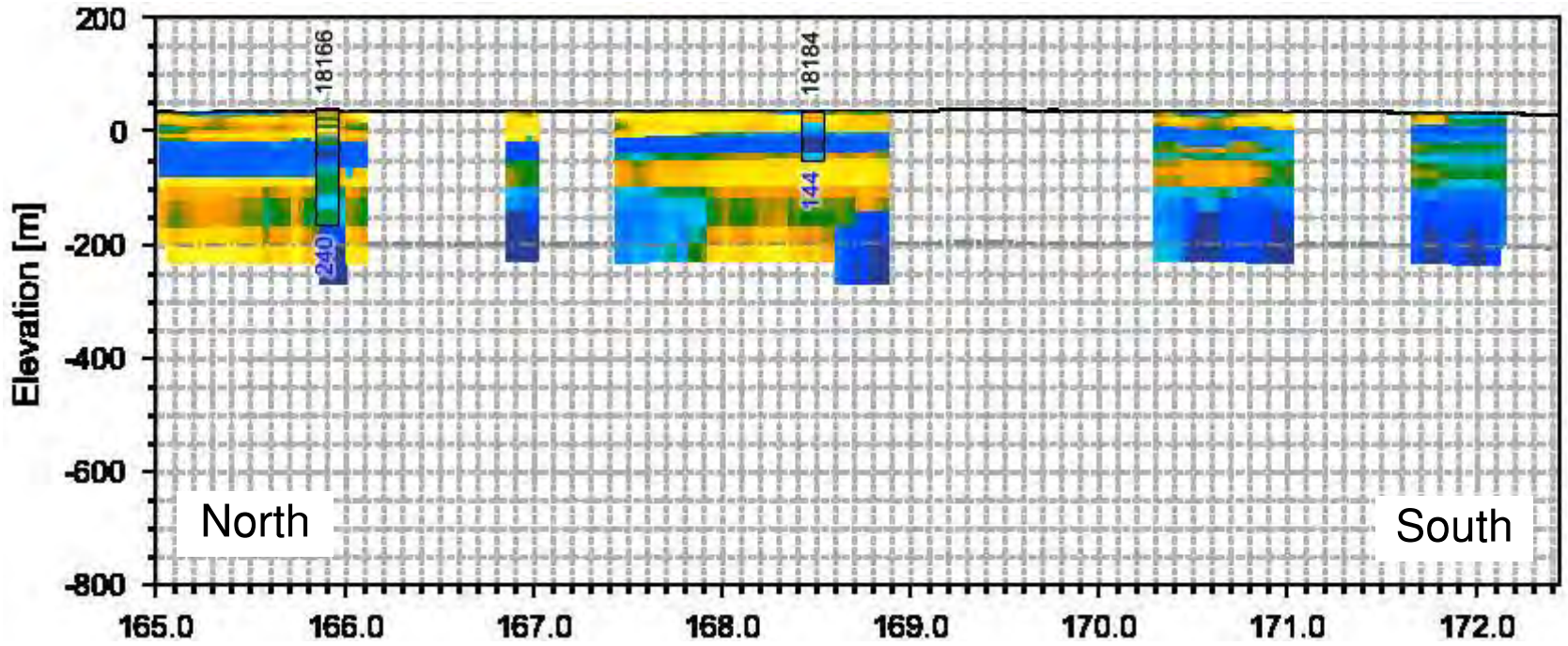


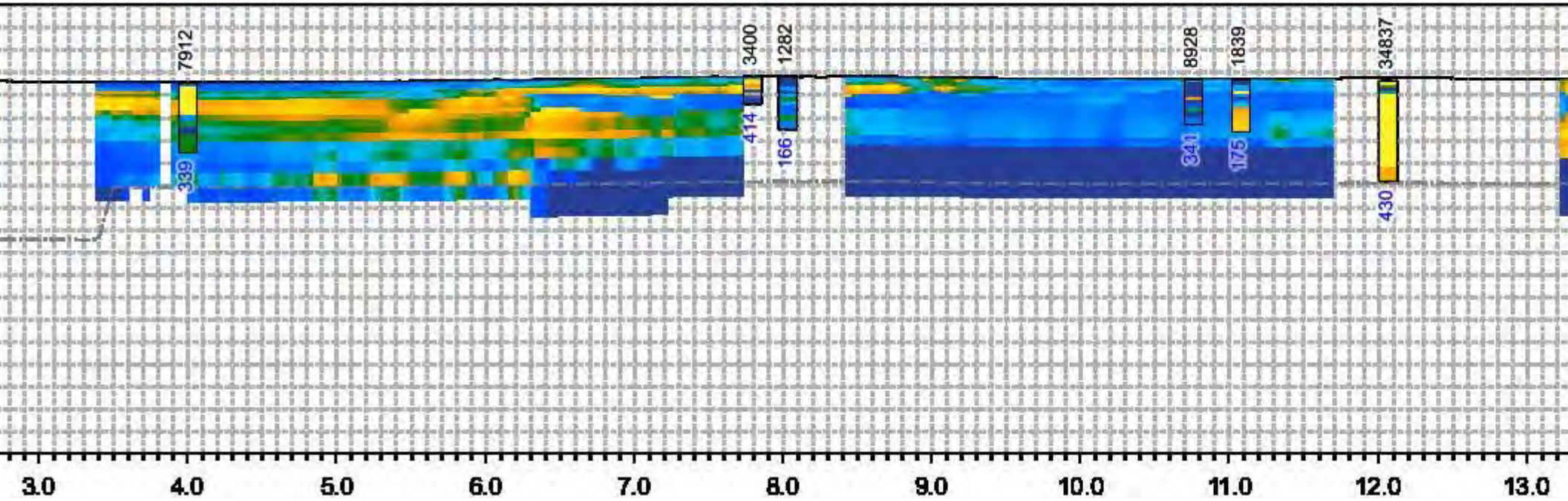
Figure CC-25: Cross-Section A-A' (Hotchkiss, 1972)

A - A' Nearest AEM Log

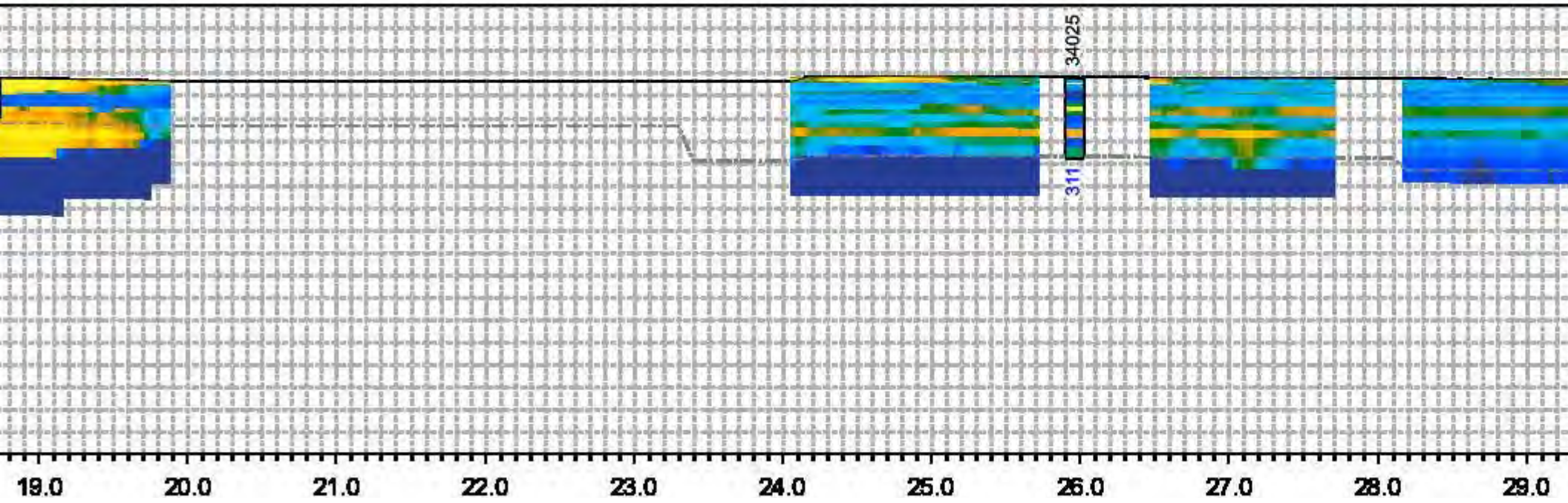




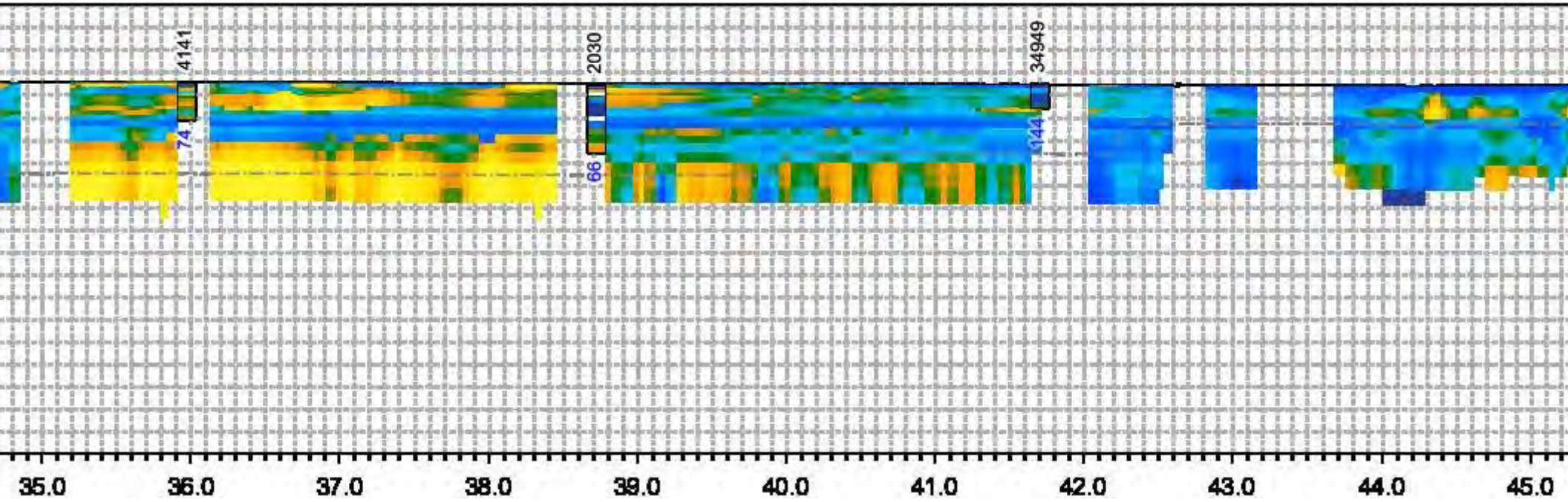
A - A' Nearest AEM Log

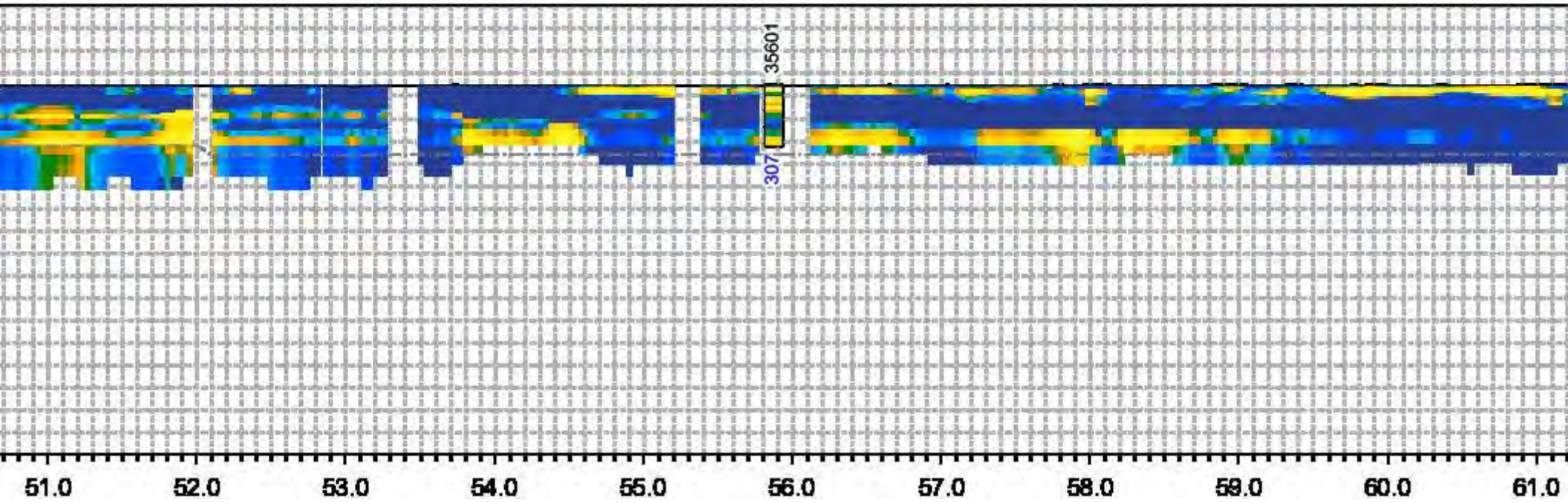


This AEM log is NOT continuous with the previous AEM log.

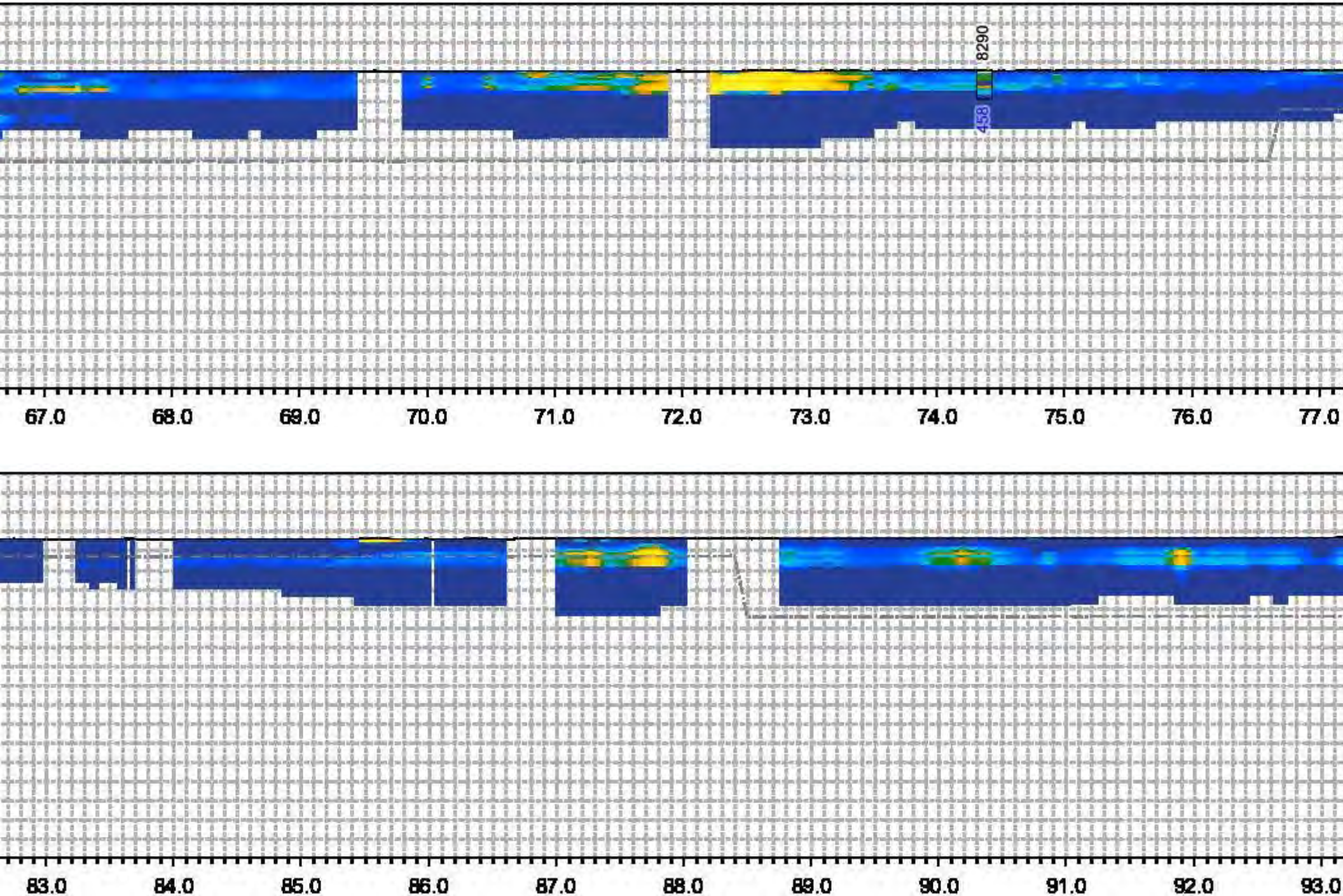


A - A' Nearest AEM Log

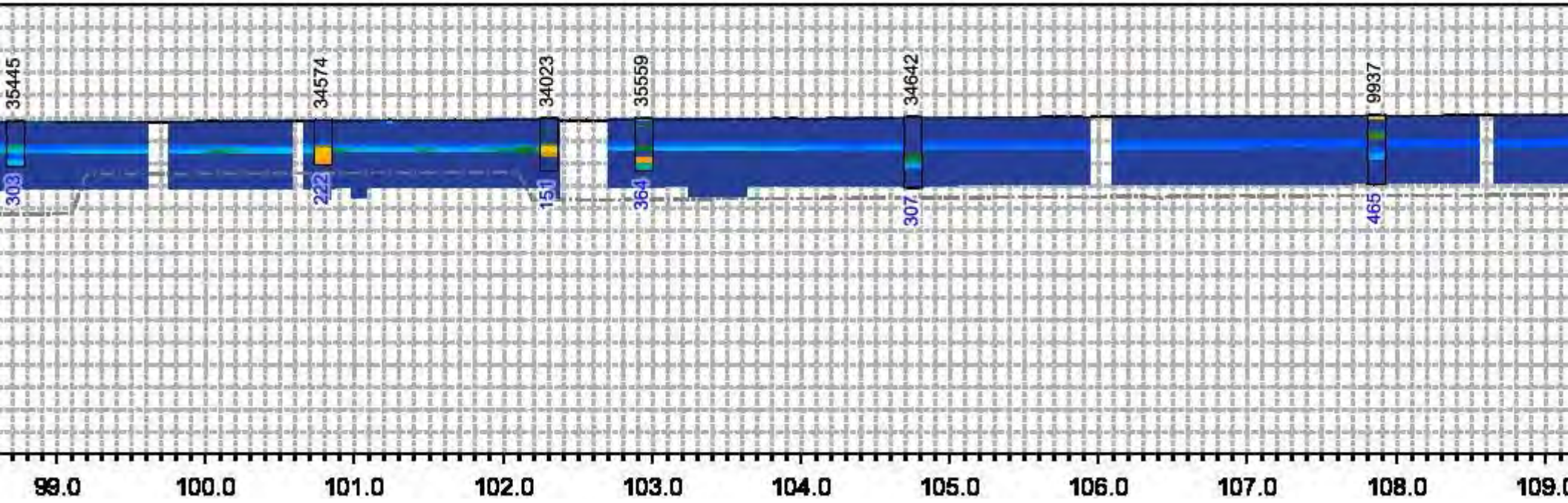


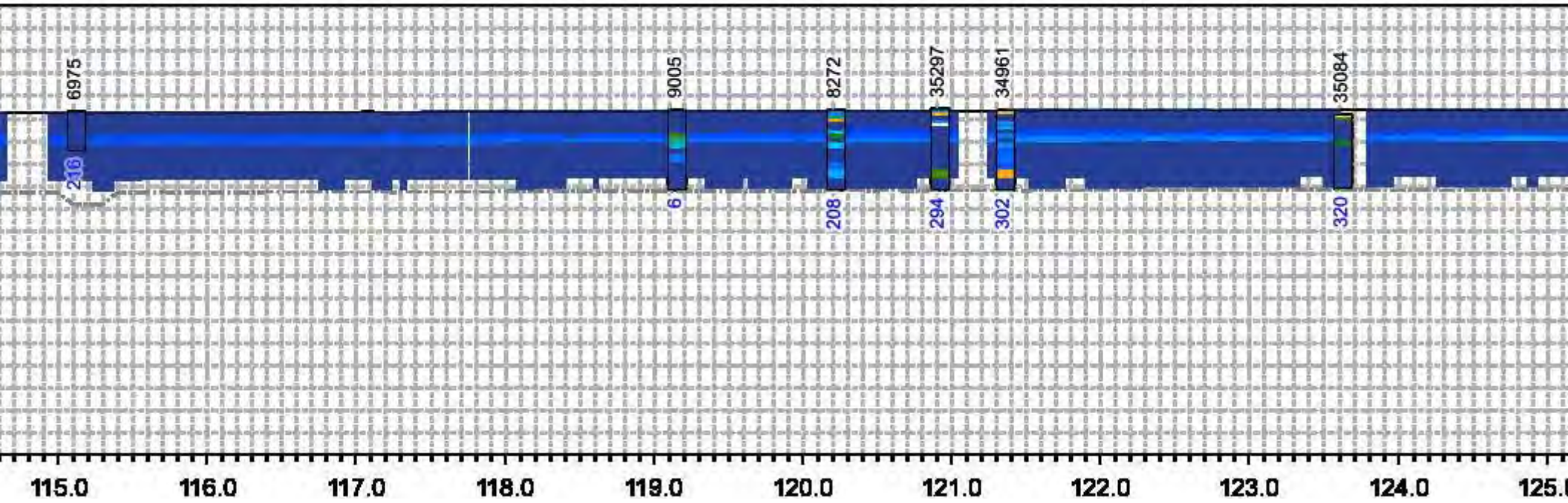


A - A' Nearest AEM Log



A - A' Nearest AEM Log





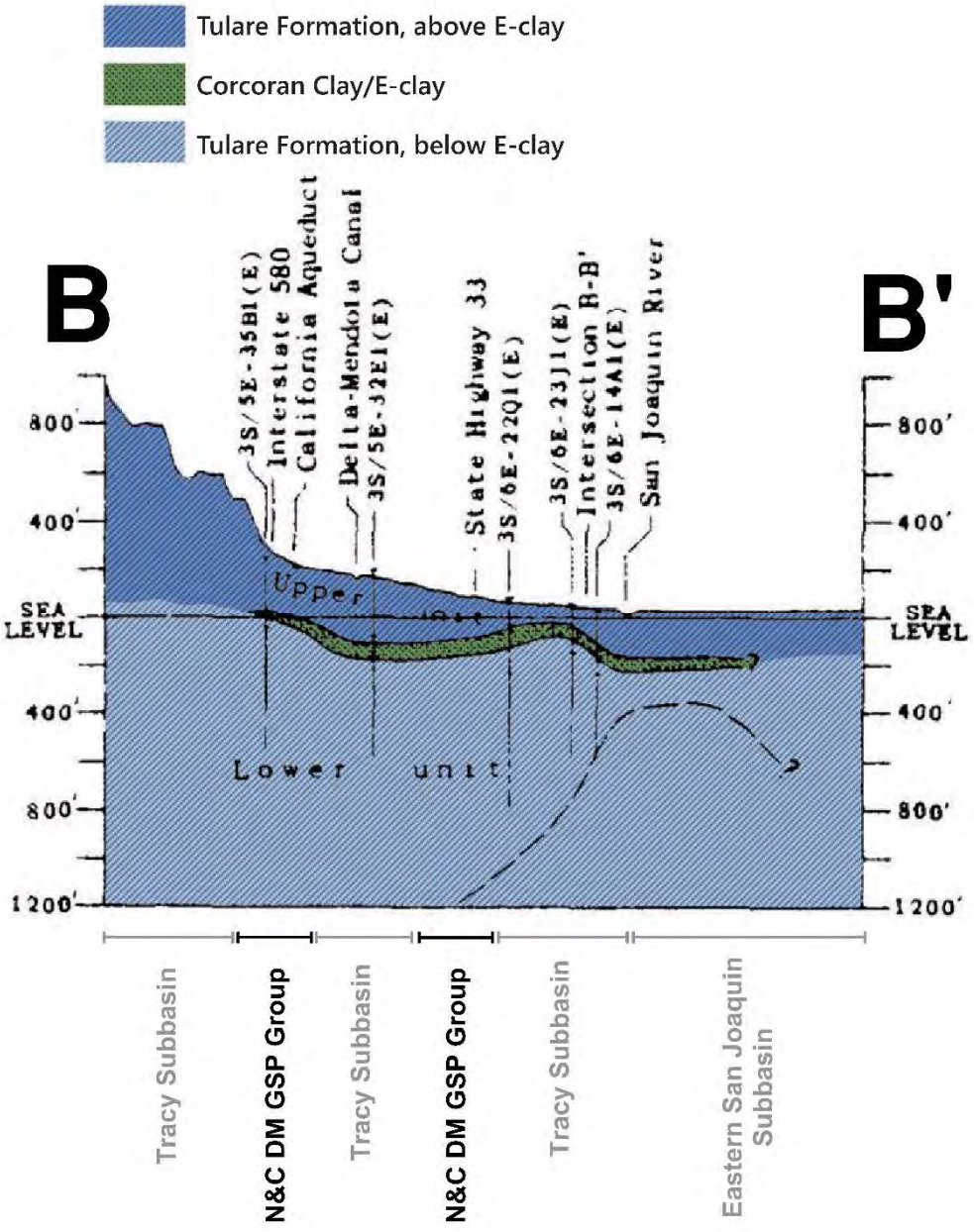


Figure CC-26: Cross-Section B-B' (Hotchkiss, 1972)

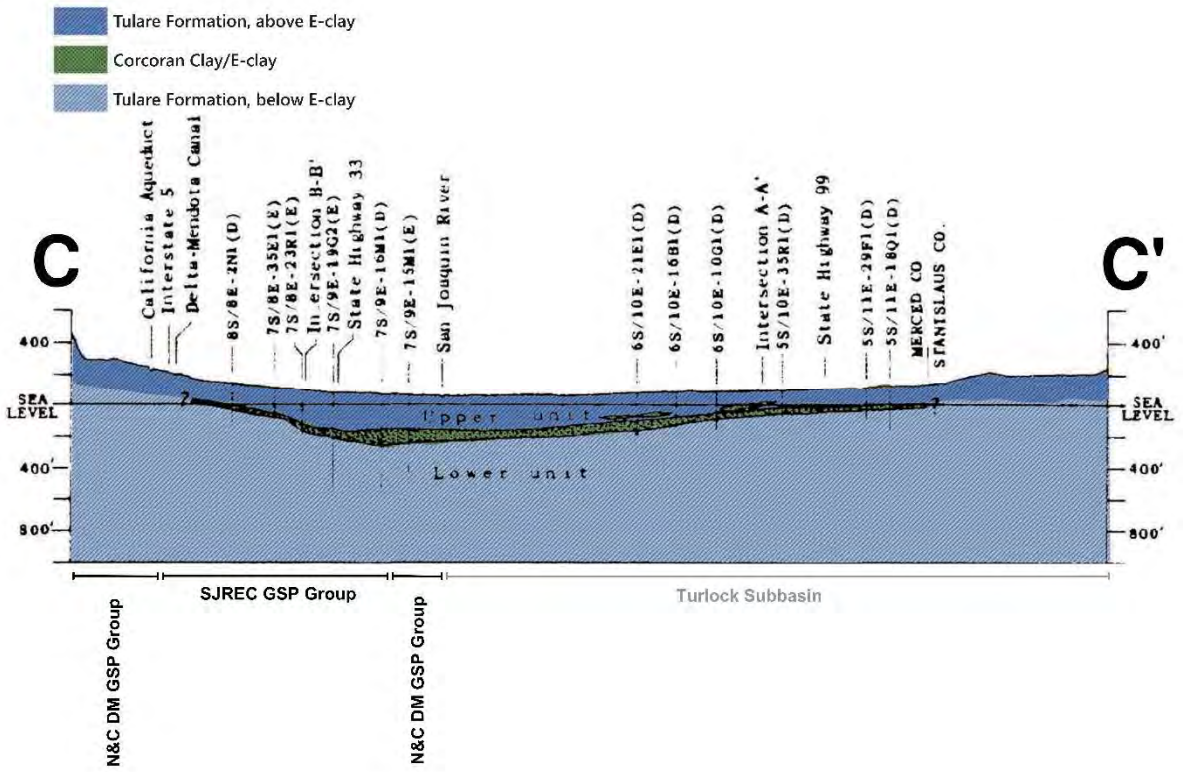


Figure CC-27: Cross-Section C-C' (Hotchkiss, 1972)

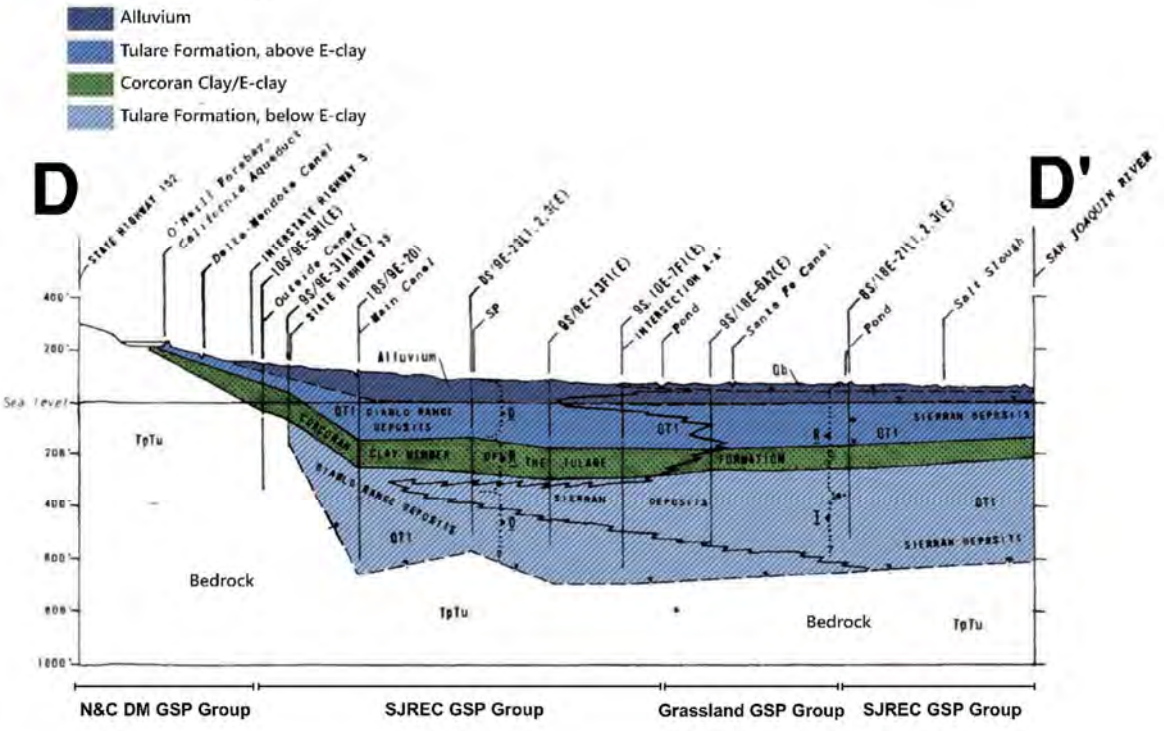


Figure CC-28: Cross-Section D-D' (Hotchkiss & Balding, 1971)

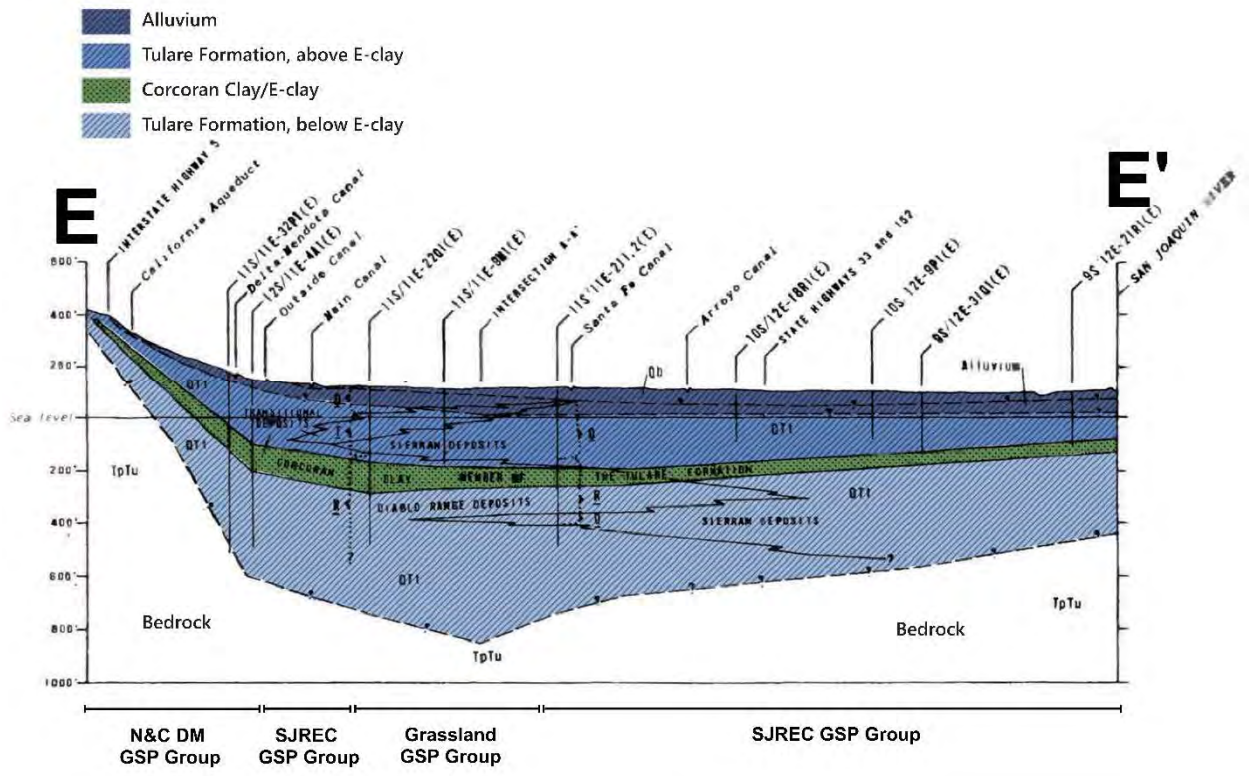
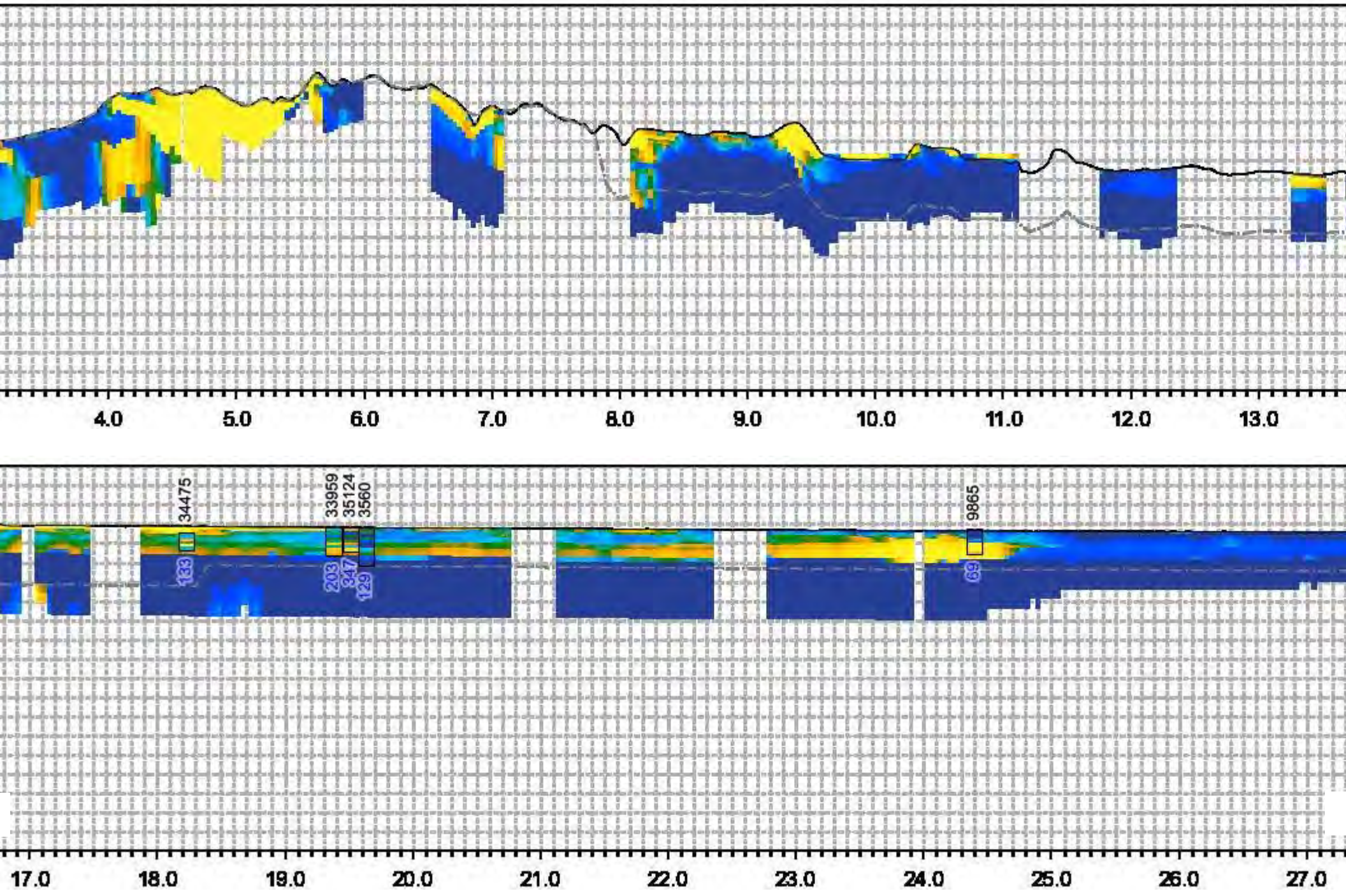
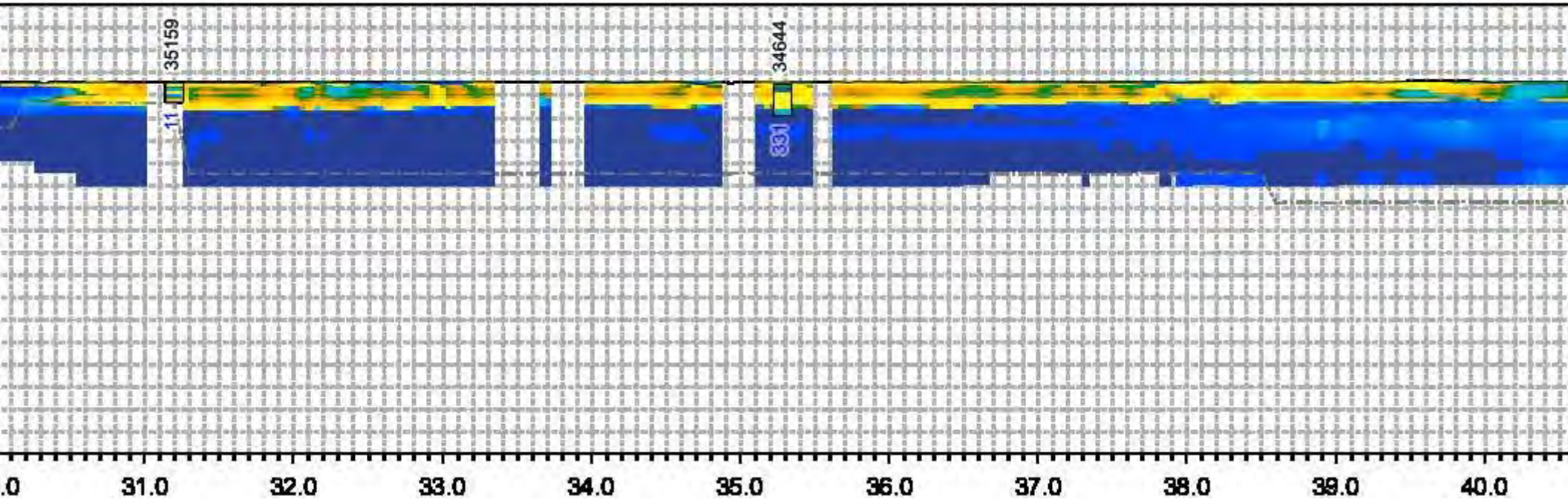


Figure CC-29: Cross-Section E-E' (Hotchkiss & Balding, 1971)

E - E' Nearest AEM Log



E - E' Nearest AEM Log



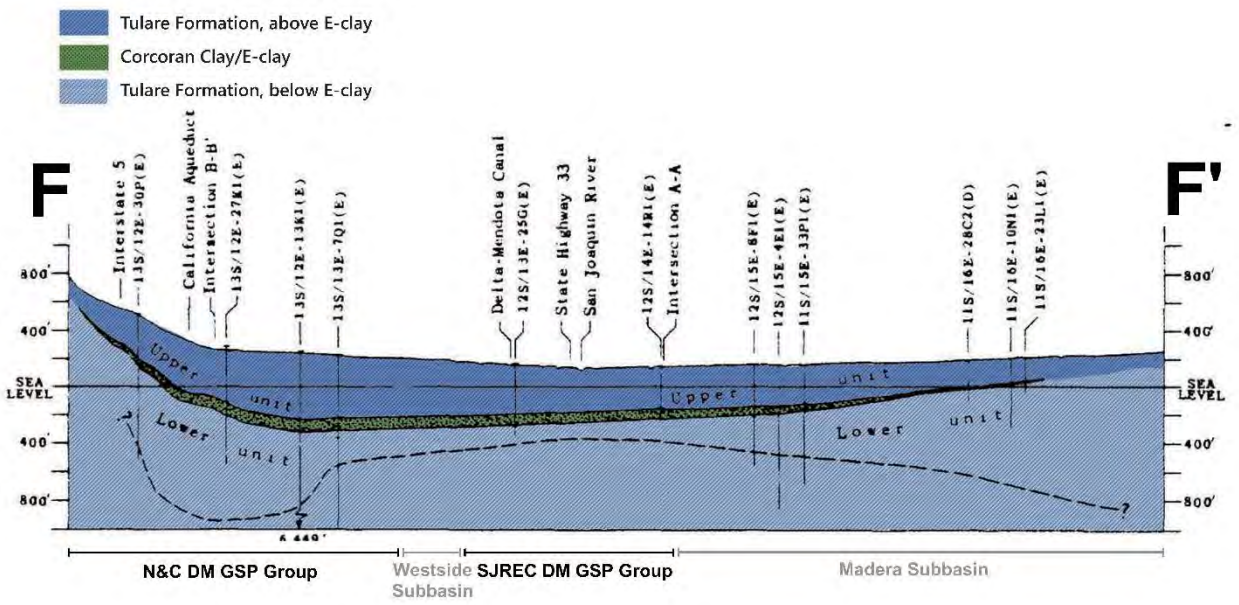


Figure CC-30: Cross-Section F-F' (Hotchkiss, 1972)

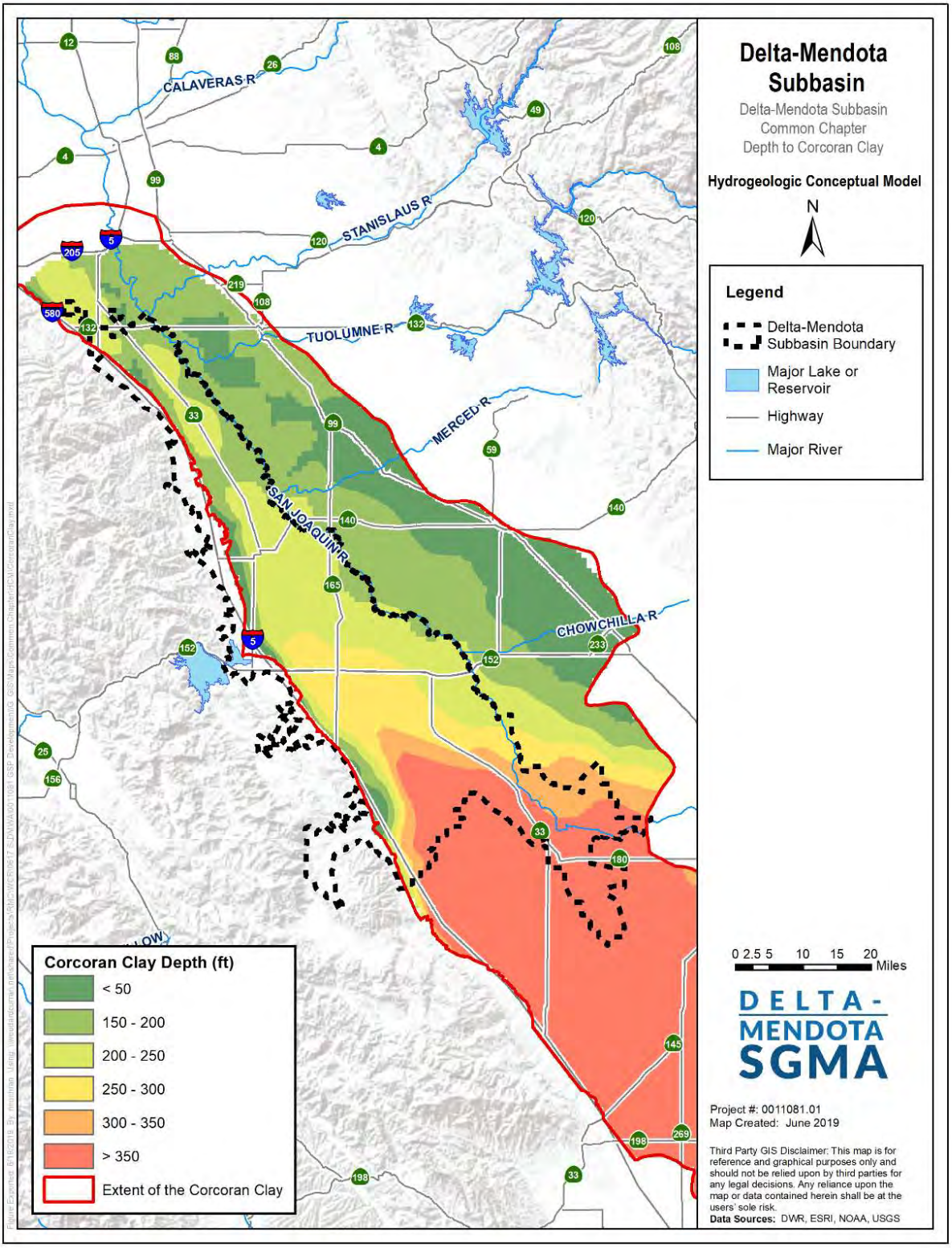


Figure CC-31: Depth to Corcoran Clay

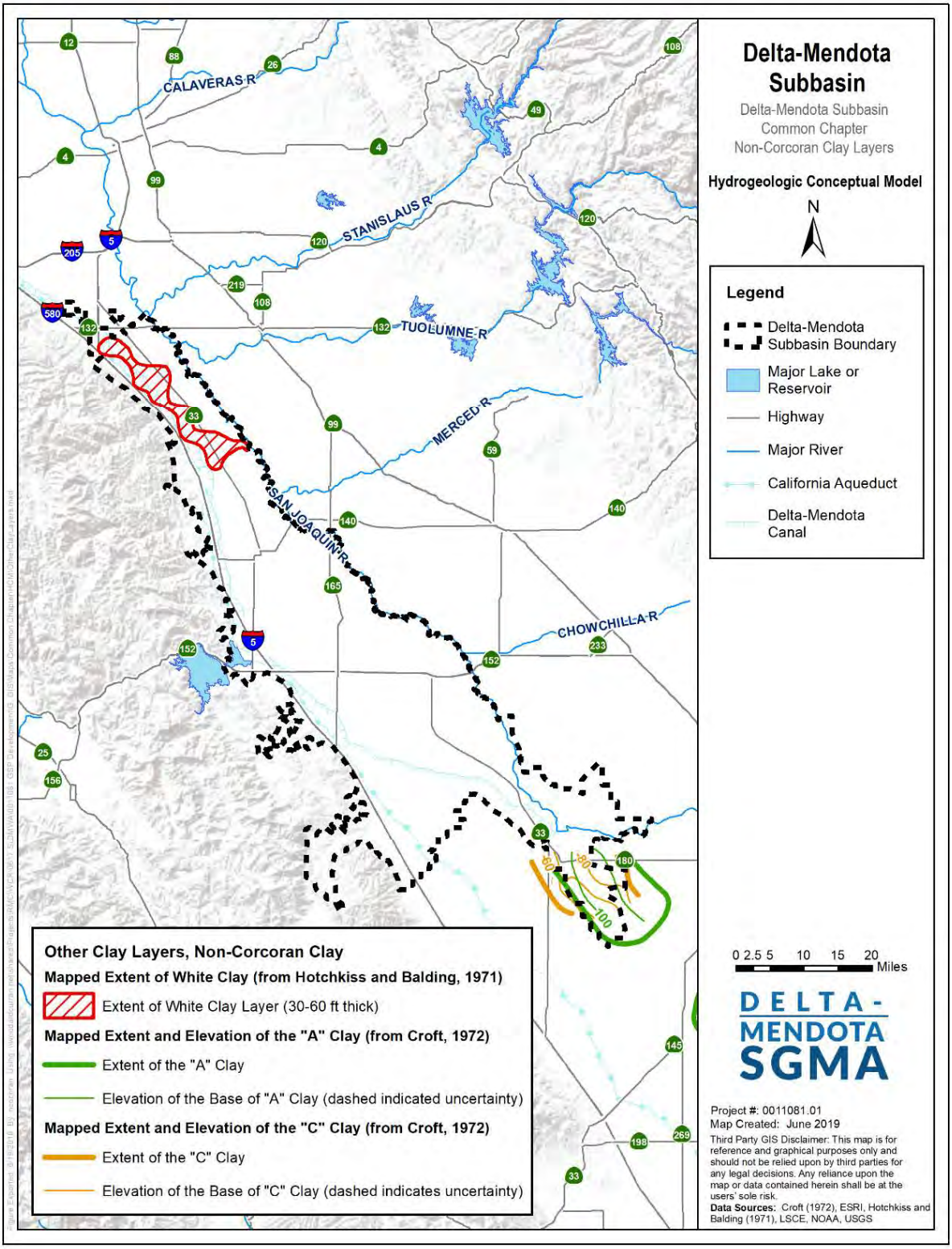


Figure CC-32: Non-Corcoran Clay Layers

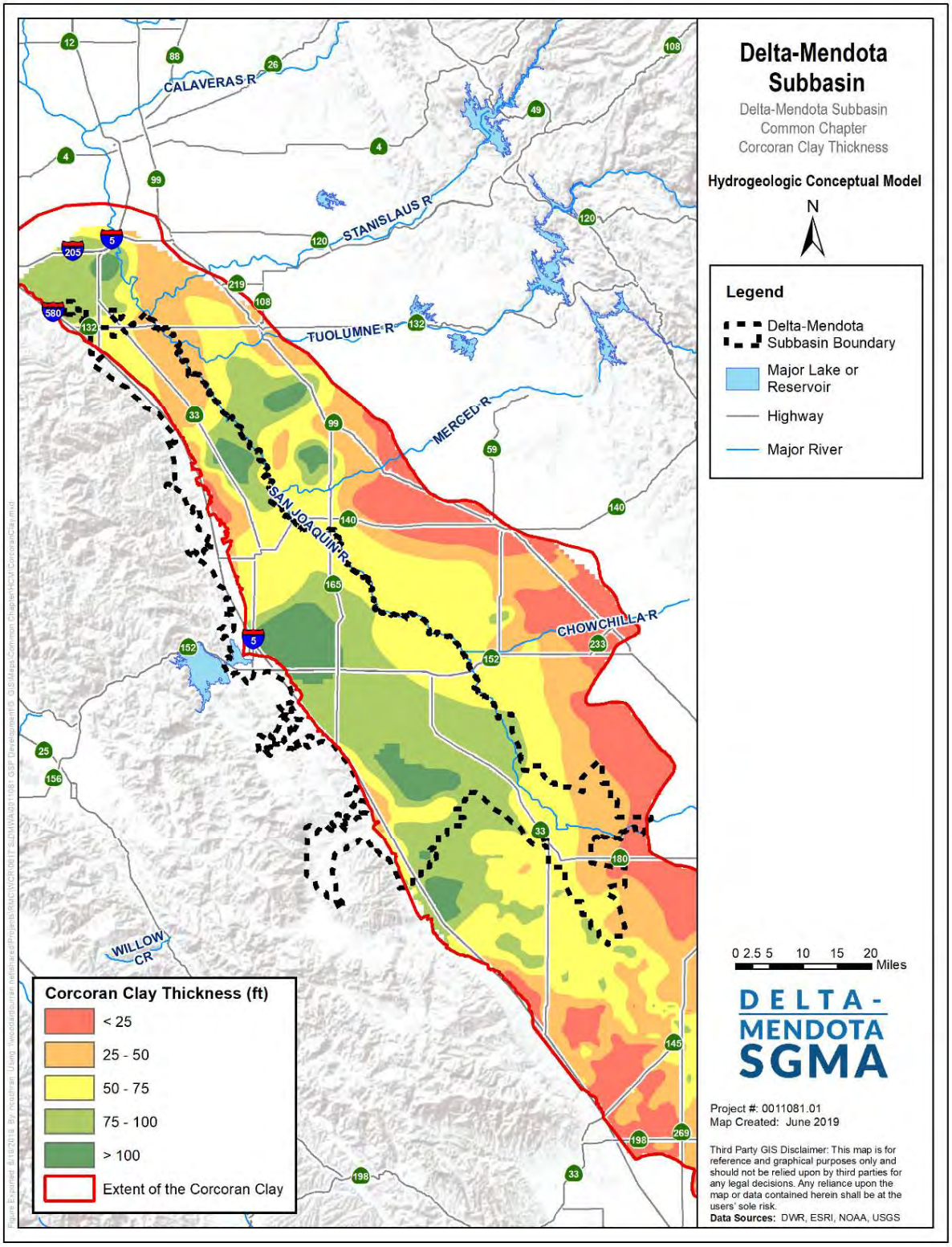


Figure CC-33: Thickness of Corcoran Clay

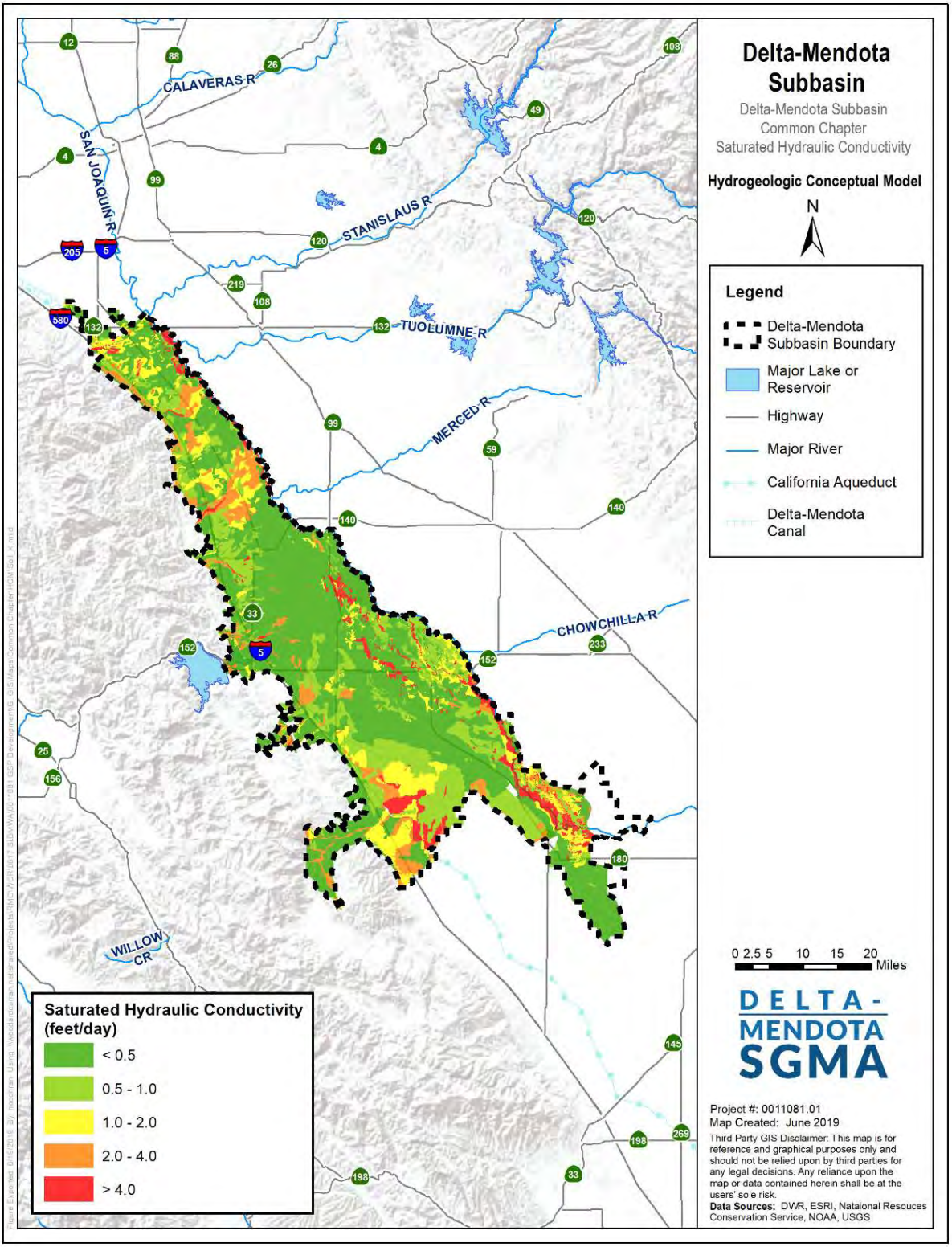


Figure CC-34: Soil Hydraulic Conductivity

4.1.8 Structural Properties and Restricted Groundwater Flow

Under natural (pre-development) conditions, the prevailing groundwater flow within the Upper and Lower Aquifer systems of the western San Joaquin Valley was predominantly in a generally northeasterly direction from the Coast Range towards and parallel to the San Joaquin River and the Sacramento-San Joaquin Delta (LSCE, 2015; Hotchkiss and Balding, 1971; KDSA, 2015). Historically, numerous flowing artesian wells within the Lower Aquifer existed throughout the Delta-Mendota Subbasin (Mendenhall et al., 1916) and the pressure gradient for groundwater flow was upward from the Lower Aquifer to the Upper Aquifer. These flowing artesian conditions have disappeared in many areas as a result of increased development of groundwater resources within the Tulare Formation (Hotchkiss and Balding, 1971). Additionally, the Delta-Mendota Subbasin has experienced periods of considerable decline in groundwater levels during which hydraulic heads in the Lower Aquifer decreased considerably in some areas due to heavy pumping (Bertoldi et al., 1991).

Despite the presence of local pumping depressions within parts of the Subbasin, the prevailing northeastward flow direction for groundwater in the Upper Aquifer within the region has remained (AECOM, 2011; DWR, 2010; Hotchkiss and Balding, 1971). Groundwater generally flows outward from the Delta-Mendota Subbasin, except along the southern and western margins where there is some recharge from local streams and canal seepage (KDSA, 2015), in addition to northward subbasin boundary flows. Within the Upper Aquifer, there are similar groundwater flow directions in most of the Subbasin with groundwater outflow to the northeast or towards the San Joaquin River in much of the Subbasin during wet and normal periods. One exception is in the Orestimba Creek area west of Newman where groundwater flows to the west during drought conditions and east during wet periods. Calculations based on aquifer transmissivity indicate the net groundwater outflow in the Upper Aquifer has been about three times greater during drought periods than during normal periods (KDSA, 1997a and 1997b).

Within the Lower Aquifer, there is a groundwater divide generally in the area between Mendota and the point near the San Joaquin River in the Turner Island area, northeast of Los Banos. Groundwater southwest of this divide generally flows southwest toward Panoche Water District and Westlands Water District. Groundwater northeast of this divide flows to the northeast into Madera and Merced Counties. Net groundwater outflow in the Lower Aquifer under drought conditions has been about two and a half times greater than for normal conditions (KDSA, 1997a and 1997b). Based on current and historical groundwater elevation maps, groundwater barriers do not appear to exist in the Delta-Mendota Subbasin (DWR, 2006).

The combined effect of pumping below the Corcoran Clay and increased leakage from the Upper Aquifer to the Lower Aquifer where the Corcoran Clay does not exist or has been perforated has developed a generally downward flow gradient in the Tulare Formation which changes with variable pumping and irrigation over time (Bertoldi et al., 1991). Periods of great groundwater level declines have also resulted in inelastic compaction of fine-grained materials in some locations, particularly between Los Banos and Mendota, potentially resulting in considerable decreases (between 1.5 and 6 times) in permeability of clay members within the Tulare Formation, including the Corcoran Clay (Bertoldi et al., 1991). However, the number of wells penetrating the Corcoran Clay may be enabling vertical hydraulic communication across the Corcoran Clay aquitard and other clay layers (Davis et al., 1959; Davis et al., 1964).

4.1.9 Water Quality

Groundwater in the Delta-Mendota Subbasin is characterized by mixed sulfate to bicarbonate water types in the northern and central portion of the Subbasin, with areas of sodium chloride and sodium sulfate waters in the central and southern portions (DWR, 2003). Total Dissolved Solids (TDS) values range from 400 to 1,600 mg/L in the northern portion, and 730 to 6,000 mg/L in the southern portion of the

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January 2020; Revised July 2022

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be thinner than those that underlie the axis of the valley, causing a majority of the confined groundwater to occur near the axis where deposits are the greatest. The flanks of the valley are at a higher elevation than the axis, allowing tributaries and rivers to produce higher heads of water than at the axis, which causes groundwater to move from the flanks towards the axis. Within the southern SJR, anticline folds can be found which restrict groundwater movement, but such folds occur far south, well beyond the FWD and Subbasin area. Two faults are located to the northeast of FWD, however, Page (1986) noted that they have not shown a definitive restriction of groundwater movement.

3.1.3 Aquifer and Aquitard Properties

Bulletin 118 defines three water-bearing units in the Subbasin. These zones include the confined lower aquifer with fresh water in the Tulare Formation, an upper zone which contains confined, semi-confined, and unconfined water in the upper sections of the Tulare Formation, and an unconfined zone (Shallow Zone) that contains groundwater within 25 feet of the surface (Davis 1959). This GSP defines two principal aquifers. The Lower Aquifer is defined as the lower zone in Bulletin 118, and the Upper Aquifer consists of the upper zone.

Aquifer properties which govern the movement and storage of groundwater were determined from field observations and existing technical studies. These properties are described in using Hydraulic Conductivity and Storativity. Hydraulic conductivity is the rate at which water flows through a porous medium and Storativity is the amount of water an aquifer can release or take into storage given a unit change in hydraulic head. When available, aquifer tests were used to quantify both parameters. Aquifer parameters were assigned using generally accepted values for sediment textures or the type of aquifer that is present, and, where possible, constrained using what limited aquifer test data may be available. Seasonal variation in groundwater levels, geology, and well construction features were used in estimating the type of aquifer and storage coefficient in the absence of aquifer test data.

3.1.3.1 Upper Aquifer

The Upper Aquifer, which lies above the Corcoran Clay, is an unconfined to semi-confined aquifer due to the intermittent presence of the A- and C-Clays. As described above, the A-Clay separates the Upper Aquifer into two zones: the Shallow Zone and the Deep Zone. The C-Clay further divides the Deep Zone into the upper Deep Zone and the lower Deep Zone. The focus of this description will be on the Shallow and Deep Zone separated by the A-Clay, as these aquifer zones have greater importance for groundwater management. Pumping restrictions currently exist (Herminghouse Agreement) for the Shallow Zone in FWD to minimize stream depletion.

The Shallow Zone of the Upper Aquifer lies above the A-Clay. The only beneficial uses of water from this portion of the Upper Aquifer are for environmental and domestic purposes. The Shallow Zone is used for irrigation outside of FWD. Regional pump test data shows the range of hydraulic conductivity values in the Shallow Zone. To the south of FWD in Fresno County Management Area A, there are a significant number of pumping tests where hydraulic conductivity (K) values range between 50 and 500 ft/day, with an average of 230 ft/day. To the west of FWD, K values range between 400 and 600 ft/day. Technical studies in the area have reported a range of values for the Shallow Zone between 10 and 230 ft/day,

with the highest values occurring along the SJR (150-230 ft/day), and the lowest values west of the Fresno Slough and SJR (10-50 ft/day) (LSCE 2018).

The Deep Zone of the Upper Aquifer is overlain by the A-Clay and extending to the top of the underlying Corcoran Clay. The primary use for this aquifer is irrigation. There are a significant number of pumping test results within Fresno County Management Area A that show values of K near Meyers Water Bank and the former Spreckels Sugar Company ranging from 20 to 170 ft/day with an average of 70 ft/day. Values to the west near the City of Mendota range from 50 to 250 ft/day. Values to the north near Central California Irrigation District (CCID), Wonder Orchards, and Columbia Canal Company have values that range from 30 to 260 ft/day. Technical studies in the area have reported a range of hydraulic conductivity values between 50 and 330 ft/day with higher values generally occurring in the lower portion of the Deep Zone between the C-Clay and Corcoran Clay (Luhdorff & Scalmanini Consulting Engineers [LSCE] 2018)

The Upper Aquifer is treated as an unconfined aquifer. Specific yield values have been estimated to be between 0.18 and 0.24 based on examination of geologic materials and model calibration efforts in the development of the FWD historical water budget. Specific yield is the ratio of the volume of water drained to the total volume of aquifer material.

3.1.3.2 Lower Aquifer

The Lower Aquifer is overlain by the Corcoran Clay. This aquifer will not be utilized for groundwater production in FWD; however, it is in adjacent GSAs to the north of FWD within the Subbasin. FWD currently has one well, which has a small portion of the well perforated in the upper portion of the Lower Aquifer. This well is planned to be destroyed as part of the San Joaquin River Restoration Project and currently is seldom used by FWD.

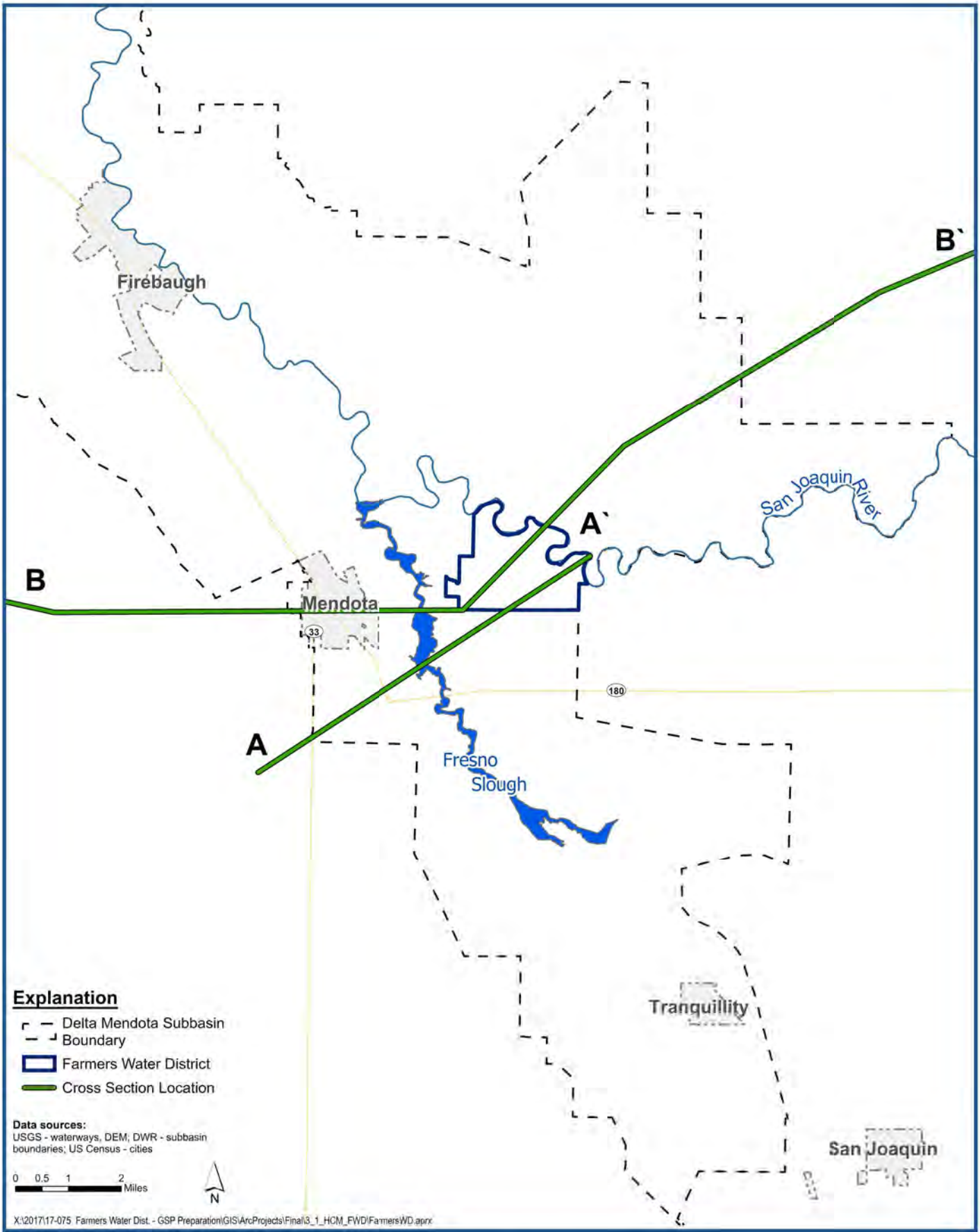
There is a total of five wells screened in the Lower Aquifer in the vicinity of FWD resulting in a limited amount of historical data available for review and analysis of lower aquifer groundwater conditions. There is no available aquifer test for the lower aquifer in the vicinity of FWD. Hydraulic conductivity values in the area generally range from 10 to 100 ft/day. Values near FWD are slightly lower with values ranging between 10 and 50 ft/day (LSCE 2018).

The Lower Aquifer is a confined aquifer and the estimated storativity value is 4.1×10^{-3}. These values are based on model calibration to historical conditions in the southern portion of the Delta-Mendota Subbasin.

3.1.4 Groundwater Quality

3.1.4.1 Local Groundwater Quality Monitoring

Existing groundwater monitoring programs include the Mendota Pool Group's annual monitoring program and the Groundwater Monitoring Program for the former Spreckels Sugar Beet Processing Facility located south of FWD in Fresno County's Management Area A. These programs monitor for general minerals and trace elements. The primary constituent of concern within FWD is total dissolved solids (TDS) due to the elevated TDS concentrations from the former Spreckels Sugar Company



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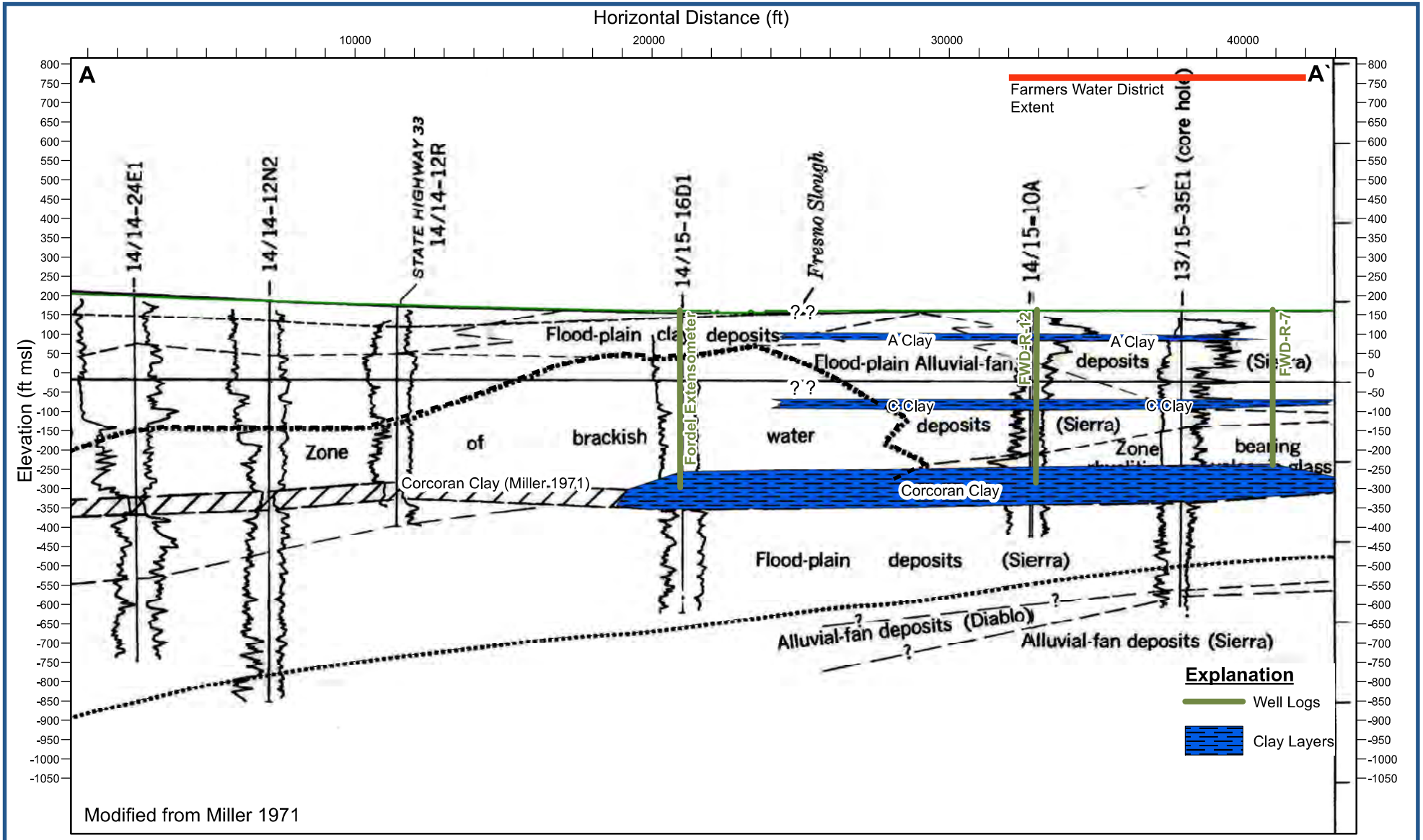
Geologic Cross-Section Locations

Groundwater Sustainability Plan
Farmers Water District
Delta-Mendota Subbasin

Figure 3-3



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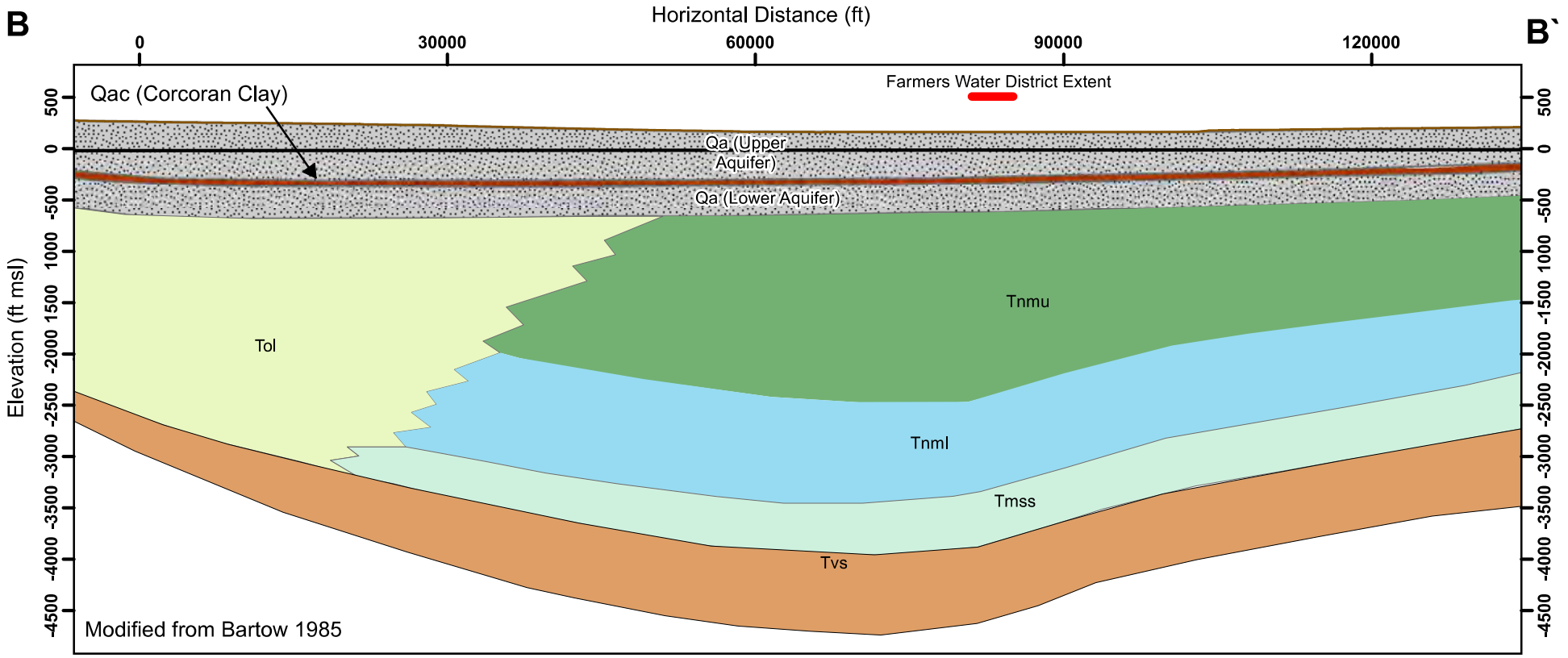
Consulting Engineers

Cross Section A-A'

Groundwater Sustainability Plan
Farmers Water District
Delta-Mendota Subbasin

Figure 3-4



Qa - Alluvial Deposits, Undivided (Holocene and Pleistocene)

Qac - Corcoran Clay Member of Turlock Lake Formation

Tol - Oro Loma Formation (Pliocene and Upper Miocene)

Tnmu - Nonmarine Sedimentary Rocks Upper Part (Pliocene and Miocene)

Tnml - Nonmarine Sedimentary Rocks Lower Part (Pliocene and Miocene)

Tmss - Marine Sandstone (Miocene)

Tvs - Valley Springs Formation (Lower Miocene and Upper Oligocene)

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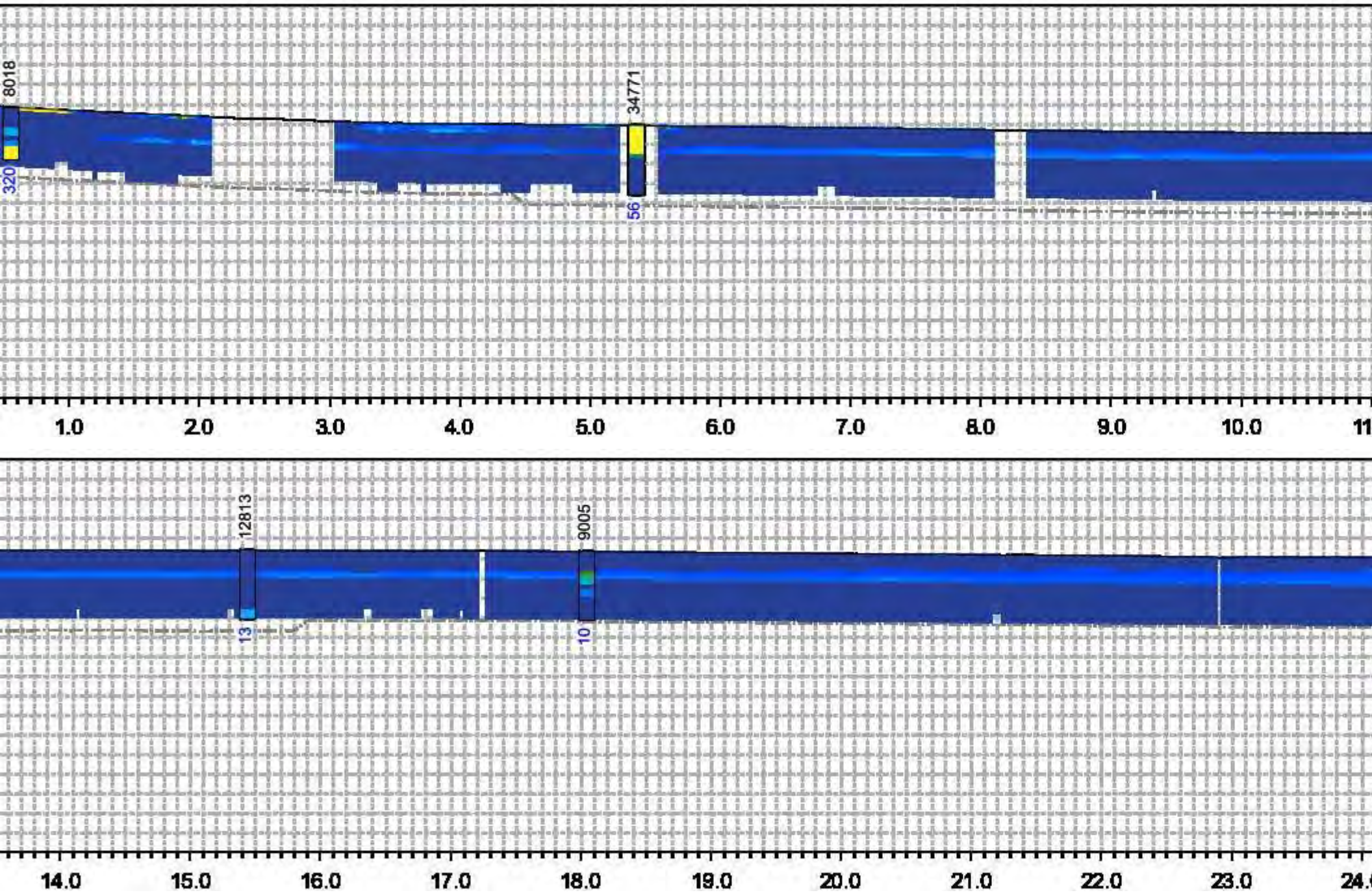
Cross Section B-B'

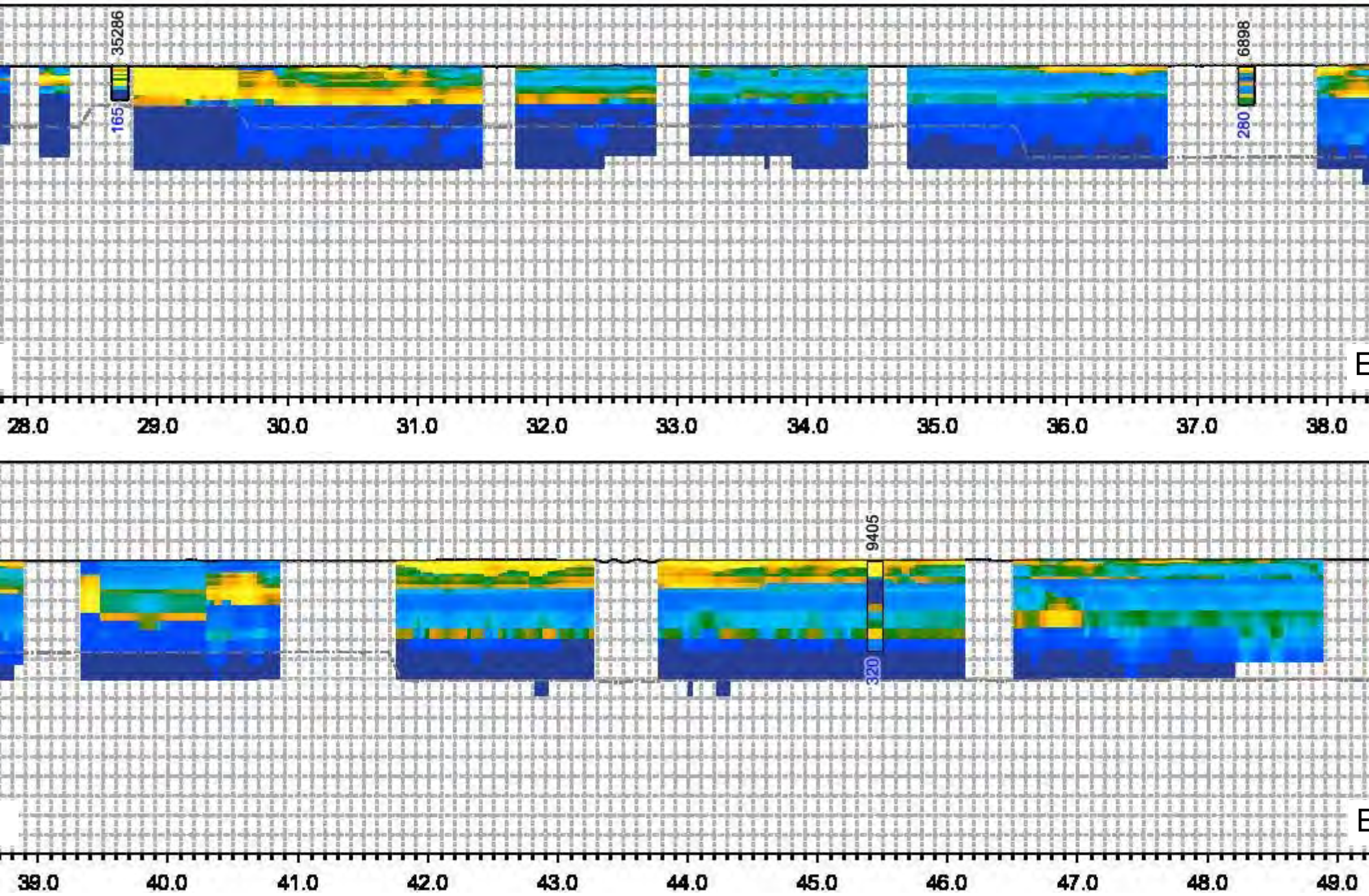
Groundwater Sustainability Plan
Farmers Water District
Delta-Mendota Subbasin

Figure 3-5

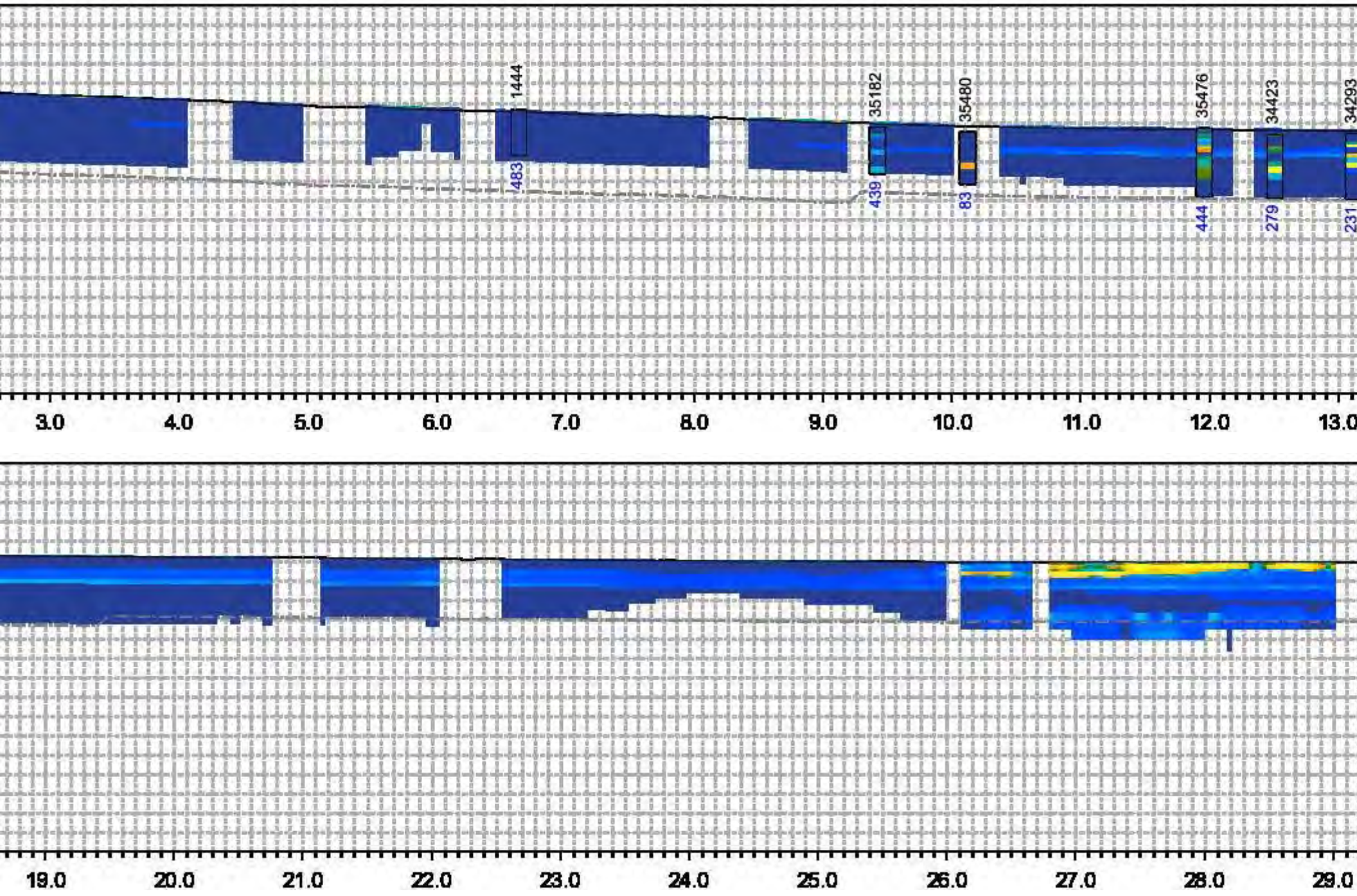
B - B' Nearest AEM Log, North



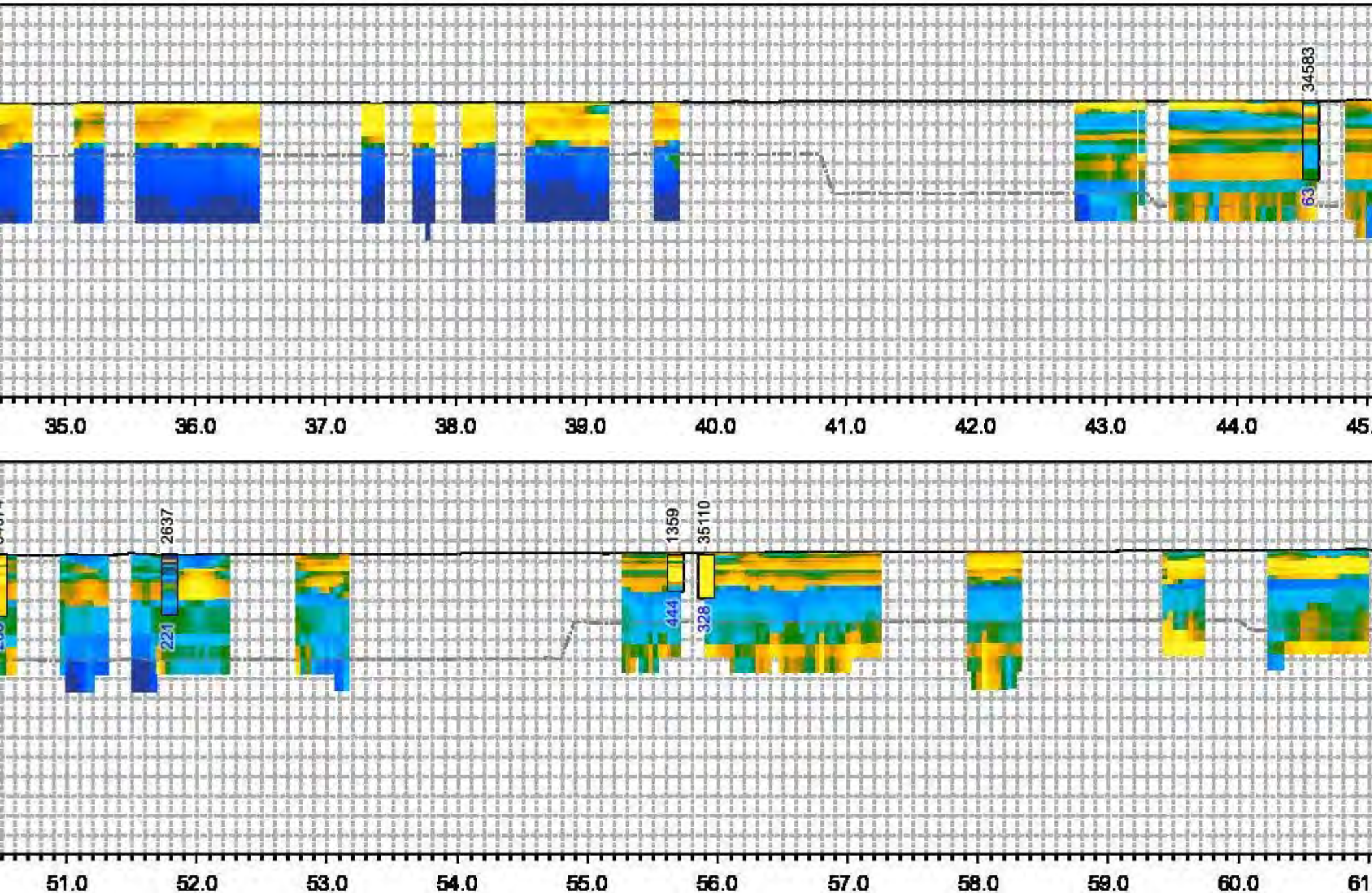
A - A', B - B' Nearest AEM Log, North



A - A', B - B' Nearest AEM Log, South



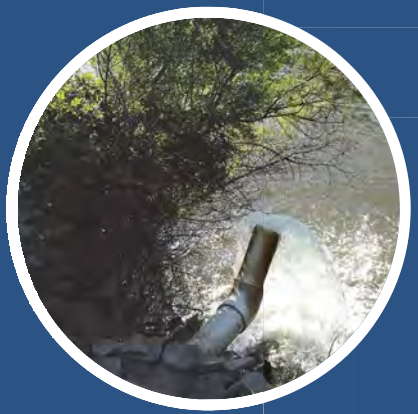
B - B' Nearest AEM Log, South



Revised Groundwater Sustainability Plan

County of Fresno GSA Management Area A & Management Area B Delta-Mendota Subbasin

January 2020; Revised July 2022



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Clay ranges from about 80 to 120 ft bgs. The depth to the A-Clay is deepest in the western portion of the FCMA and decrease in depth in a west to east direction. In some areas, the A-Clay is composed of two or three clay units separated by several feet of sand. In FCMA, the A-Clay represents the boundary between two water-bearing zones: the shallow and deep zones of the Upper Aquifer. The shallow zone overlies the A-Clay, and the deep zone is located between the A-Clay and the Corcoran Clay. The shallow zone is primarily composed of fine to coarse sand and gravel and is considered an unconfined unit. The deep zone is also composed primarily of fine to coarse sand and gravel with some interbedded clays. The vertical hydraulic conductivity of the A-Clay can be quite variable throughout the FCMA, exhibiting apparent gaps which could be post-depositional erosional features, or the result of poorly constructed deep zone wells completed below the A-Clay.

The structural geology of the San Joaquin Valley and FCMA area is described by Page (1986). Page describes the large, asymmetrical, northwest trending trough of the Central Valley is the principal structure responsible for the movement of groundwater in the area. The confining deposits near the flanks of the Valley tend to be thinner than those that underlie the axis of the Valley, resulting in a majority of the confined ground water to occur near the axis where deposits are the greatest. The flanks of the Valley are at a higher elevation than the valley floor where the axis is located, allowing tributaries and rivers to produce higher heads of water than at the axis. The difference in head causes groundwater to move from the flanks towards the axis. Within the southern portion of the Valley, anticline folds can be found that restrict groundwater movement, but such folds occur well beyond the GSA boundary. Two faults are located to the northeast of the FCMA, however, Page (1986) noted that they have not been shown to cause a definitive restriction of groundwater movement.

3.1.3 Principal Aquifers and Aquitards

DWR Bulletin 118 defines three water-bearing zones within the Subbasin. These include the lower zone (defined as the Lower Aquifer), which contains confined fresh water in the lower section of the Tulare Formation, an upper zone (defined as the Upper Aquifer) which contains confined, semi-confined, and unconfined water in the upper section of the Tulare Formation and younger deposits, and a shallow zone which contains unconfined water within about 25 feet of the land surface (Davis 1959). This GSP defines two principal aquifers. The Lower Aquifer which is defined as the lower zone in Bulletin 118, and the Upper Aquifer which consists of the upper zone.

Aquifer properties which govern the movement and storage of groundwater were determined from field observations and existing technical studies. Hydraulic conductivity is the rate at which water flows through a porous medium. Storativity is the amount of water an aquifer can release or take into storage given a unit change in hydraulic head. When available, aquifer tests were used to quantify both parameters. Most of the time aquifer parameters were assigned using generally accepted values for sediment textures or the type of aquifer that is present, and where possible constrained using what limited aquifer test data may be available. Seasonal variation in groundwater levels, geology and well

construction features were used in estimating the type of aquifer and storage coefficient in the absence of aquifer test data.

3.1.3.1 Upper Aquifer

The Upper Aquifer which lies above the Corcoran Clay, is an unconfined to semi-confined aquifer due the presence of the A and C-Clays. As described above, the A-Clay separates the Upper Aquifer into two zones, the shallow zone and the deep zone. The C-Clay, where present, further divides the deep zone into the upper deep zone and the lower deep zone. The focus of this description will be on the shallow and deep zone separated by the A-Clay as these aquifer zones have greater importance for groundwater management and production in the FCMA. There are existing management programs regulating groundwater pumping by some landowners in the FCMA as a condition of exchange programs with the Bureau of Reclamation.

The shallow zone of the Upper Aquifer within the FCMA is above the A-Clay. The beneficial water uses in the shallow zone are for irrigation, environmental, and domestic purposes. Regional pump test data shows a range of hydraulic conductivity values in the shallow zone. In the northern portion of FCMA, near the Meyers Water Bank and the former Spreckels Sugar Company, there are a significant number of pumping tests where hydraulic conductivity (K) values range between 50 to 500 ft/day, with an average of 230 ft/day. To the northwest of FCMA, values range between 400 to 600 ft/day. Technical studies in the area have reported a range of values for the Shallow Zone between 10 to 230 ft/day, with the highest values occurring along the SJR (150 to 230 ft/day), and the lowest values west of the Fresno Slough and SJR (10 to 50 ft/day) (Luhdorff & Scalmanini Consulting Engineers [LSCE] 2018).

The deep zone of the Upper Aquifer is overlain by the A-Clay and extends to the top of the underlying Corcoran Clay. The primary use for this aquifer is irrigation with a small amount use for domestic purposes. There are a significant number of pumping test results for the area within the northwest portion of the FCMA in MAA. Values in MAA range from 20 to 170 ft/day with an average of 70 ft/day. Values to the west near the City of Mendota range from 50 to 250 ft/day. Values to the north near Central California Irrigation District (CCID), Wonder Orchard (WO), and Columbia Canal Company (CCC) have values that range from 30 to 260 ft day. Technical studies in the area have reported a range of hydraulic conductivity values between 50 to 330 ft/day with higher values generally occurring in the lower portion of the deep zone between the C-Clay and Corcoran Clay (LSCE 2018).

The Upper Aquifer is treated as an unconfined aquifer. Specific yield values have been estimated to be between 0.18 to 0.24.

3.1.3.2 Lower Aquifer

The Lower Aquifer is overlain by the Corcoran Clay. This aquifer is not utilized for groundwater production in FCMA; however, this aquifer is utilized for groundwater production in neighboring GSAs and Subbasins through the use of composite wells that are screened both above and below the Corcoran Clay.

There are a total of five wells screened in the Lower Aquifer in the vicinity of FCMA resulting in a limited amount of data. There are no available aquifer test data for the lower aquifer in the vicinity of the FCMA. Hydraulic conductivity values in the area generally range from 10 to 100 ft/day. Values near the FCMA are slightly lower with values ranging between 10 to 50 ft/day (LSCE 2018).

The Lower Aquifer is a confined aquifer and the estimated storativity value is4.1×10^{-3}.

3.1.4 General Groundwater Quality

Current groundwater quality monitoring programs include the MPG's annual monitoring program and the Groundwater Monitoring Report for the former Spreckels Sugar Beet Processing Facility. These programs monitor for general minerals and trace elements. The primary concern of groundwater contamination in FCMA is high salinity due to the former Spreckels Sugar Company processing operations and the natural occurrence of saline water in some portions of the FCMA west of the Mendota Pool. Other than the plume identified in MAA, there are no other contamination sites that have been identified by the Regional Water Quality Control Board in the FCMA. The impact of the Steffens plume will be discussed further in Section 3.2.3. The table below provides a summary of groundwater quality conditions for those constituents of concern for agricultural and other beneficial users and provide beneficial uses within FCMA. Those constituents of interest are electrical conductivity (EC) and TDS for both the Upper and Lower Aquifers (**Table 3-1**). No other constituents are at concentrations that would impact beneficial uses of groundwater within FCMA. For the Upper Aquifer, there are historical EC and TDS records for over 130 wells. Measurements date back to 1962, but most of the measurements were made since 1990. Water Quality data are limited for the Lower Aquifer, where groundwater extraction does not occur and no known wells in FCMA are present that are solely screened below the Corcoran Clay.

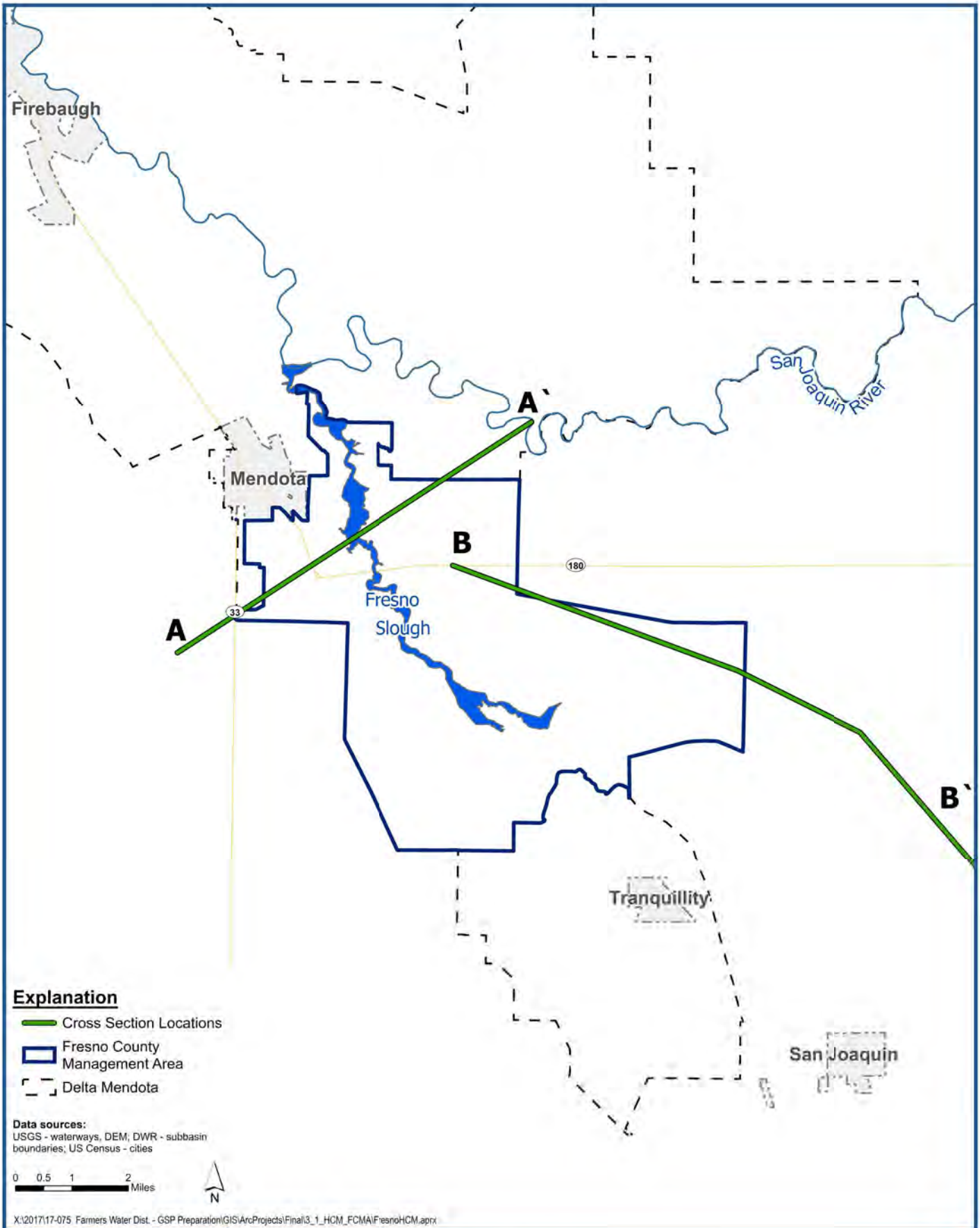
Table 3-1: General Groundwater Quality

Constituent	Mean	Max	Min	Count
Upper Aquifer				
EC (umhos/cm)	2730	39,000	88	3370
TDS (mg/L)	1771	32,000	44	3401
Lower Aquifer				
EC (umhos/cm)	2598	4,080	1200	6
TDS (mg/L)	1370	2,000	740	2

mg/L = milligrams per liter

3.1.5 Soil Characteristics

Soil types in FCMA were obtained from the United States Department of Agriculture (USDA) Natural Resources Conservation Service Web Soil Survey (Soils Survey Staff 2018). The soil types in FCMA are



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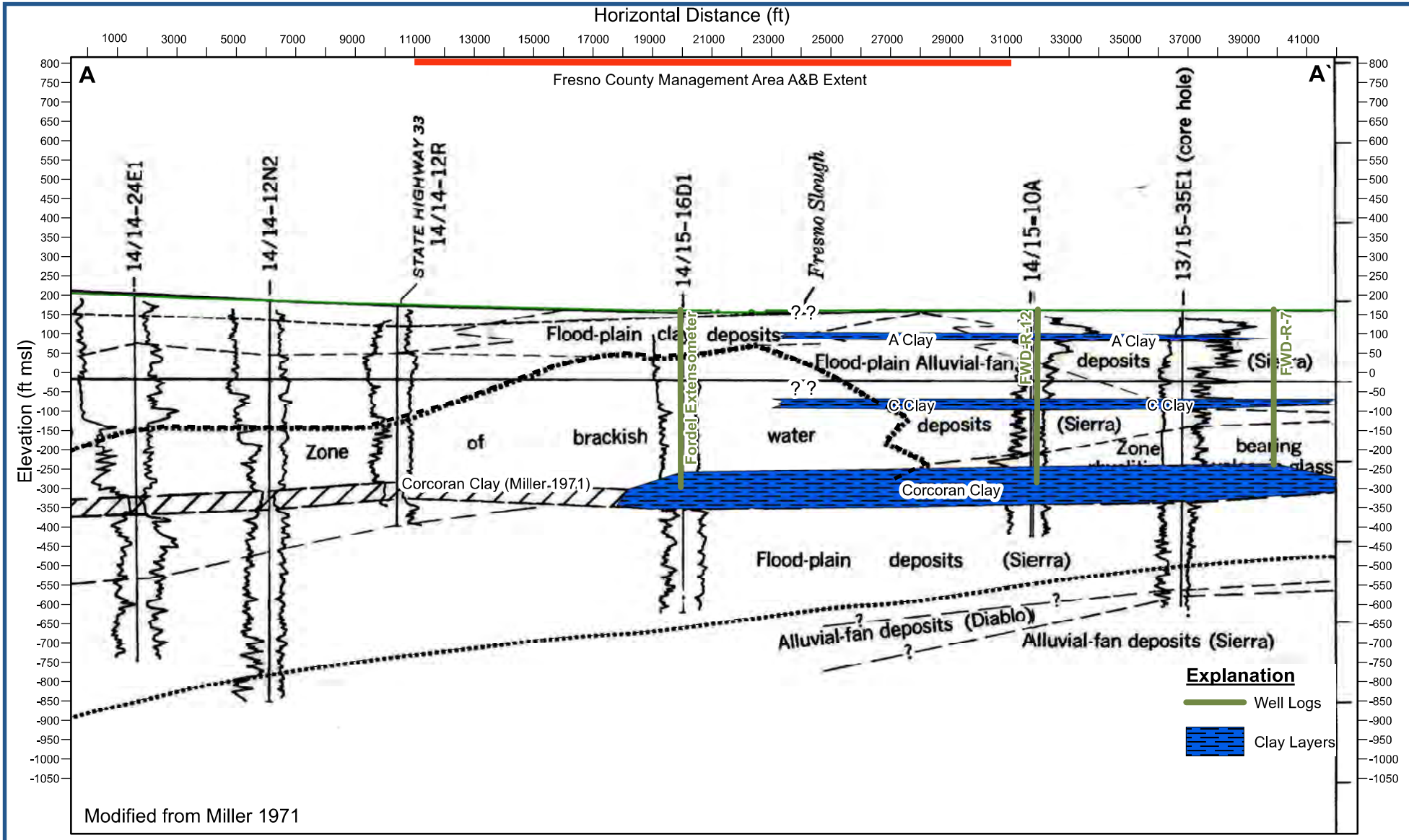
Geologic Cross-Section Locations

Groundwater Sustainability Plan
County of Fresno
Delta-Mendota Subbasin

Figure 3-3



X:\2017\17-075 Farmers Water Dist. - GSP Preparation\GIS\CrossView_CrossSections\FresnoCounty\CrossSectionAA\Figure 3-4.mxd

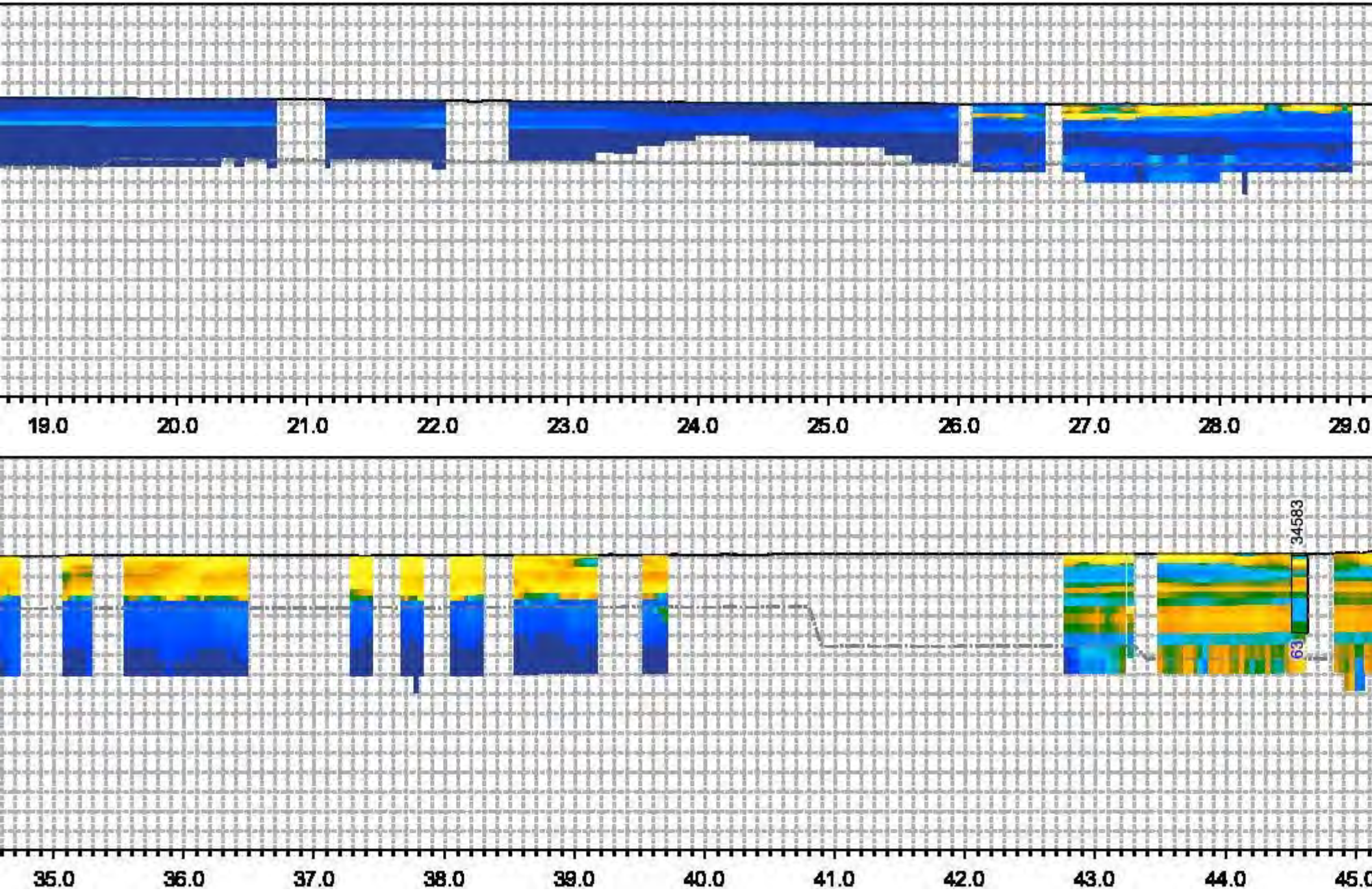
Luhdorff & Scalmanini Consulting Engineers

Cross Section A-A'

Groundwater Sustainability Plan
County of Fresno
Delta-Mendota Subbasin

Figure 3-4

A - A' Nearest AEM Log



B Fresno County Management Area Extent

NORTH

B' SOUTH

TULARE LAKE BED

14S/15E-10A | 14S/16E-8N | 14S/16E-24N | 15S/17E-5F | 15S/17E-16H1 | 15S/17E-23A | 16S/18E-16A, section A-A' | 16S/18E-26E | 17S/19E-6N | 17S/19E-20D | 17S/19E-35N | 18S/19E-12Z | 18S/19E-36D | 19S/19E-24D1 | 20S/19E-24D1 | 20S/19E-35C1, section B-B' | 21S/20E-19D1 | 22S/20E-17K | 23S/21E-13E, section C-C'

600' 400' 200' SEA LEVEL 200' 400' 600' 800' 1000' 1200' 1400' 1600' 1800' 2000' 2200' 2400' 2600' 2800' 3000'

Qas

A clay

B clay

C clay

D clay

E clay

F clay

Upper Water-Bearing Zone

Lower WB Zone

5 th Sand

4 th Sand

3rd Sand

2nd Sand

1st Sand

Lower Water-Bearing Zone

Sierra Nevada Sourced

Pleistocene Sierra Nevada Sourced

TQsn

Pliocene to Pleistocene Sierra Nevada Sourced

Tm/nm Pliocene & Older Marine & Nonmarine

Sierra Nevada & Some Coast Range Sourced

//// bfw

0-30

0-10

S~

Qlb

Upper Lb

Corcoran Clay

Middle Lb

Lower Lb

Tulare Lake Beds

TQlb

Tlb

Tm

Pliocene Marine

Horizontal Scale

0 5 10 15 Miles

EXPLANATION

UNCONSOLIDATED DEPOSITS

Pleistocene and Holocene — Coast Ranges

Tehachapi and San Emigdio Mountains: Qat — Alluvium

Sierra Nevada: Qas — Alluvium

QUATERNARY

Pliocene to Holocene — Coast Ranges: QTcc — Continental and alluvial deposits

QTf A clay — Flood-basin, lacustrine, and marsh deposits (A through F clays shown by denser pattern)

Tehachapi and San Emigdio Mountains: QTct — Continental deposits

Sierra Nevada: QTcs — Continental deposits

Pliocene and Pleistocene(?)

TERTIARY AND QUATERNARY(?)

CONSOLIDATED ROCKS

Tmn — Marine and nonmarine sedimentary rocks — TERTIARY

pTb — Basement complex — PRE-TERTIARY

Lithologic contact

0/R — Generalized contact between oxidized (O) and reduced (R) deposits

0-30 Resistivity scale

s~ Top Saline Water – LSCE

//// bfw Base Fresh Water Page 1973

Modified From: Croft, 1972, Plate 3, G-G'

CAD FILE: G:\Projects\Westlands Water\15-1-104\Geologic Cross Section 1-1' (R).dwg DATE: 8/1/2018 12:44 PM

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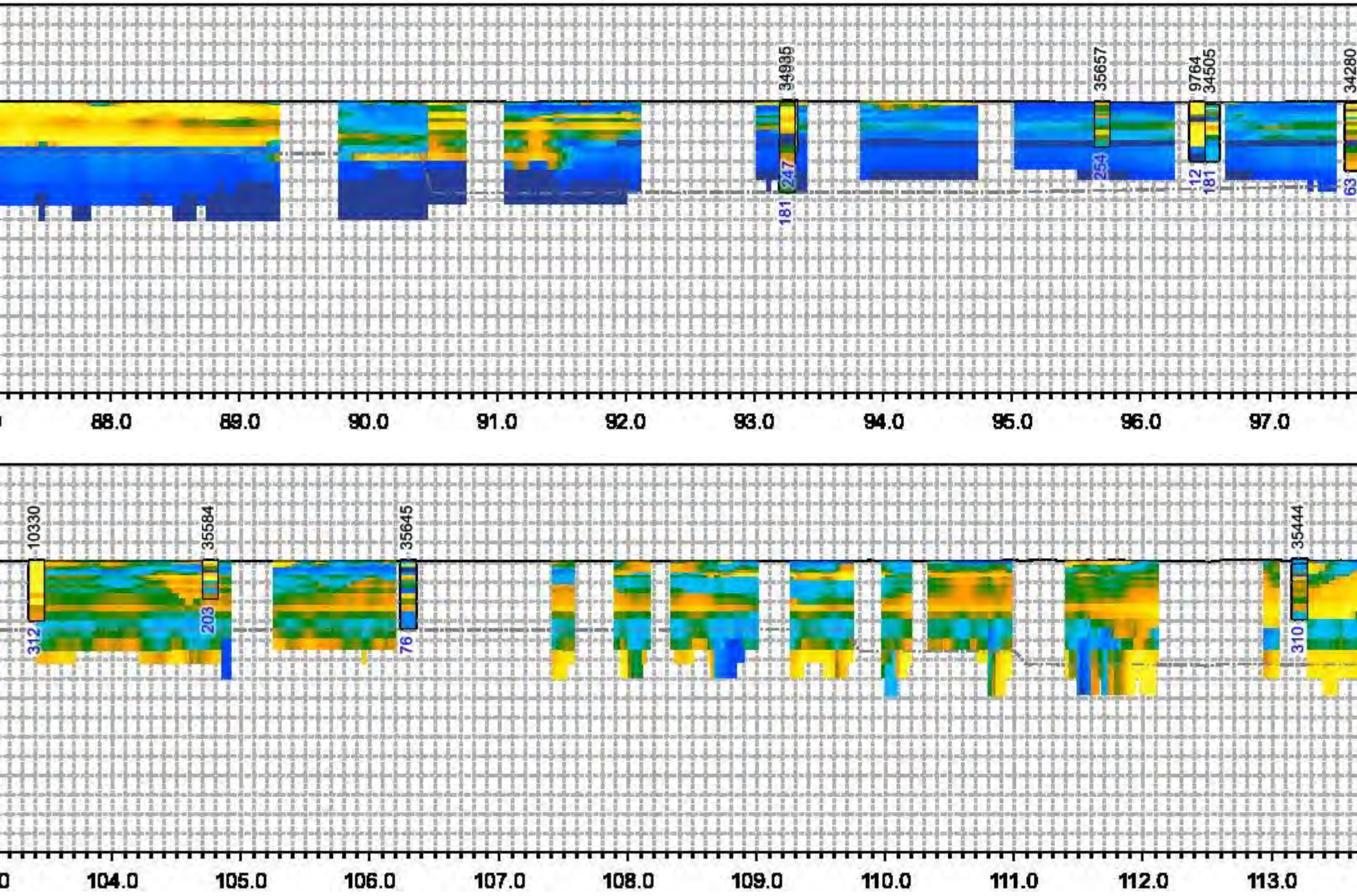
FIGURE 3-5
B-B' (North-South)Geologic Cross Section

Groundwater Sustainability Plan
County of Fresno
Delta-Mendota Subbasin

B - B' Nearest AEM Log



NORTHERN & CENTRAL DELTA-MENDOTA

Groundwater Sustainability Plan

For the Northern and Central Delta-Mendota Regions

November 2019; Revised June 2022

DEPARTMENT OF WATER RESOURCES · STATE OF CALIFORNIA ·

PROP 1
WATER BOND 2014

5.2.5.2 Definable Bottom of Basin

In the San Joaquin Valley, the bottom of the Delta-Mendota Subbasin is typically defined as the interface of saline water of marine origin within the uppermost beds of the San Joaquin Formation. The San Joaquin Formation is characterized by blue and green fine-grained rocks and principally composed of fine-grained silty sands, silt, and clay (Foss and Blaisdell 1968). The San Joaquin Formation is predominantly marine in origin and is considered late Pliocene and possibly early Pleistocene in age. This formation is the upper shaley part of the Pliocene sequence. The top of the San Joaquin Formation is generally encountered around -2,000 feet above mean sea level throughout the Delta-Mendota Subbasin. For the purposes of this GSP, the base of freshwater is defined by a total dissolved solids (TDS) concentration of 3,000 micromhos per centimeter at 25 °C (or about 2,000 mg/L), as presented by Page (1973).

5.2.6 Principal Aquifers and Aquitards

DWR's Groundwater Glossary defines an aquifer as "a body of rock or sediment that is sufficiently porous and permeable to store, transmit, and yield significant or economic quantities of groundwater to wells, and springs". There are two primary aquifers within the Delta-Mendota Subbasin: a semi-confined aquifer above the Corcoran Clay and a confined aquifer below the Corcoran Clay, with the Corcoran Clay acting as the principal aquitard within the Delta-Mendota Subbasin. **Figure 5-6** shows the locations of the representative cross-sections for the Northern & Central Delta-Mendota Region GSP Plan area, where **Figure 5-7** through **Figure 5-16** show the hydrostratigraphy of the representative cross-sections.

While the two-aquifer system described above is generally true across the Delta-Mendota Subbasin, there are portions of the basin where the Corcoran Clay does not exist (predominantly along the western margin of the Subbasin) and hydrogeology is generally controlled by localized interfingering clays, and/or where local hydrostratigraphy results in shallow groundwater conditions that differ, to some extent, from that seen in the Subbasin as a whole. Additionally, in the southern portion of the Subbasin in the Mendota and Tranquillity areas, there are A and C Clay layers in addition to the Corcoran Clay that inhibit groundwater flow. However, while there are localized complexities throughout the Subbasin, the Corcoran Clay (or E Clay) extends through much of the Delta-Mendota Subbasin generally creating a two-aquifer system.

5.2.6.1 Principal Aquifers

In the Delta-Mendota Subbasin, there are two primary aquifers composed of alluvial deposits separated by the Corcoran Clay (Schmidt, 2015): a semi-confined Upper Aquifer zone (generally the ground surface to the top of the Corcoran Clay), and a confined Lower Aquifer zone starting at the bottom of the Corcoran Clay to the base of fresh water. However, as previously described, the localized presence of the A and C Clay layers in the southern portion of the Subbasin, the absence of the Corcoran Clay at the western margin of the Subbasin and/or local hydrostratigraphy result in differing shallow groundwater conditions and/or perched groundwater conditions in some portions of the Subbasin. To this end, in addition the descriptions of the two principal aquifers in the Delta-Mendota Subbasin, a description of 'Very Shallow Unconfined Groundwater' is also provided for those portions of the basin where such conditions are present.

<u>Upper Aquifer</u>

The Upper Aquifer is represented by materials extending from the upper groundwater table to the top of the Corcoran Clay. The Upper Aquifer includes shallow geologic units of younger and older alluvium and upper parts of the Tulare Formation. Sediments within the upper Tulare Formation have variable sources and subdivision of units can be distinguished between eastern and western sourced materials. Alluvial fan materials above the Corcoran Clay in the Delta-Mendota Subbasin are generally more extensive than older alluvial fan deposits within the Tulare Formation below the Corcoran Clay. As shown in **Figure 5-17** by the depth to the top of the Corcoran Clay, the Upper Aquifer extends to depths ranging between approximately 150 feet and greater than 350 feet. Other notable mapped clay

units also exist within the upper part of the Tulare Formation in the Delta-Mendota Subbasin, including the A and C Clay members of the Tulare Formation and a white clay mapped by Hotchkiss and Balding (1971).

The A and C Clay occur near the Mendota and Tranquillity areas in the southeastern portion of the Delta-Mendota Subbasin. The mapped extent and elevation of the A and C Clay layers, as presented by Croft (1972) and Hotchkiss and Balding (1971), are shown in **Figure 5-19** indicating areas where considerable barriers to vertical groundwater movement within the Upper Aquifer are known to exist. As shown in **Figure 5-19,** the extent and thickness of both the A and C Clays are somewhat uncertain, although they have been mapped to exist in the general area of Mendota. The A Clay occurs at elevations ranging from about 100 to 160 feet above mean sea level, corresponding to depths of generally between 100 and 200 feet below the ground surface. The deeper C Clay exists at correspondingly lower elevations from between 20 to 100 feet above mean sea level (**Figure 5-19**).

A traceable continuous white clay layer, mapped by Hotchkiss and Balding (1971), exists within the northern part of the Delta-Mendota Subbasin in the vicinity and north of Patterson. This layer ranges in thickness from 30 to 60 feet at depths between 100 and 200 feet below grade and is an effective confining layer in many areas. Although not explicitly mapped, less extensive and unmapped clay units within the Upper Aquifer also exist in other parts of the Subbasin.

Lower Aquifer

The Lower Aquifer is the portion of the Tulare Formation that is confined beneath the Corcoran Clay, extending downward to the underlying San Joaquin Formation and the interface of saline water of marine origin within its uppermost beds. The Lower Aquifer is generally characterized by groundwater that tends to be dominantly sodium-sulfate type, which is often of better quality than the Upper Aquifer (Davis et al., 1957; Hotchkiss and Balding, 1971). Exceptions to this quality do exist in the Subbasin, particularly in the southwestern portion of the Subbasin. Because of its relatively shallow depth within the Delta-Mendota Subbasin and lower salinity in areas when compared to other groundwater resources, the Lower Aquifer is heavily utilized as a source of groundwater for agricultural and drinking water uses within the Subbasin, where groundwater is beyond suitable for these uses in some areas.

The base of the Lower Aquifer generally decreases from south to north, changing in depth from about 1,100 to 1,200 feet deep in the south to about 600 feet to the north. Depth to the top of the Corcoran Clay ranges from less than 100 feet on the west near Interstate 5 (I-5) to more than 500 feet in the area near Tranquillity. The Corcoran Clay pinches out or is above the water level near the California Aqueduct in the western part of the Subbasin, where the Upper and Lower Aquifers merge into interfingered layers of sand, gravel, and clay.

Corcoran Clay

The Corcoran Clay, as a regional aquitard, is a notable hydrogeologic feature throughout most of the Delta-Mendota Subbasin, impeding vertical flow between the Upper and Lower Aquifers. The Corcoran Clay is present at varying depths across most of the Central Valley floor (**Figure 5-17** and **Figure 5-18**). The depths to the top of the Corcoran Clay ranges between approximately 150 and 500 feet below the ground surface throughout most of the Subbasin, with a general spatial pattern of deepening to the south and east. In the far southeastern area of the Subbasin, in the vicinity of Mendota and Tranquillity, the top of the Corcoran Clay is at depths of greater than 350 feet (**Figure 5-17**). The thickness of the Corcoran Clay, which likely influences the degree of hydraulic separation between the Upper and Lower Aquifers, is greater than 50 feet across most of the Delta-Mendota Subbasin with thicknesses of more than 75 feet in central Subbasin areas in the vicinity of Los Banos and Dos Palos, and 140 feet in the eastern portions of the Subbasin. The Corcoran Clay appears thinner in areas north of Patterson, between Patterson and Gustine, and also in the vicinity of Tranquillity to the south (**Figure 5-18**). Along the westernmost portions of the Delta-Mendota Subbasin, the Corcoran Clay layer is generally non-existent or is exists as Corcoran-equivalent clays (clays existing at the same approximate depth but not part of the mapped aquitard) (**Figure 5-17** and **Figure 5-18**).

Very Shallow Unconfined Groundwater

Floodplain deposits along the eastern side of the Subbasin, and the associated poorly-drained soils, cause naturally percolating water and applied irrigation water to build up in the very shallow zone. Shallow groundwater stagnation (where soils remain saturated within about 5 feet of the land surface) can increase salt accumulation in shallow soils and groundwater resulting from evaporation occurring directly from the water table (Corwin, 2012). The increased presence of the fine-grained floodplain deposits towards the Central Valley axis on the eastern side of the Delta-Mendota Subbasin results in low-permeability shallow soils that restrict the percolation of water, creating very shallow groundwater commonly within 25 feet of the ground surface. The combined effect of the many very shallow fine-grained lenses impeding vertical flow, especially in the distal fan and floodplain areas closer to the valley axis, can be great and represent a more substantial barrier to vertical movement of water (Bertoldi et al., 1991).

Tile drains are typically used in the eastern and southern portions of the Delta-Mendota Subbasin within the zone of Very Shallow Water (0 to 15 feet below ground surface) to manage impacts of shallow groundwater on the root zone. If groundwater within the semi-confined Upper Aquifer rises into the Very Shallow Water zone, tile drains can intercept and route such groundwater to sump pumps for removal via surface drainage networks. Further, it should be noted that some tile drains are likely within perched water zones that are not connected to the principal aquifers. Because of the generally shallow nature and high salinity, very shallow groundwater is not used to provide a major supply of water for agricultural or drinking uses within the Subbasin, although some projects are being developed to reuse this water on more salt-tolerant crops.

5.2.6.2 Aquifer Properties

The following subsections include discussion of generalized aquifer properties within the Delta-Mendota Subbasin. These include hydraulic conductivity, transmissivity, specific yield and specific storage.

DWR defines hydraulic conductivity as the "measure of a rock or sediment's ability to transmit water" and transmissivity as the "aquifer's ability to transmit groundwater through its entire saturated thickness" (DWR, 2003). High hydraulic conductivity values correlate with areas of transmissive groundwater conditions with transmissivity generally equaling hydraulic conductivity times the saturated thickness of the formation. Storage of water within the aquifer system can be quantified in terms of the specific yield for unconfined groundwater flow and the storage coefficient for confined flow, respectively (Faunt et al., 2009). Specific yield represents gravity-driven dewatering of shallow, unconfined sediments at a declining water table, but also accommodates a rising water table. The specific yield is dimensionless and represents the volume of water released from or taken into storage per unit head change per unit area of the water table. Specific yield is a function of porosity and specific retention of the sediments in the zone of water-table fluctuation.

Where the aquifer system is confined, storage change is governed by the storage coefficient, which is the product of the thickness of the confined-flow system and its specific storage. The specific storage is the sum of two component specific storages – the fluid (water) specific storage and the matrix (skeletal) specific storage, which are governed by the compressibilities of the water and skeleton, respectively (Jacob, 1940). Specific storage has units of 1 over length and represents the volume of water released from or taken into storage in a confined flow system per unit change in head per unit volume of the confined flow system (Faunt et al., 2009). Therefore, the storage coefficient of a confined flow system is dimensionless and, similar to specific yield, represents the volume of water released from or taken into storage per unit head change.

5.2.6.2.1 Hydraulic Conductivity

Figure 5-20 shows the saturated C-horizon vertical hydraulic conductivity of surficial soils within the Delta-Mendota Subbasin based on the National Resource Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO). Soil survey data for counties within the Subbasin were combined using the weighted harmonic mean of

these representative layers to depict the saturated hydraulic conductivity of the C-horizon for each soil map unit. The soil profile represented by these data is variable but commonly extends to a depth of 6 or more feet.

Floodplain deposits are evident as soils with relatively low hydraulic conductivity (less than 0.5 feet per day [ft/day]) blanketing much of the Central Valley Floor, although localized areas of soils with higher hydraulic conductivity are present in association with modern and ancient surface waterways and alluvial fan features (**Figure 5-20**). Coarse soils of distributary alluvial fan sediments deposited by Del Puerto Creek, Orestimba Creek, and Little Panoche Creek, in addition to other ephemeral northeasterly creek flows off the Coast Ranges, are notably apparent as areas of soils of high hydraulic conductivity located along active and inactive stream channels extending eastward from the fan apex areas along the Valley Floor margins to the current alignment of the San Joaquin River in the valley axis. Additionally, soils in areas adjacent to the active channel of the San Joaquin River also exhibit high hydraulic conductivities, including values of greater than 4 ft/day which are particularly apparent in an area north of Mendota. Soils of similarly high hydraulic conductivity trending as linear features in a general northwest-southeast alignment to the north of Dos Palos and Los Banos are likely the result of historical depositional processes and paleochannels associated with the San Joaquin River (**Figure 5-20**). In areas peripheral to the Central Valley floor, soils tend to be characterized by relatively low hydraulic conductivity, although soils of somewhat higher hydraulic conductivity associated with distinct geologic units are mapped across much of the peripheral area to the west of Patterson and Gustine and also in localized bands associated with surface water courses.

5.2.6.2.2 Transmissivity

Transmissivity varies greatly above the Corcoran Clay, within the Corcoran Clay, and below the Corcoran Clay within the Delta-Mendota Subbasin, with transmissivities in the confined Lower Aquifer generally being larger than those in the semi-confined Upper Aquifer. Based on testing conducted at multiple locations within both the Upper and Lower Aquifers of the Delta-Mendota Subbasin, average transmissivities in the Subbasin are approximately 109,000 gallons per day per square foot (gpd/ft^2) (SJRECWA, 2018).

5.2.6.2.3 Specific Yield

DWR defines specific yield as the "amount of water that would drain freely from rocks or sediments due to gravity and describes the proportion of groundwater that could actually be available for extraction" (DWR, 2003). Specific yield is a measurement specific to unconfined aquifers.

The estimated specific yield of the Delta-Mendota Subbasin is 0.118 (DWR, 2006). Within the southern portion of the Delta-Mendota Subbasin, specific yield ranges from 0.2 to 0.3 (Beltiz et al., 1993). Specific yield estimates for the Delta-Mendota Subbasin are fairly limited in literature since the Upper Aquifer above the Corcoran Clay is semi-confined and the Lower Aquifer below the Corcoran Clay is confined. Therefore, specific yield values only characterize the shallow, unconfined groundwater within the Subbasin.

5.2.6.2.4 Specific Storage

Values for specific storage were extracted from the Central Valley Hydrologic Model 2 (CVHM2), which is currently under development by the United States Geological Survey (USGS) and includes refinements for the Delta-Mendota Subbasin. Specific storage varies above, within, and below the Corcoran Clay with CVMH2. Above the Corcoran Clay, specific storage ranges from 1.34×10^{-6} to 6.46×10^{-2} meters^{-1} (m^{-1}) with average values ranging from 6.16×10^{-3} to 1.97×10^{-2} m^{-1}. Specific storage within the Corcoran Clay is considerably smaller than above the Corcoran Clay, ranging between 1.41×10^{-6} and 2.35×10^{-6} m^{-1} and average values between 1.96×10^{-6} and 2.02×10^{-6} m^{-1}. Below the Corcoran Clay, specific storage is comparable to within the Corcoran Clay with overall ranges the same as within the Corcoran Clay and average values ranging from 1.86×10^{-6} to 2.01×10^{-6} m^{-1}. Therefore, specific storage is greatest within the semi-confined aquifer overlying the Corcoran Clay layer, with considerably smaller specific storage values with the low permeability Corcoran Clay and confined aquifer underlying the Corcoran Clay layer.

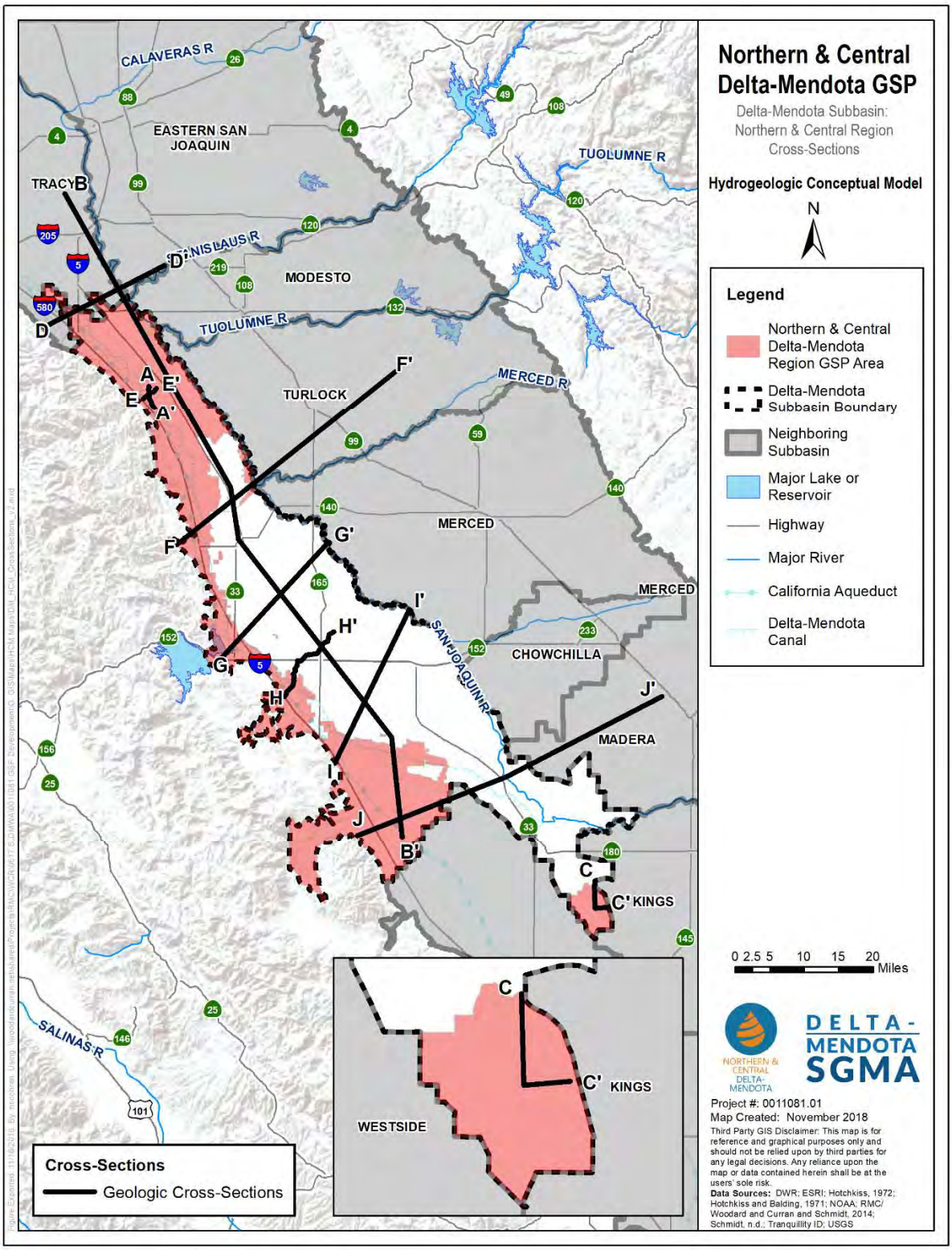


Figure 5-6. Representative Cross-Sections, Northern & Central Delta-Mendota Region GSP

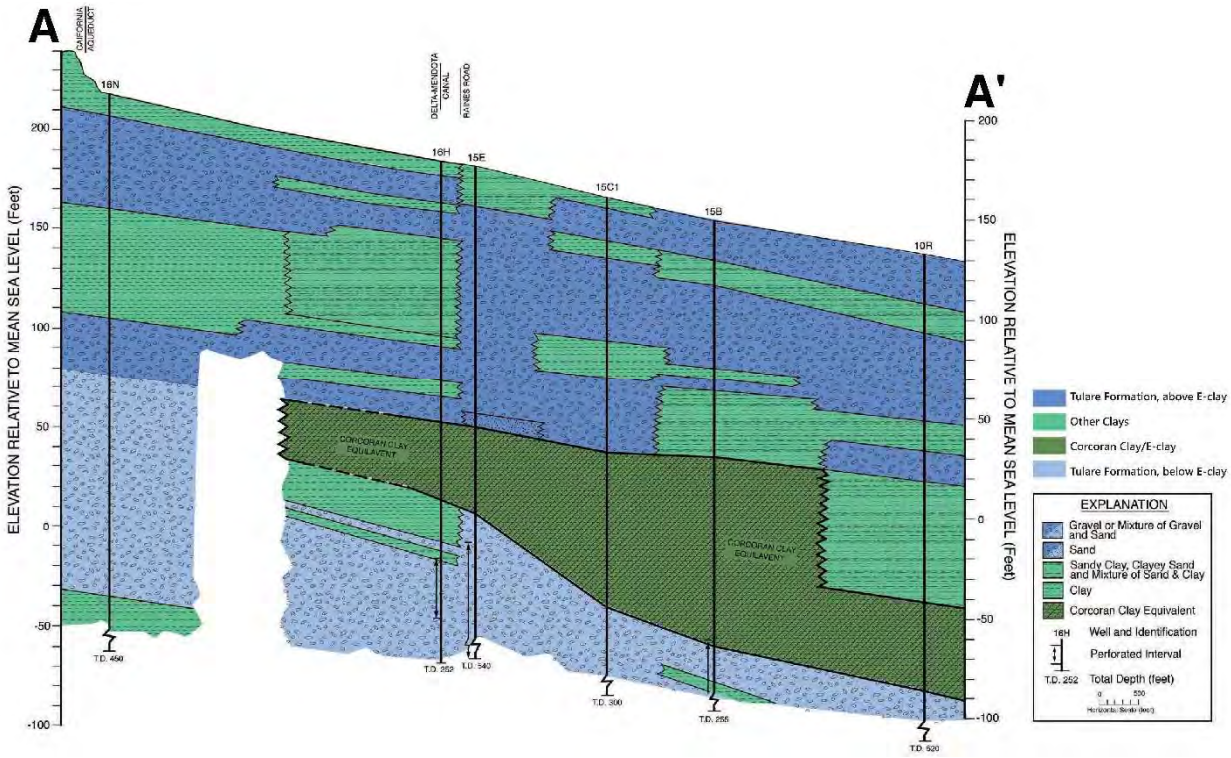


Figure 5-7. Cross-Section A-A' (RMC/W&C and Schmidt, 2014)

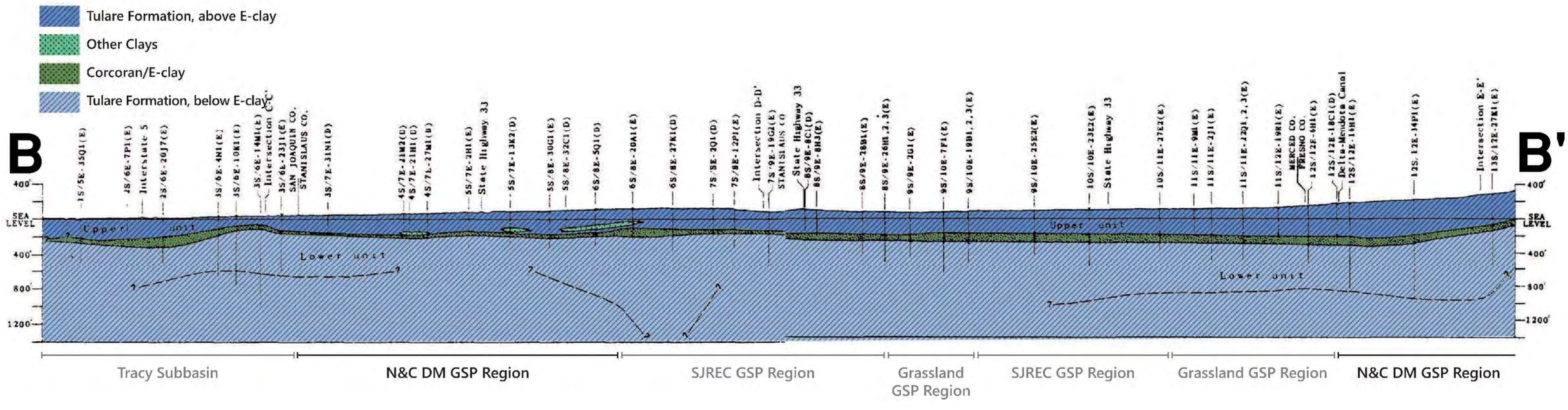
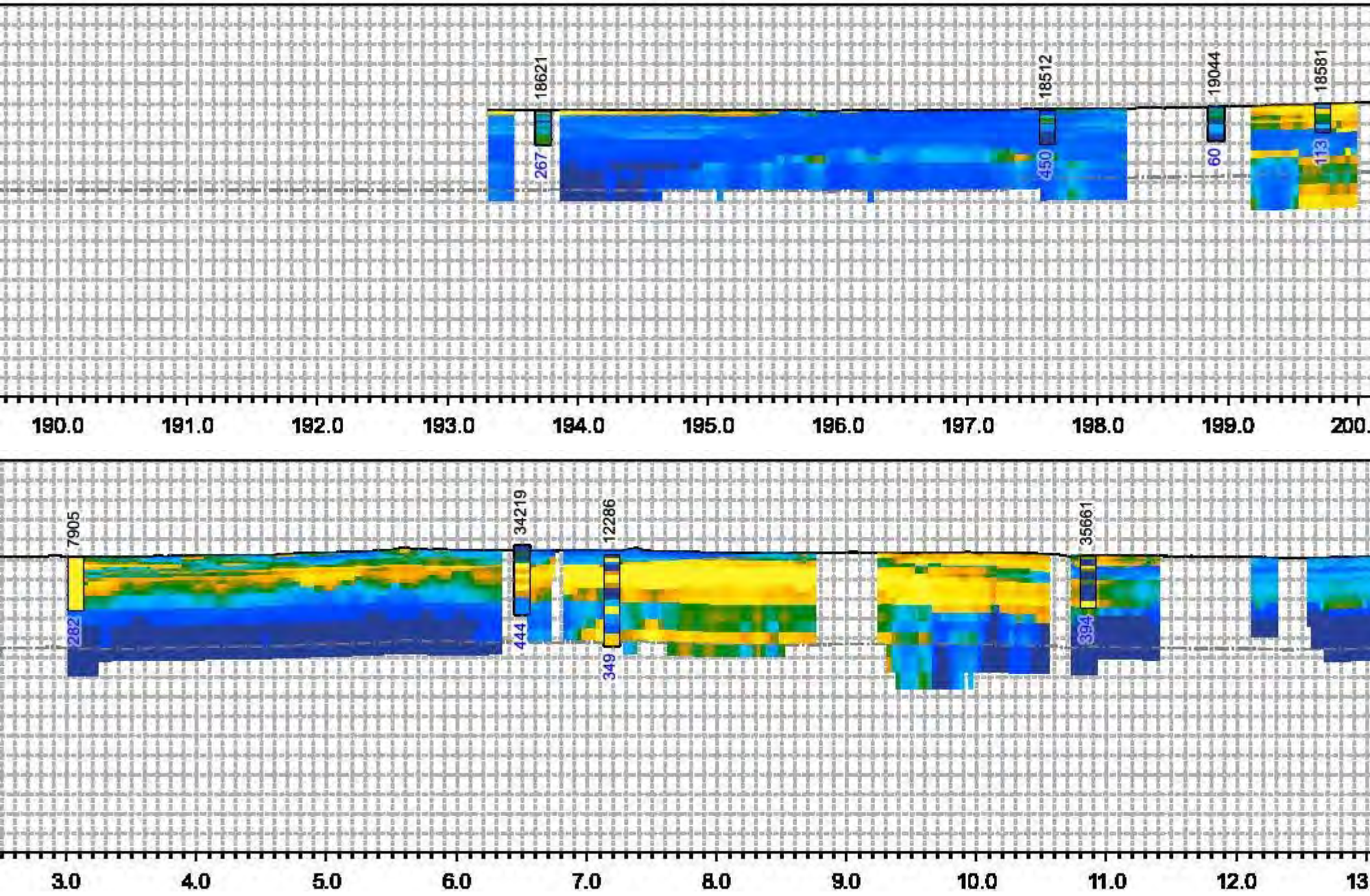
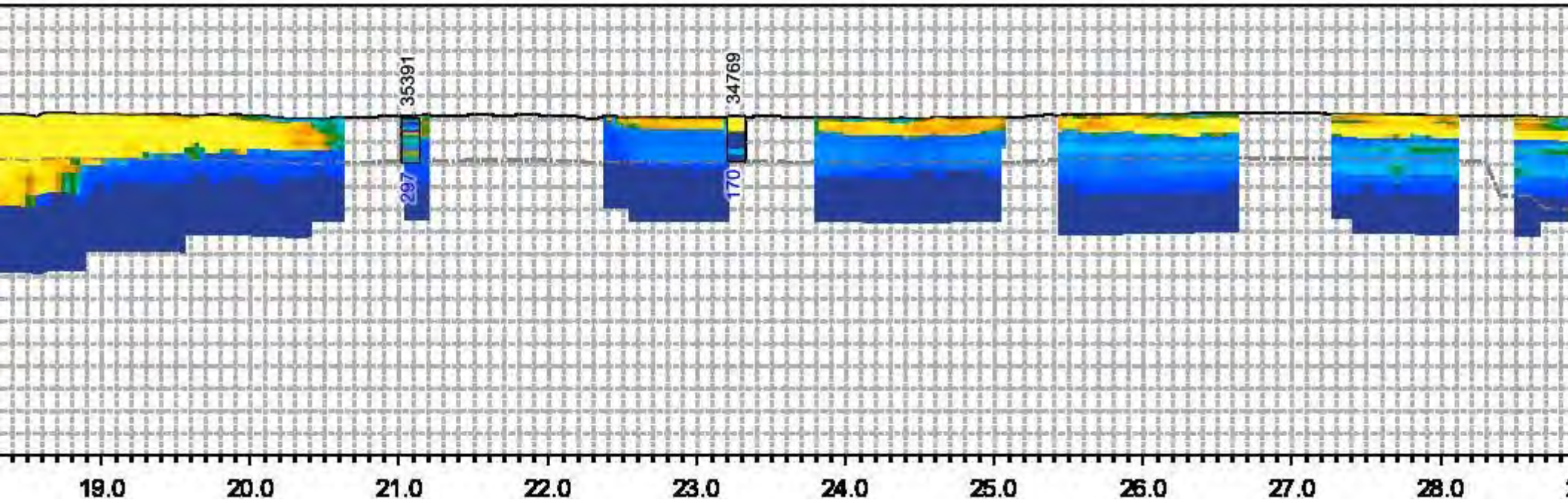


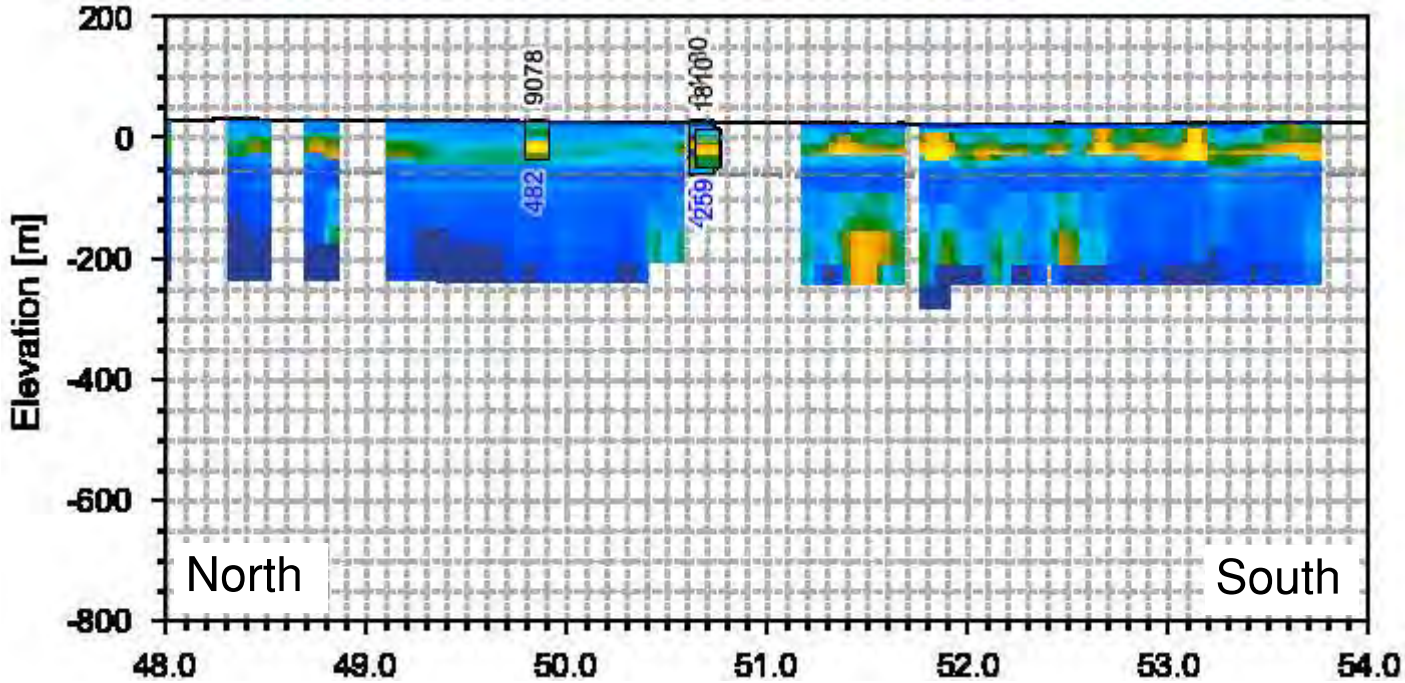
Figure 5-8. Cross-Section B-B' (Hotchkiss, 1972)

B - B' Nearest AEM Logs

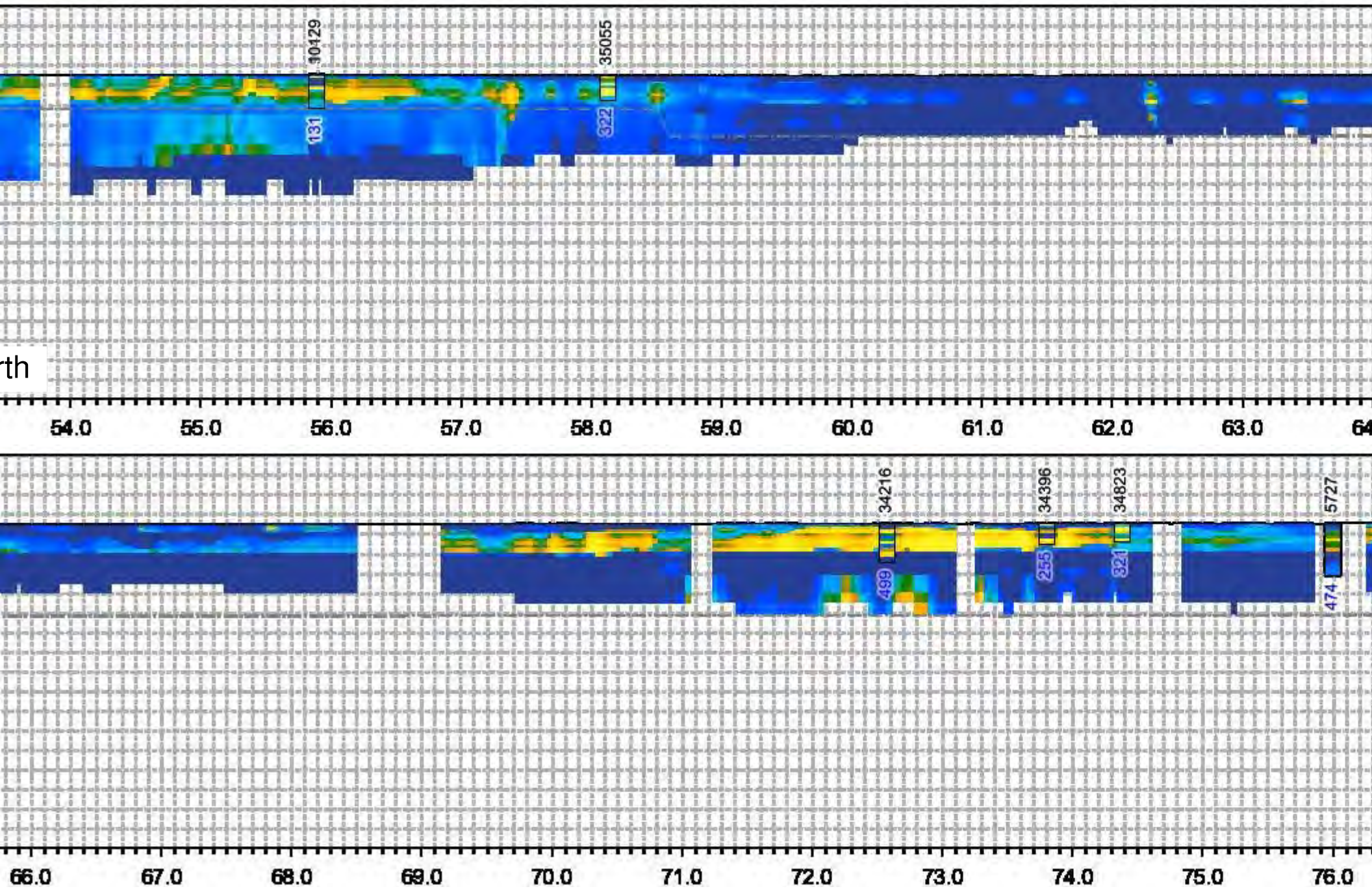


B - B' Nearest AEM Logs

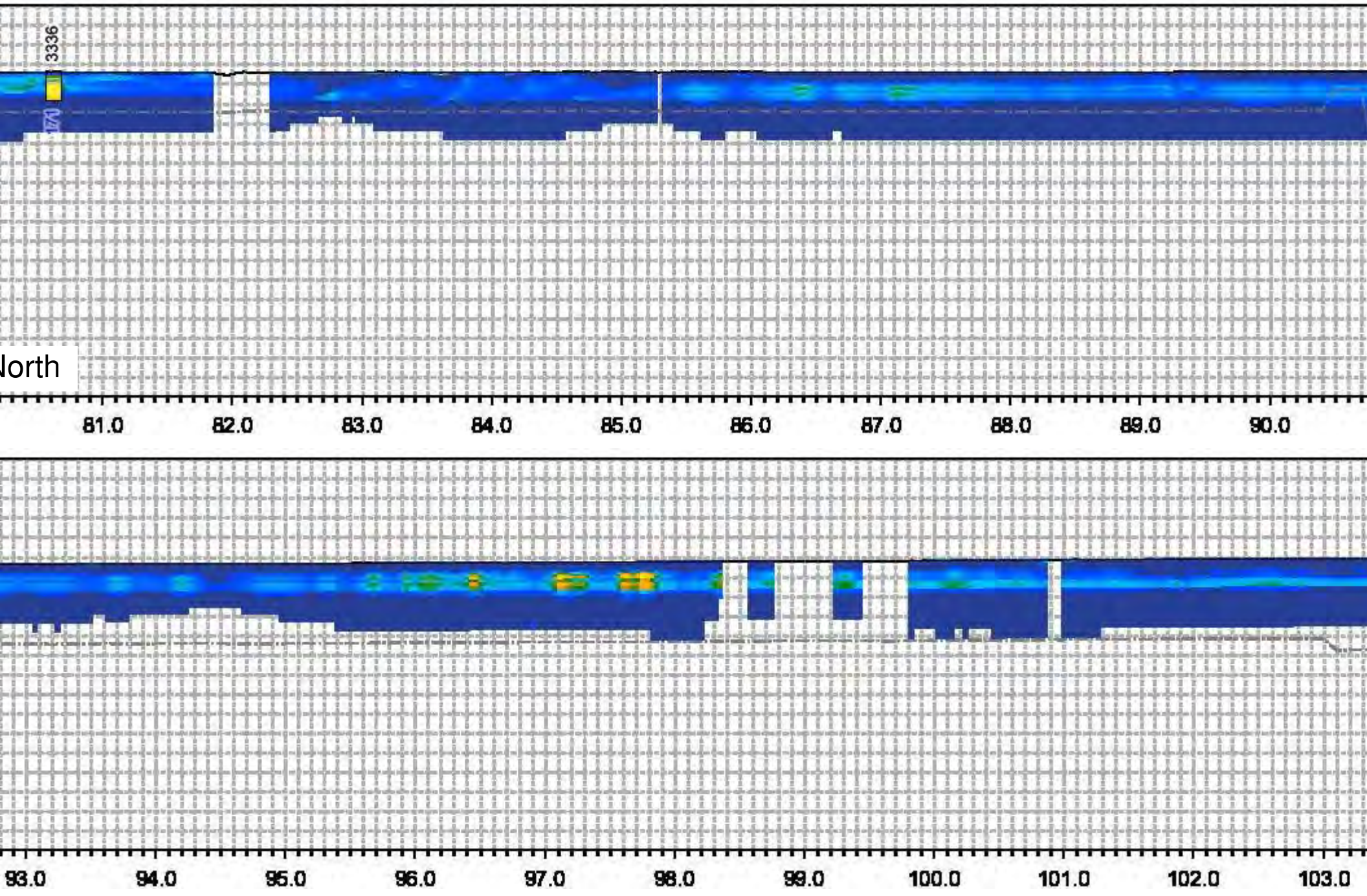




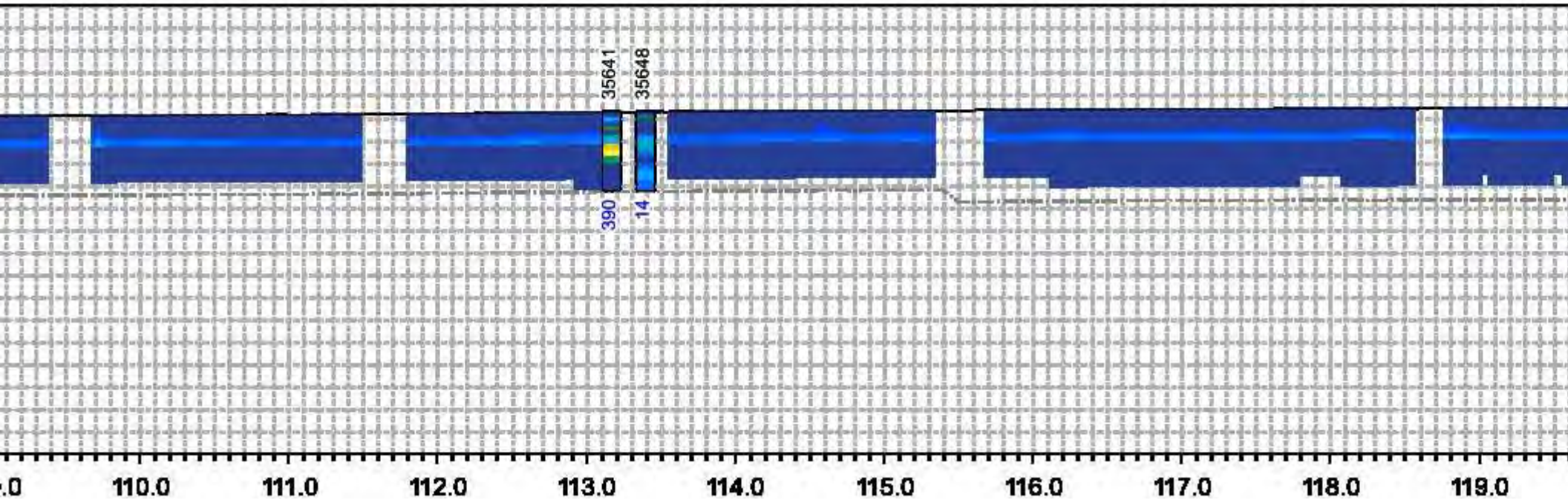
B - B' Nearest AEM Logs



B - B' Nearest AEM Logs



B - B' Nearest AEM Logs



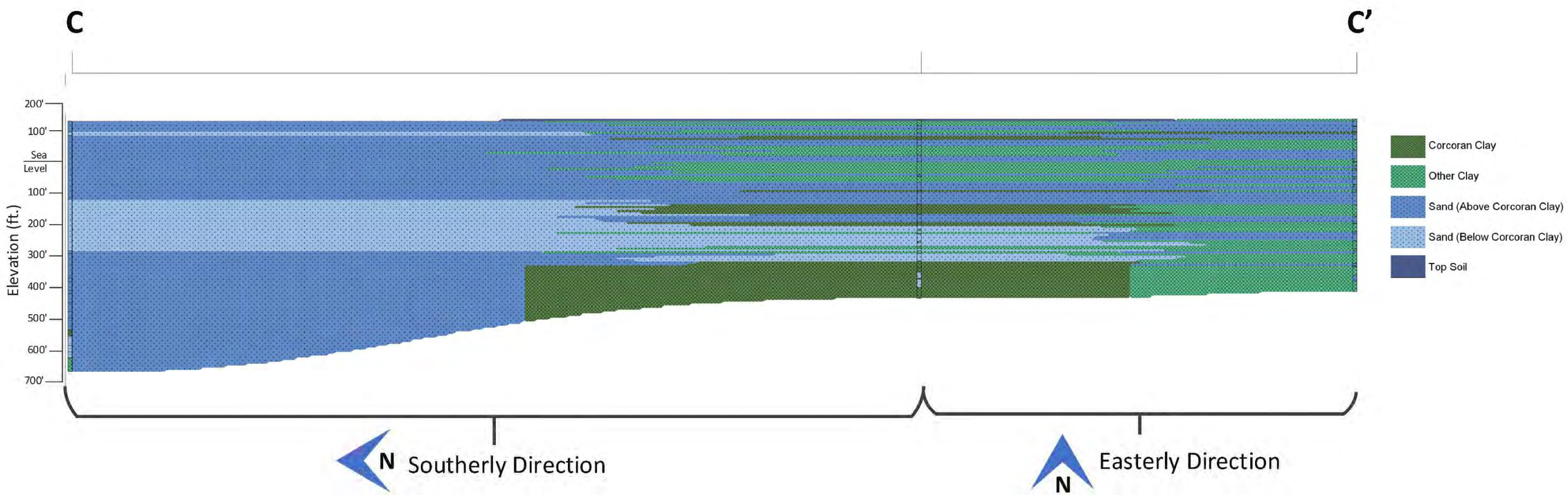
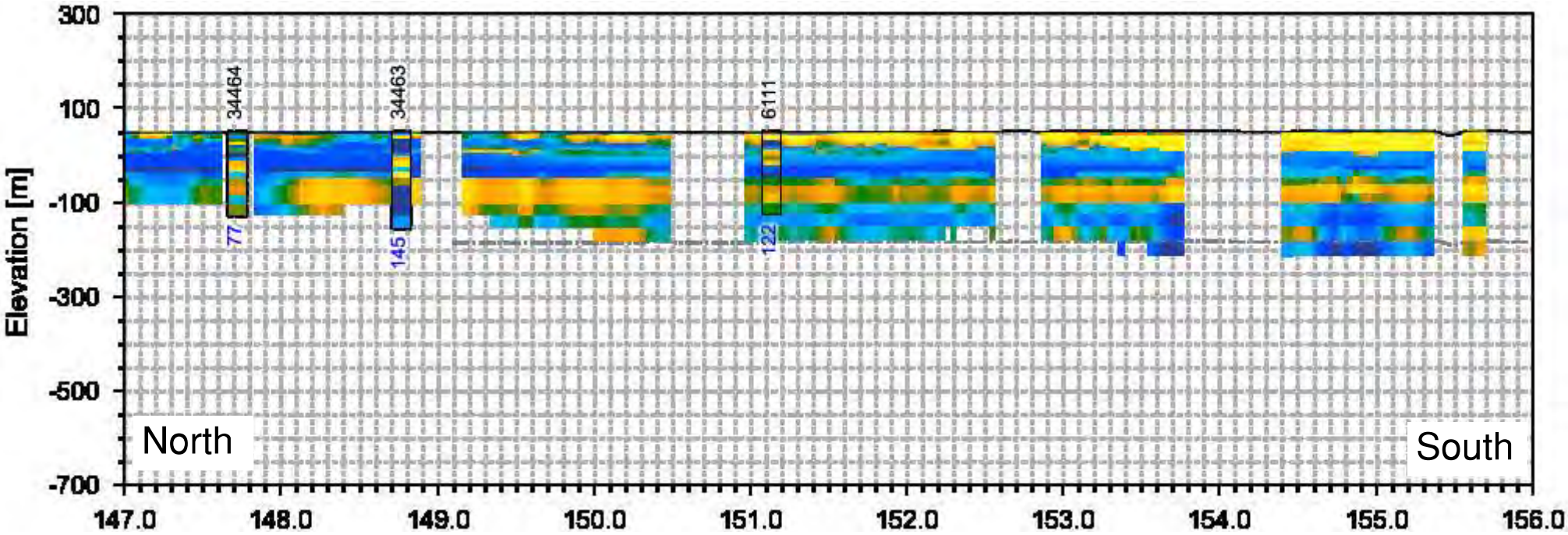


Figure 5-9. Cross-Section C-C' (Tranquillity ID, 1994 and 2000 and LSCE, 2011)

C - C' Nearest AEM Logs



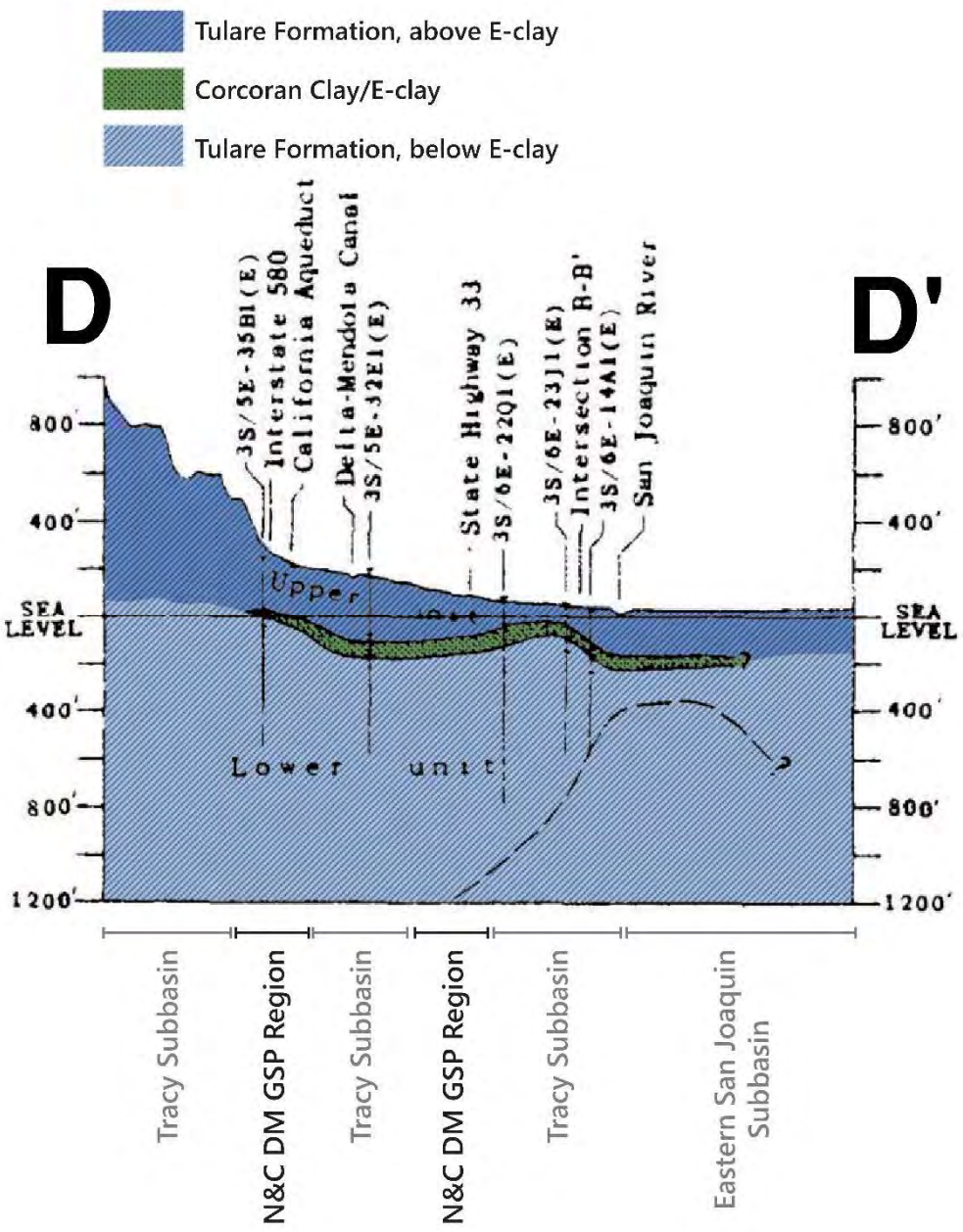
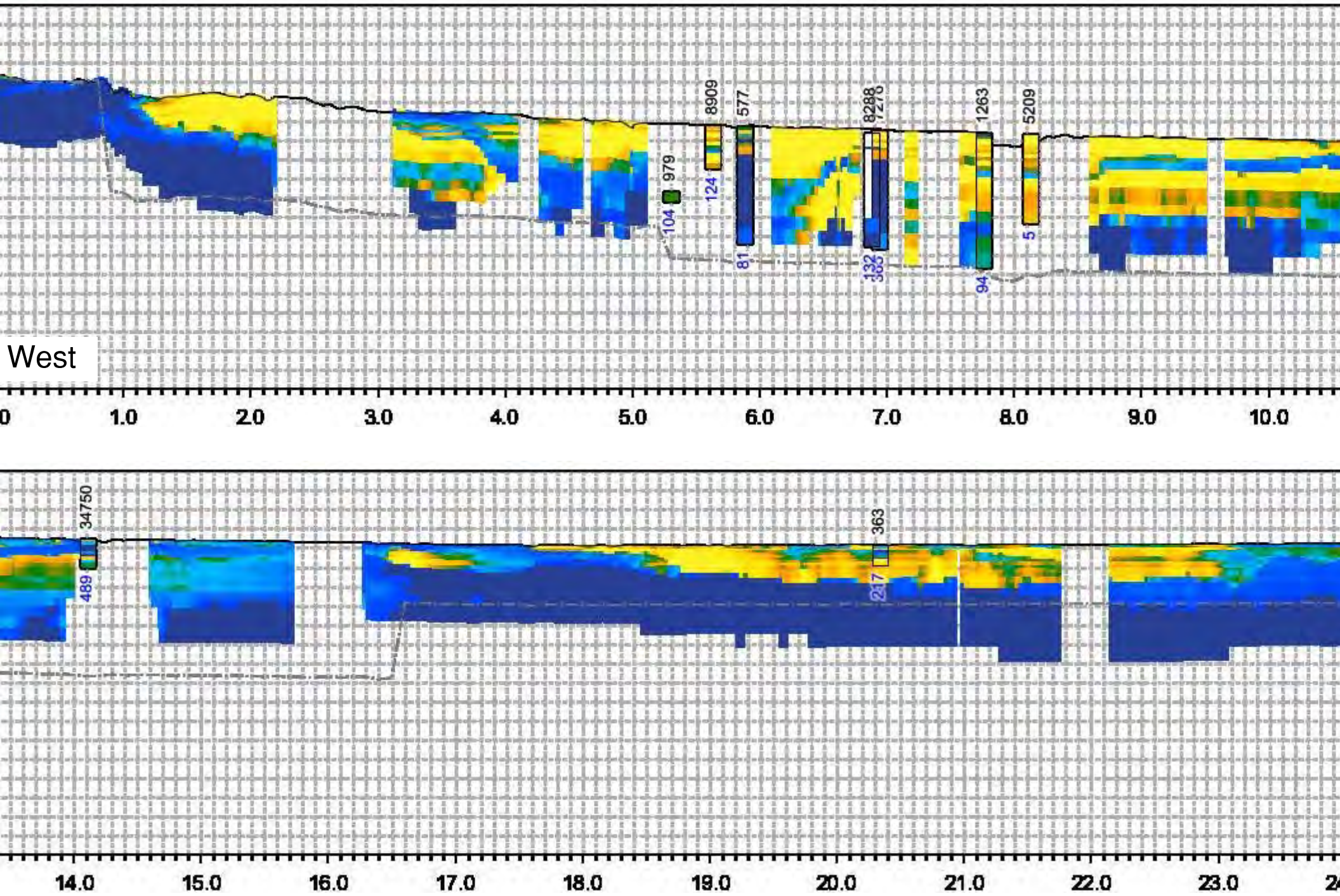
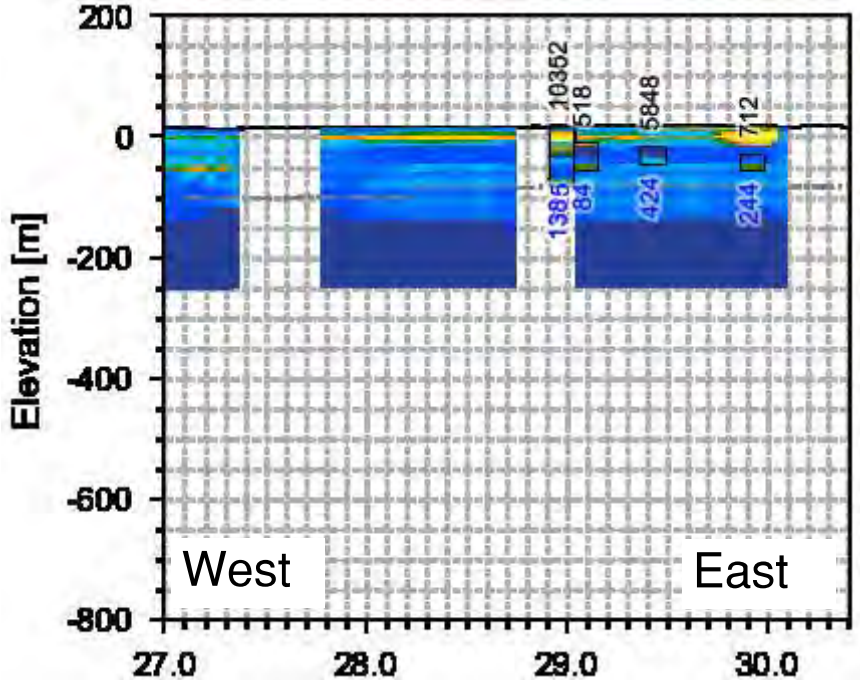


Figure 5-10. Cross-Section D-D' (Hotchkiss, 1972)

D - D' Nearest AEM Logs



D - D' Nearest AEM Logs



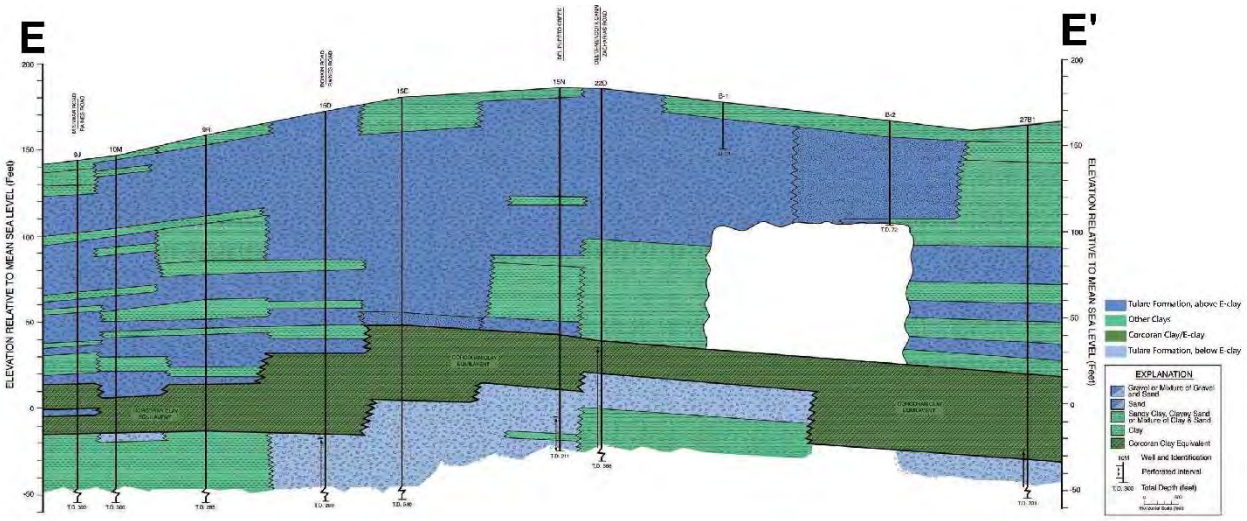


Figure 5-11. Cross-Section E-E' (RMC/W&C and Schmidt, 2014)

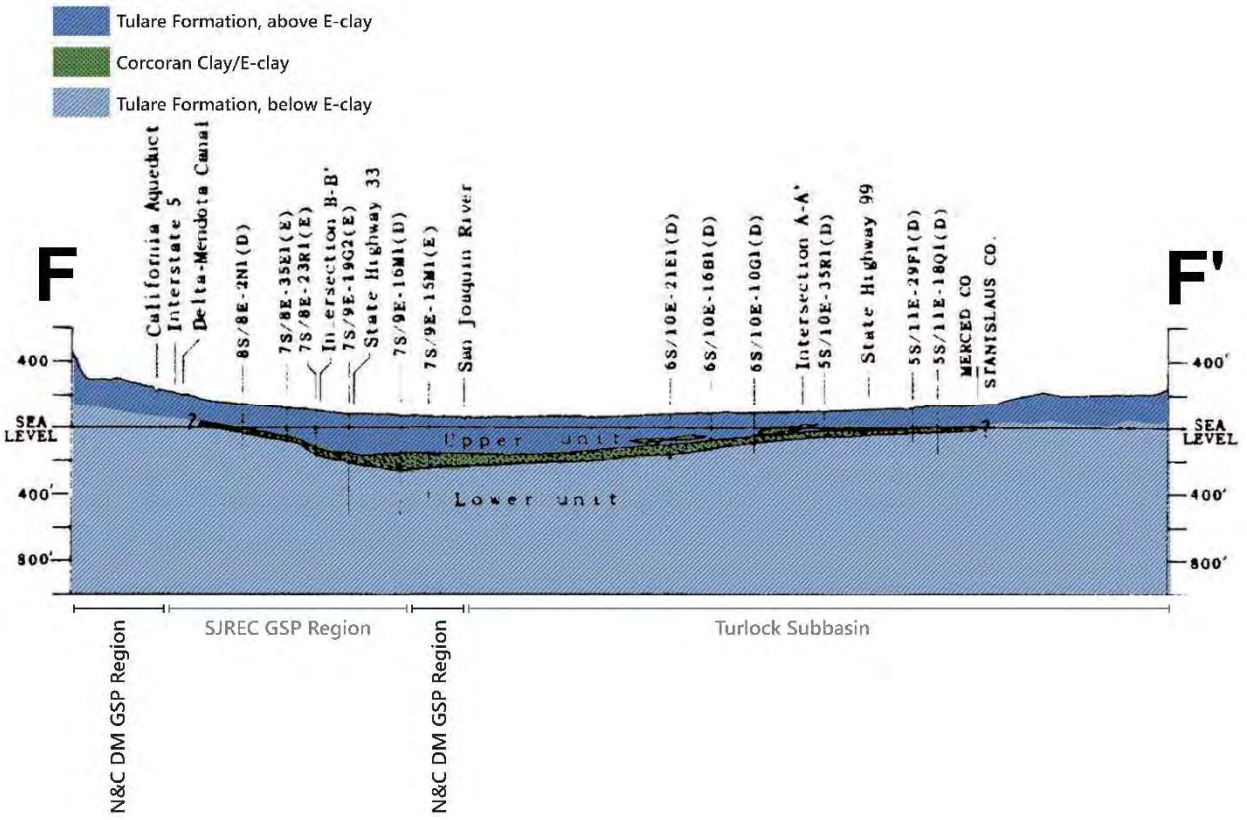
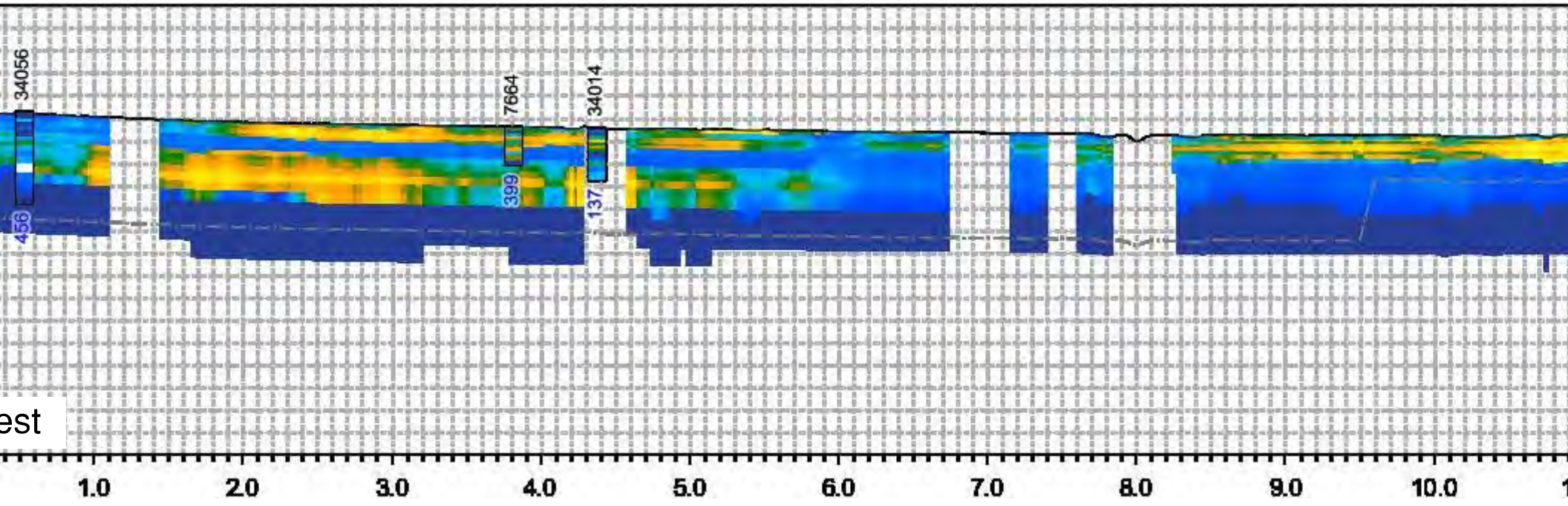
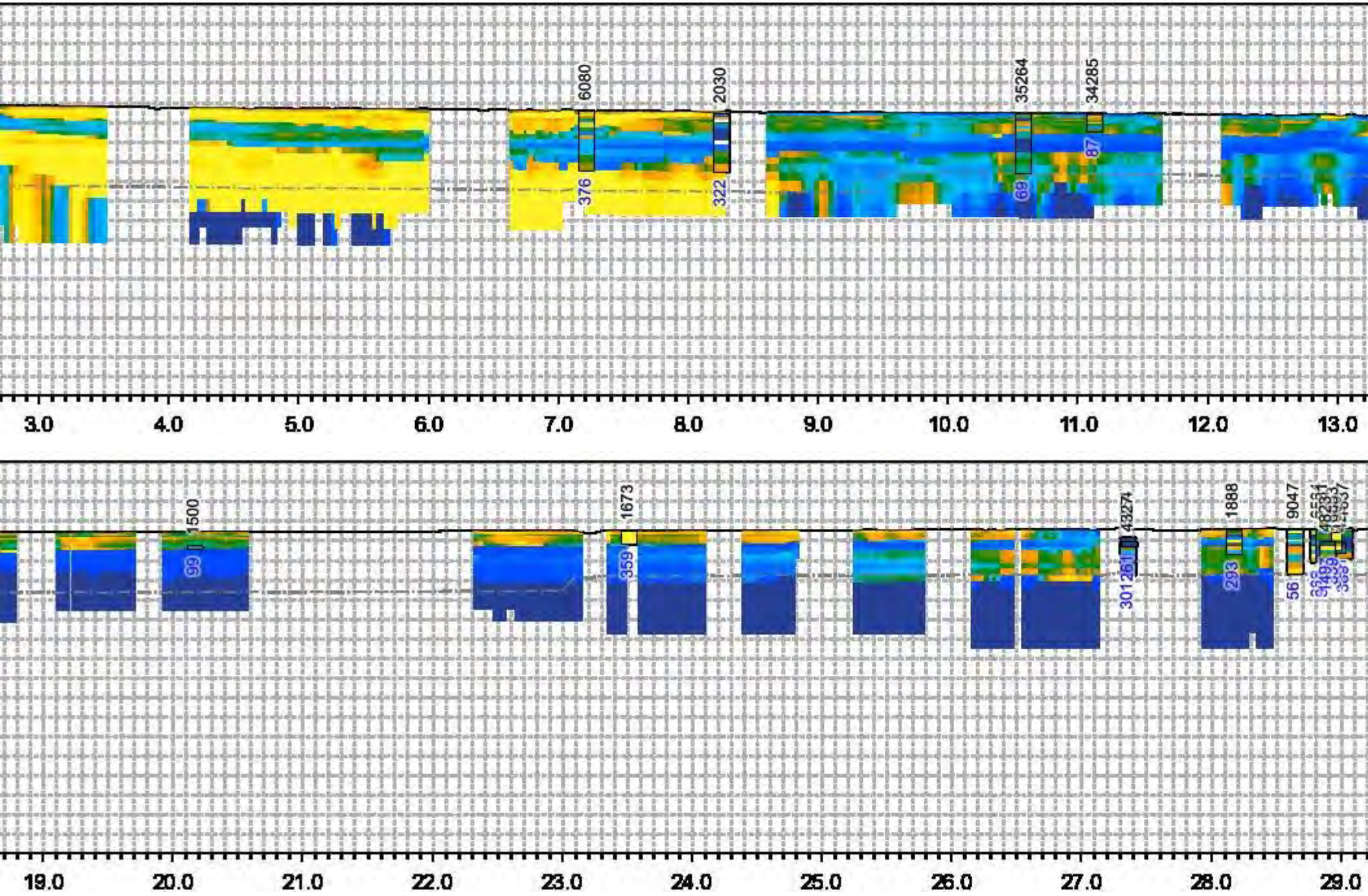


Figure 5-12. Cross-Section F-F' (Hotchkiss, 1972)

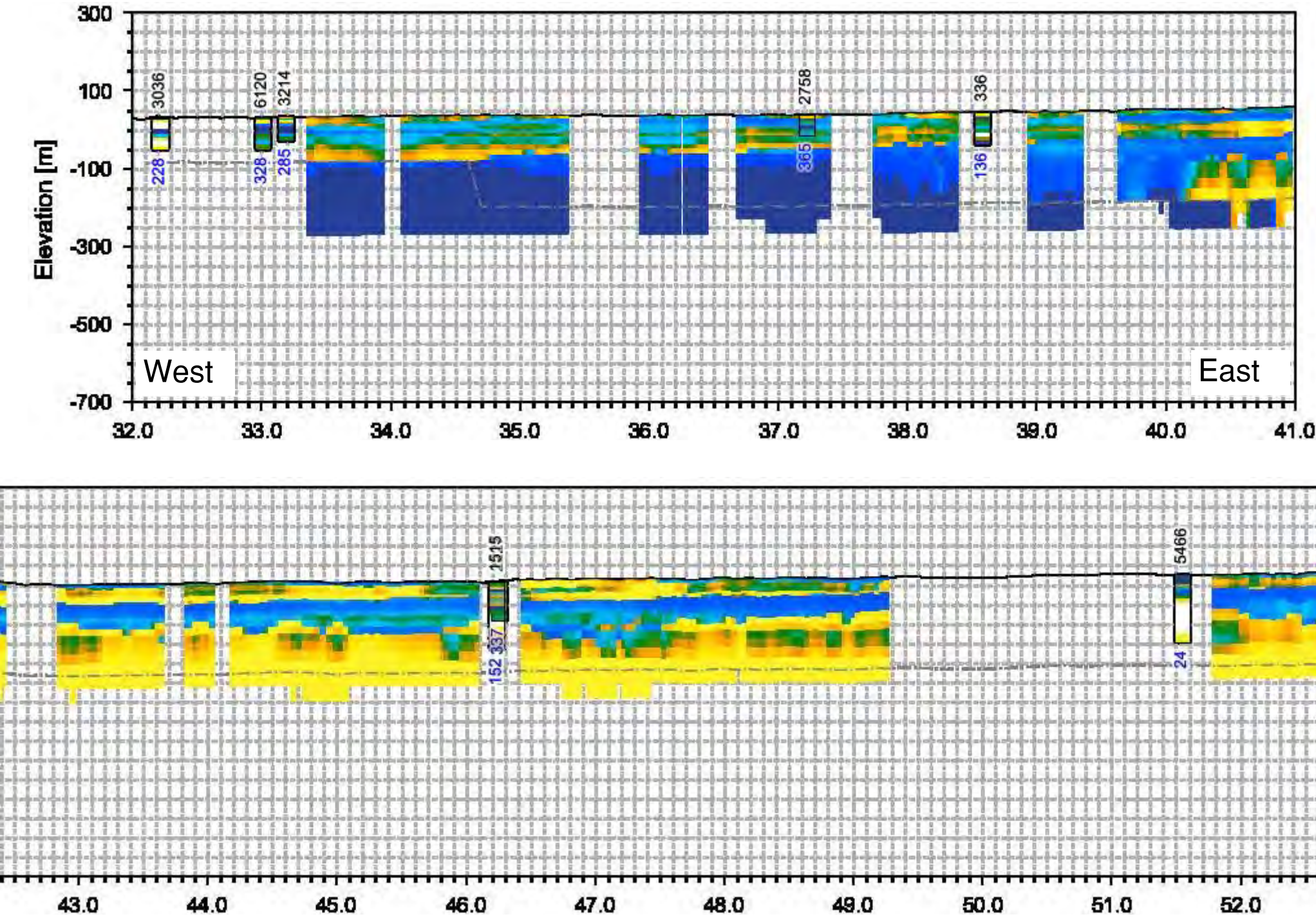
E - E' Nearest AEM Logs



F - F' Nearest AEM Logs



F - F' Nearest AEM Logs



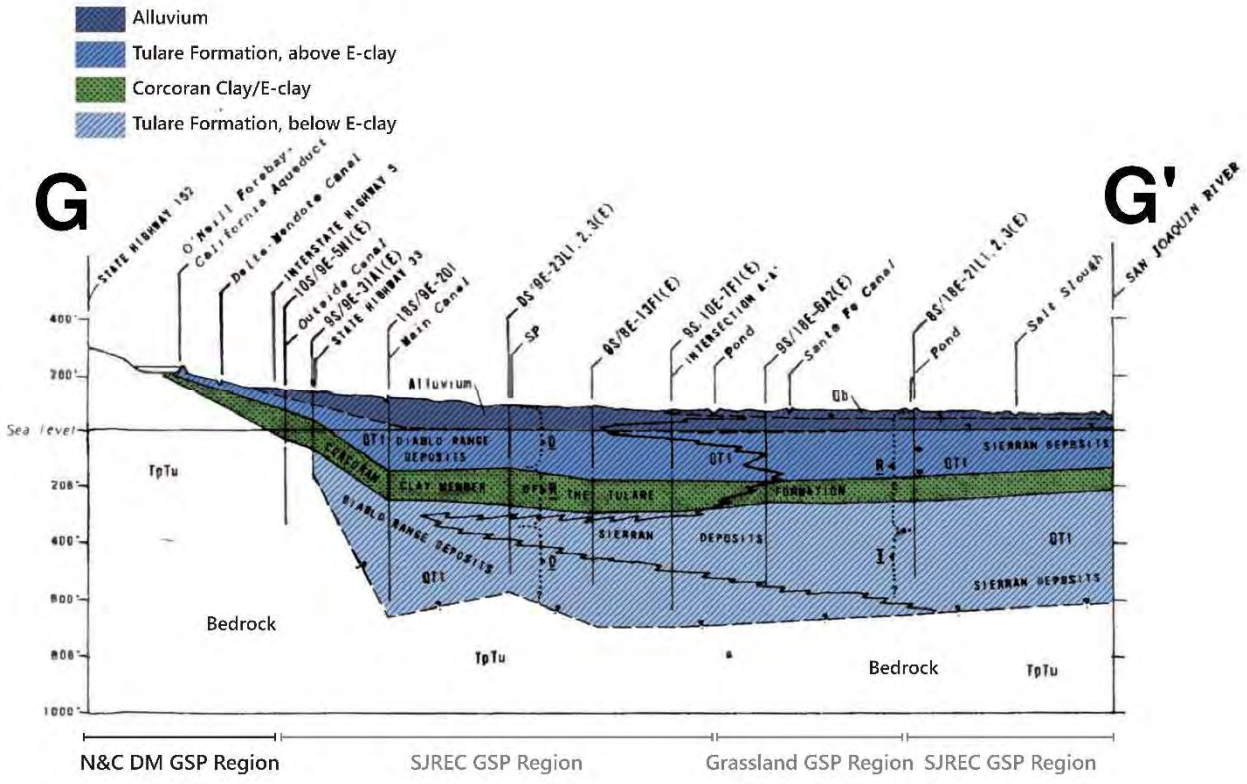
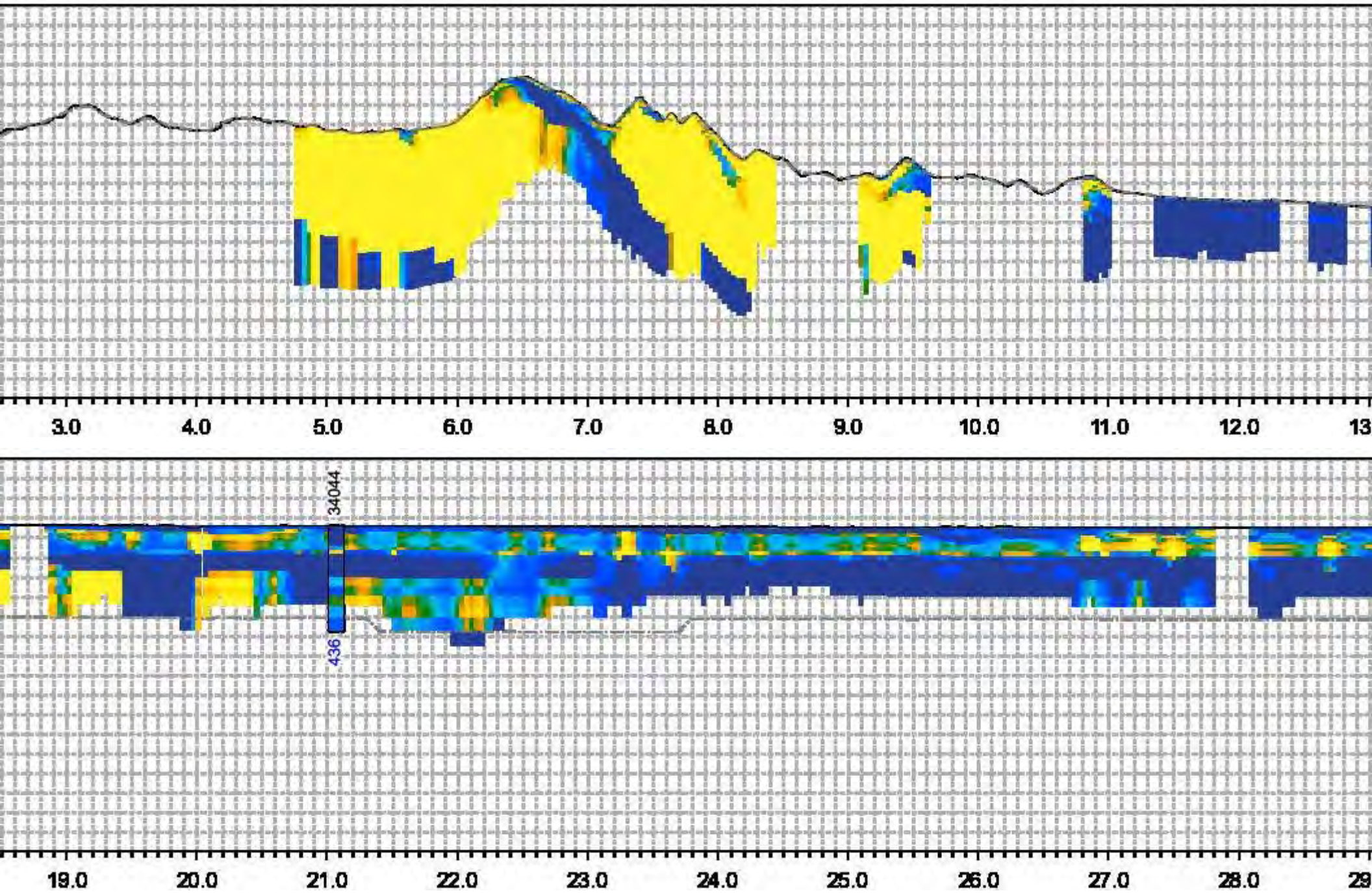
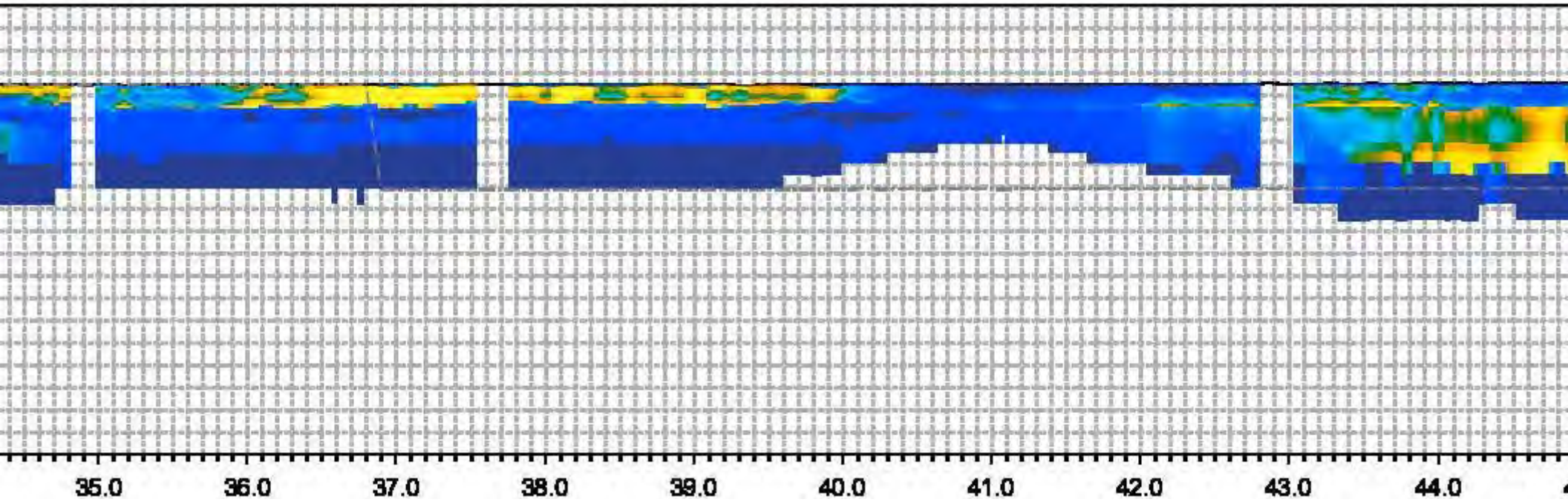


Figure 5-13. Cross-Section G-G' (Hotchkiss & Balding, 1971)

G - G' Nearest AEM Logs



G - G' Nearest AEM Logs



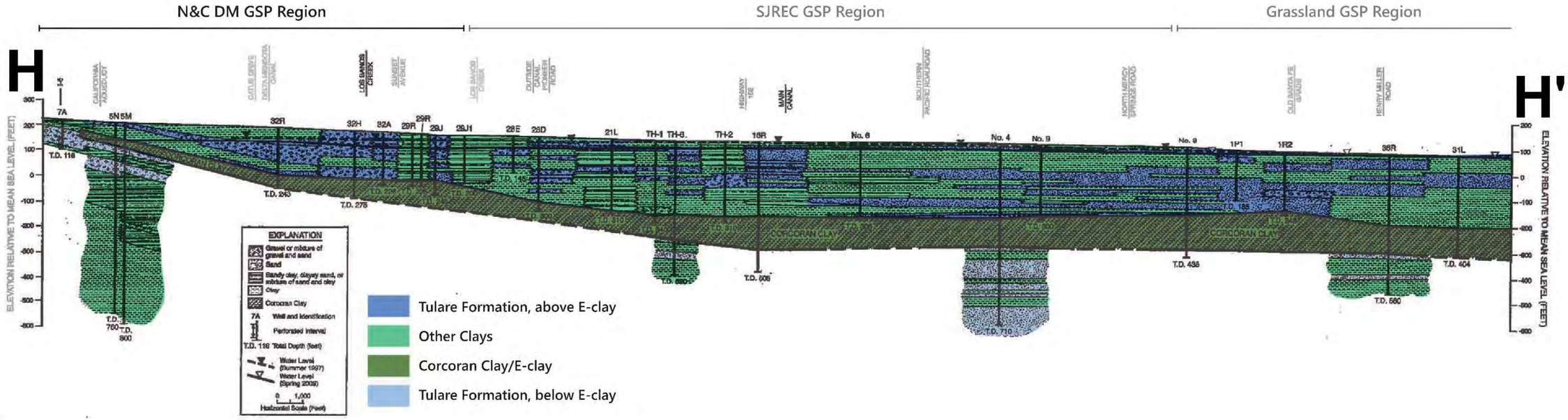
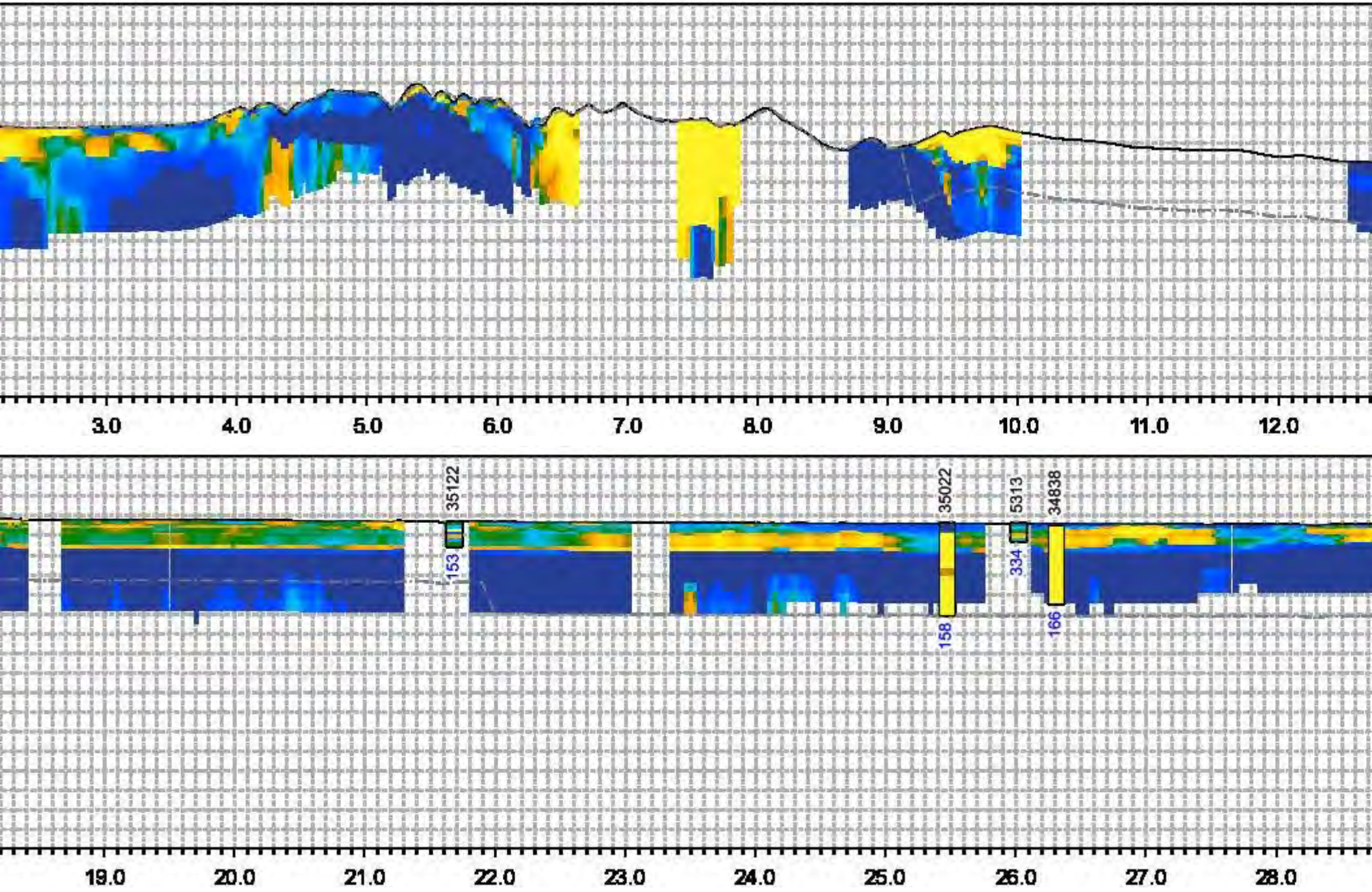


Figure 5-14. Cross-Section H-H' (Schmidt, 2018)

H - H' Nearest AEM Logs



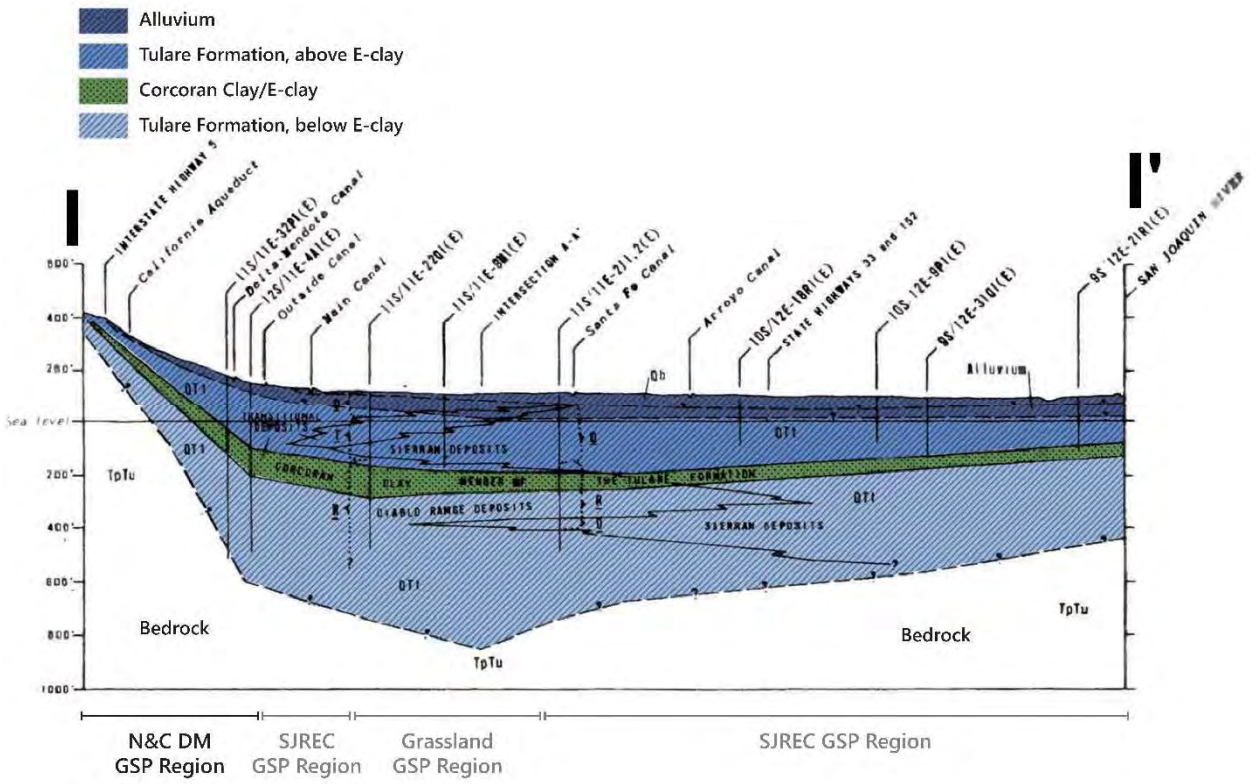


Figure 5-15. Cross-Section I-I' (Hotchkiss & Balding, 1971)

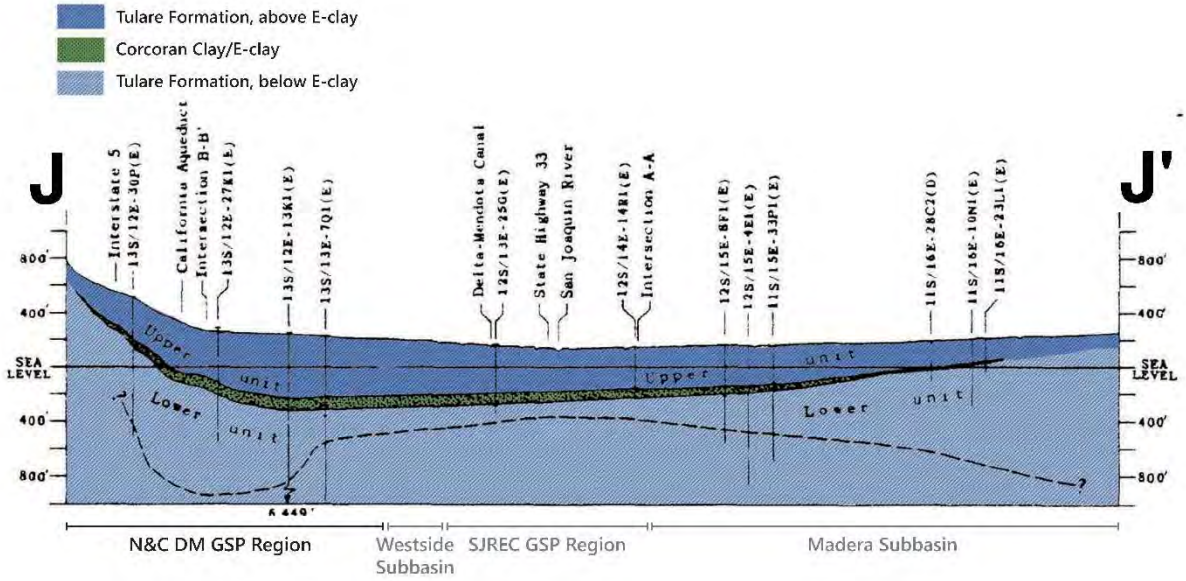
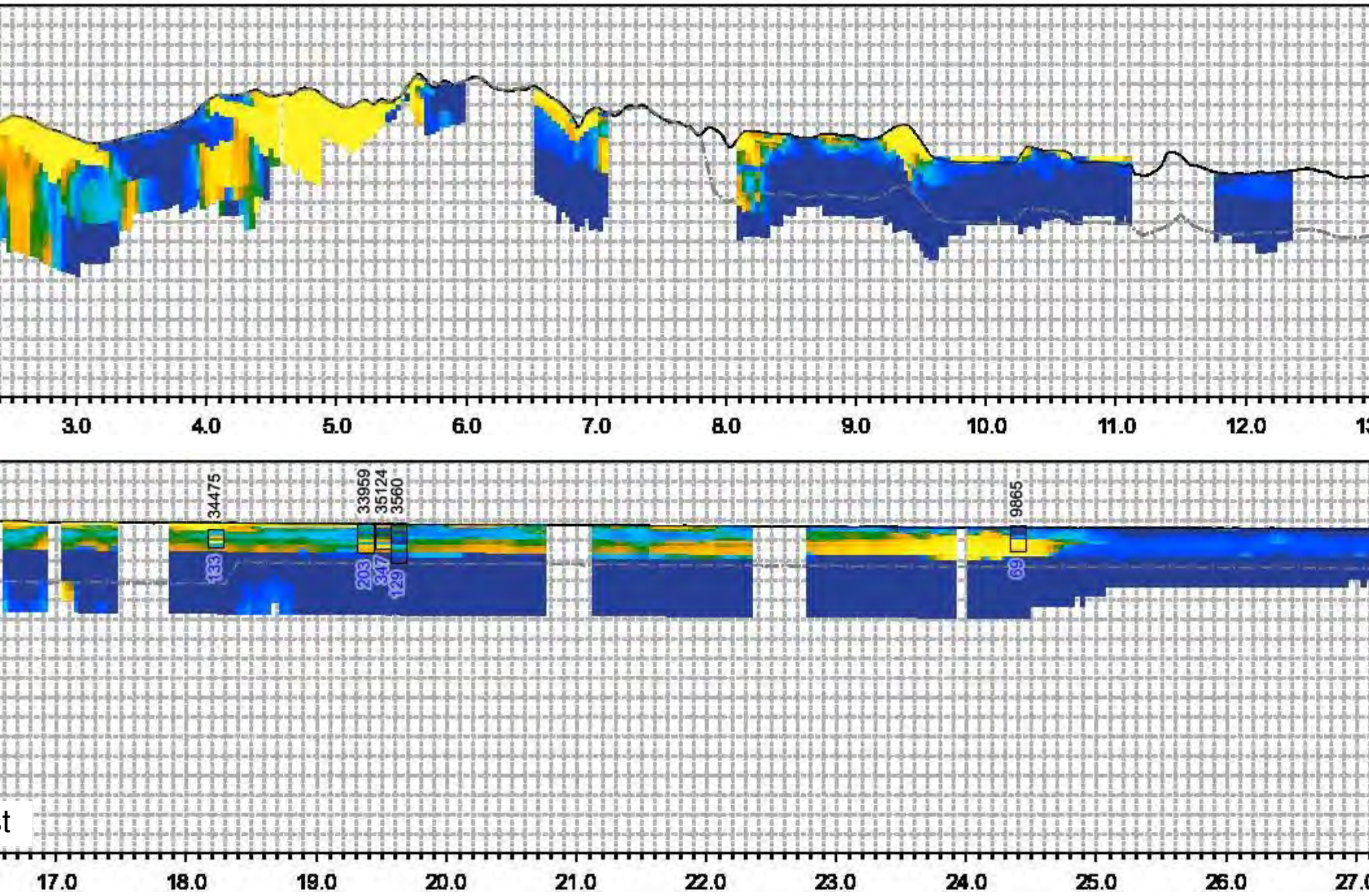
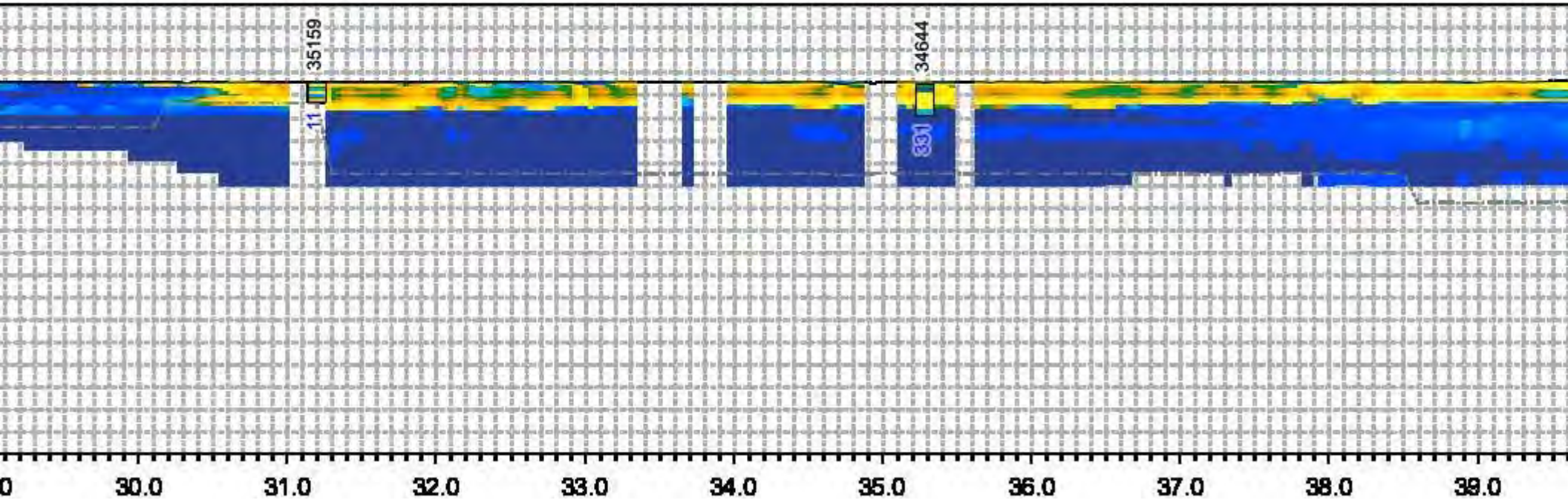


Figure 5-16. Cross-Section J-J' (Hotchkiss, 1972)

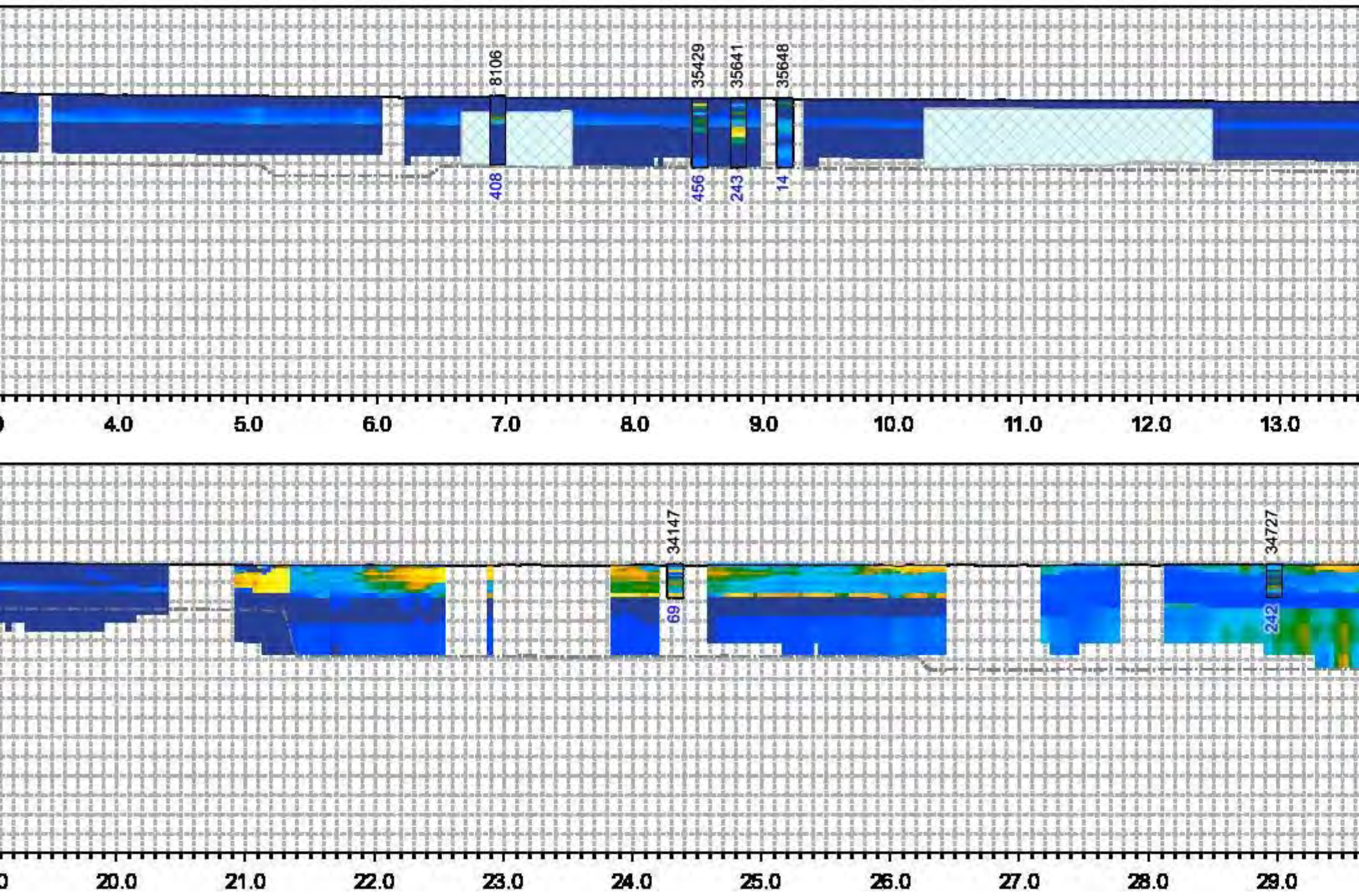
I - I' Nearest AEM Logs



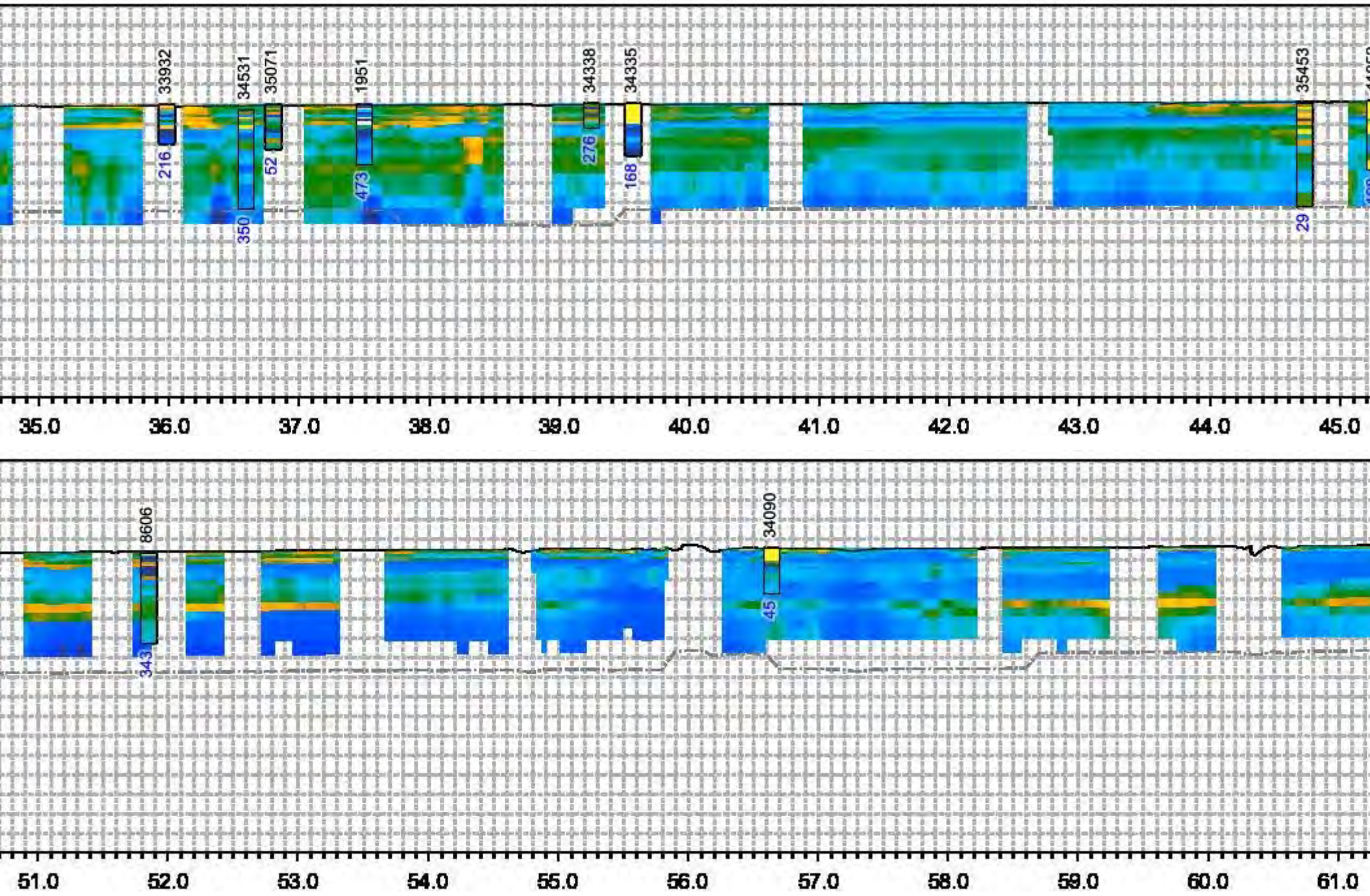
I - I' Nearest AEM Logs



J - J' Nearest AEM Logs



J - J' Nearest AEM Logs



San Joaquin River Exchange Contractors GSA

- City of Newman GSA
- City of Gustine GSA
- City of Los Banos GSA
- City of Dos Palos GSA
- City of Firebaugh GSA
- City of Mendota GSA
- Turner Island Water District-2 GSA
- County of Madera-3 GSA
- Portion of Merced County – Delta-Mendota GSA
- Portion of Fresno County – Management Area B GSA

Groundwater Sustainability Plan

for the

San Joaquin River Exchange Contractors GSP Group

in the

Delta-Mendota Subbasin (5-022.07)

June 2022

4.1.6 Definable Bottom of Basin

In the San Joaquin Valley, the bottom of the Delta-Mendota Subbasin is defined as the interface of saline water of marine origin (base of fresh water) within the uppermost beds of the Tulare Formation. The Tulare Formation is characterized by blue and green fine-grained rocks and principally composed of fine-grained silty sands, silt, and clay (Foss and Blaisdell 1968). The Tulare Formation is predominantly marine in origin and is considered late Pliocene and possibly early Pleistocene in age. This formation is the upper shaley part of the Pliocene sequence. The top of the Tulare Formation is generally encountered around -2,000 feet mean sea level throughout the Delta-Mendota Subbasin. As agreed upon by the Delta-Mendota Subbasin GSP Groups, the base of freshwater is specifically defined by an electrical conductivity of 3,000 micromhos per centimeter at 25 °C, as presented by Page (1973). If and when significant use of water beyond the defined bottom takes place, the definition of the bottom will be revised appropriately.

4.1.7 Principal Aquifers and Aquitards

DWR's Groundwater Glossary defines an aquifer as "a body of rock or sediment that is sufficiently porous and permeable to store, transmit, and yield significant or economic quantities of groundwater to wells, and springs". There are two primary aquifers within the Delta-Mendota Subbasin: a semi-confined aquifer above the Corcoran Clay and a confined aquifer below the Corcoran Clay, with the Corcoran Clay acting as the principal aquitard within the Delta-Mendota Subbasin. **Figure CC-24** shows the locations of the representative cross-sections for the Delta-Mendota Subbasin, where **Figure CC-25** through **Figure CC-30** show the hydrostratigraphy of the representative cross-sections.

While the two-aquifer system described above is generally true across the Delta-Mendota Subbasin, there are portions of the Subbasin where the Corcoran Clay does not exist (predominantly along the western margin of the Subbasin) and hydrogeology is generally controlled by localized interfingering clays, and/or where local hydrostratigraphy results in shallow groundwater conditions that differ, to some extent, from that seen in the Subbasin as a whole. Additionally, in the southern portion of the Subbasin in the Mendota, Aliso and Tranquillity areas, there are A and C Clay layers in addition to the Corcoran Clay that inhibit vertical groundwater flow. However, while there are localized complexities throughout the Subbasin, the Corcoran Clay (or E Clay) extends through much of the Delta-Mendota Subbasin, generally creating a two-aquifer system.

Principal Aquifers

In the Delta-Mendota Subbasin, there are two primary aquifers composed of alluvial deposits separated by the Corcoran Clay (KDSA, 2015): a semi-confined Upper Aquifer (generally the ground surface to the top of the Corcoran Clay), and a confined Lower Aquifer starting at the bottom of the Corcoran Clay to the base of fresh water. However, as previously described, the localized presence of the A and C Clay layers in the southern portion of the Subbasin, the absence of the Corcoran Clay at the western margin of the Subbasin, and/or local hydrostratigraphy result in differing shallow groundwater conditions and/or perched groundwater conditions in some portions of the Subbasin. See the individual GSPs for more detailed descriptions of hydrostratigraphy in the respective Plan areas.

associated with distinct geologic units are mapped across much of the peripheral area to the west of Patterson and Gustine and also in localized bands associated with surface water courses.

Transmissivity

Transmissivity varies greatly above the Corcoran Clay, within the Corcoran Clay, and below the Corcoran Clay within the Delta-Mendota Subbasin, with transmissivities in the confined Lower Aquifer generally being larger than those in the semi-confined Upper Aquifer. Based on testing conducted at multiple locations within both the Upper and Lower Aquifers of the Delta-Mendota Subbasin, average transmissivities in the Subbasin are approximately 109,000 gallons per day per square foot (gpd/ft^2) (KDSA, 1997b).

Specific Yield

DWR defines specific yield as the "amount of water that would drain freely from rocks or sediments due to gravity and describes the proportion of groundwater that could actually be available for extraction" (DWR, 2003). Specific yield is a measurement specific to unconfined aquifers.

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Specific Storage

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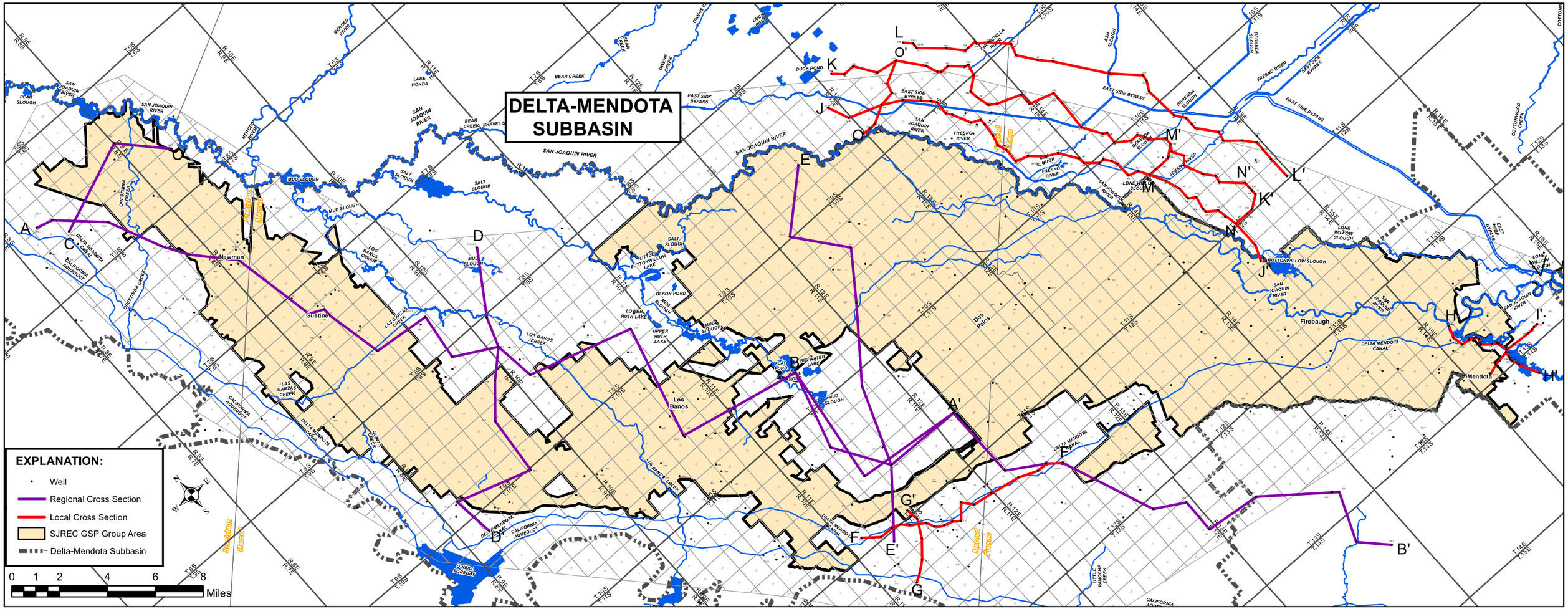


FIGURE 9 - LOCATION OF SUBSURFACE GEOLOGIC CROSS SECTIONS

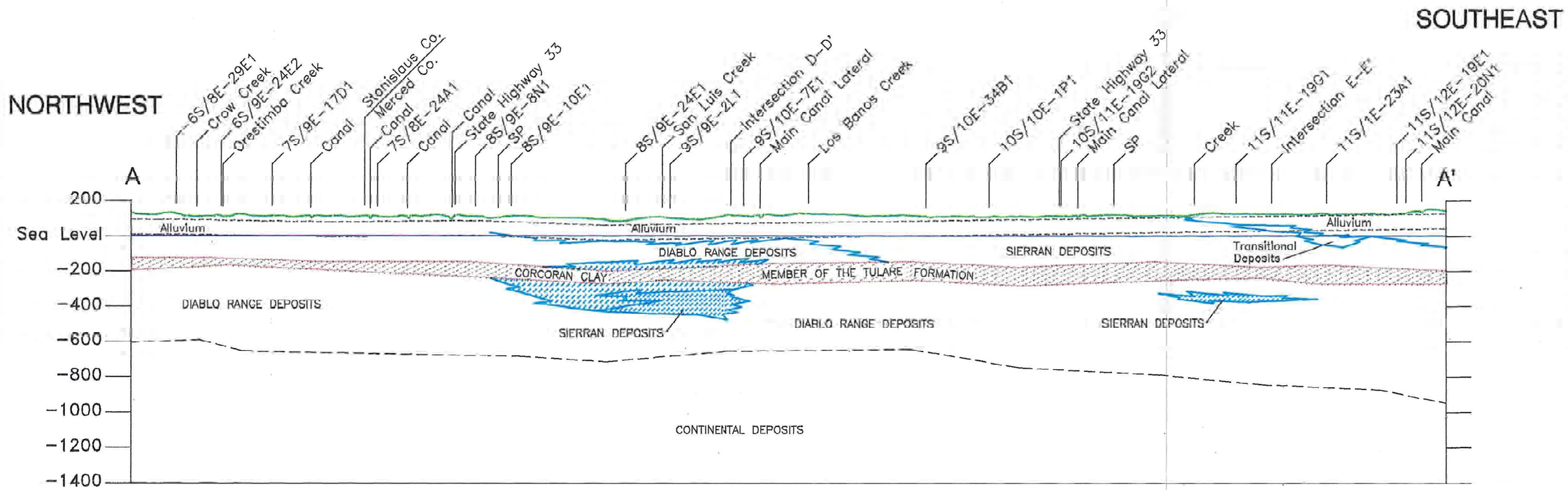
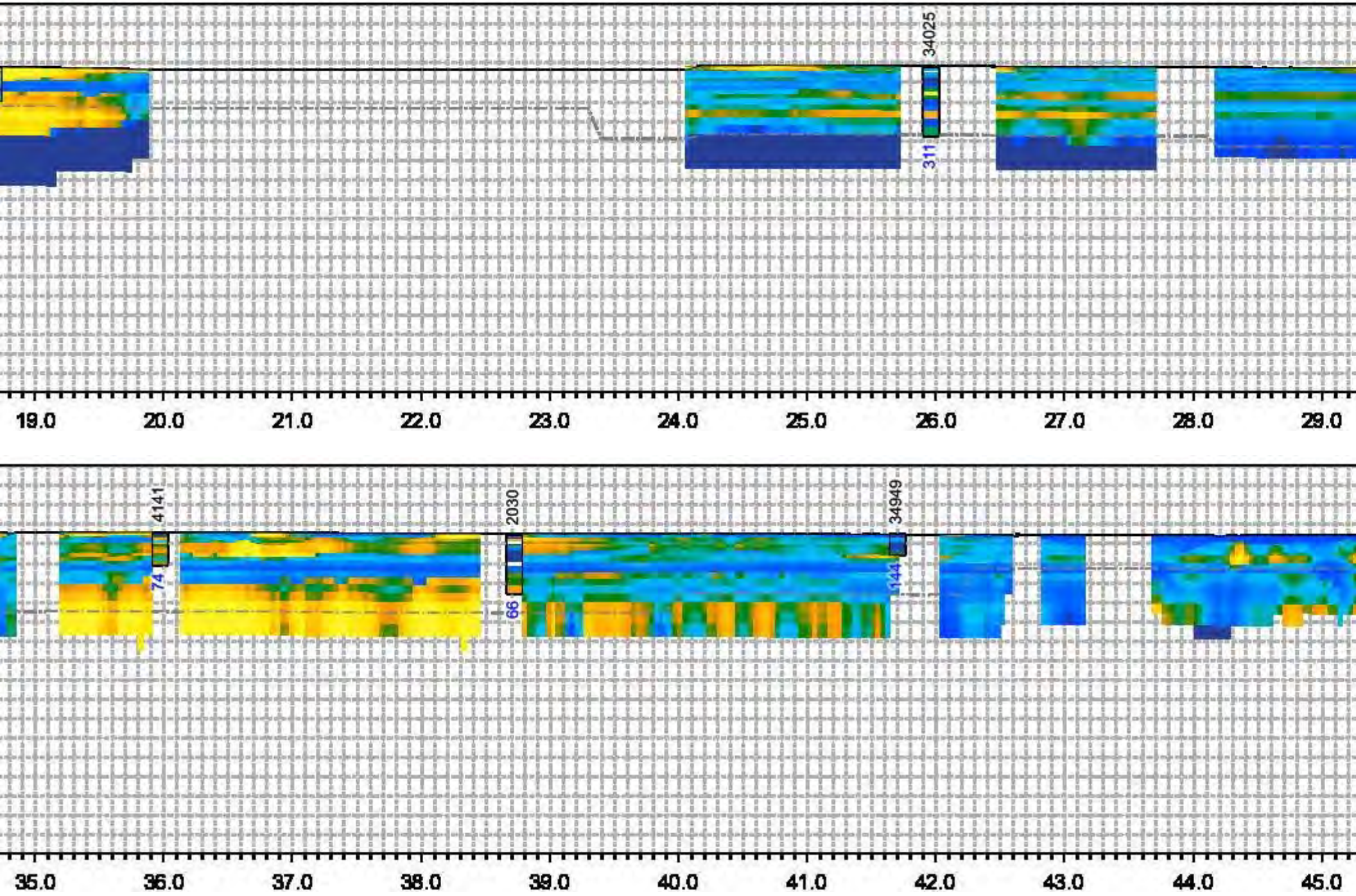


FIGURE 10-REGIONAL SUBSURFACE GEOLOGIC CROSS SECTION A-A'

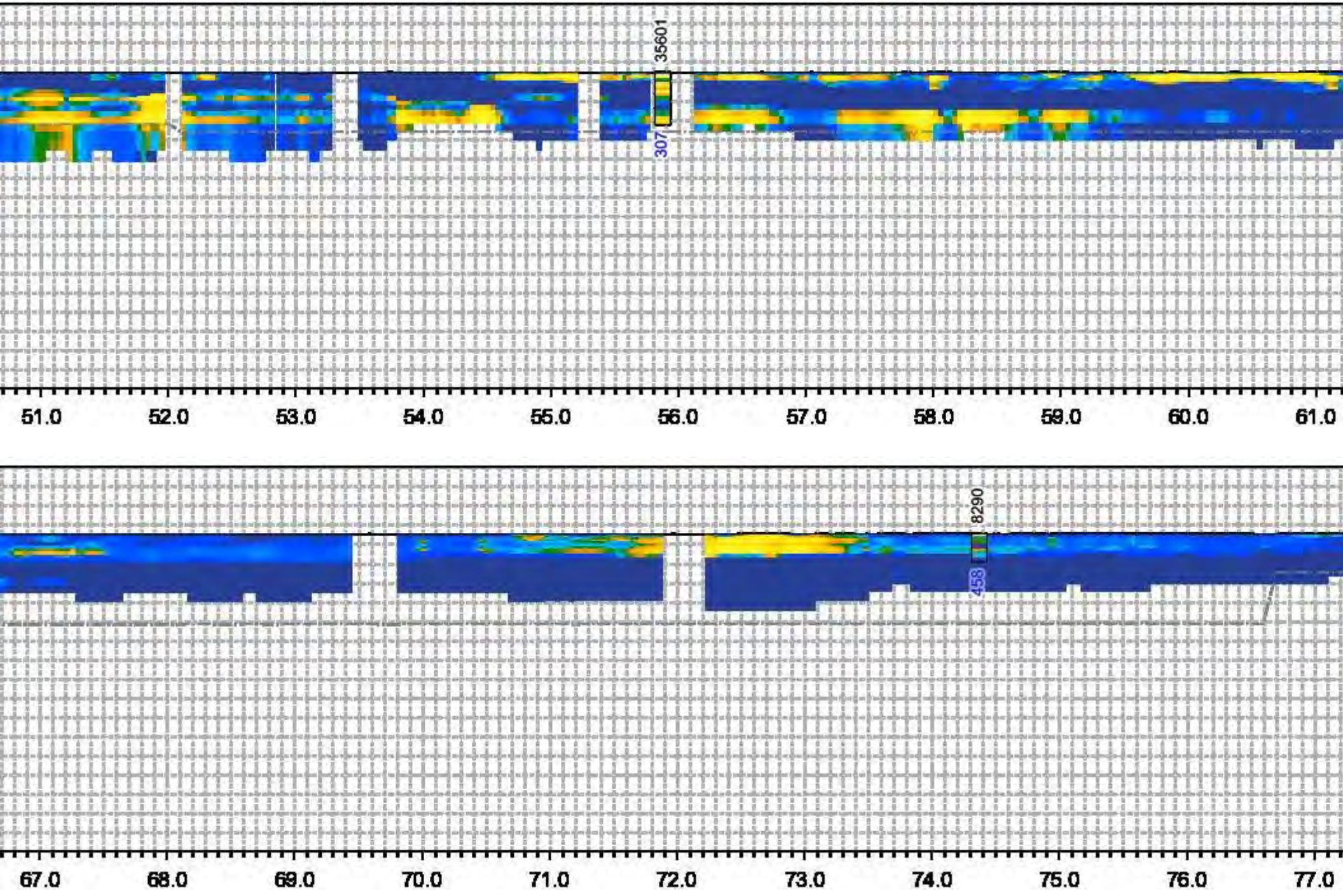
5 0 5 10 15 20 25 MILES

REVISIONS	DESIGNED _____ CHECKED G. WHITE DRAWN A. THOMSON DATE MARCH 1997 APPROVED _____ DISTRICT ENGINEER RCE No. APPROVED _____ MANAGER DATE	CENTRAL CALIFORNIA IRRIGATION DISTRICT 1335 West I Street - Post Office Box 1231 Los Banos, California 93635 Telephone (209) 826-1421	MODIFIED FROM HOTCHKISS AND BALDING (1971)

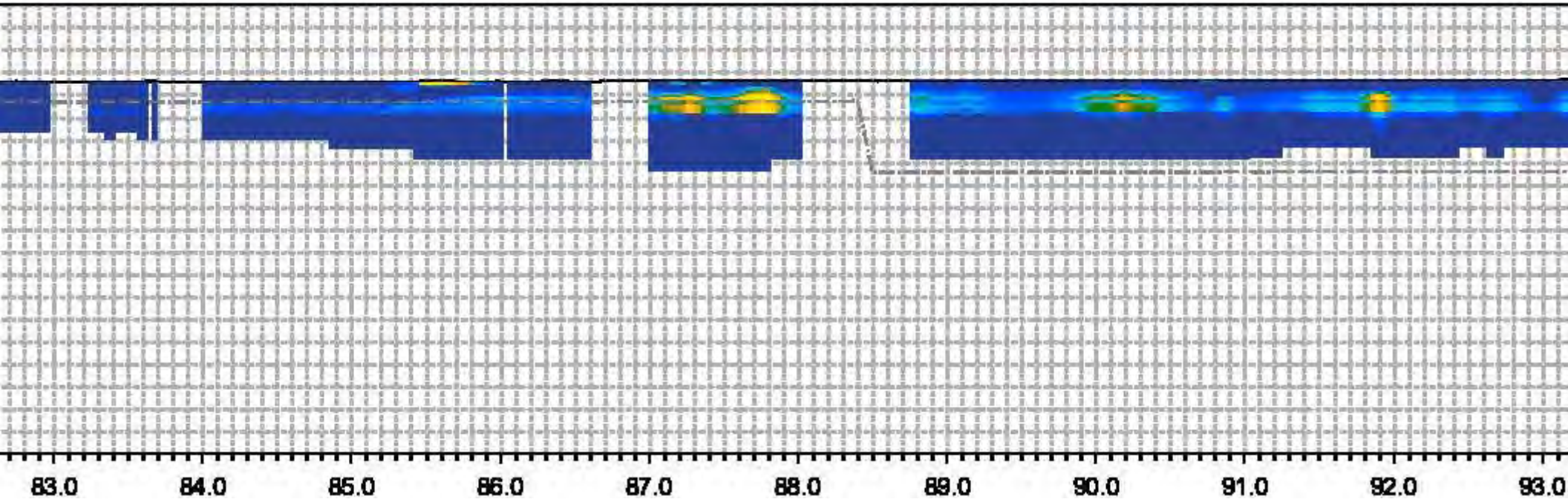
A - A' Nearest AEM Log



A - A' Nearest AEM Log



A - A' Nearest AEM Log



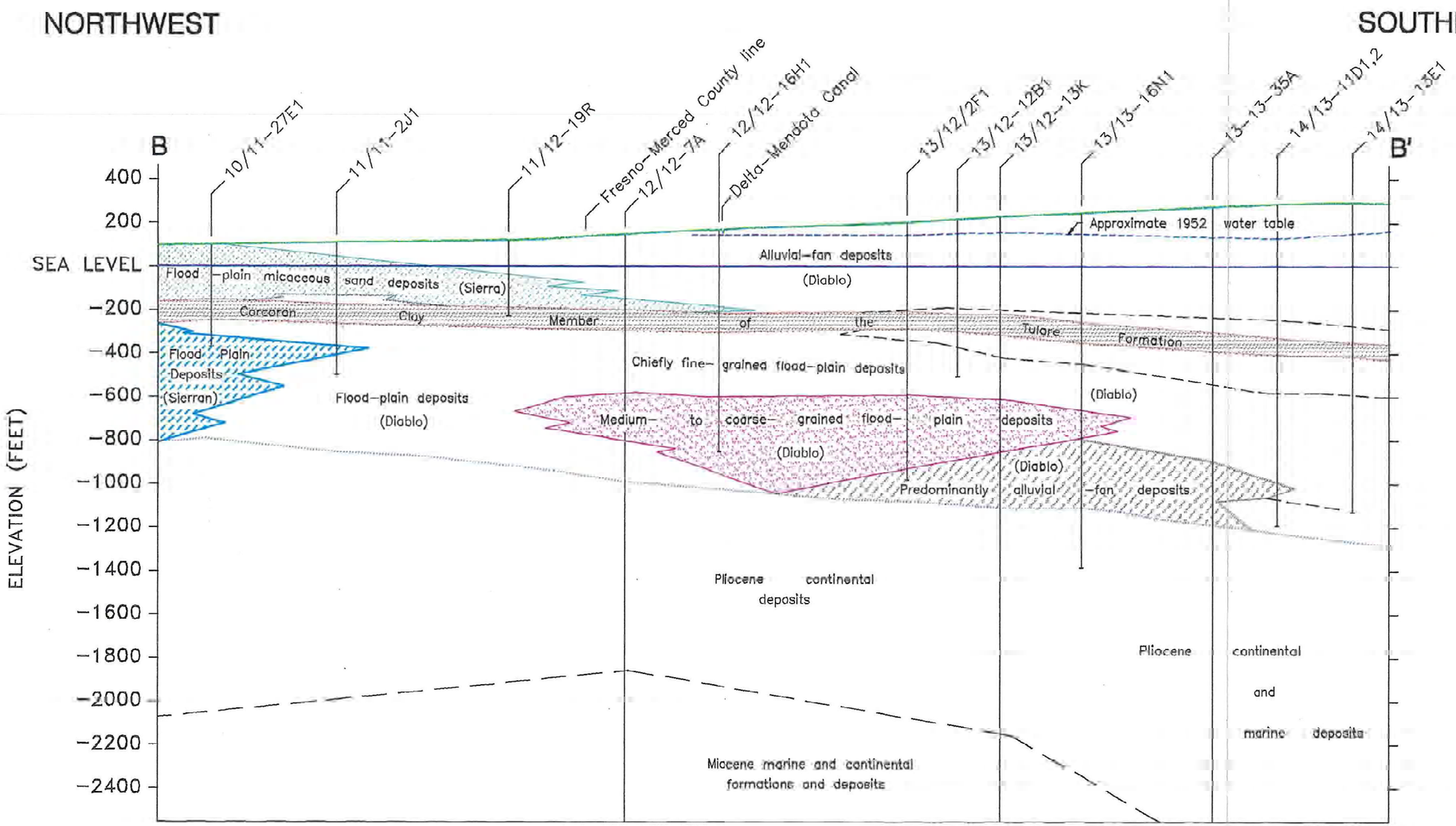


FIGURE 11-REGIONAL SUBSURFACE GEOLOGIC CROSS SECTION B-B'

2 1 0 2 4 6 8 10 MILES

REVISIONS	DESIGNED ____ CHECKED C. WHITE DRAWN A. THOMSON DATE MARCH 1997 APPROVED DISTRICT ENGINEER RCE No. APPROVED MANAGER DATE	CENTRAL CALIFORNIA IRRIGATION DISTRICT 1335 West I Street - Post Office Box 1231 Los Banos, California 93635 Telephone (209) 826-1421	MODIFIED FROM MEADE (1968)

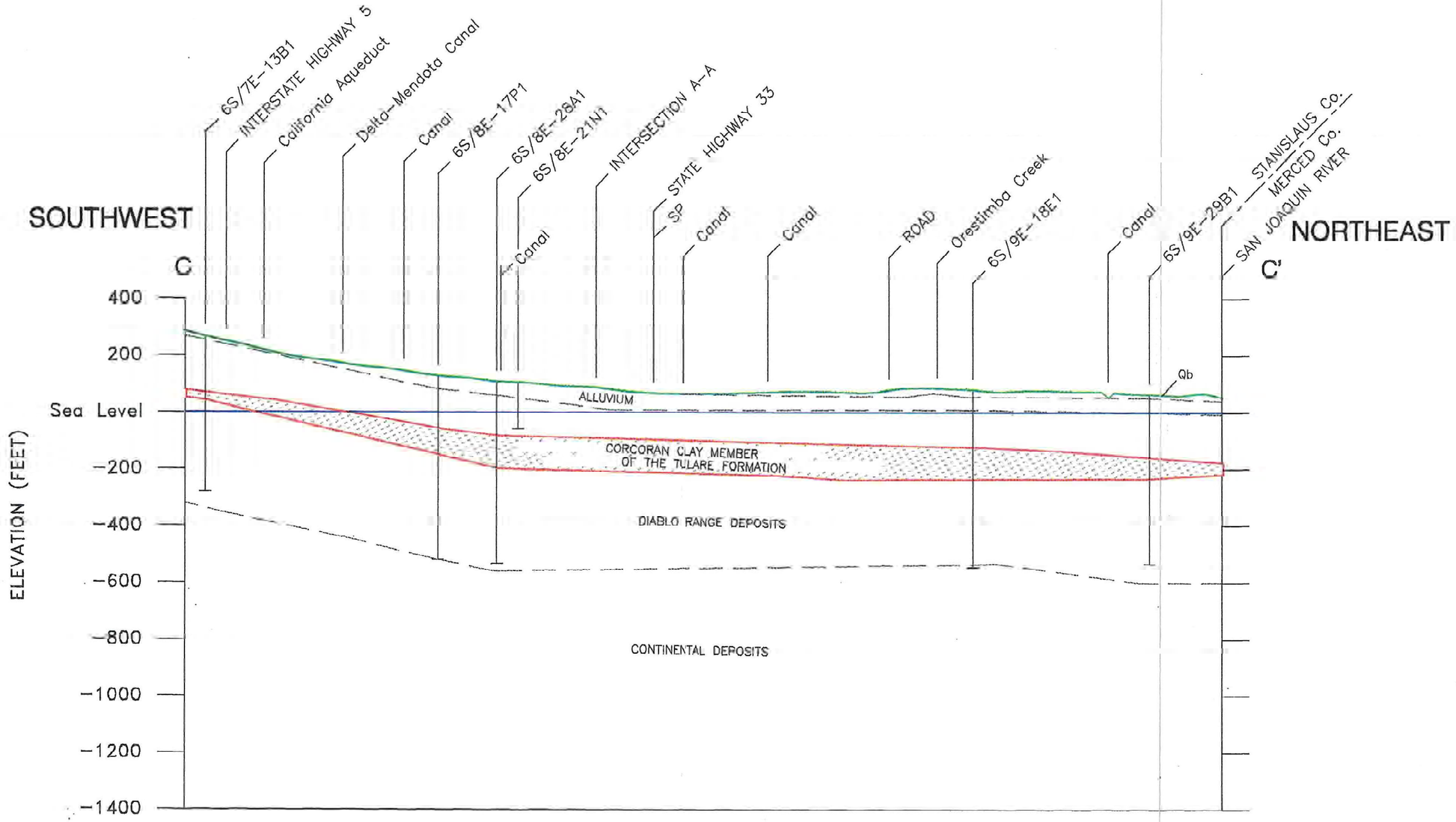


FIGURE 12-REGIONAL SUBSURFACE GEOLOGIC CROSS SECTION C-C'

2 1 0 2 4 6 8 10 MILES

REVISIONS	DESIGNED _____ CHECKED C. WHITE DRAWN A. THOMSON DATE MARCH 1997 APPROVED _____ DISTRICT ENGINEER RCE No. APPROVED _____ MANAGER DATE	CENTRAL CALIFORNIA IRRIGATION DISTRICT 1335 West I Street - Post Office Box 1231 Los Banos, California 93635 Telephone (209) 826-1421	MODIFIED FROM HOTCHKISS AND BALDING (1971)

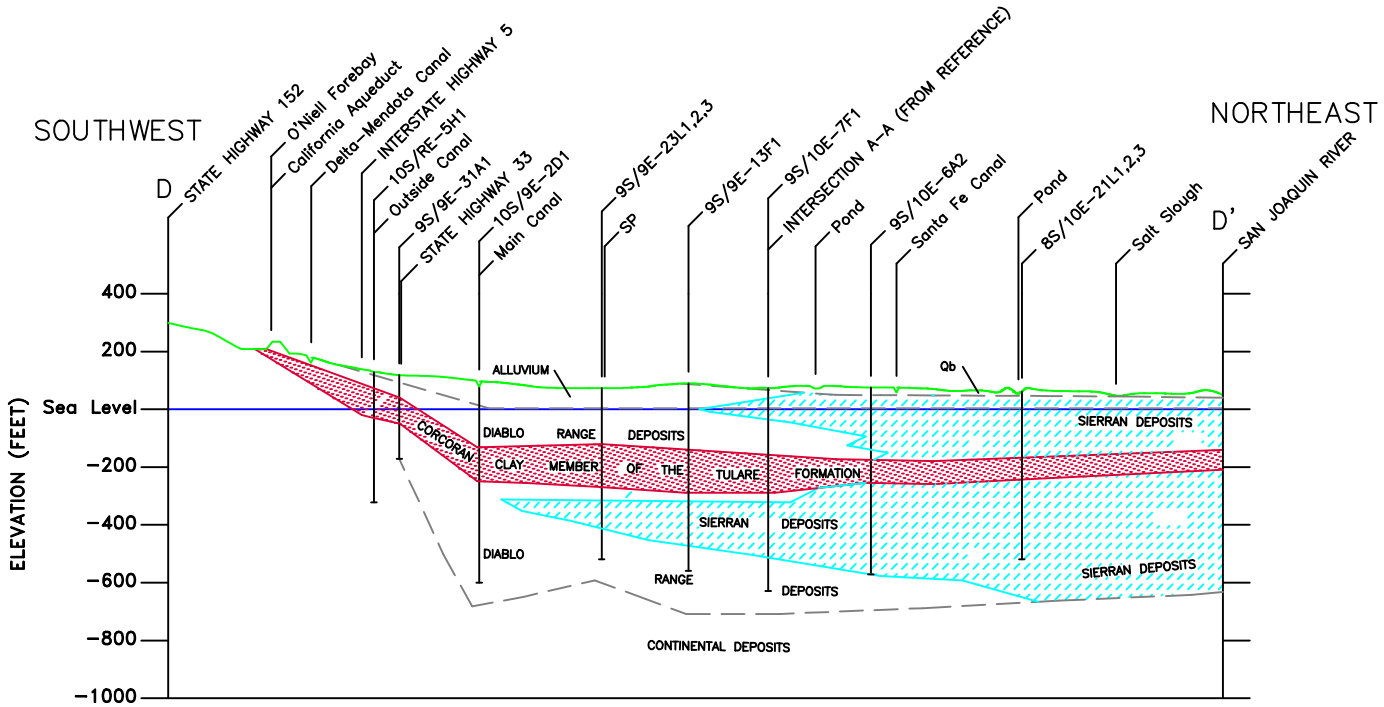


FIGURE No. 13

SUBSURFACE GEOLOGIC CROSS SECTION D–D'

2 1 0 2 4 6 8 10 MILES

REVISIONS					

DESIGNED ____ CHECKED C. WHITE
DRAWN ____ DATE MARCH 1997
APPROVED ____ DISTRICT ENGINEER ____ RCE No.
APPROVED ____ MANAGER ____ DATE

CENTRAL CALIFORNIA IRRIGATION DISTRICT
1335 West I Street – Post Office Box 1231
Los Banos, California 93635
Telephone (209) 826-1421

MODIFIED FROM HOTCHKISS AND BALDING (1971)

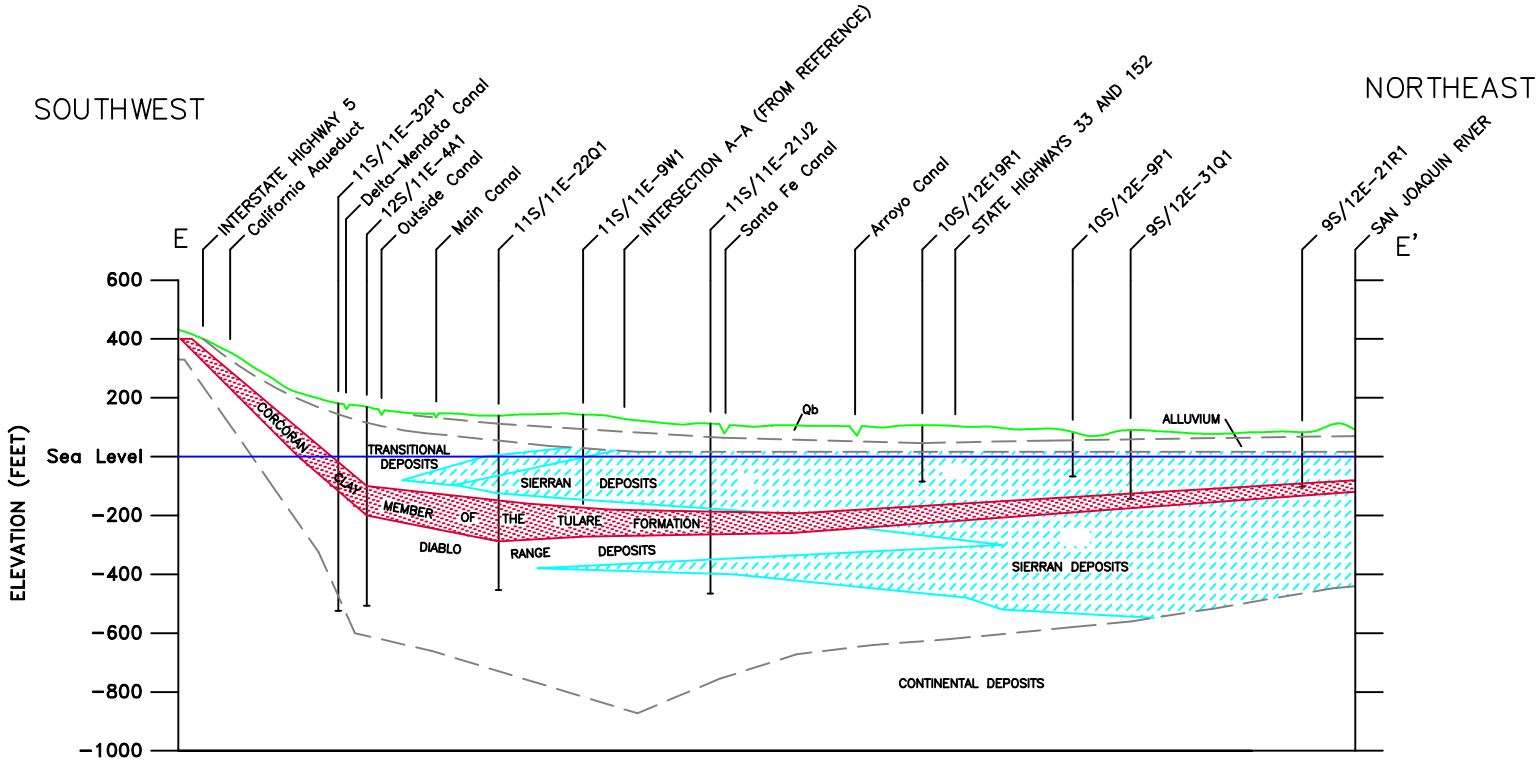


FIGURE No. 14

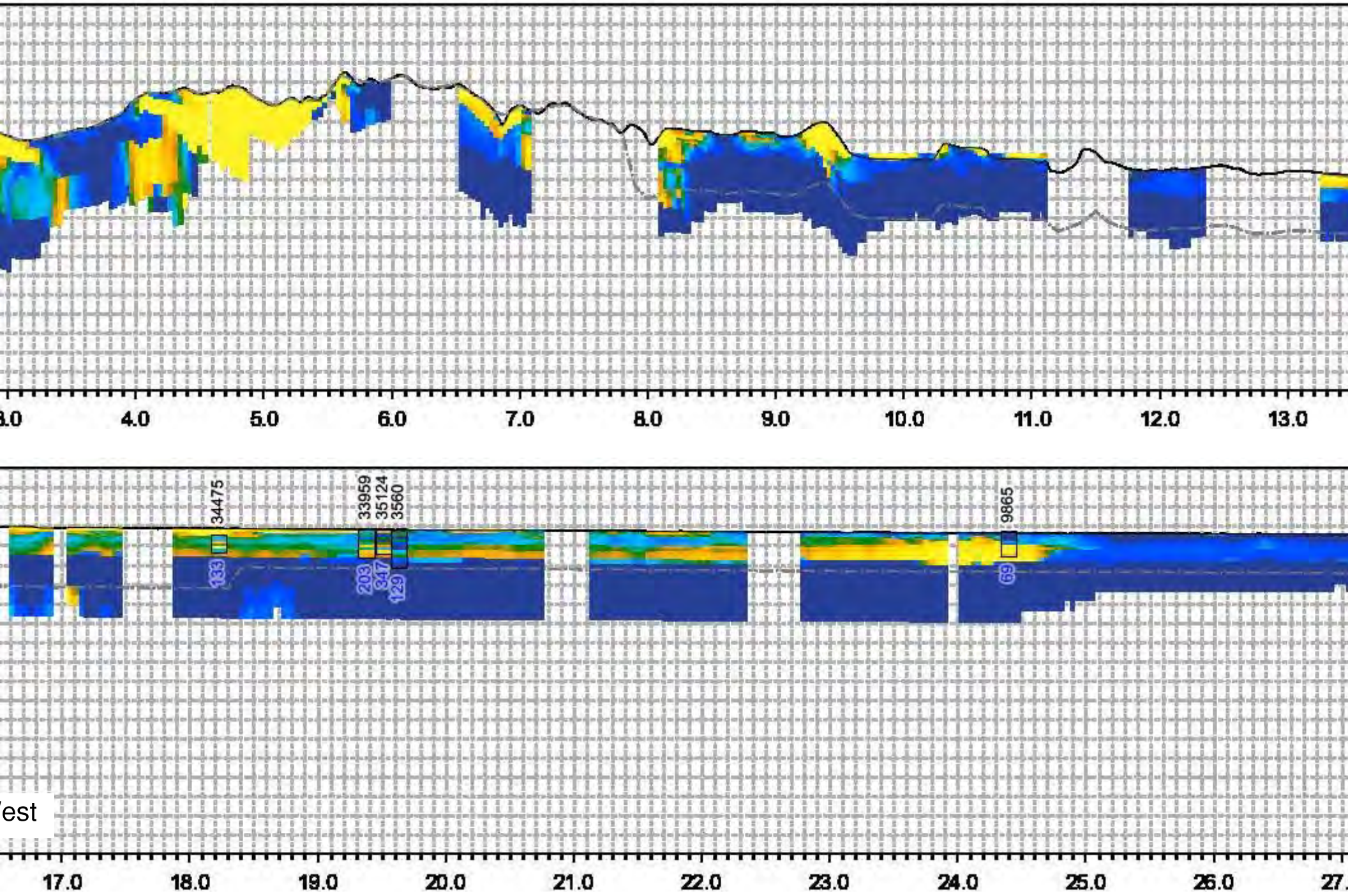
SUBSURFACE GEOLOGIC CROSS SECTION E–E'

2 1 0 2 4 6 8 10 MILES

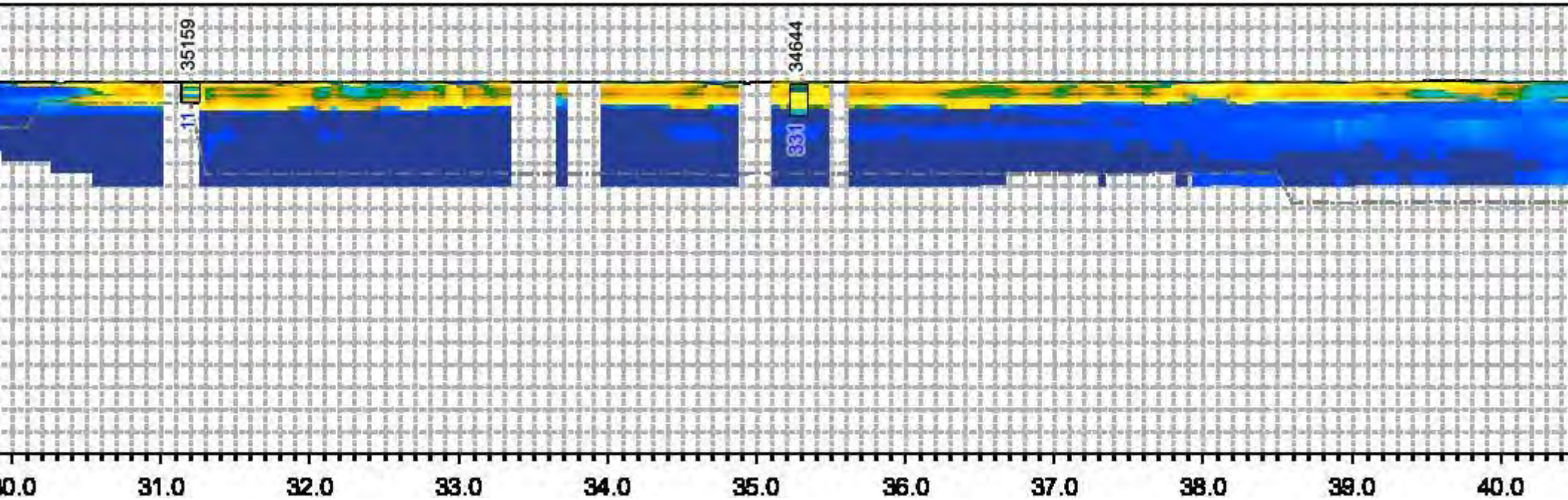
REVISIONS		CENTRAL CALIFORNIA IRRIGATION DISTRICT 1335 West I Street – Post Office Box 1231 Los Banos, California 93635 Telephone (209) 826-1421	MODIFIED FROM HOTCHKISS AND BALDING (1971)

DESIGNED ____ CHECKED C. WHITE
DRAWN ____ DATE MARCH 1997
APPROVED ____ DISTRICT ENGINEER ____ RCE No.
APPROVED ____ MANAGER ____ DATE

E - E' Nearest AEM Log



E - E' Nearest AEM Log



NORTHWEST
F

SOUTHEAST
F'

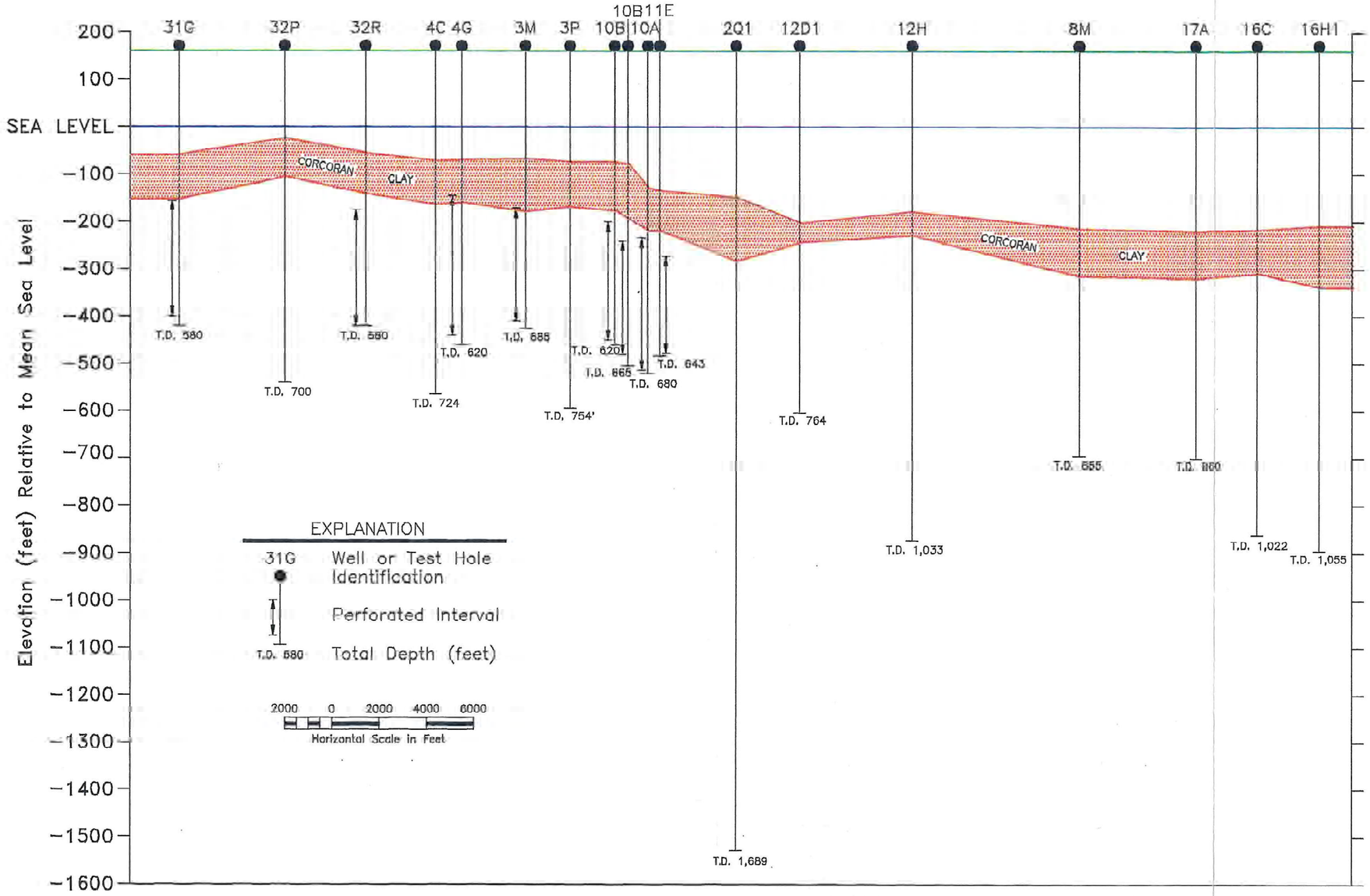


FIGURE 15-LOCAL SUBSURFACE GEOLOGIC CROSS SECTION F-F'

REVISIONS						

DESIGNED _____ CHECKED C. WHITE
DRAWN A. THOMSON DATE MARCH 1997
APPROVED _____ DISTRICT ENGINEER _____ RCE No.
APPROVED _____ MANAGER _____ DATE

CENTRAL CALIFORNIA IRRIGATION DISTRICT
1335 West I Street - Post Office Box 1231
Los Banos, California 93635
Telephone (209) 826-1421

DMC PUMPING AREA

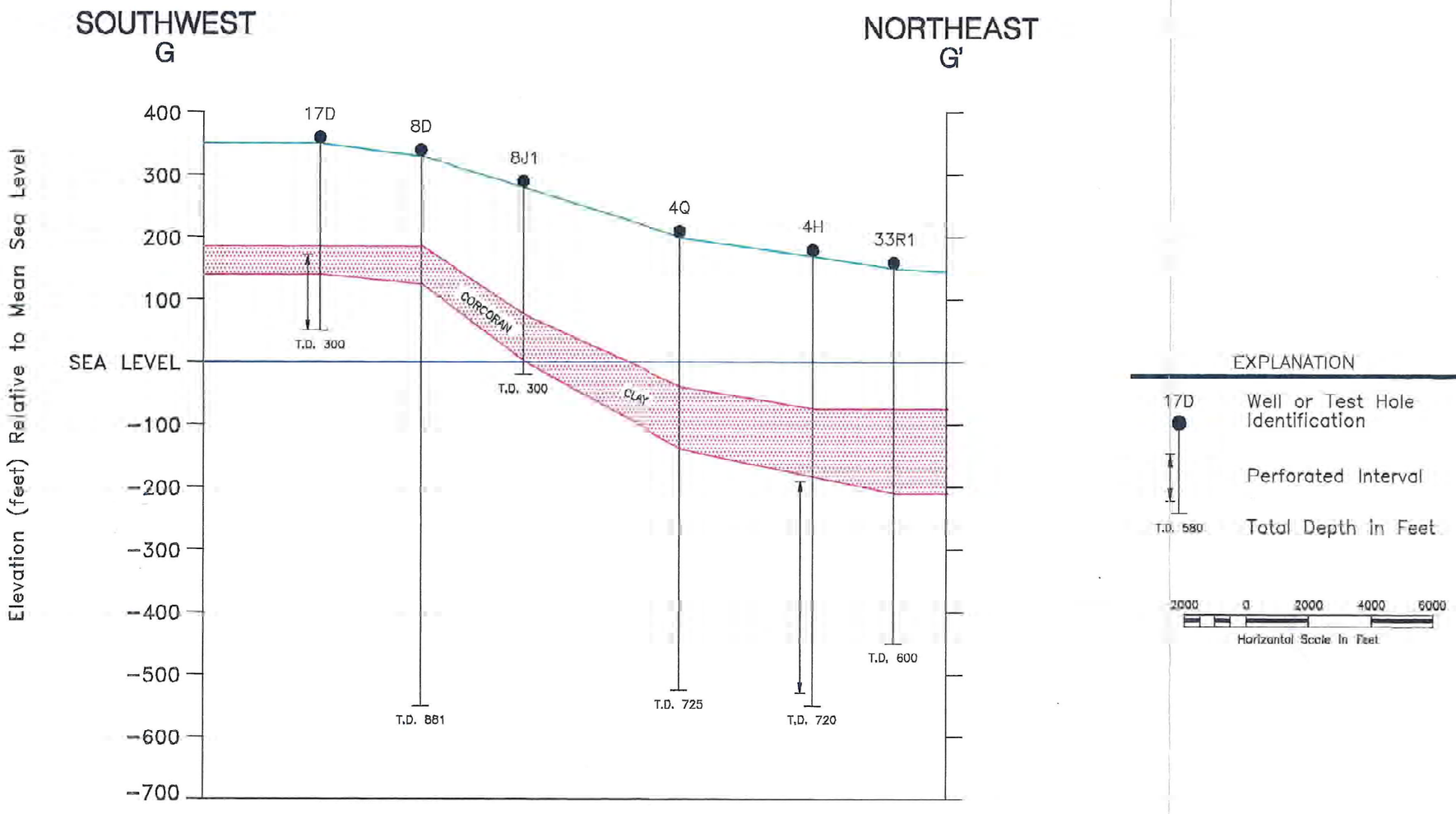


FIGURE 16-LOCAL SUBSURFACE GEOLOGIC CROSS SECTION G-G'

REVISIONS					DESIGNED _____ CHECKED C. WHITE DRAWN _____ DATE MARCH 1997 APPROVED _____ DISTRICT ENGINEER RCE No. APPROVED _____ MANAGER DATE	CENTRAL CALIFORNIA IRRIGATION DISTRICT 1335 West I Street - Post Office Box 1231 Los Banos, California 93635 Telephone (209) 826-1421	DMC PUMPING AREA

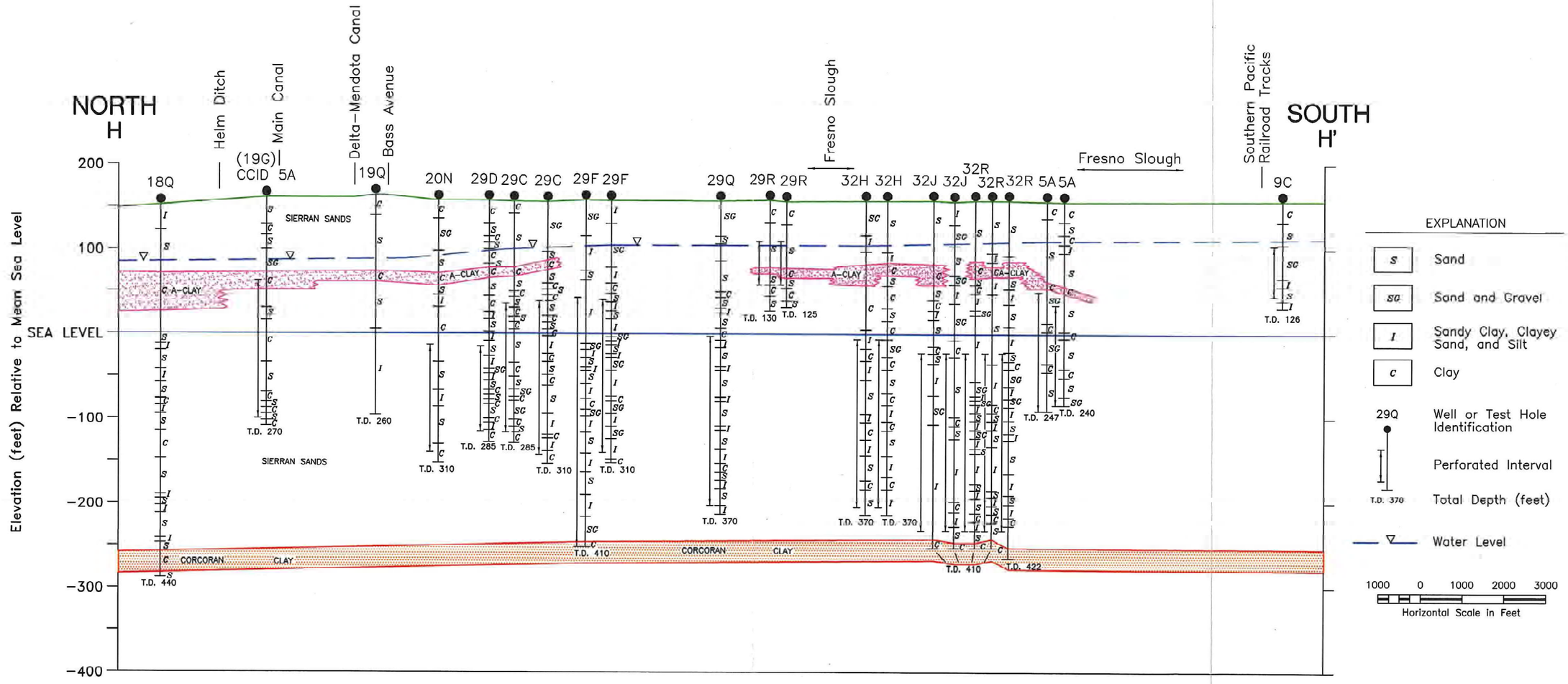


FIGURE 17-LOCAL SUBSURFACE GEOLOGIC CROSS SECTION H-H'

REVISIONS	DESIGNED ____ CHECKED C. WHITE DRAWN ____ DATE MARCH 1997 APPROVED ____ DISTRICT ENGINEER RCE No. APPROVED ____ MANAGER DATE	CENTRAL CALIFORNIA IRRIGATION DISTRICT 1335 West I Street - Post Office Box 1231 Los Banos, California 93635 Telephone (209) 826-1421	MENDOTA POOL AREA

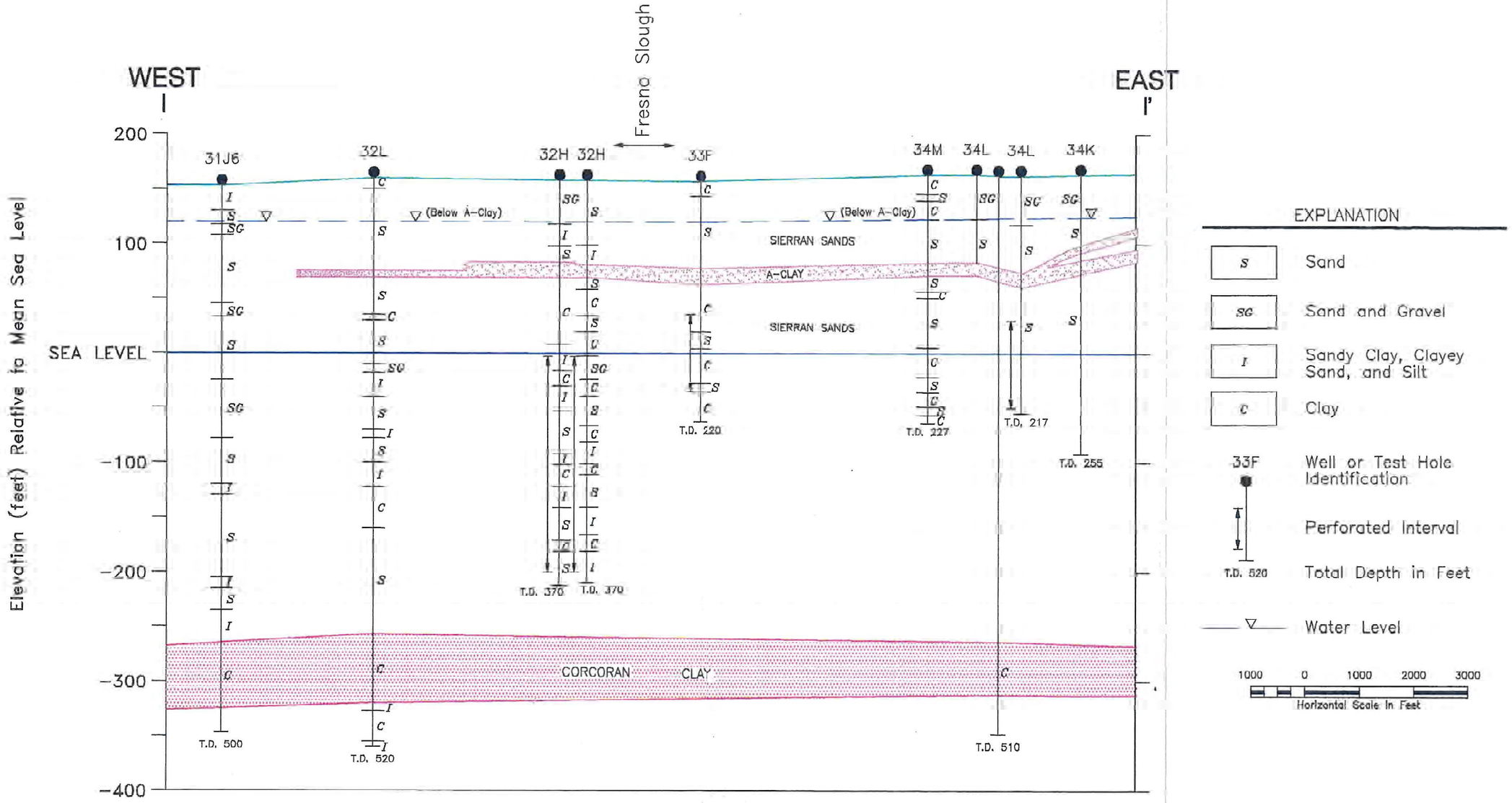


FIGURE 18-LOCAL SUBSURFACE GEOLOGIC CROSS SECTION I-I'

REVISIONS	DESIGNED ____ CHECKED C. WHITE DRAWN ____ DATE MARCH 1997 APPROVED ____ DISTRICT ENGINEER ____ RCE No. APPROVED ____ MANAGER ____ DATE	CENTRAL CALIFORNIA IRRIGATION DISTRICT 1335 West I Street - Post Office Box 1231 Los Banos, California 93635 Telephone (209) 826-1421	MENDOTA POOL AREA

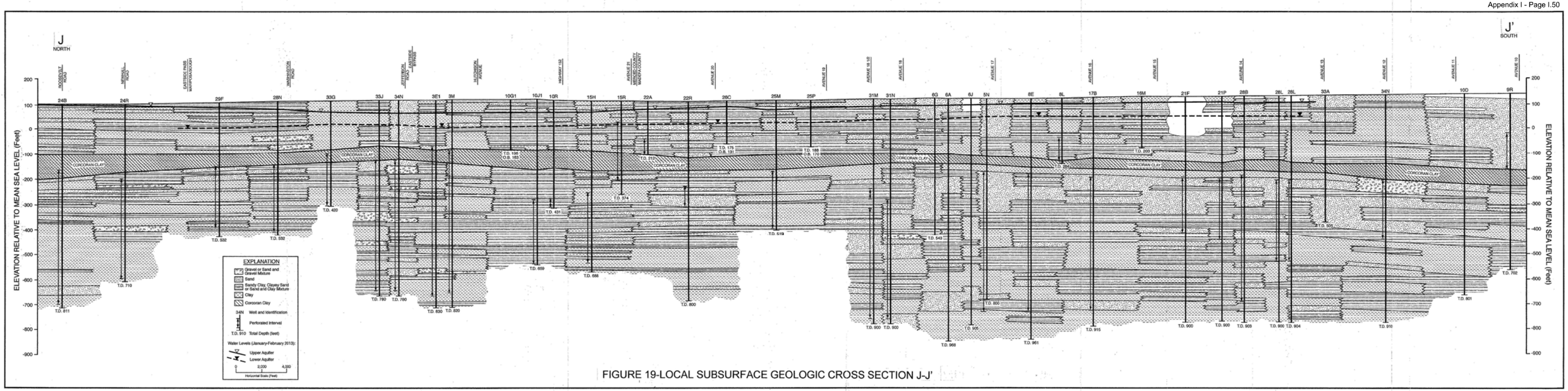


FIGURE 19-LOCAL SUBSURFACE GEOLOGIC CROSS SECTION J-J'

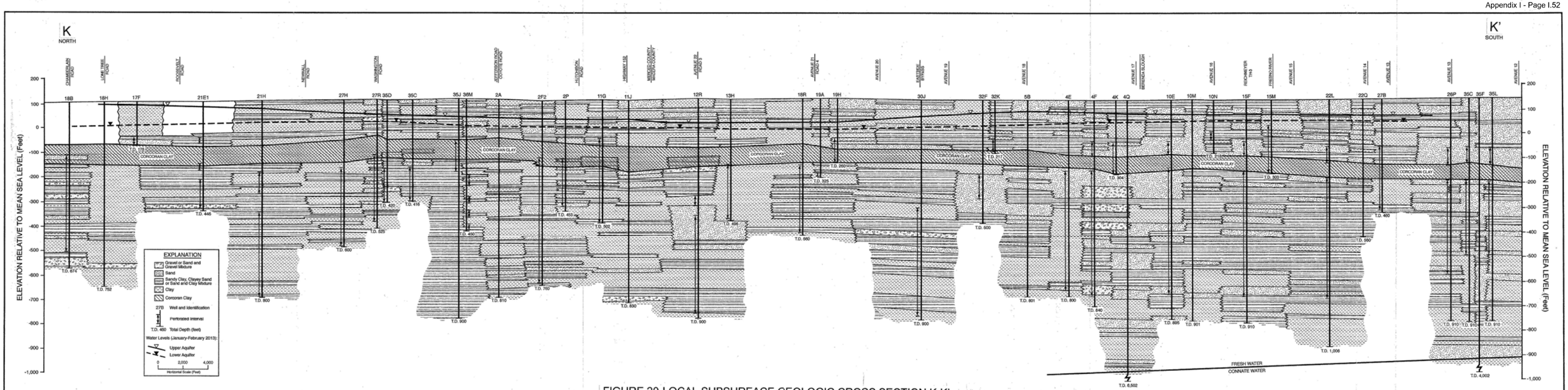


FIGURE 20-LOCAL SUBSURFACE GEOLOGIC CROSS SECTION K-K'

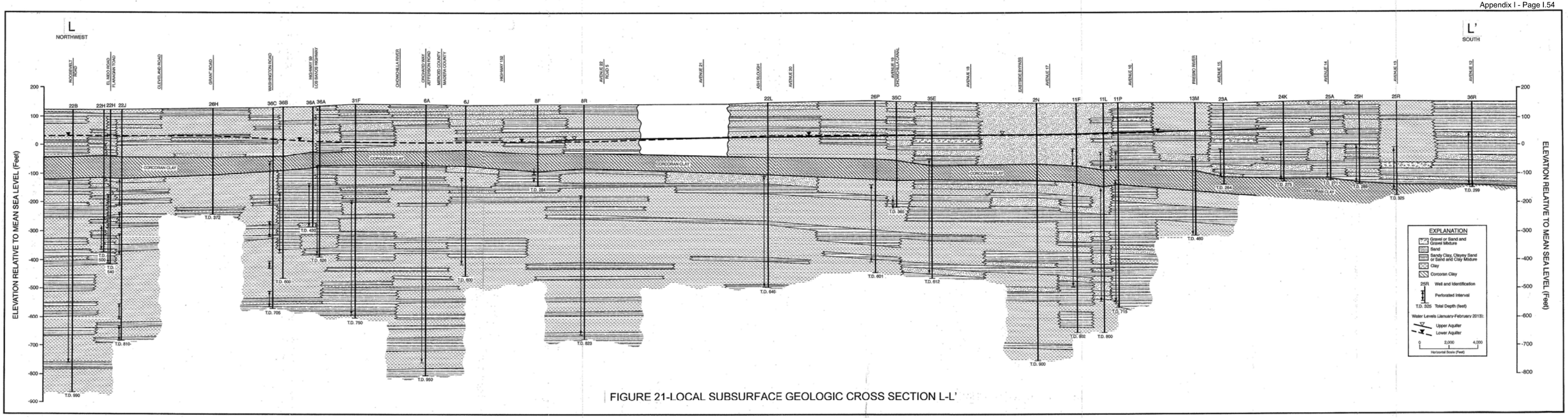


FIGURE 21-LOCAL SUBSURFACE GEOLOGIC CROSS SECTION L-L'

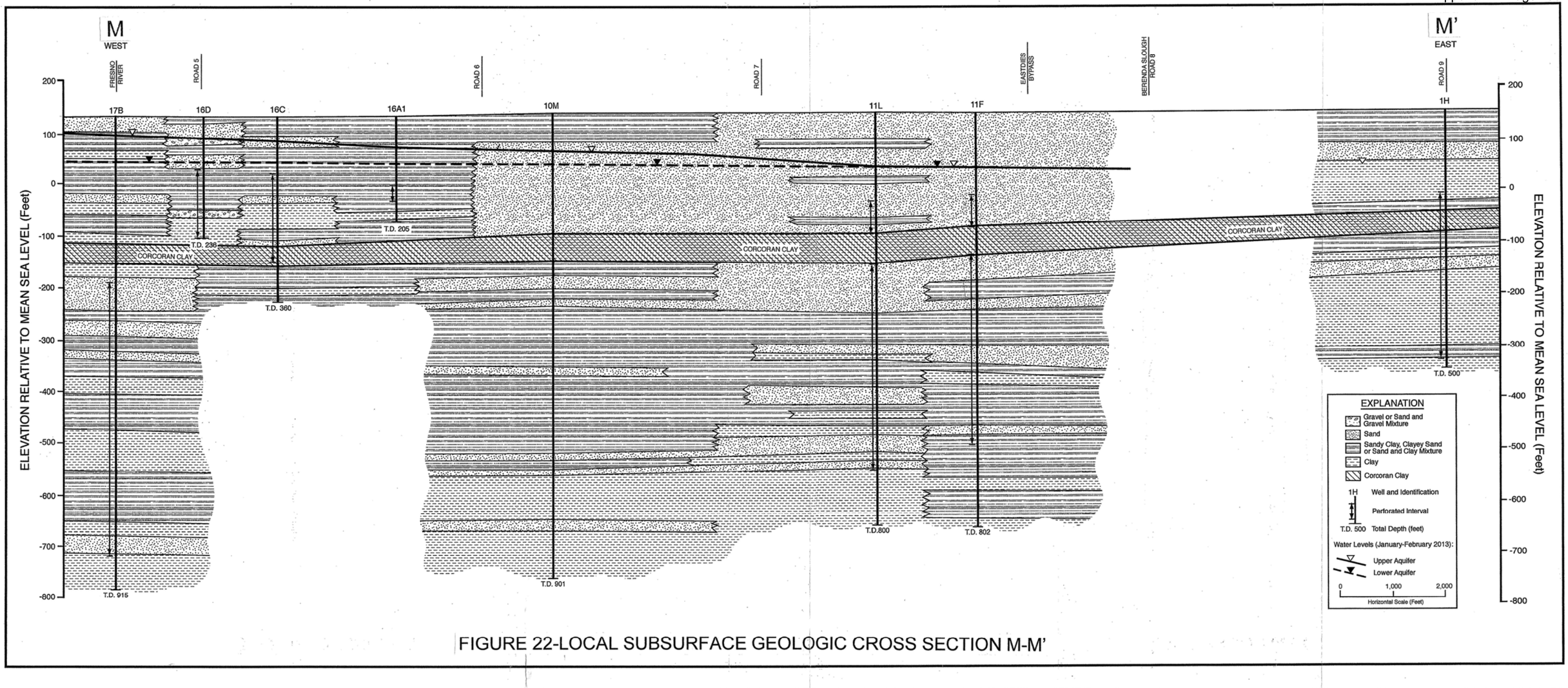


FIGURE 22-LOCAL SUBSURFACE GEOLOGIC CROSS SECTION M-M'

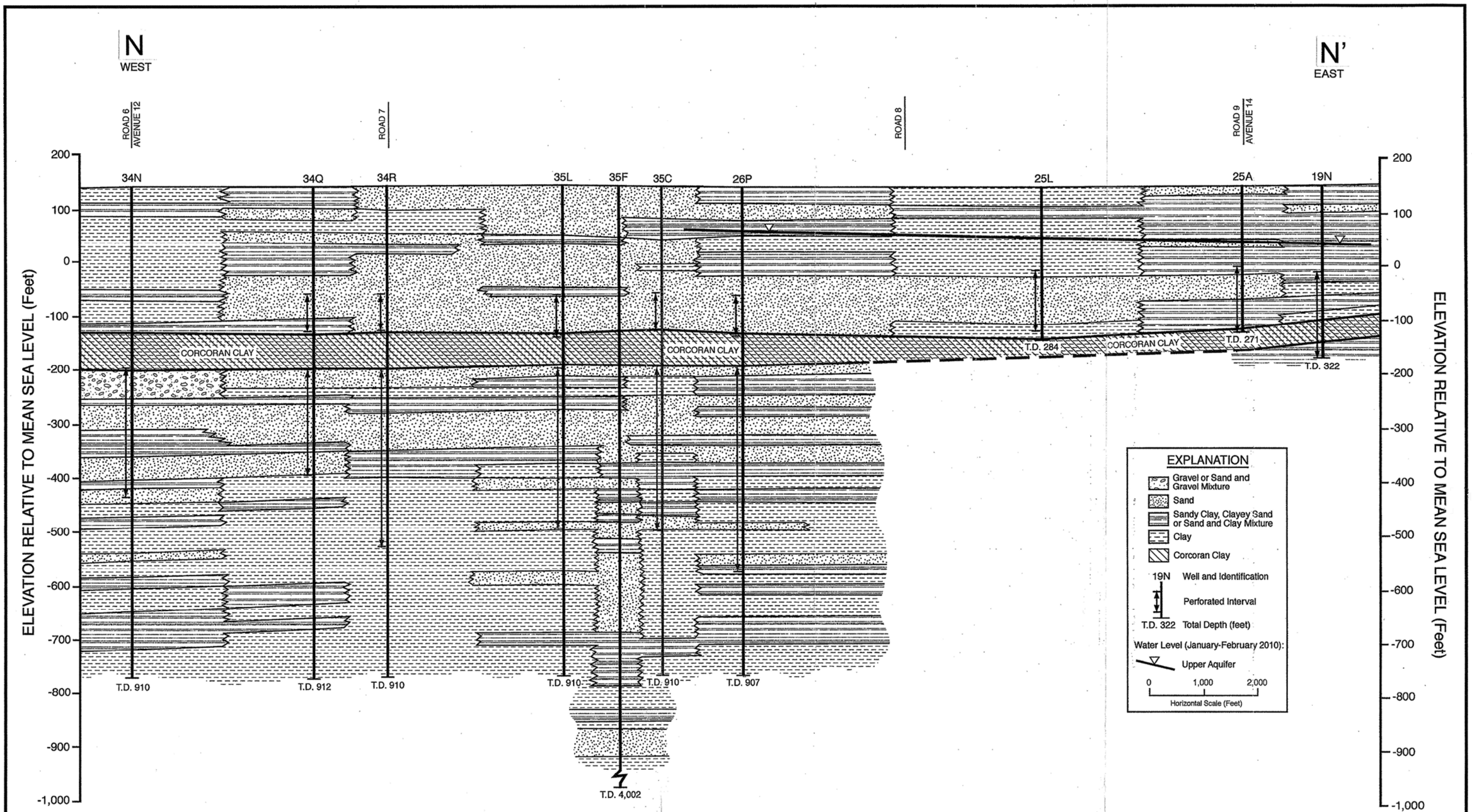


FIGURE 23-LOCAL SUBSURFACE GEOLOGIC CROSS SECTION N-N'

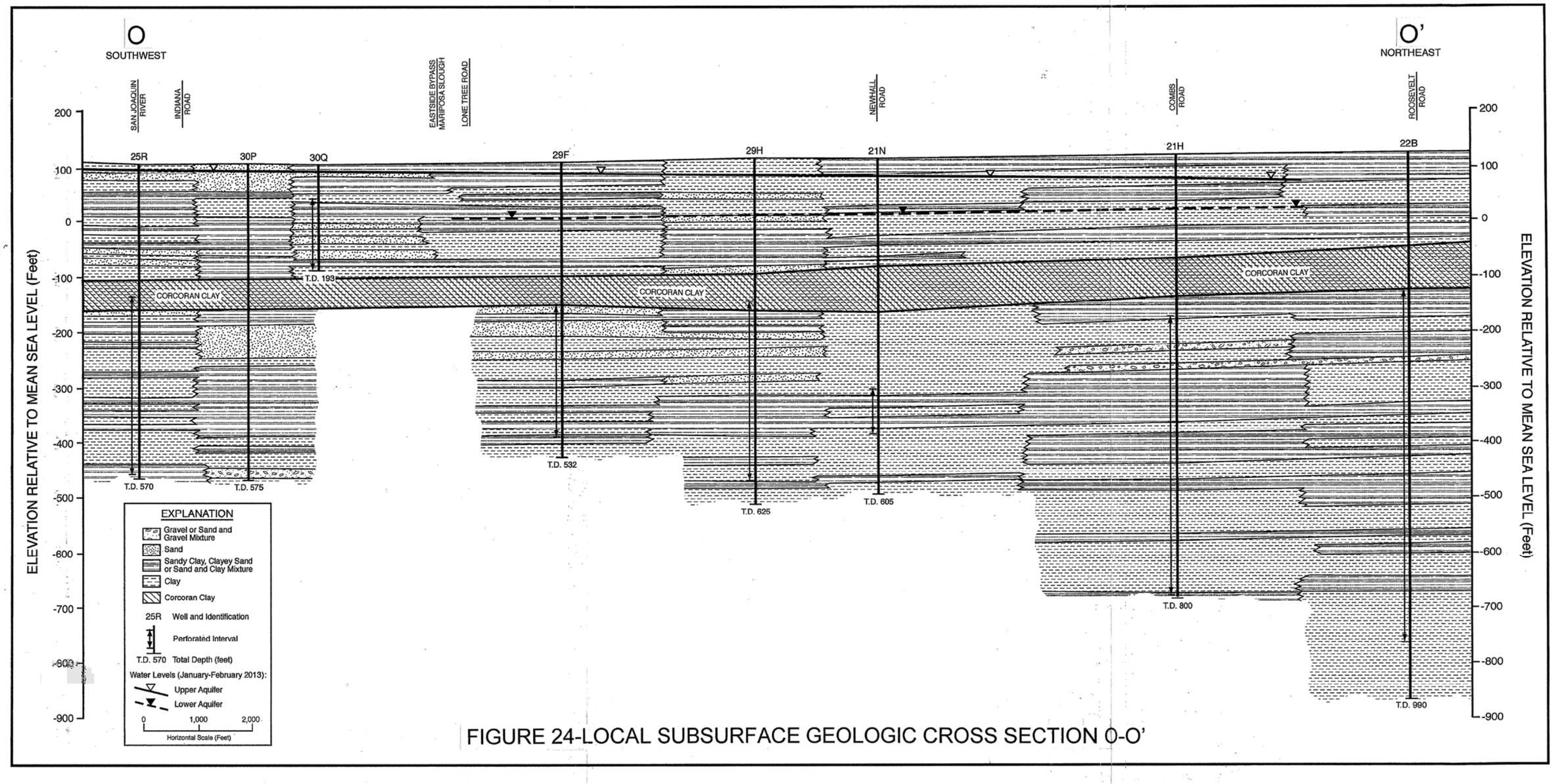
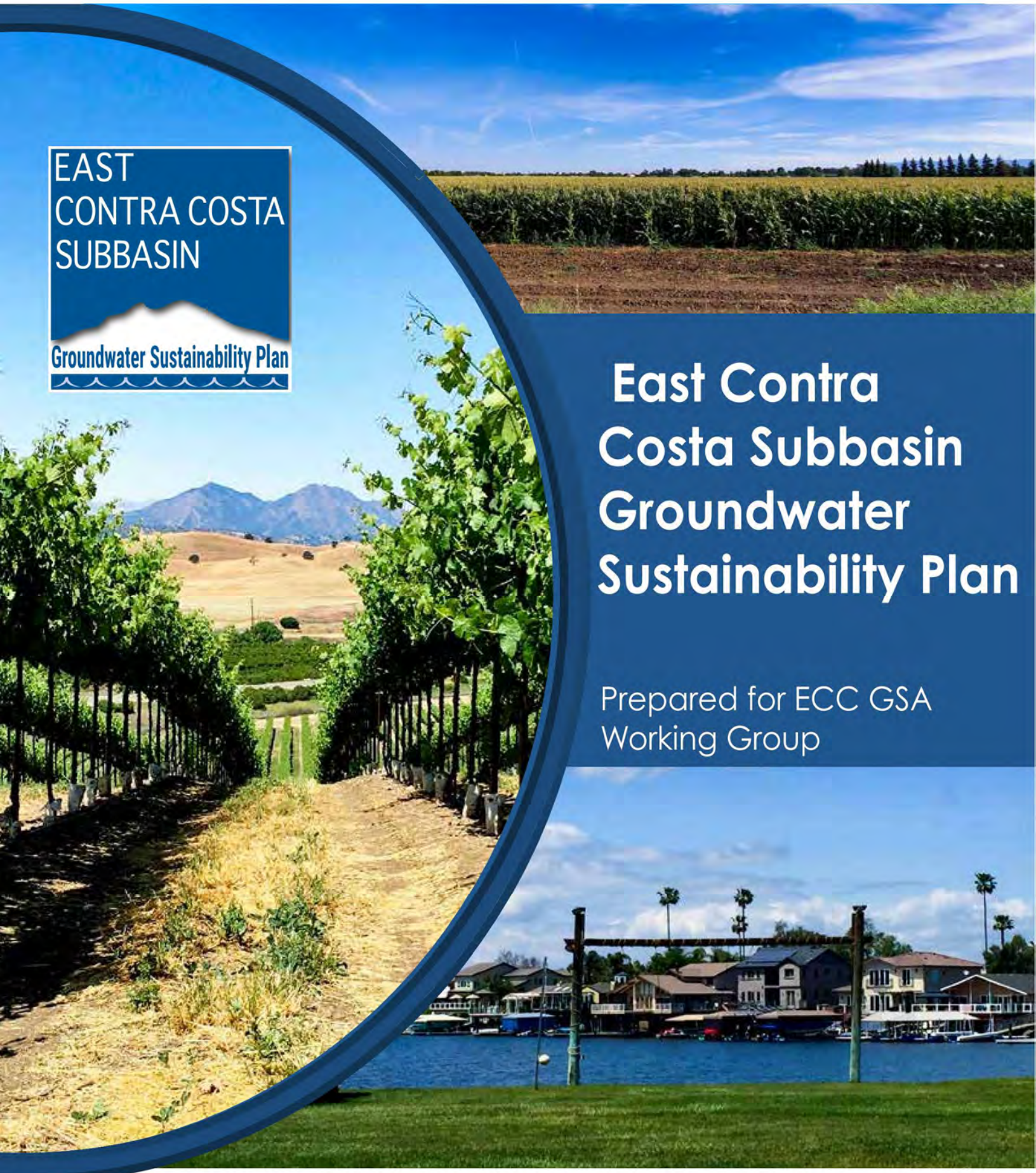


FIGURE 24-LOCAL SUBSURFACE GEOLOGIC CROSS SECTION O-O'



EAST CONTRA COSTA SUBBASIN

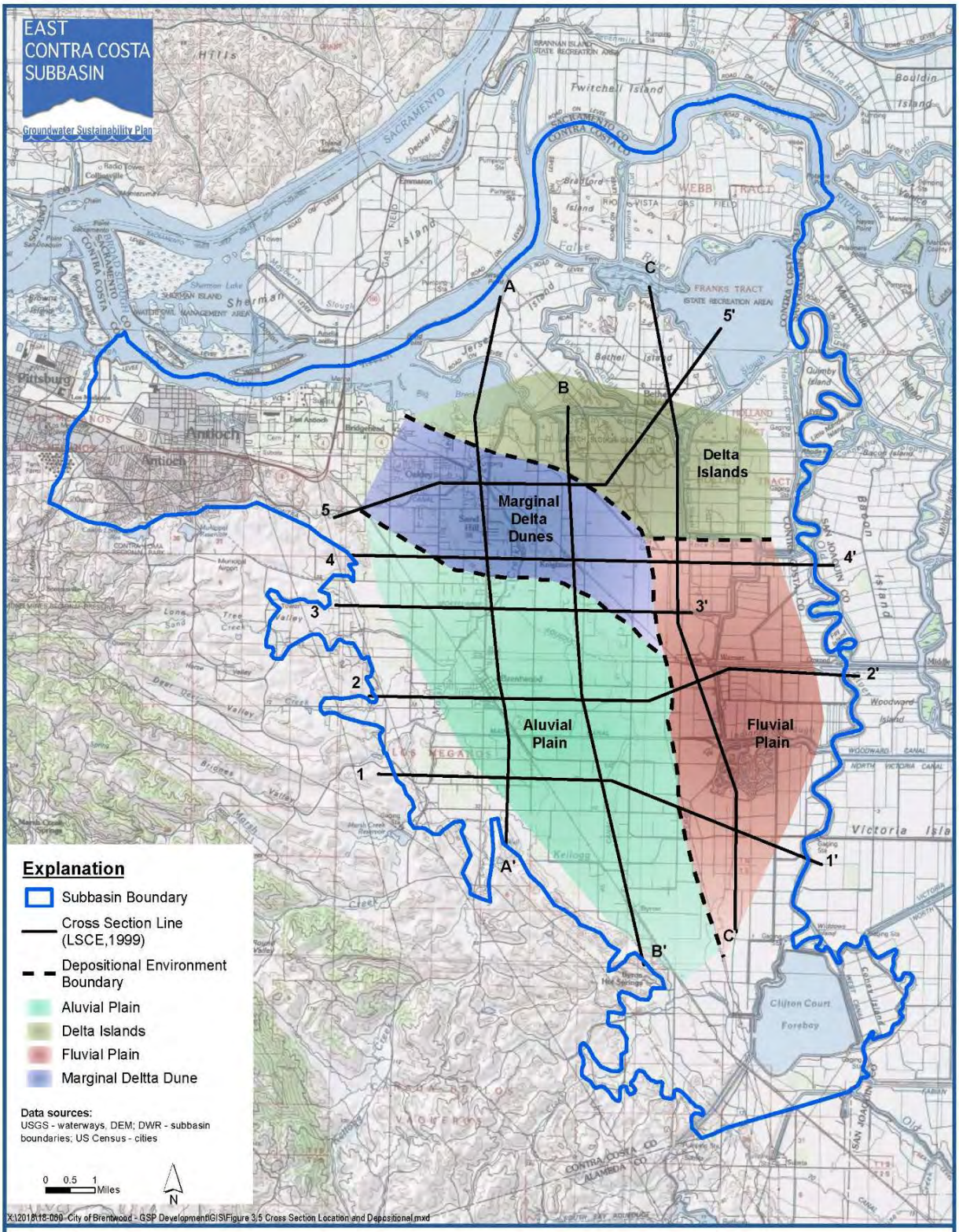
Groundwater Sustainability Plan

East Contra Costa Subbasin Groundwater Sustainability Plan

Prepared for ECC GSA Working Group

Luhdorff & Scalmanini
Consulting Engineers

October, 2021

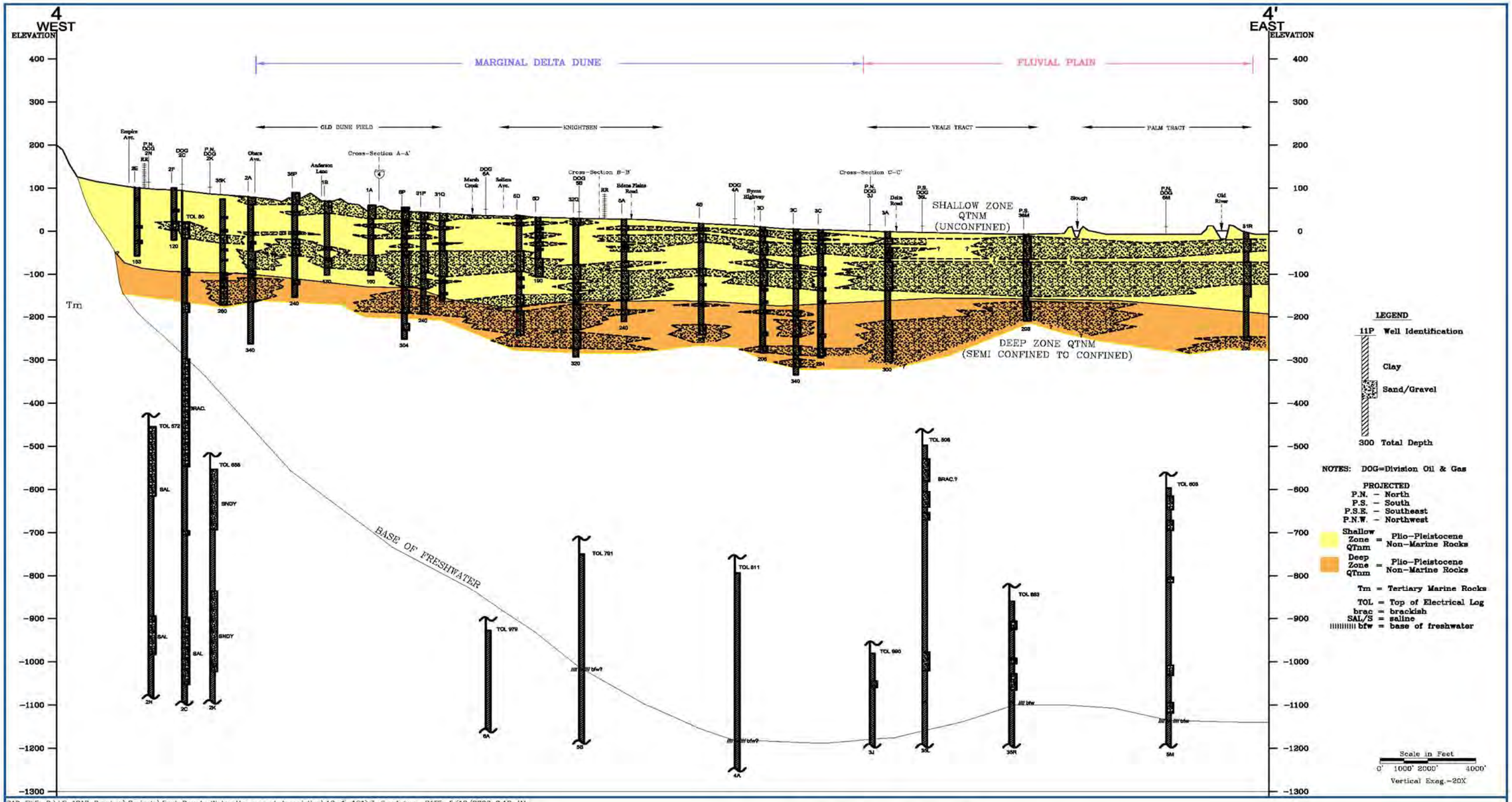


Luhdorff & Scalmanini Consulting Engineers

Cross Section Location and Depositional Environment

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-5



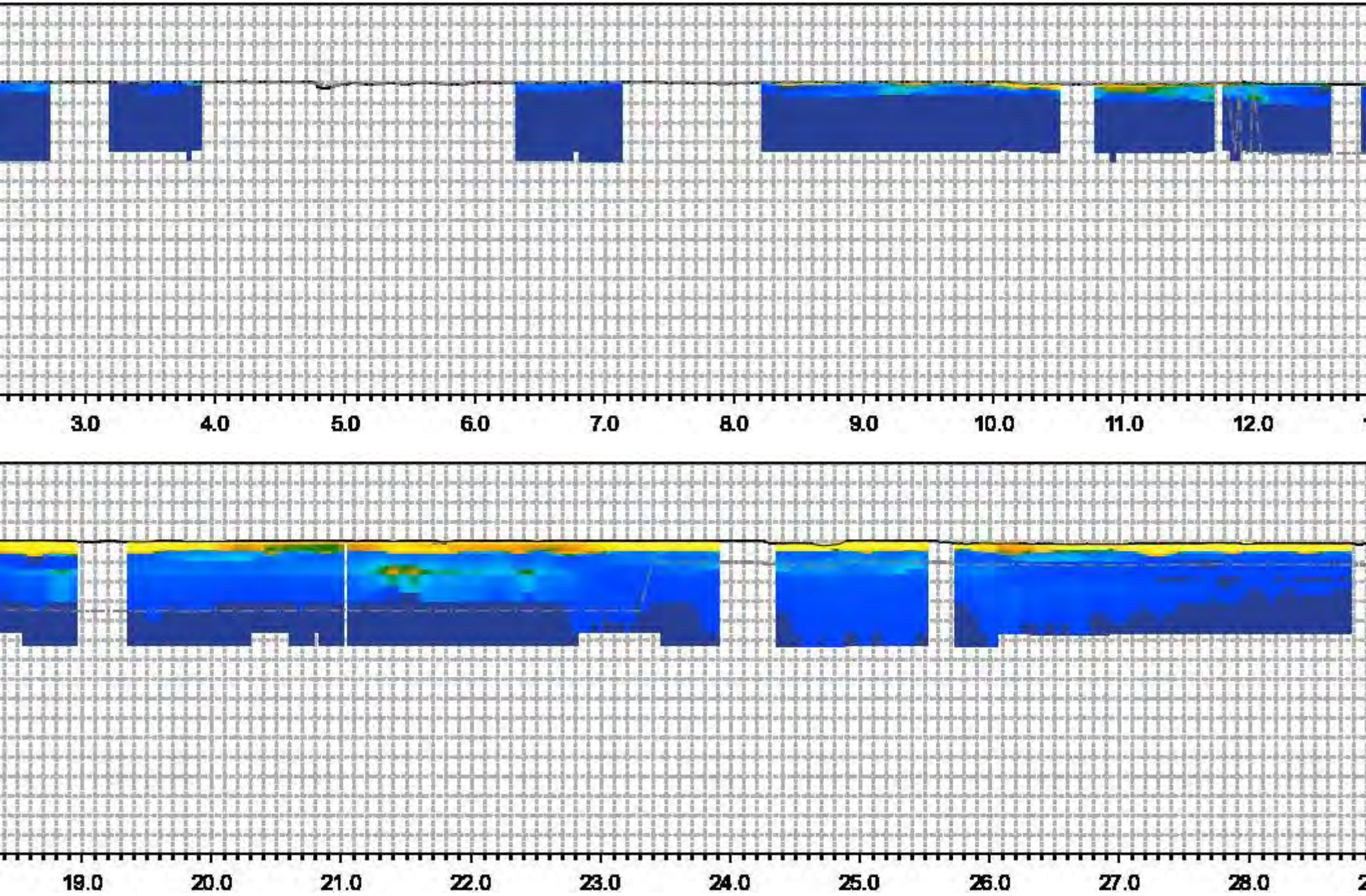
Luhdorff & Scalmanini
Consulting Engineers

Geologic Cross Section 4-4'

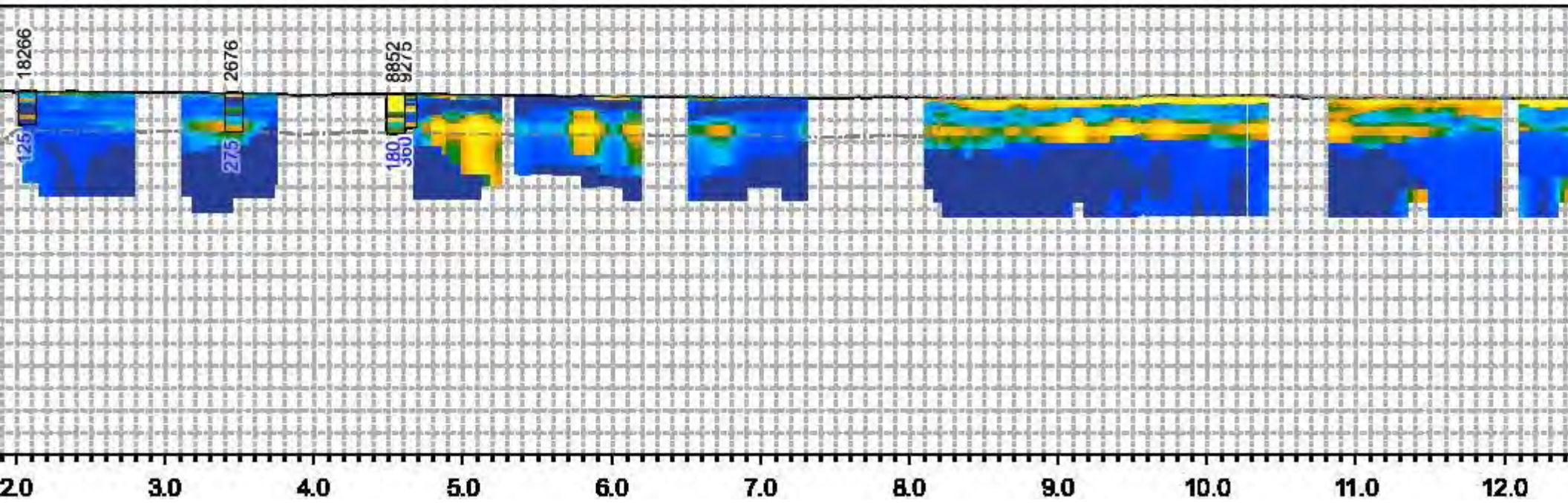
East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-6a

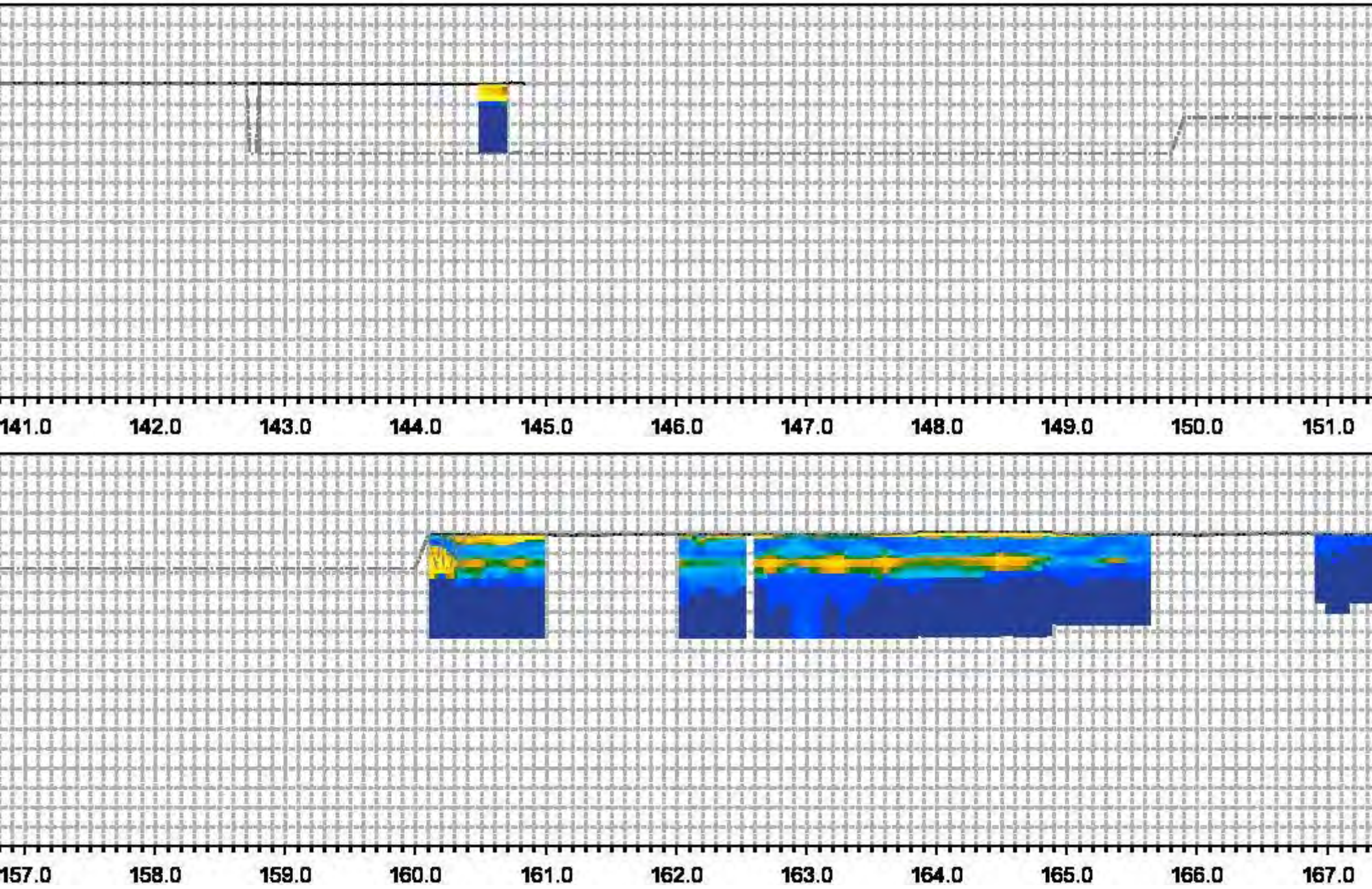
5 - 5' Nearest AEM Log

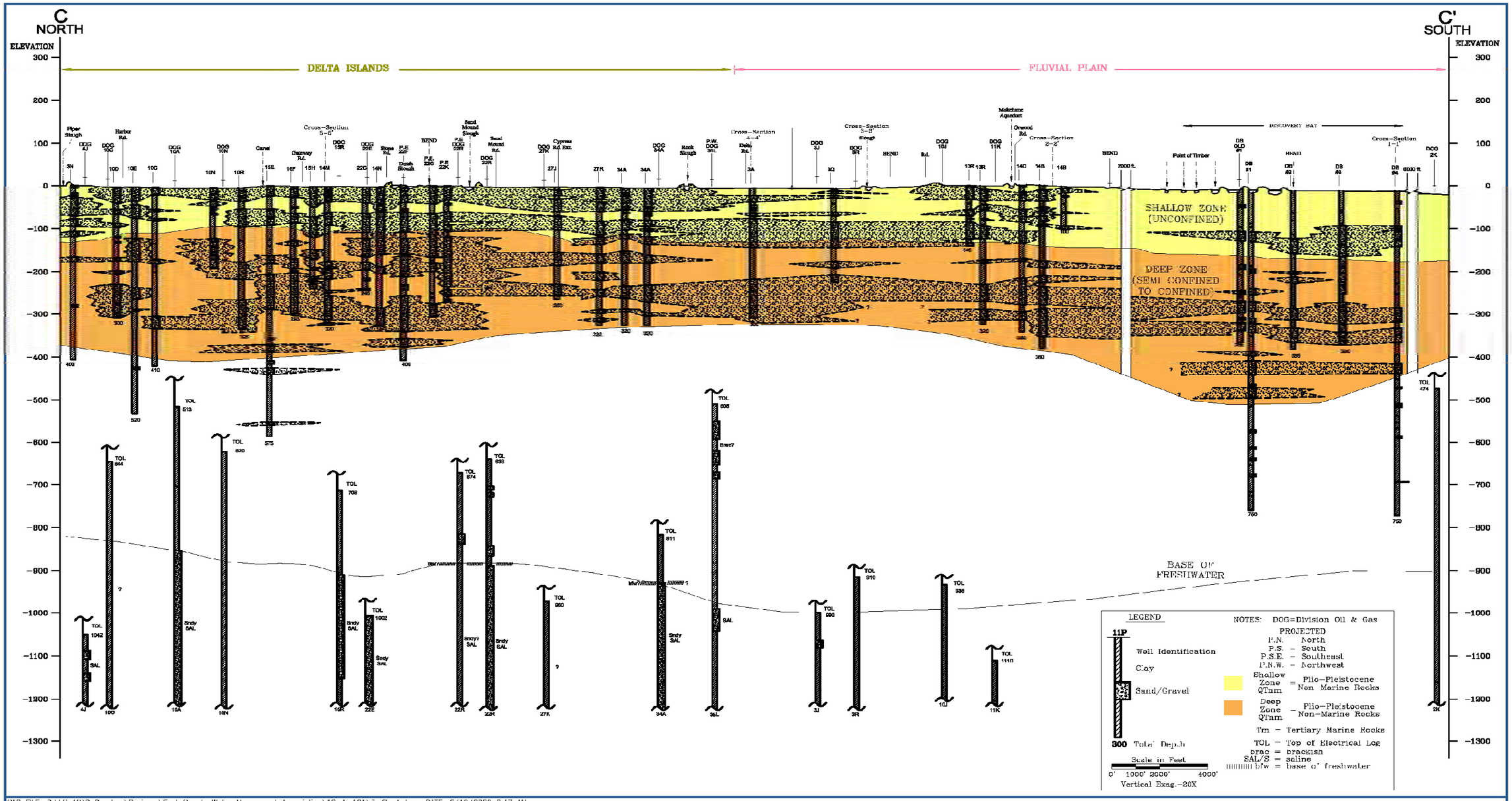


3 - 3' Nearest AEM Log



B - B' Nearest AEM Log





CAD FILE: D:\LS ACAD Dropbox\Projects\East County Water Managment Association\19-1-101\3-6b.r1.dwg DATE: 6/19/2020 8:47 AM

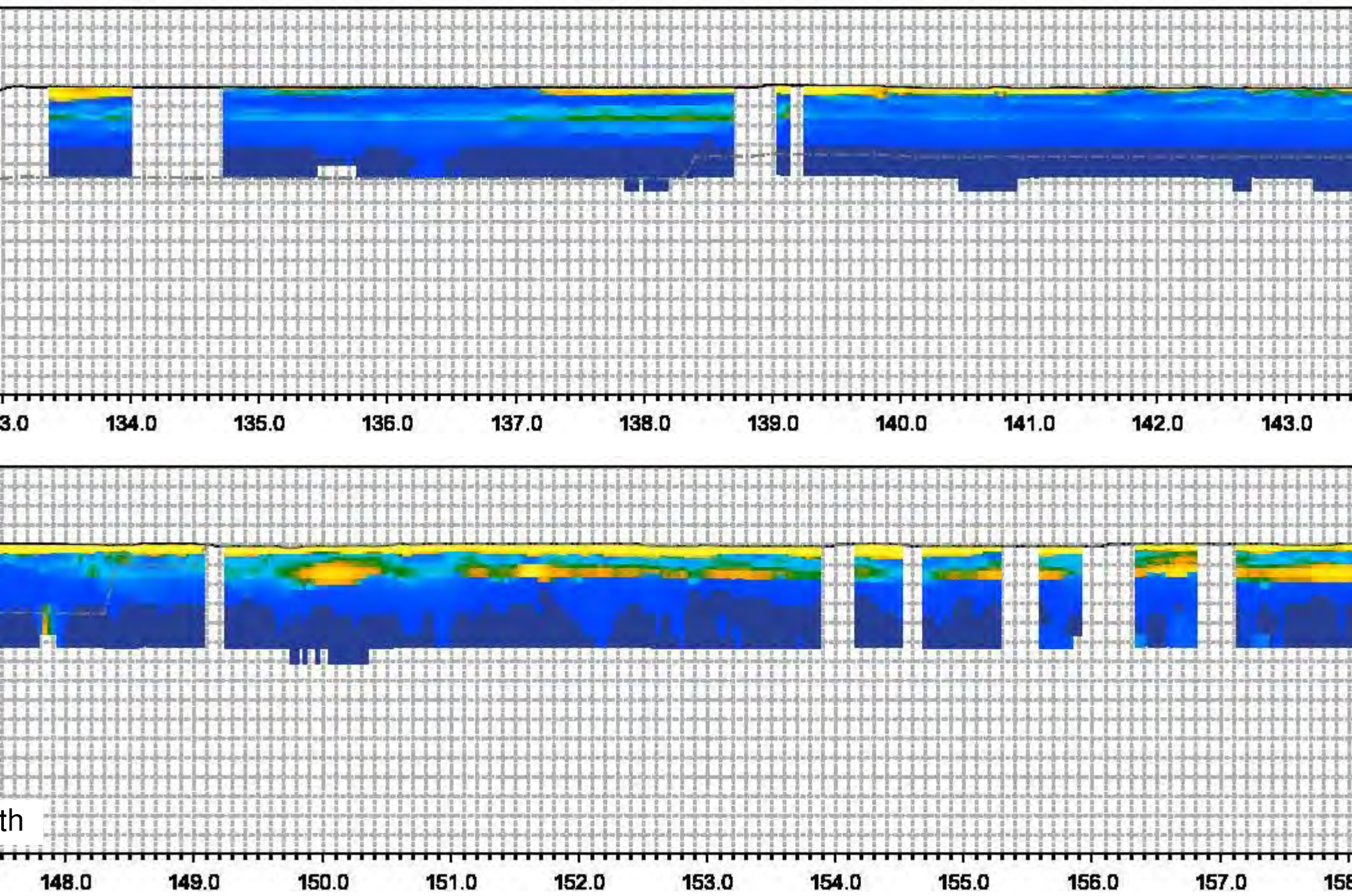
Luhdorff & Scalmanini
Consulting Engineers

Geologic Cross Section C-C'

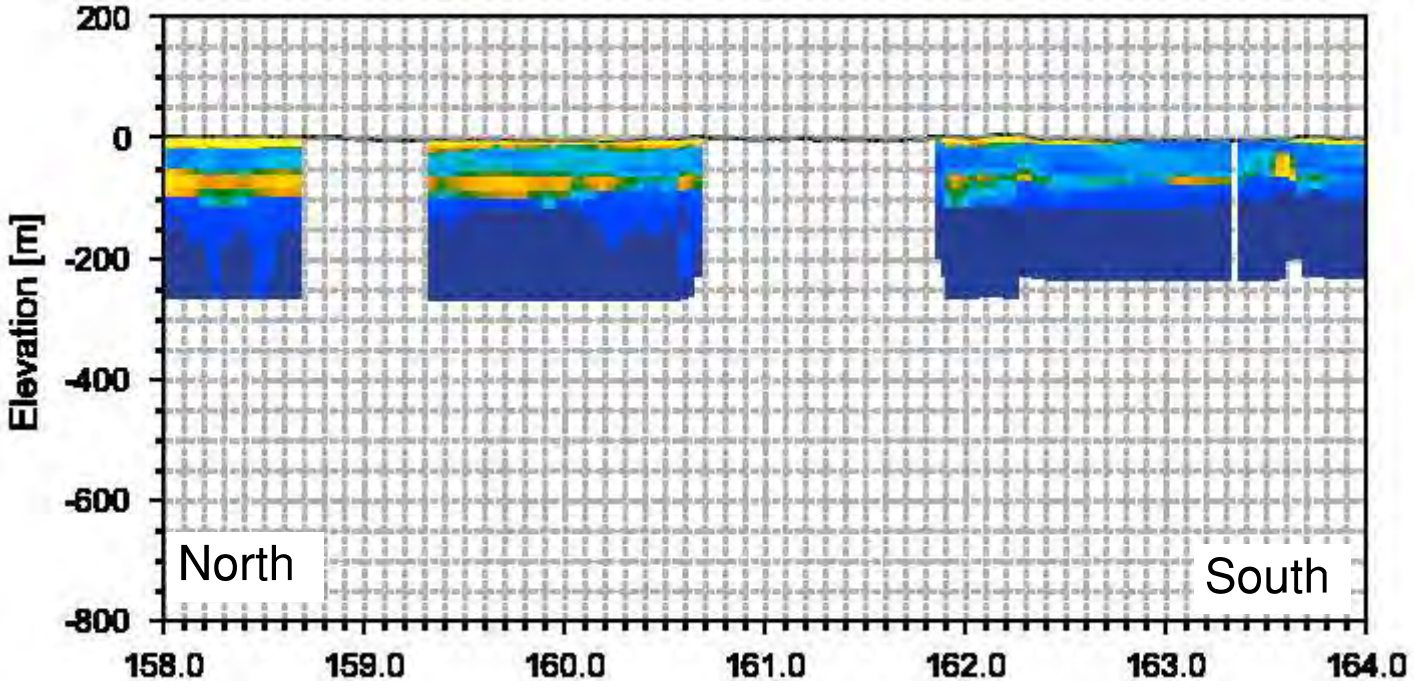
East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

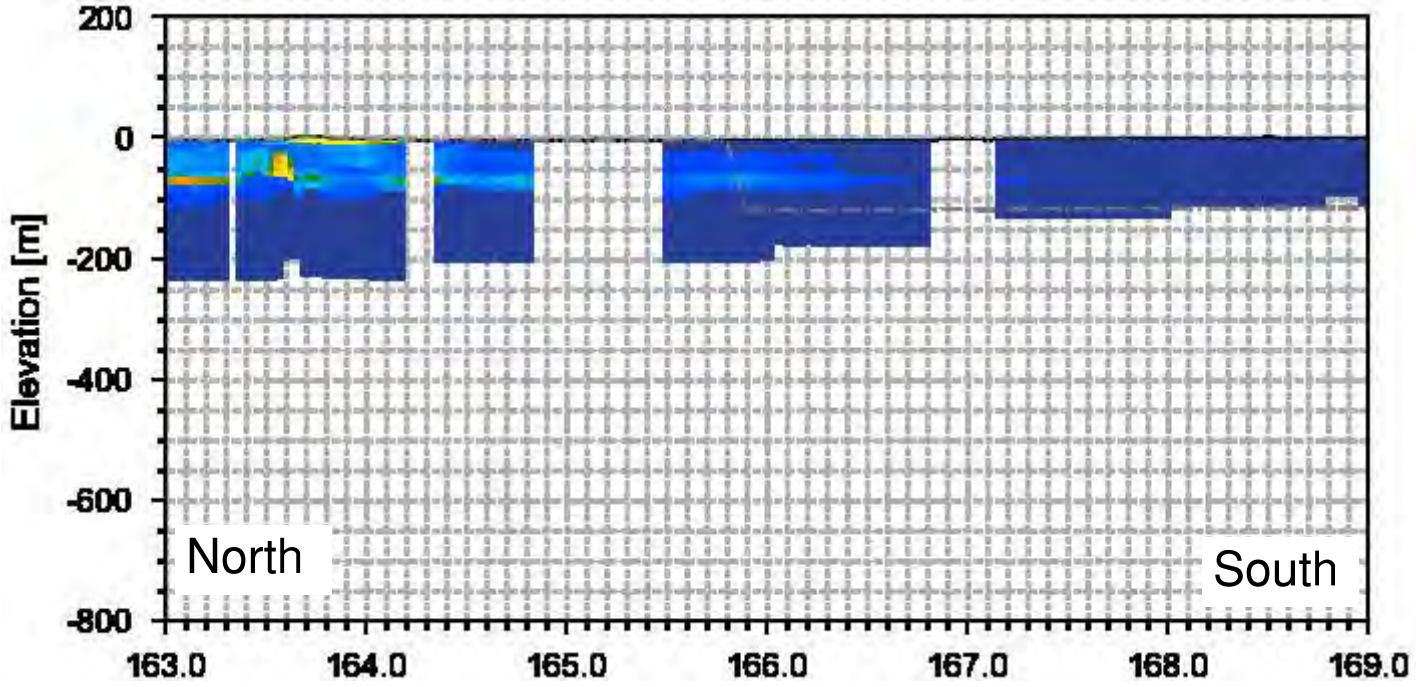
Figure 3-6b

C - C' Nearest AEM Log



C - C' Nearest AEM Log





Marginal Delta Dunes

This is representative of the Oakley area and defined by numerous thin to thick sand beds that are on the order of 30 to 60 feet thick per 100 feet. The depositional environment is a mixture of delta fluvial distributary channels and possibly aeolian dune fields. A surface deposit of rolling gentle hills of relic sand dunes occurs between Oakley and northern Brentwood. These sand dunes are believed to have been generated by strong winds blowing sand off the delta margins. Some deeper sand beds across the Marginal Delta Dunes area may be older dune fields.

Alluvial Plain

This is representative of greater Brentwood south of the Marginal Delta Dune and City of Oakley, and west of the Fluvial Plain and defined by thin sand and gravel beds with a lower sand thickness (less than 20 feet per 100 feet). The depositional environment is small streams draining eastward from the Coast Range foothills to the west. Flood flows of these streams spread out from the hills depositing fine-grained materials, possibly as mudflows with high sediment content. Stream flows deposited thicker sand and gravel beds that tended to stack upon each other causing the thicker bands of sand beds. The thicker stream deposited sand and gravel bands extend eastward until the sands either thin out or have not been reached by wells. In the north, the stream deposits appear to reach into the Marginal Delta Dunes area, blending into the sand units that are present there.

Antioch and Byron Areas

Due to lack of well control, these two areas could not be examined in detail. The Antioch area is poorly defined, but it appears to be a thin alluvial plain with thin sand beds overlying Plio-Pleistocene non-marine deposits. The Byron area appears to have only a few thin sand beds in a small alluvial plan area that is marginal to the Fluvial Plain region where fine-grained deposits dominate.

3.2.5 Principal Aquifers and Aquitards

Two primary aquifer zones are identified in the East Contra Costa Subbasin: an unconfined to semi- confined Shallow Zone and a semi-confined to confined Deep Zone, with clay layers separating the two. These aquifers are composed of alluvial deposits as illustrated on the representative cross sections (**Figures 3-6a** and **3-6b)**. The Shallow Zone extends from ground surface to a less permeable material (i.e., clay and silt) generally to a depth of less than 150 feet bgs. The Deep Zone directly underlies the shallow zone, is the primary production zone for public supply wells (generally 200-400 feet in depth, LSCE, 2011), and extends to the base of fresh water (a maximum of 1,200 feet from mean sea level).

As indicated previously, the Corcoran Clay does not extend into the ECC Subbasin nor does a similar feature occur that separates major aquifer units. However, in the Alluvial Plain (around the City of Brentwood) there appears to be local confinement by multiple clay layers which separates shallow and deep zones (LSCE, 1999). This separation is seen through distinctive water levels (see **Section 3.3.1**). The Fluvial Plain (around Discovery Bay, **Figure 3-6a**) and Marginal Delta Dune (around Oakley) both have a confined Deep Zone with an extensive layer of clay separating a shallow zone from the deep zone that serves as the primary production aquifer. The Delta Islands area does not have clay layers separating a deep confined zone from shallower aquifer materials nor water levels that reflect it. The primary use of the Shallow Zone is by domestic wells and small community water systems which may have poorer water quality due to Bay-Delta influences. The primary use of the Deep Zone is for municipal supply (City of Brentwood, Discovery Bay and DWD) and agricultural irrigation supply (ECCID and BBID).

Groundwater System Conceptualization

The ECC Subbasin aquifer system is subdivided into two zones: an upper unconfined Shallow Zone that sits above discontinuous to locally continuous clay layers and, a lower semi-confined to confined Deep Zone. As illustrated in the geologic cross-sections described above, the upper 400 feet of sediments is comprised of alluvial deposits with discontinuous clay layers interspersed with more permeable coarse-grained units. Most water wells are constructed within the upper 400 feet where coarse grained units are identified. Water well information is lacking for depths below 400 feet bgs to the base of fresh water but the units are likely fine grained and become brackish at and below that depth based on the current HCM.

3.2.6 Soil Characteristics

There are many soil types found throughout the Subbasin (**Figure 3-7a**). The soil data were gathered from the Natural Resource Conservation Service (NRCS) as part of the Soil Survey Geographic Database (SSURGO). The data are compiled from various maps, which are updated on a yearly basis. The predominate soil types in the Subbasin are the Brentwood, Capay, Delhi, Marcuse, and Rindge series. The Brentwood series is reported to be a well-drained silty clay loam found in valleys and valley floors near Brentwood. The Capay series is noted to be a moderately well-drained clay and is found throughout the Subbasin often near the Brentwood series. The Delhi series is noted to be a somewhat excessively drained sand found primarily in Oakley and Antioch and is derived from eolian deposits. The Marcuse series is noted to be a poorly drained clay and silty clay with a small amount of sand and is found throughout the center of the Subbasin. The Rindge is noted to be a very poorly drained silty clay loam to muck, and is found along the Delta Islands (i.e., Bethel Island) and near the Old River boundary.

3.2.6.1 Soil Properties

Soil properties are important to the HCM to the extent that they provide a pathway for groundwater infiltration through the soil and have high or low runoff potential. This information is used to calculate surface water recharge and to estimate deep percolation for surface water/ groundwater models. **Figure 3-7b** illustrates the soil texture of the surficial soils found in the Subbasin as outlined by NRCS. The dominant soil textures are clay, clay loam, sand, and muck. Clays and clay loams are found throughout the Subbasin. Sand is concentrated near Antioch and Oakley in the northwestern part of the Subbasin. Muck is found in the eastern portion of the Subbasin along the Old River and the Delta Islands. Muck is defined by the NRCS as “the most highly decomposed of all organic soil material. Muck has the least amount of plant fiber, the highest bulk density, and the lowest water content at saturation of all organic material”.

Figure 3-7c presents the average hydraulic conductivity[1] for soils in the Subbasin. The hydraulic conductivity of soils ranges from less than 1 ft per day to more than 15 ft per day (ft/day). The highest conductivity areas are those with soil textures of muck, sand, or loamy sand. The areas around Oakley and on the northeastern and eastern border of the Subbasin have the highest hydraulic conductivity possibly due to the occurrence of dune sands.

Figure 3-7d shows the soil salinity for the Subbasin. Soil salinity is measured by electric conductivity (EC) and is measured by the amount of soluble salts in the soil. Almost the entire Subbasin has electric conductivity values of less than 2 deSiemens per meter (dS/m) which is low. Higher EC is noted in the center of the Subbasin, following a similar pattern as the distribution of the Marcuse soil, which was noted to be poorly

[1] Capacity for soil to transmit water with units of Length/Time. Units used in this report are feet/day.

EASTERN SAN JOAQUIN GROUNDWATER AUTHORITY

Eastern San Joaquin Groundwater Subbasin

GROUNDWATER SUSTAINABILITY PLAN

November 2019; revised June 2022

Figure 2-19: Cross-Section Location Map

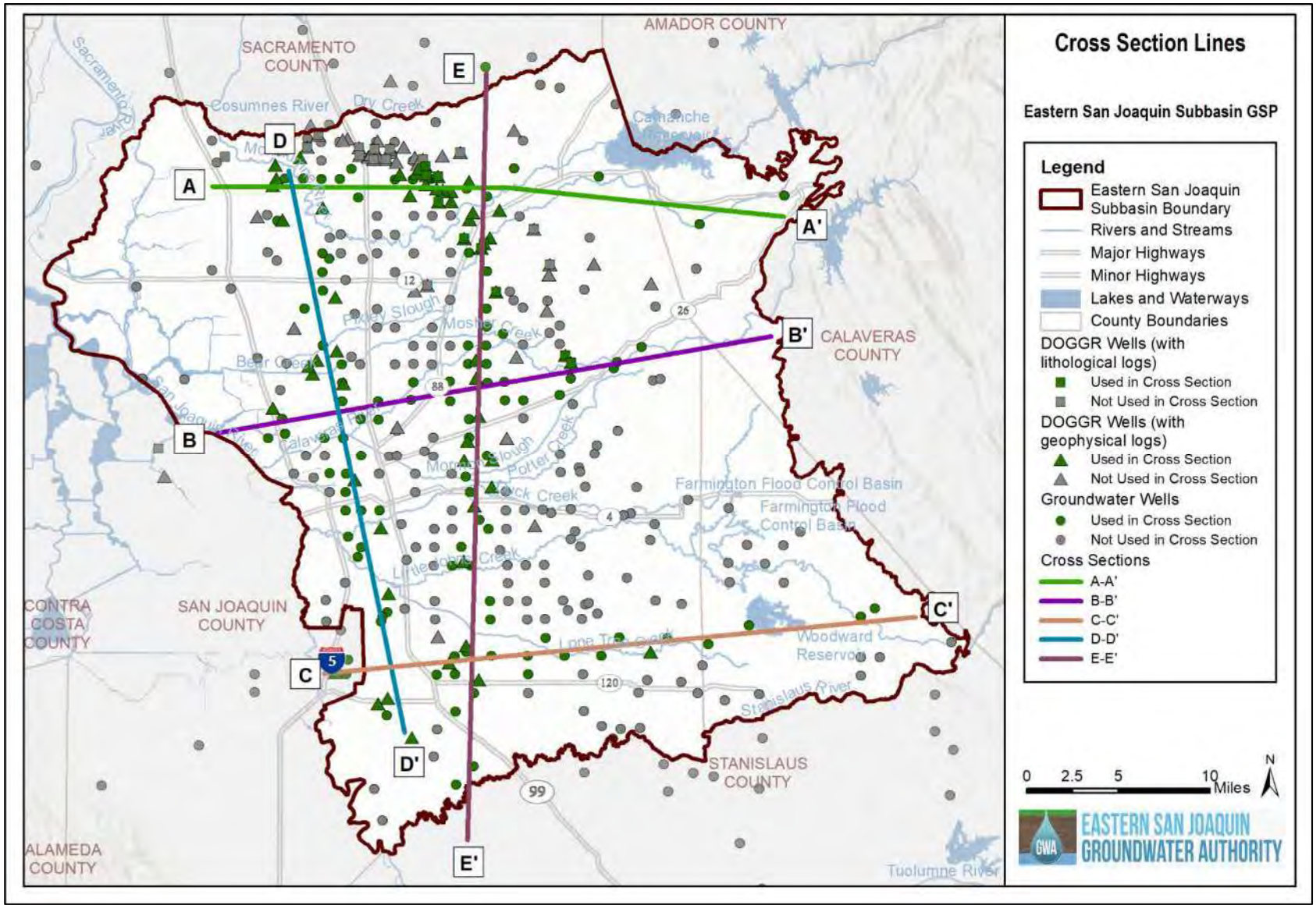
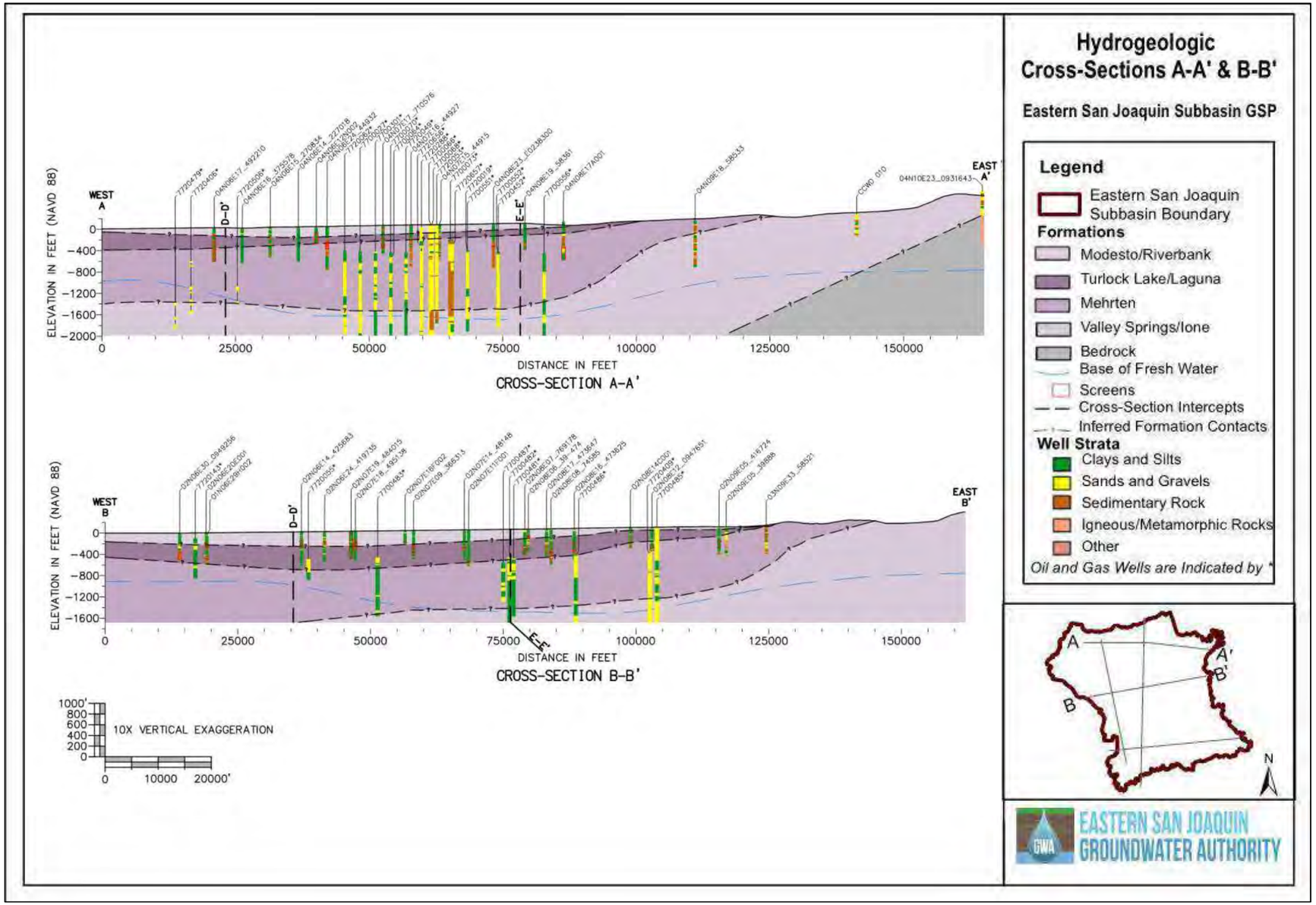
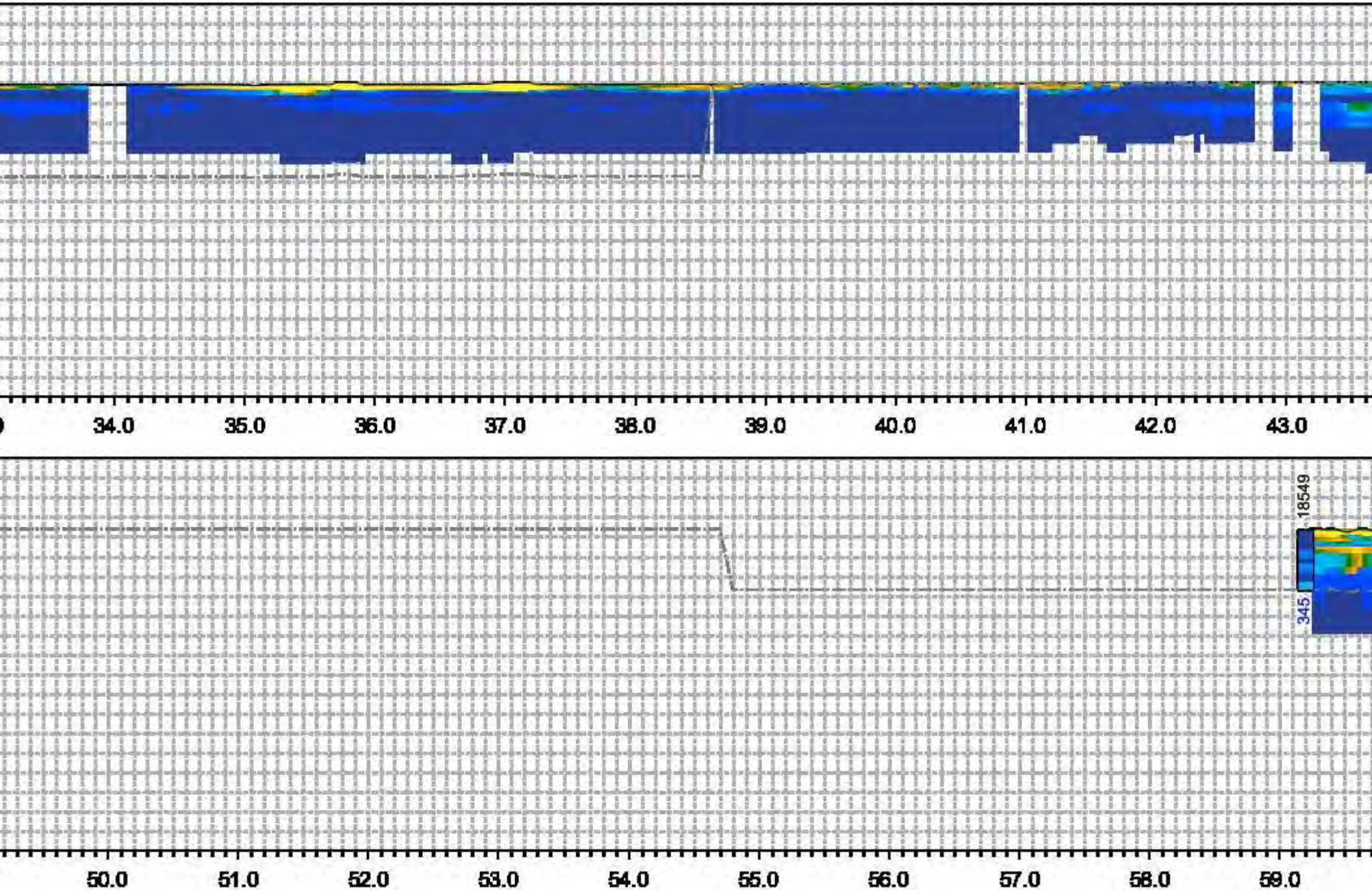


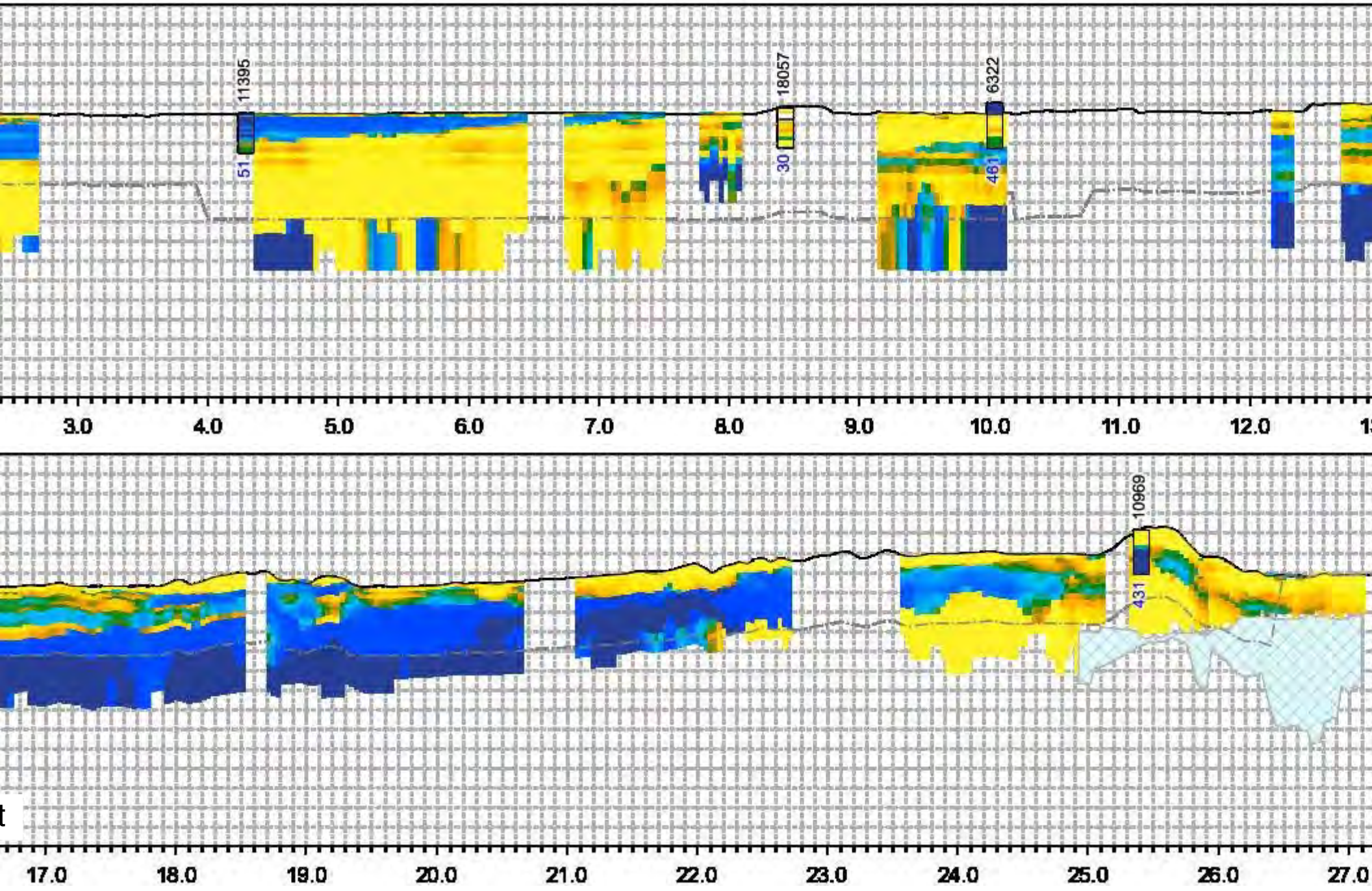
Figure 2-20: Hydrogeologic Cross-sections A-A' and B-B'



A - A' Nearest AEM Logs

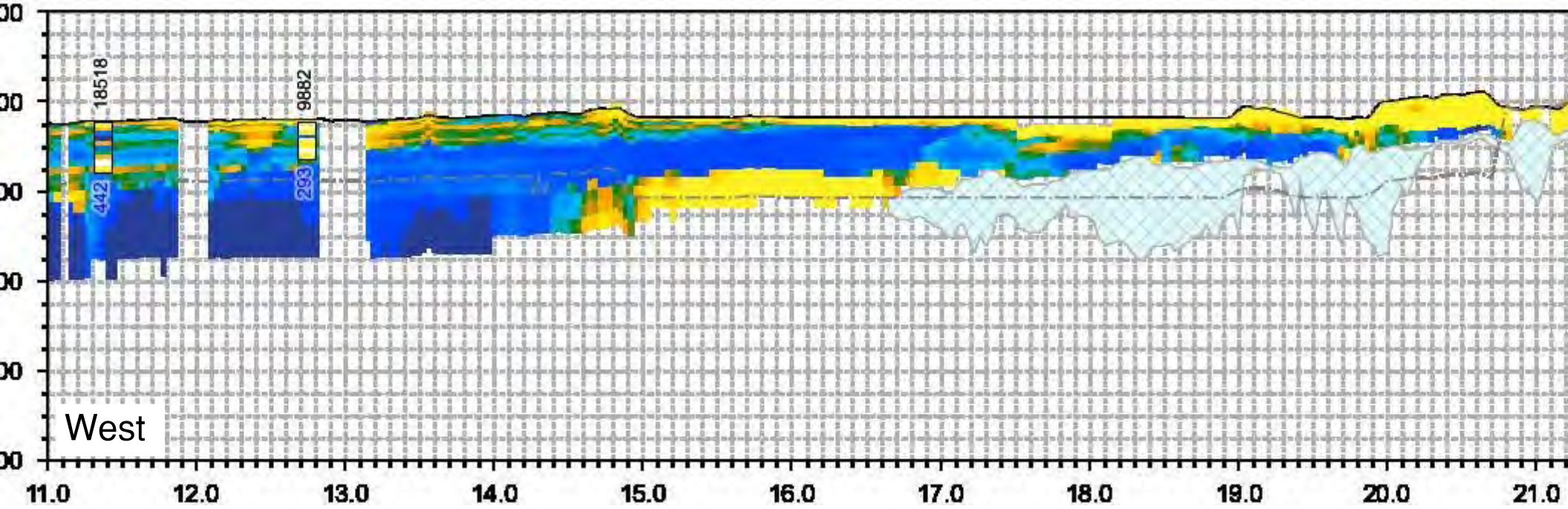


A - A' Nearest AEM Logs, East North



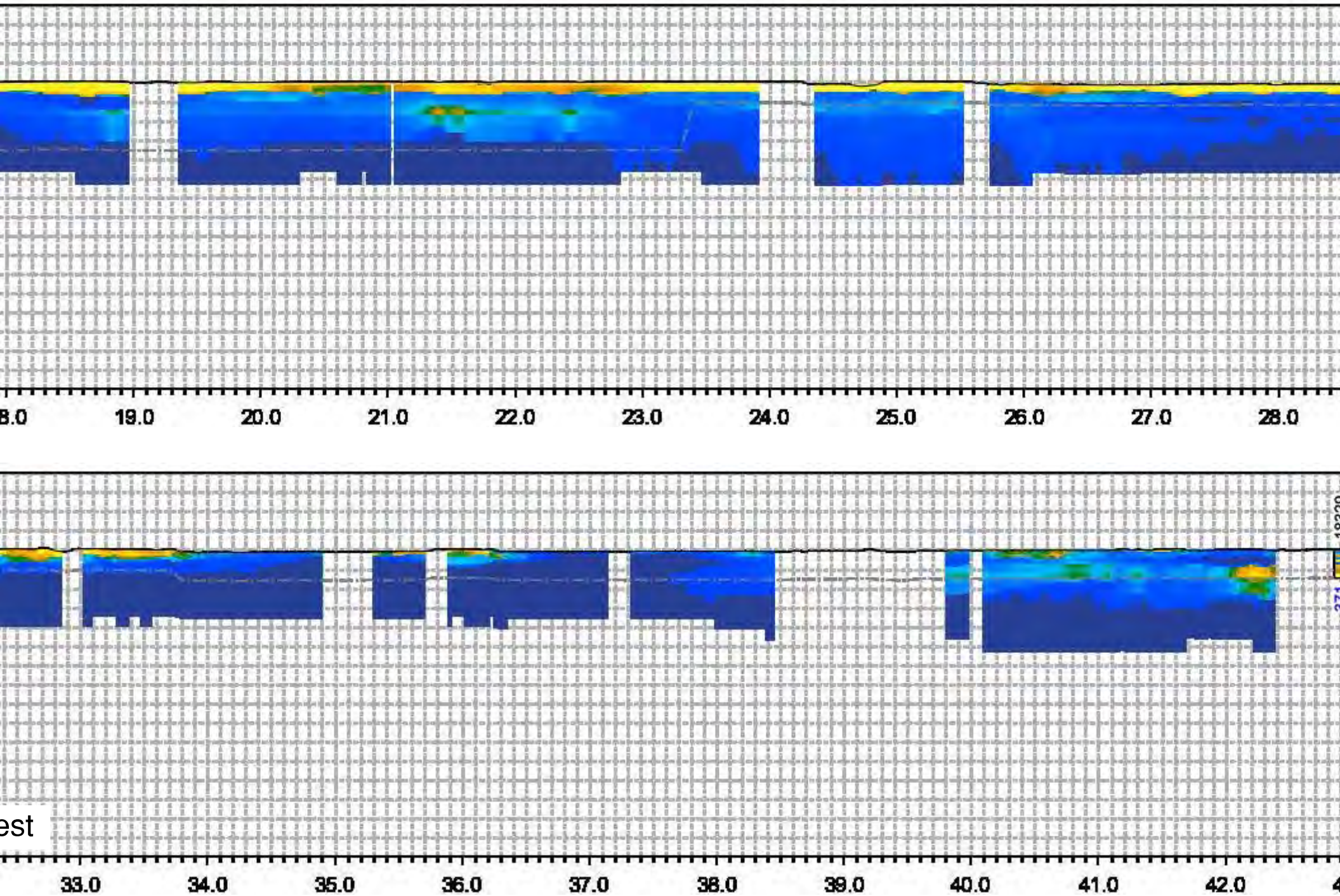
A - A' AEM Logs are NOT continuous with previous AEM Logs

A - A' Nearest AEM Logs, East South

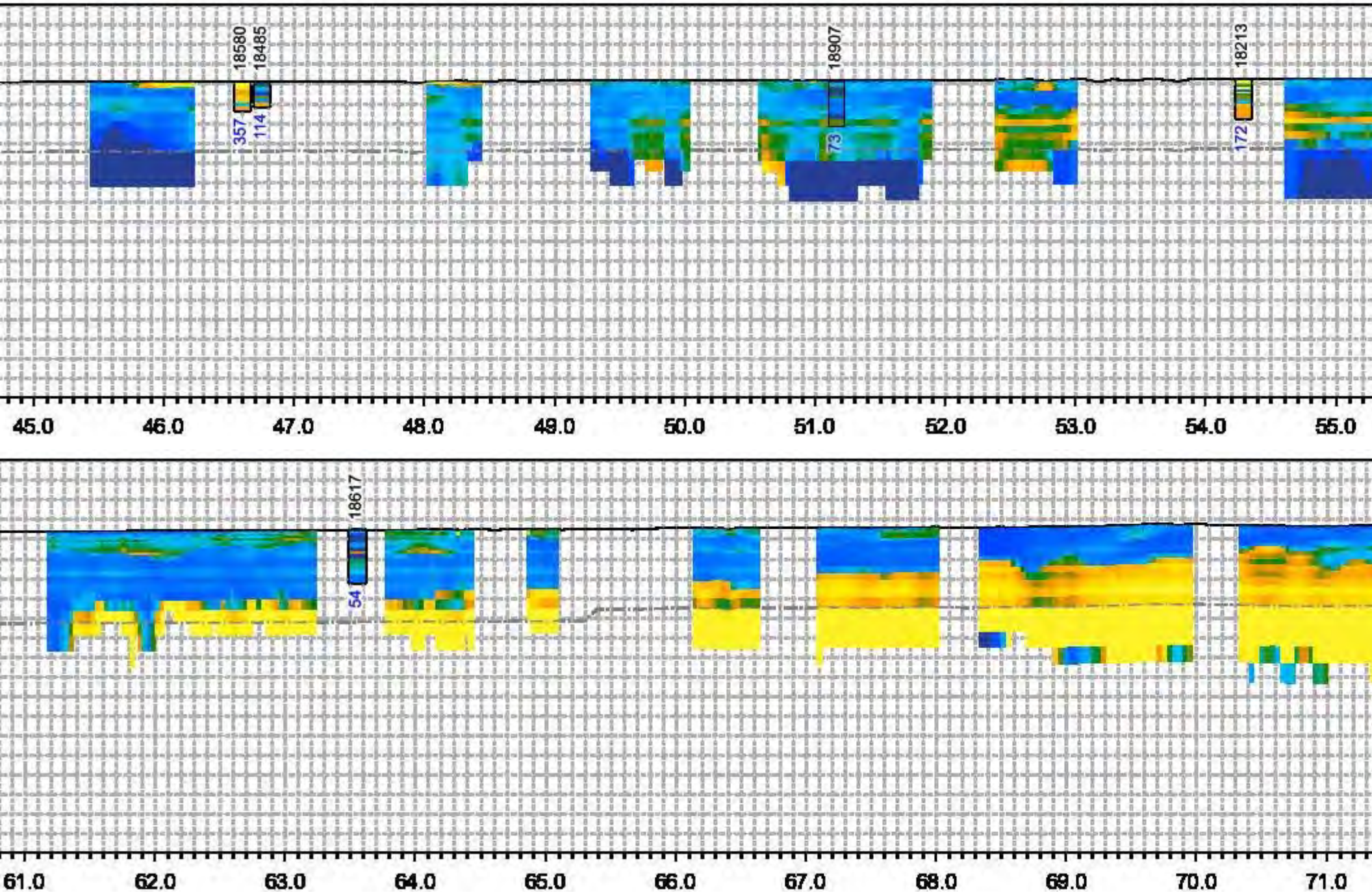


A - A' AEM Logs are NOT continuous with previous AEM Logs

B - B' Nearest AEM Logs



B - B' Nearest AEM Logs



B - B' Nearest AEM Logs

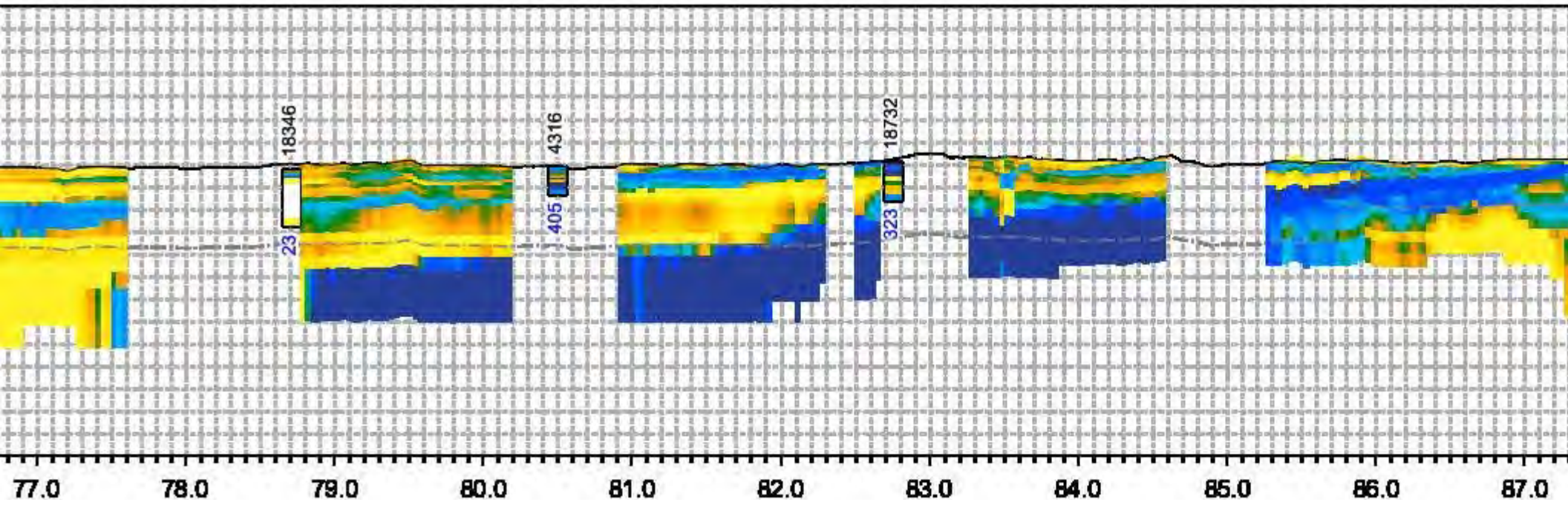
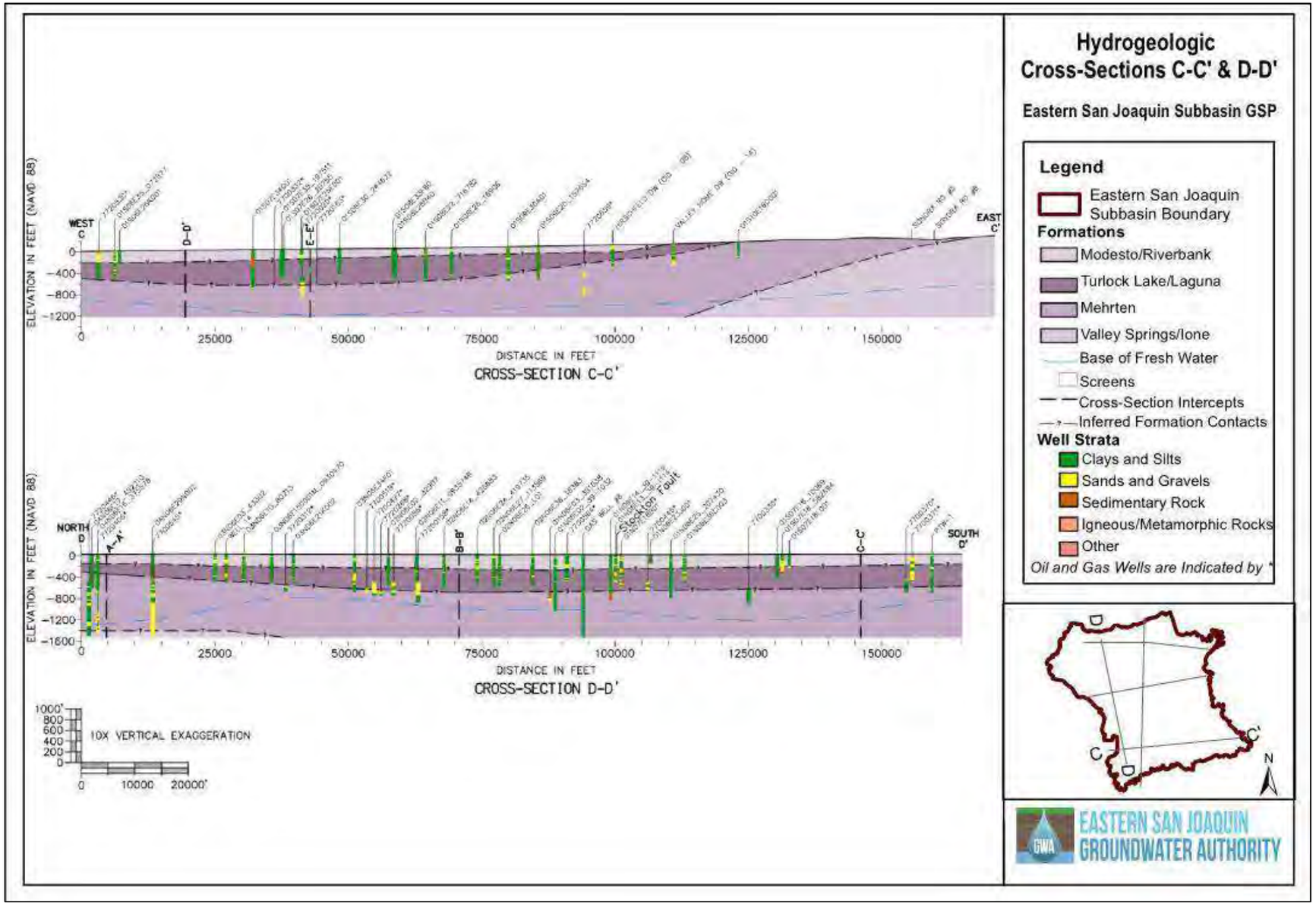
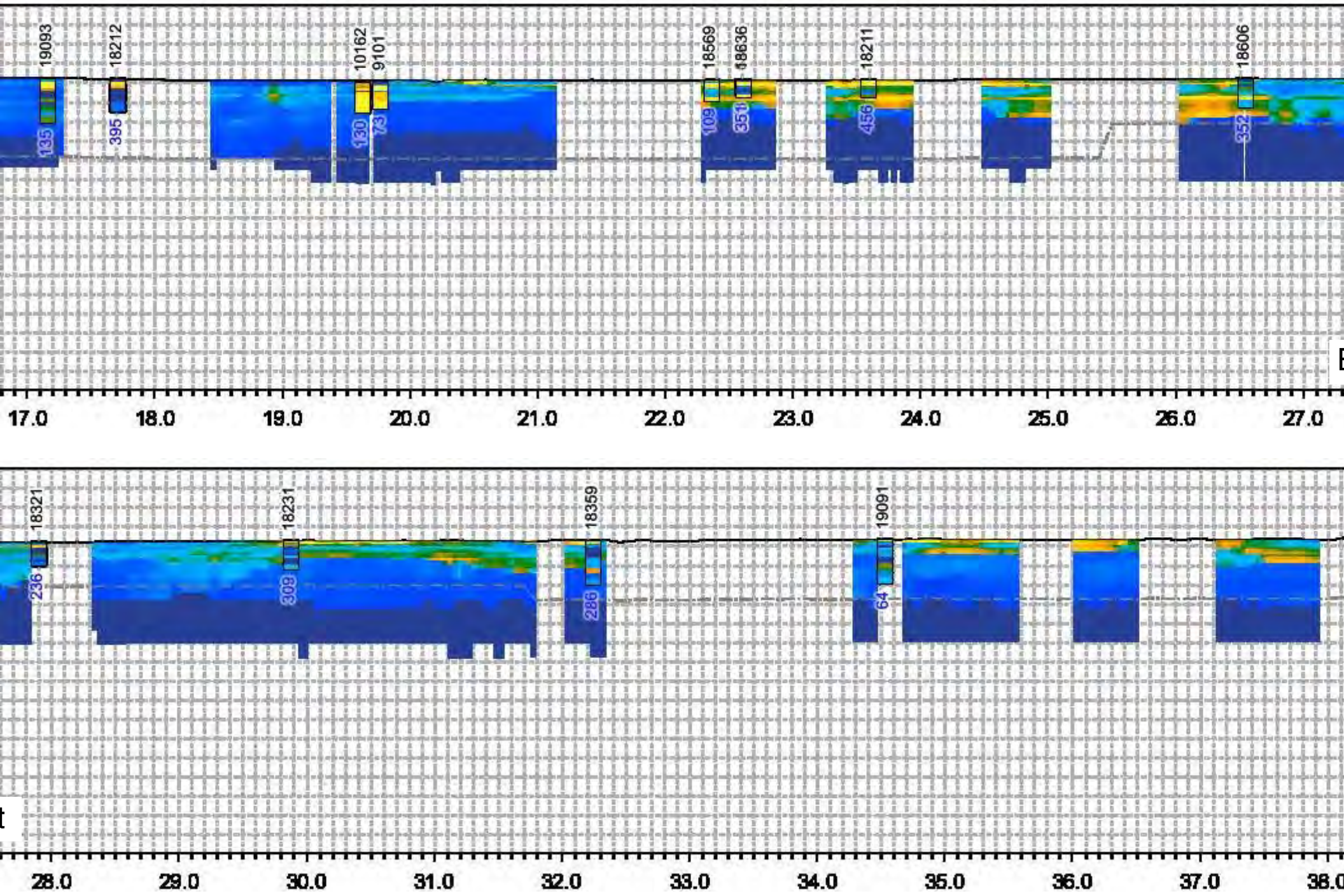


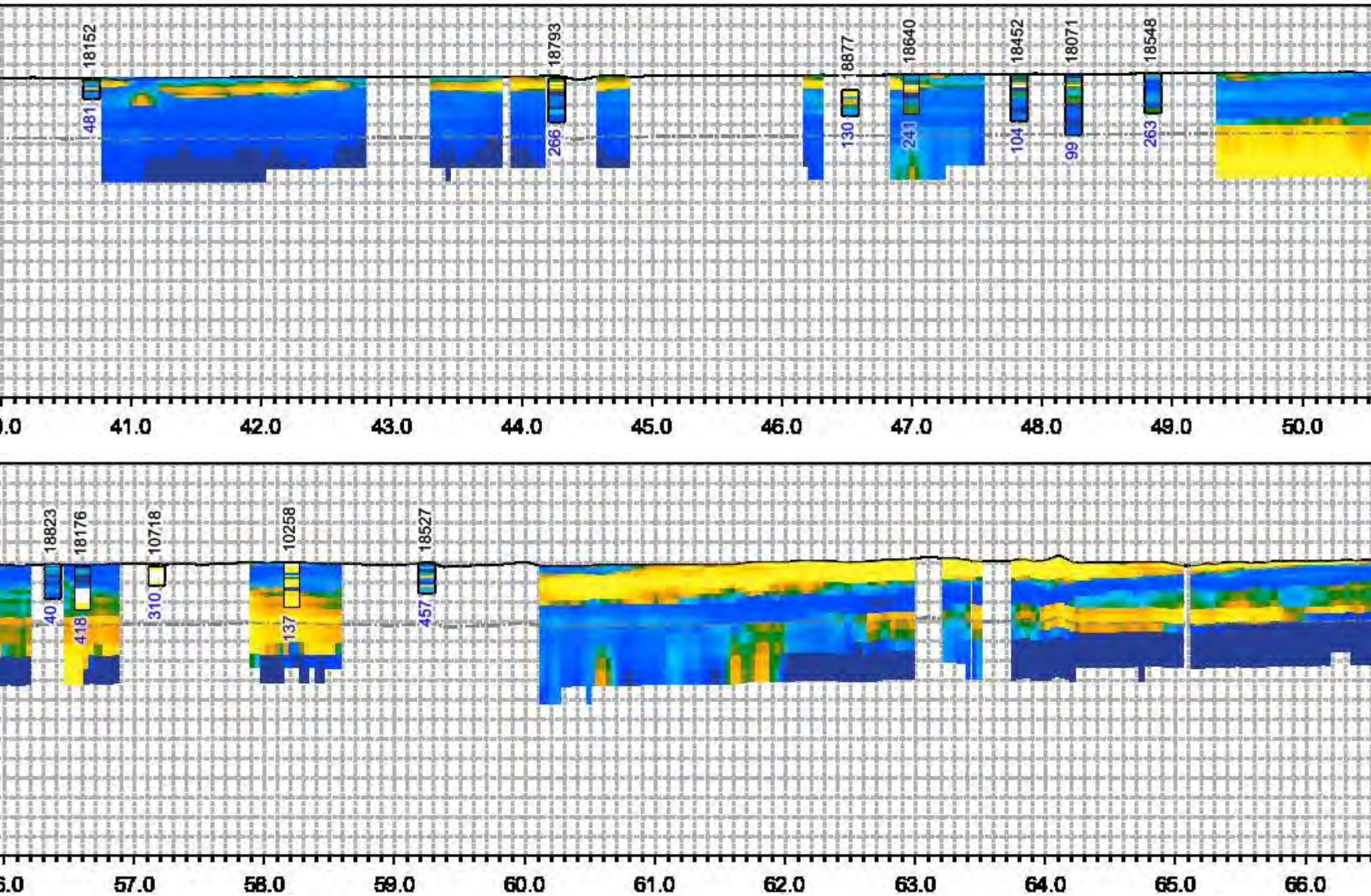
Figure 2-21: Hydrogeologic Cross-sections C-C' and D-D'



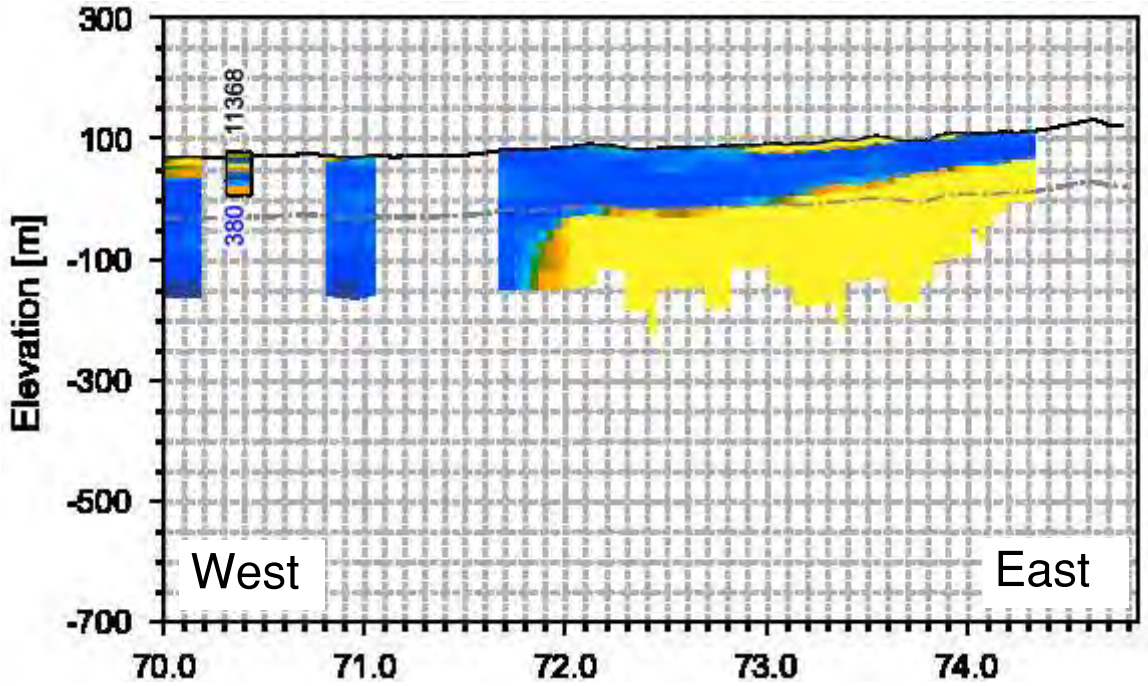
C - C' Nearest AEM Logs



C - C' Nearest AEM Logs



C - C' Nearest AEM Logs



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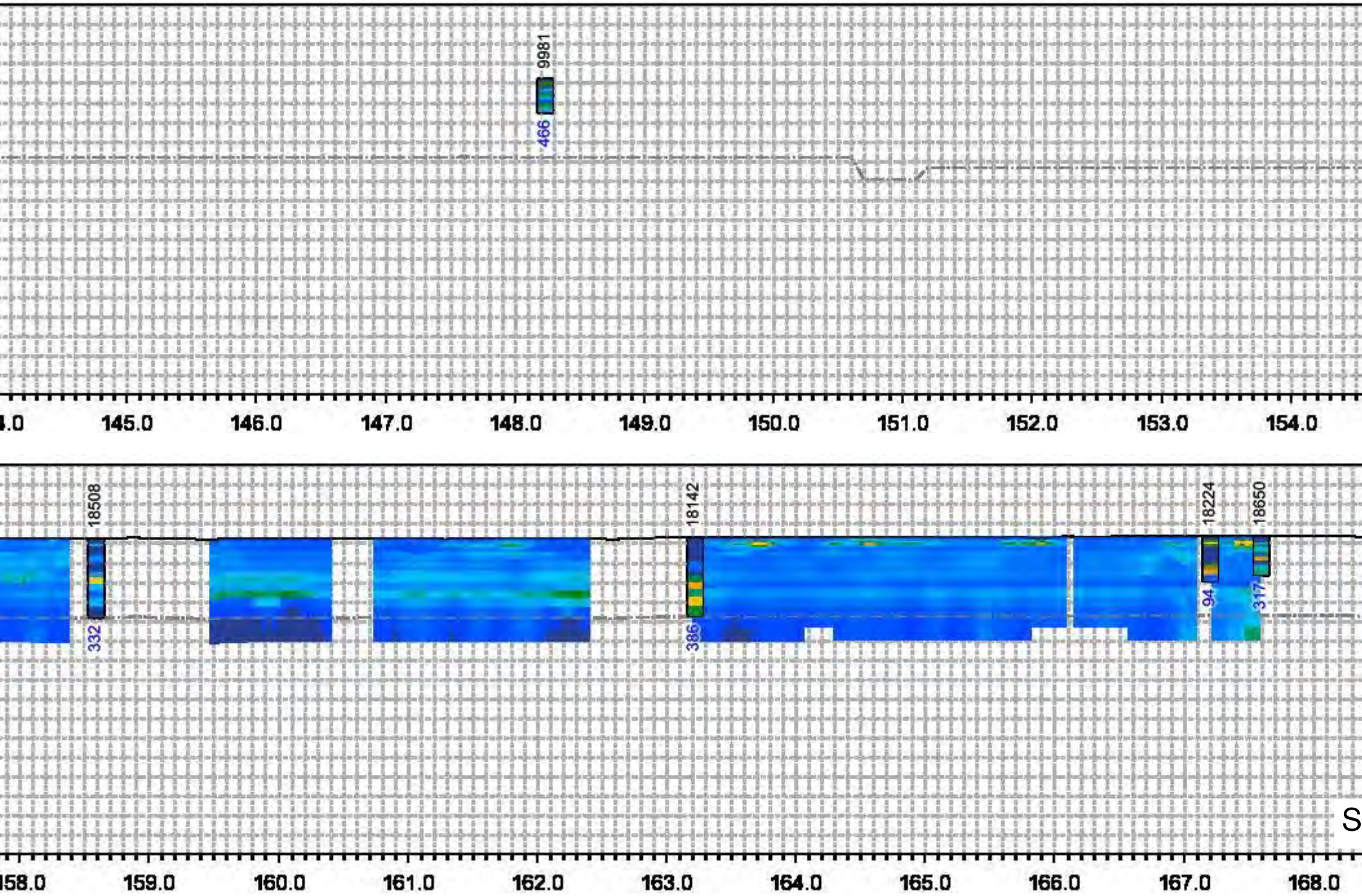


D - D' Nearest AEM Logs

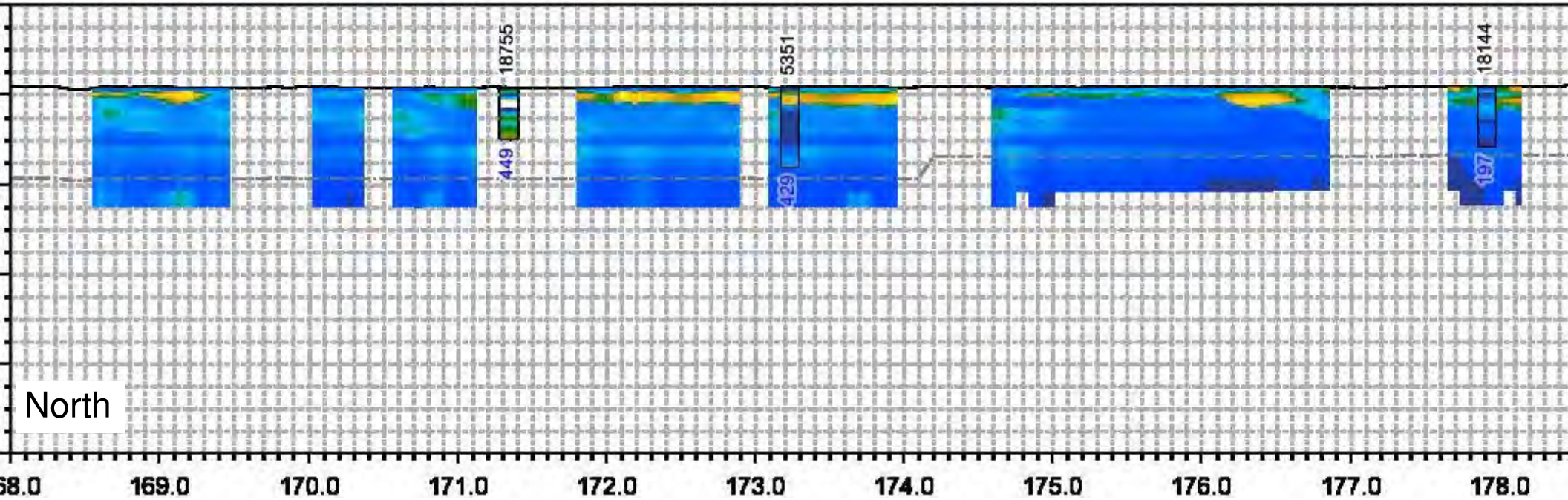
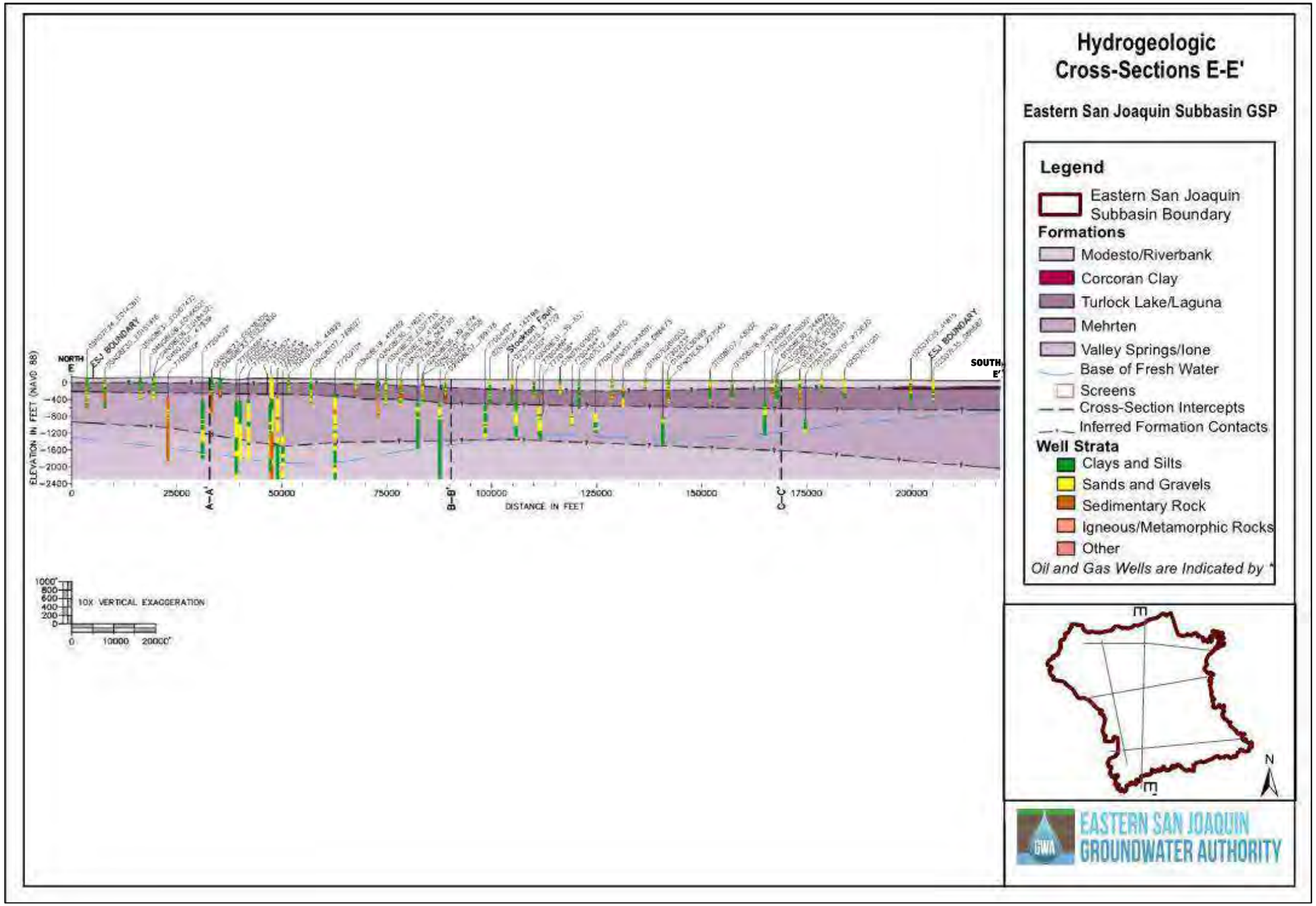
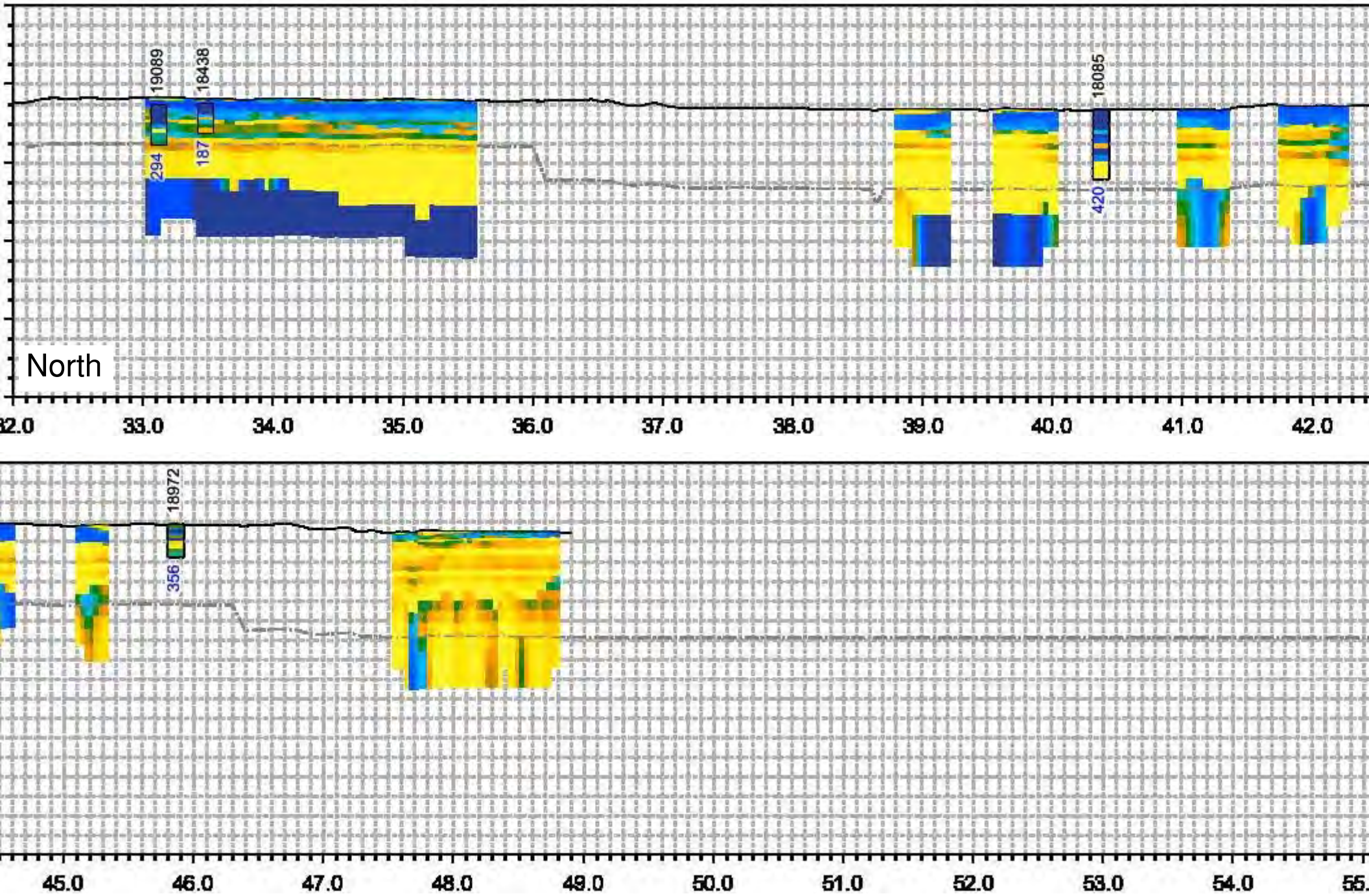


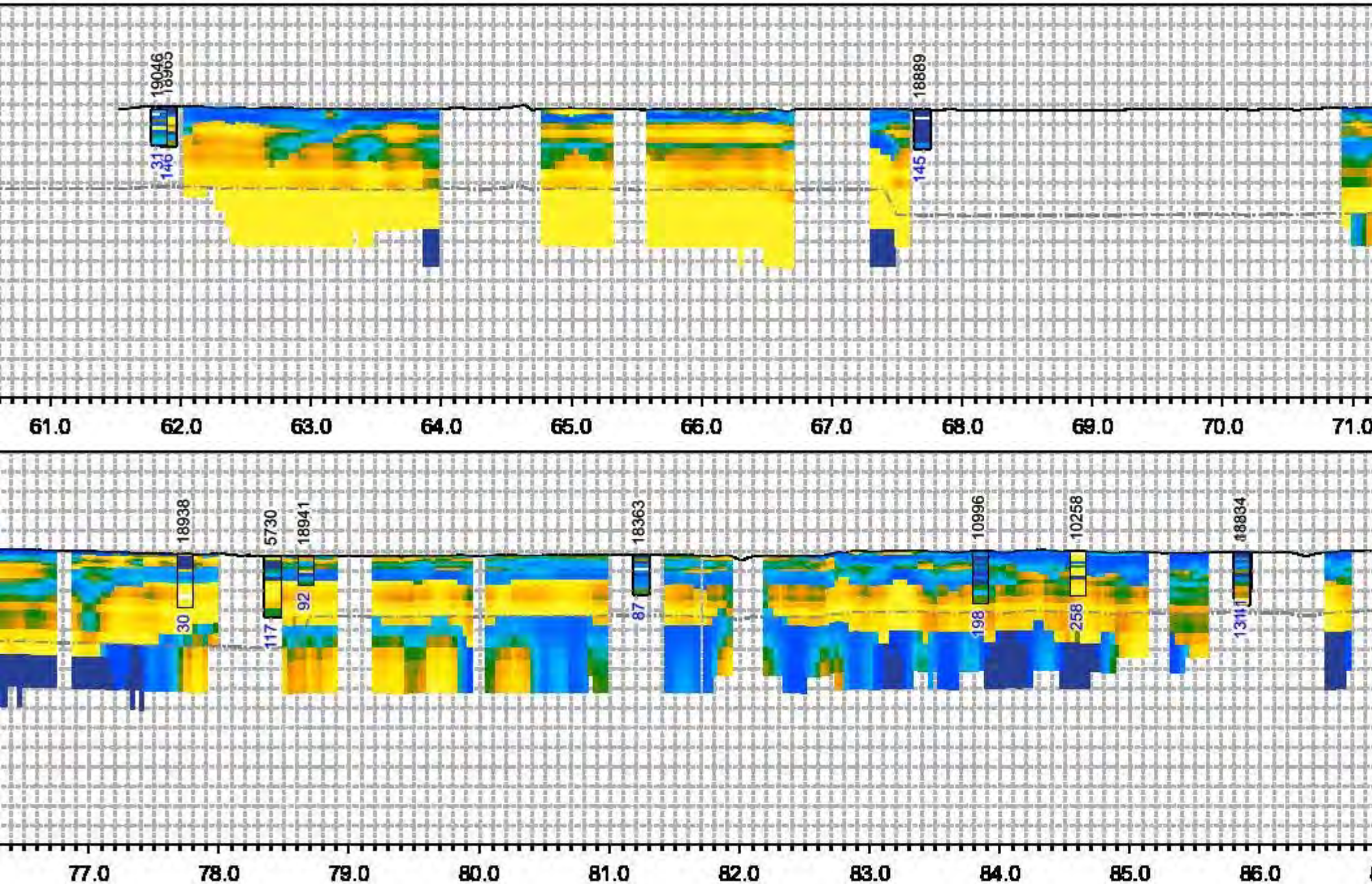
Figure 2-22: Hydrogeologic Cross- section E-E'



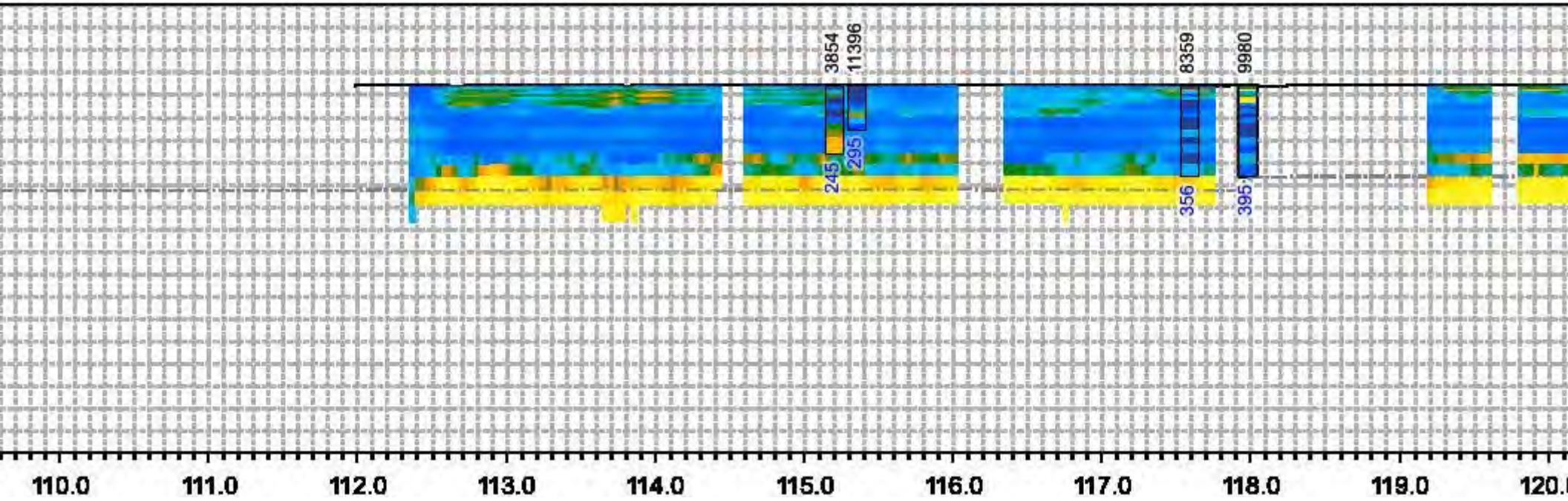
E - E' Nearest AEM Logs, West

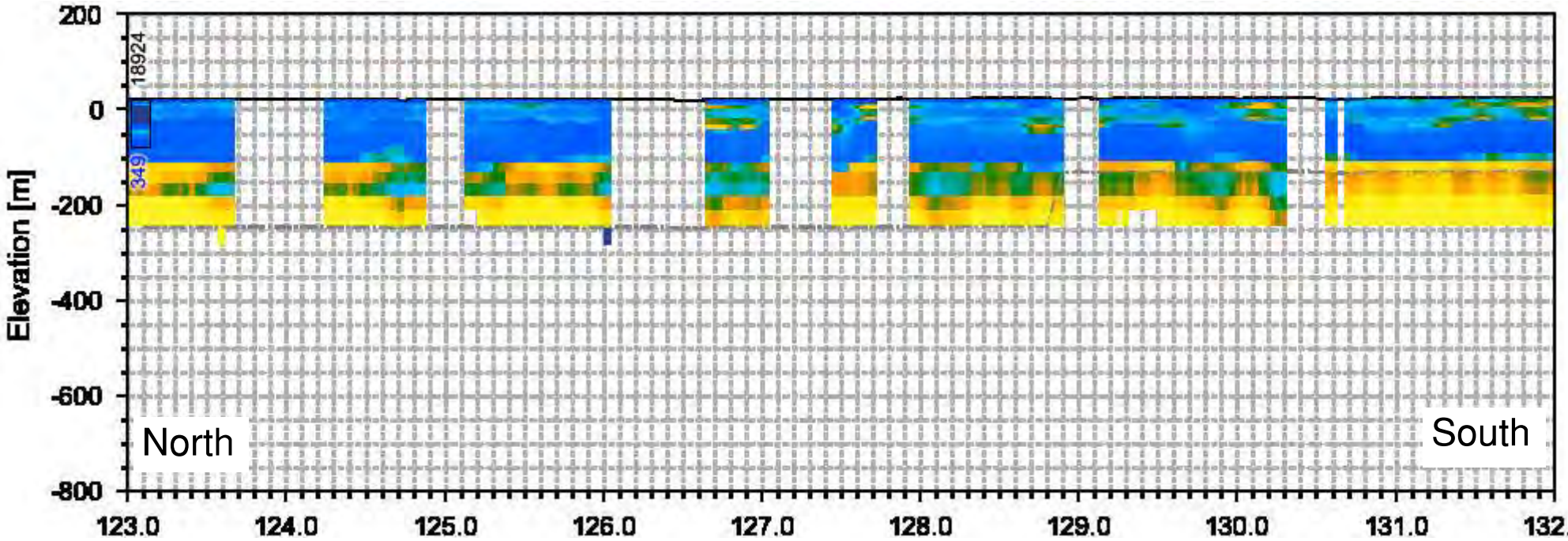


E - E' Nearest AEM Logs, West

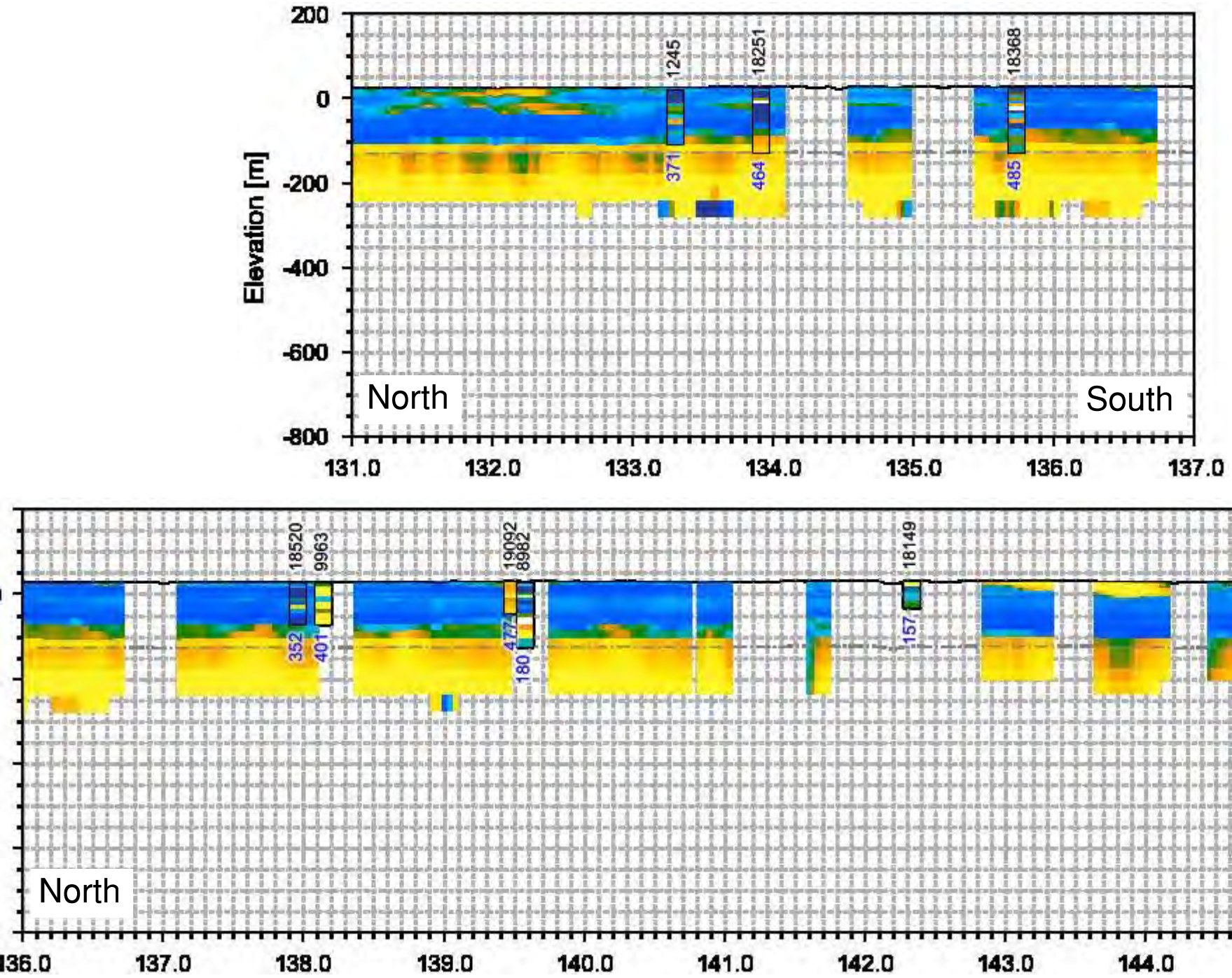


E - E' Nearest AEM Logs, East

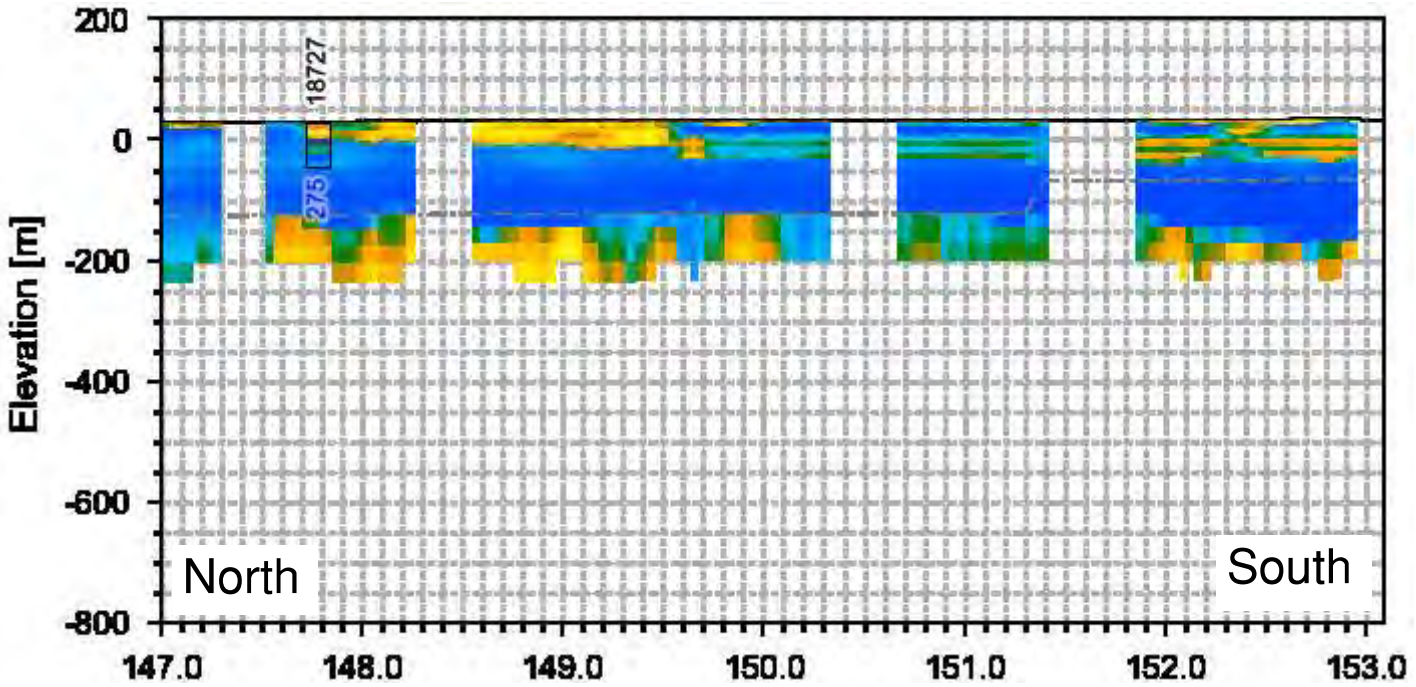




E - E' Nearest AEM Logs, East



E - E' Nearest AEM Logs, East



- East Contra Costa Subbasin to the west of the San Joaquin River
- Tracy Subbasin to the west of the San Joaquin River

Foothill and bedrock highs are to the east within Calaveras and Amador Counties.

2.1.8.2 Definable Bottom of the Basin

The base of the fresh water defines the bottom of the basin, the maximum vertical extent of fresh non-saline groundwater within the Eastern San Joaquin Subbasin. While water-bearing materials exist below this depth, the saline nature of the groundwater, in addition to the depth itself, generally makes accessing deeper groundwater not economically viable.

Because of the extreme depths to the base of fresh water shown in Figure 2-18, efforts by the USGS have been used to define the "base of fresh water" through the interpretation of the California DOGGR well logs and deep oil well geophysical logs as depicted on maps and cross-sections above. Base of fresh water (encountered saline) has been observed as shallow as 650 feet below ground surface (bgs) in the eastern part of the basin to over 2,000 feet bgs in the northern part of the basin as depicted on the surface contour map and supported by work completed by Williamson (1989).

2.1.9 Principal Aquifer

The Eastern San Joaquin Subbasin HCM has one principal aquifer that provides water for domestic, irrigation, and municipal water supply and that is composed of three water production zones. The zones have favorable aquifer characteristics that deliver a reliable water resource because of their basin location and sand thickness.

The zones are:

- Shallow Zone that consists of the alluvial sands and gravels of the Modesto, Riverbank, and Upper Turlock Lake Formations
- Intermediate Zone that consists of the Lower Turlock Lake and Laguna Formations
- Deep Zone that consists of the consolidated sands and gravels of the Mehrten Formation

Details on the formations are provided in Section 2.1.5.

2.1.9.1 Zones within Principal Aquifer

Zones within the principal aquifer are based on the compilation of five hydrogeologic cross-sections (see Figure 2-20 through Figure 2-22). Cross-sections were based on over 330 well logs in the Subbasin. From this data, well depths for municipal and irrigation wells range from 75 to over 800 feet bgs, with an average depth of 350 feet bgs. Well logs were reviewed for the following information used in putting together the cross-sections:

- Depth of water table
- Depth and thickness of saturated fine to coarse grained sand and gravel layers
- Depth and thickness of discrete layers of sands
- Depth and thickness of discrete clay or silt layers that locally confine groundwater
- Depth of water-bearing aquifer materials (e.g., sands and gravels) down to the base of fresh water and deeper, where available

Analysis identified significant permeable zones with high production rates and good water quality at relatively shallow depths (less than 700 feet bgs) due to the following conditions:

- The relatively shallow depths of production wells had high specific capacity that met the water supply demand and reduced the cost associated with drilling deeper
- The base of fresh groundwater is deep; ranging from depths of 700 to 1,900 feet bgs
- Deeper water is saline and not considered suitable for potable or agricultural use

Figure 2-23 and Figure 2-24 depict the wells used during this hydrogeologic characterization effort. Information compiled was used to detail the three permeable water-bearing zones described from surface downward in the following sections.

Figure 2-23: Bottom Elevation of Water-Bearing Zones (Shallow)

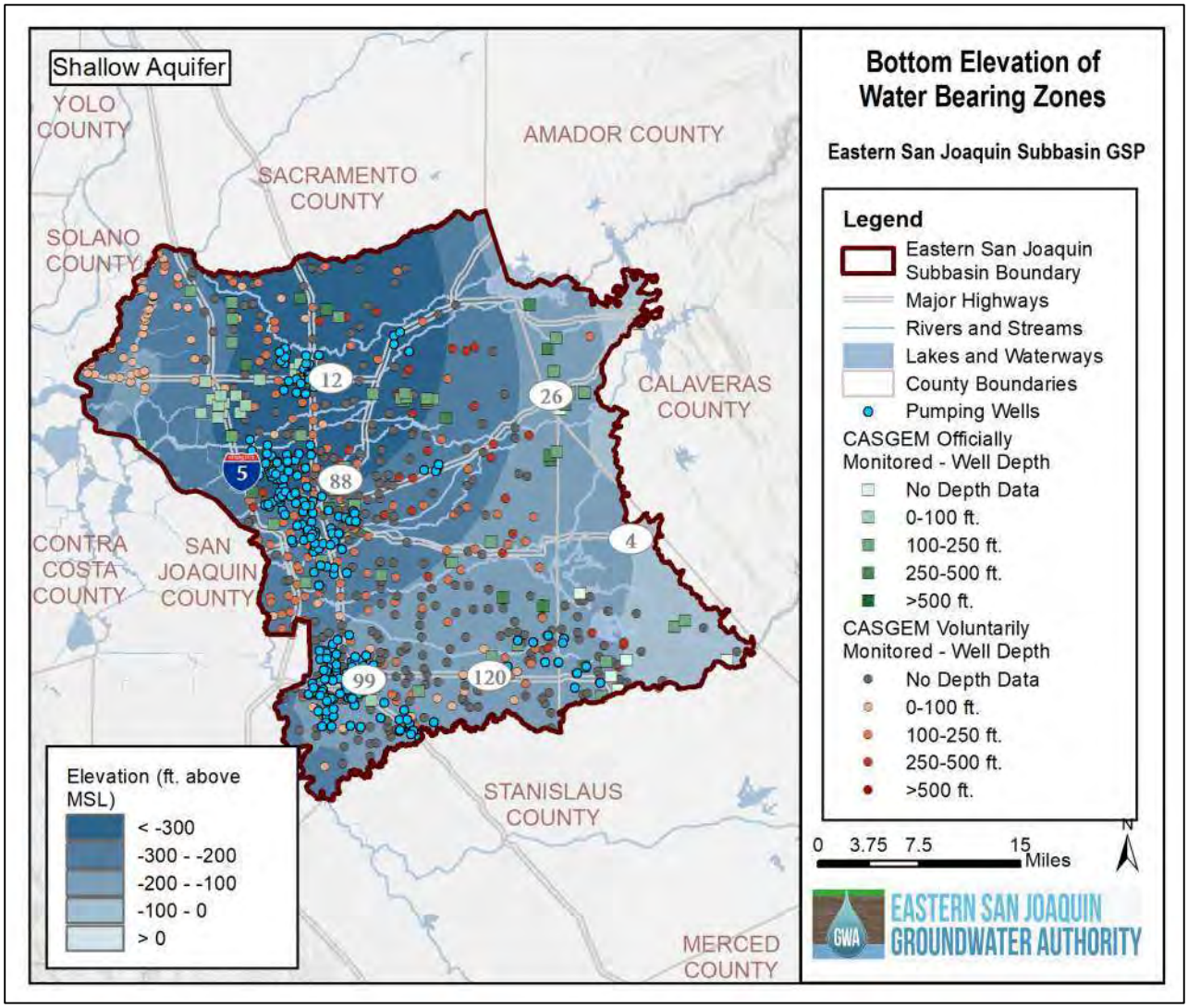
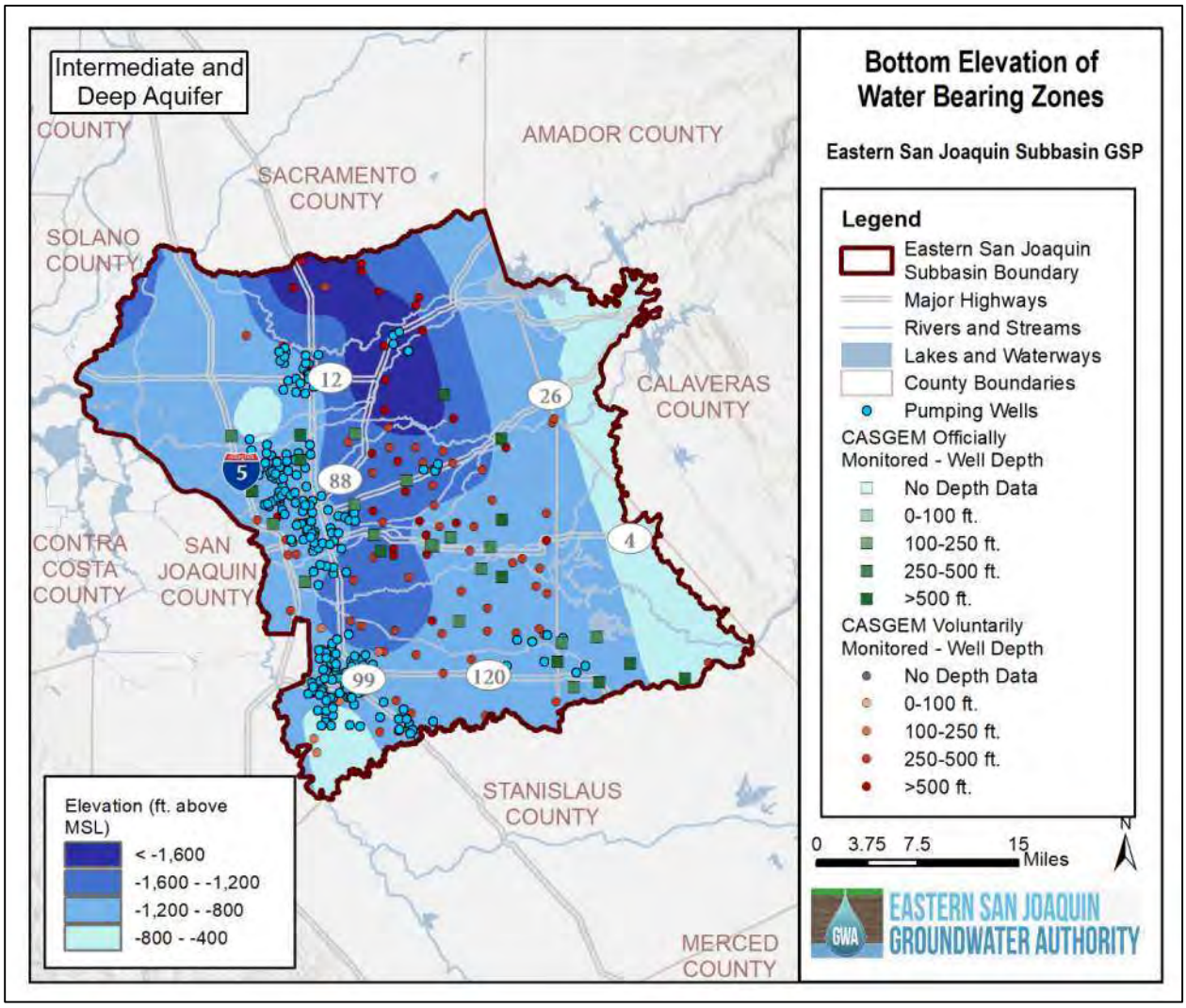


Figure 2-24: Bottom Elevation of Water-Bearing Zones (Deep and Intermediate)



2.1.9.1.1 Shallow Zone

The shallow water-bearing zone is composed of permeable sediments from recent alluvium, Modesto/Riverbank Formations, and the upper unit of the Turlock Lake Formation that are present west of the older geologic formations and extend across the majority of the Eastern San Joaquin Subbasin. This zone is generally unconfined above the aquitards (clays/silts, including Corcoran clay, and old soil horizons/hardpan layers).

The depositional structure on the eastern side of the valley trough is depicted on the hydrogeologic cross-sections A-A' through E-E' (see Figure 2-20, Figure 2-21, and Figure 2-22). This structure results in the groundwater flow that follows both the dip of the beds and hydraulic head differentials. Erosional and depositional features dominate aquifer characteristics. The cross-sections also depict the aquifer thickness from 30 feet to greater than 300 feet.

The Shallow Zone characteristics are supported by the sand thickness information detailed below along with review of basin aquifer parameters. This zone has high yielding wells. Aquifer characteristic values range as follows (CA DWR, 2967; Burow et al., 2004):

- Transmissivities up to 90,000 gpd/ft

- Specific yields up to 17 percent
- Vertical permeability estimates up to 0.1 ft/day

2.1.9.1.2 Intermediate Zone

As depicted on the hydrogeologic cross-sections A-A' through E-E' (see Figure 2-20, Figure 2-21, and Figure 2-22), sands, typically from 10 to over 60 feet thick, are found below the low permeable clay layers or aquitards. The sands and gravels are developed with one relatively continuous sand unit at 350 feet bgs, within the top of the lower unit of the Turlock Lake Formation and Laguna Formation, thinning out at topographic highs to the east. Eastern basin depositional structure shows a pinching, wedging, and combination water-bearing zones with the surficial alluvium.

The aquifer characteristics are supported by the sand thickness information detailed herein for the principal aquifer. The eastern distribution of this water-bearing zone near the surface suggests unconfined groundwater conditions. Typically, this zone is found semi-confined with high yielding wells and is considered the current primary production zone. Area groundwater numerical models support the CA DWR (1967) and Burow and others (2004) aquifer characteristic values range as follows:

- Transmissivities up to 59,500 gpd/ft
- Storage coefficients typically 0.00001 (unitless)
- Vertical permeability estimates up to of 0.07 ft/day

2.1.9.1.3 Deep Zone

The water-bearing "black sands" of the semi-consolidated Mehrten Formation are considered a significant source of water for Eastern San Joaquin Subbasin production wells. The formation is thick in the west with a limited number of deep wells that penetrate the entire depth of this unit as depicted on the hydrogeologic cross-sections A-A' through E-E' (see Figure 2-20, Figure 2-21, and Figure 2-22). This water-bearing zone is confined due to the thick overlying clay units, consolidation, and basin location. Semi-confined conditions are more likely to the east because of the dipping of beds and stratigraphic layer thinning and erosion of clay/silt beds. The dipping beds of the Mehrten Formation dip are at a steeper slope of 90 to 180 feet per mile westward. Consolidated sediments of the Mehrten and Valley Springs Formations are at valley bottom depth and exposed on the eastern foothills. Recharge to these aquifer formations occurs because of the high topographic setting with increased rainfall and exposure of weathered surface and runoff from the adjacent fractured Sierran bedrock.

As depicted on the hydrogeologic cross-sections A-A' through E-E' (see Figure 2-20, Figure 2-21, and Figure 2-22), boring logs indicate a significant 30-foot thick gravel encountered at a depth from 140 to 170 feet. Thickly bedded sands were found to exceed 250 feet. At the eastern margins of the basin, consolidated portions of the Mehrten, Valley Spring, and Ione Formations are important for low-yielding bedrock wells and are considered aquifer recharge sources for the Eastern San Joaquin Subbasin. The relatively low permeability and consolidated nature of the Valley Springs and Ione Formations act as the bottom of the Deep Zone (Burow et al., 2004).

The aquifer characteristics are supported by the sand thickness information. The well yields are high in this zone, over 1,000 gallons per minute (gpm). Area groundwater numerical models support the CA DWR (1967) and Burow and others (2004) aquifer characteristic values range as follows:

- Transmissivities up to 250,000 gpd/ft
- Storage coefficients that are typically 0.0001
- Vertical permeability estimates up to of 0.05 ft/day

2.1.9.1.4 Limited Aquitards

The Corcoran Clay member of the Turlock Lake Formation and other interbedded clay/silts are aquitards that inhibit groundwater flow. The Corcoran Clay (found at the base of the upper unit of the Turlock Formation) is present at a depth of about 200 feet bgs. The Corcoran Clay has a limited distribution in the extreme southwestern extent of the Subbasin, southwest of the City of Manteca (Figure 2-22). The clay is typically 20 to over 100 feet thick and is locally eroded and interfingered with coarser materials at its margin. Groundwater below the Corcoran Clay is confined. The Corcoran Clay is found more significantly in subbasins to the south where it is a significant vertical barrier to flow.

Thick clay and silt layers are found within the Laguna and Mehrten Formations. These two formations each have two documented upward coarsening alluvial sequences (Burow et al., 2004). Significant clay and paleosols divide the water-bearing zones at the base of each sequence. The cross-sections (Figure 2-20, Figure 2-21, and Figure 2-22) show both the clay and silt horizons range in thickness from less than 10 feet to over 150 feet. The vertical permeability estimates range from 0.01 to 0.007 feet per day (Burow et al., 2004).

Discontinuous clay horizons have been eroded significantly by the movement of the ancestral rivers. As depicted on the cross-sections, thickest sequences of uppermost permeable units and overbank fines below these layers have been observed. The general thickness and depth are supported by a southeast to northwest movement of river channels to the existing channel location.

Hydraulic connection for the entire depth of the principal aquifer is supported by cross-section depictions that indicate the laterally extensive interbeds of high and low permeable layered deposits. The historical erosional and depositional history supports the referenced hydraulic interconnection. This observation is consistent with the possible thinning and wedging out of the regional clay units due to reworking or ancestral erosion (Davis et al., 1959).

In addition to the natural connectivity, the number of water wells drilled through these zones also indicates additional hydraulic connection because of the construction of long well gravel packs that connect the water-bearing zones.

2.1.9.1.5 Deep Saline Groundwater

Connate or saline water occurs from the base of fresh water (shown in Figure 2-18 or Figure 2-24) to the base of continental deposits (shown in Figure 2-25), forming a saline layer that ranges in thickness from 50 to 2,250 feet from the east to the west across the Subbasin. The deep saline layer is not currently a water production zone for consumption or land application. Information used in developing the thickness of the saline water above continental deposits is from Page's 1974 *Base and Thickness of the Post Eocene Continental Deposits in the Sacramento Valley* and the thickness of the aquifer developed by Williamson and others (1989).

GRAVELLY FORD WATER DISTRICT GROUNDWATER SUSTAINABILITY PLAN

MARCH 2023

DEFINABLE BOTTOM OF THE BASIN

Figure 4 in the KDSA report (Appendix B) shows the definable bottom of the basin. Historically, the U.S. Geological Survey has used an electrical conductivity of about 3,000 micromhos per centimeter at 25 degrees Celsius to delineate the regional base of the fresh groundwater in the San Joaquin Valley. The base of the fresh groundwater can be called the "bottom of the basin." However, another factor to consider is the depth where the deposits become fine-grained. As part of this evaluation, electric logs for deep holes were obtained from the California Division of Oil, Gas, and Geothermic Resources. A review of these logs indicated depths to the "bottom of the basin" ranging from about 800 to 1,100 feet. The bottom of the basin is generally the shallowest beneath the southwest part of the GSA and deepest beneath the north-east and east parts of the GSA.

FORMATION NAMES

Mitten, Leblanc, and Bertoldi (1970) divided the unconsolidated deposits in the Madera area into the younger alluvium (normally less than about 50 feet thick), the Quaternary older alluvium (less than 1,000 feet thick), and the Tertiary-Quaternary continental deposits (about 1,000 to 2,200 feet thick). The Corcoran Clay is a regional defining clay bed. This clay divides the groundwater into an upper aquifer and lower aquifer. Water producing deposits in the GSA are generally termed the Sierra sands, as they were derived from the Sierra Nevada.

CONFINING BEDS

The confining bed that is important beneath the GSA is the E-Clay or Corcoran Clay. The top of this clay is shallowest (about 300 feet deep) in the north part of the GSA and is deepest (about 380 feet deep) near the south edge of the GSA. The depth to the top of the Corcoran Clay essentially defines the base of the upper aquifer. The Corcoran Clay generally thickens to the southwest beneath the GSA.

PRINCIPAL AQUIFERS

Based on subsurface geologic cross sections and water well drillers' logs and completion reports, the lower part of the upper aquifer and the upper part of the lower aquifer comprise the principal strata tapped by irrigation wells in most of the District. Because of relatively shallow water levels near the San Joaquin River some wells in this part of the GSA tap only the upper aquifer.

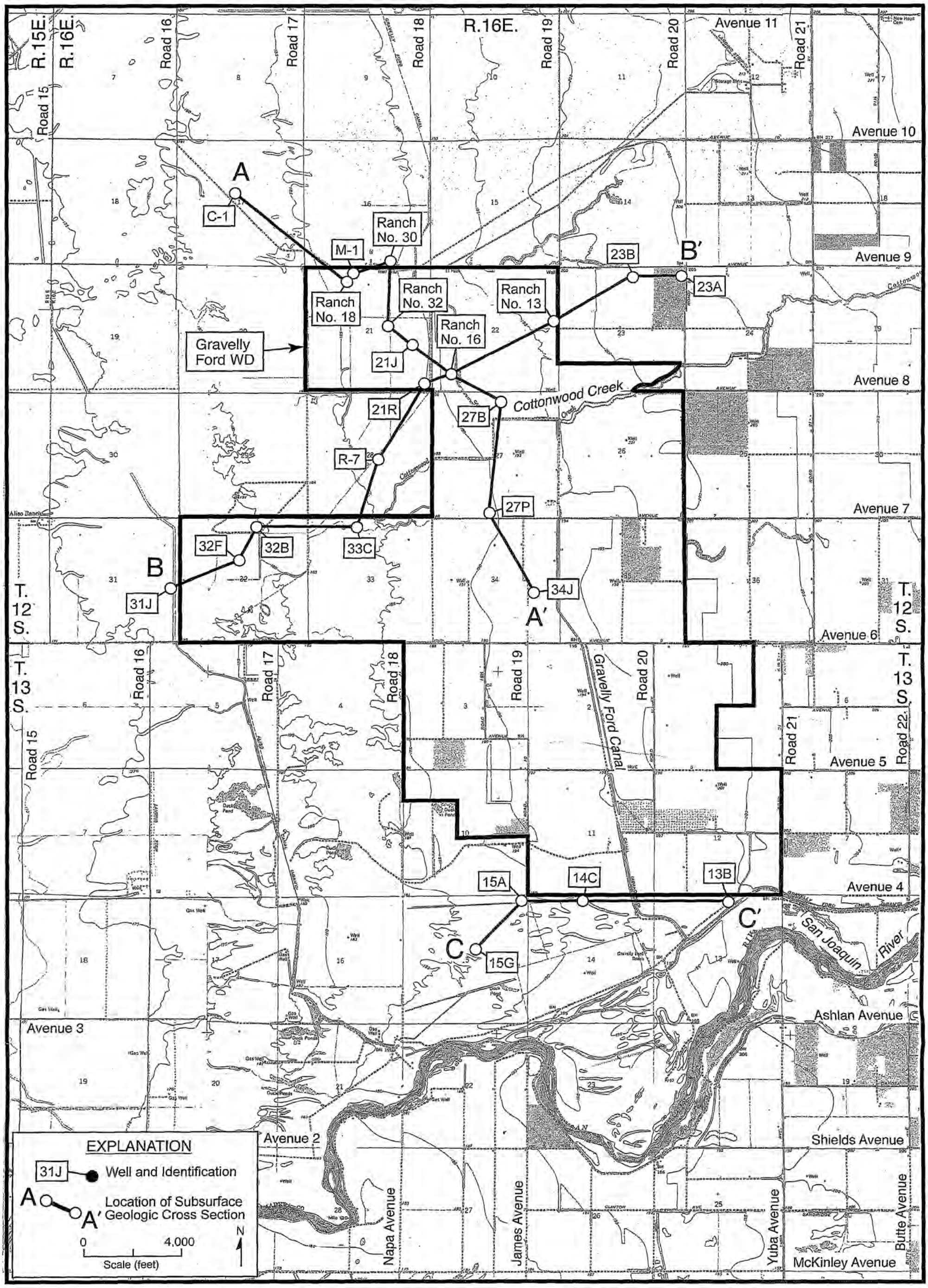


FIGURE 1 - TOPOGRAPHIC MAP OF GSA AND LOCATIONS OF SUBSURFACE GEOLOGIC CROSS SECTIONS

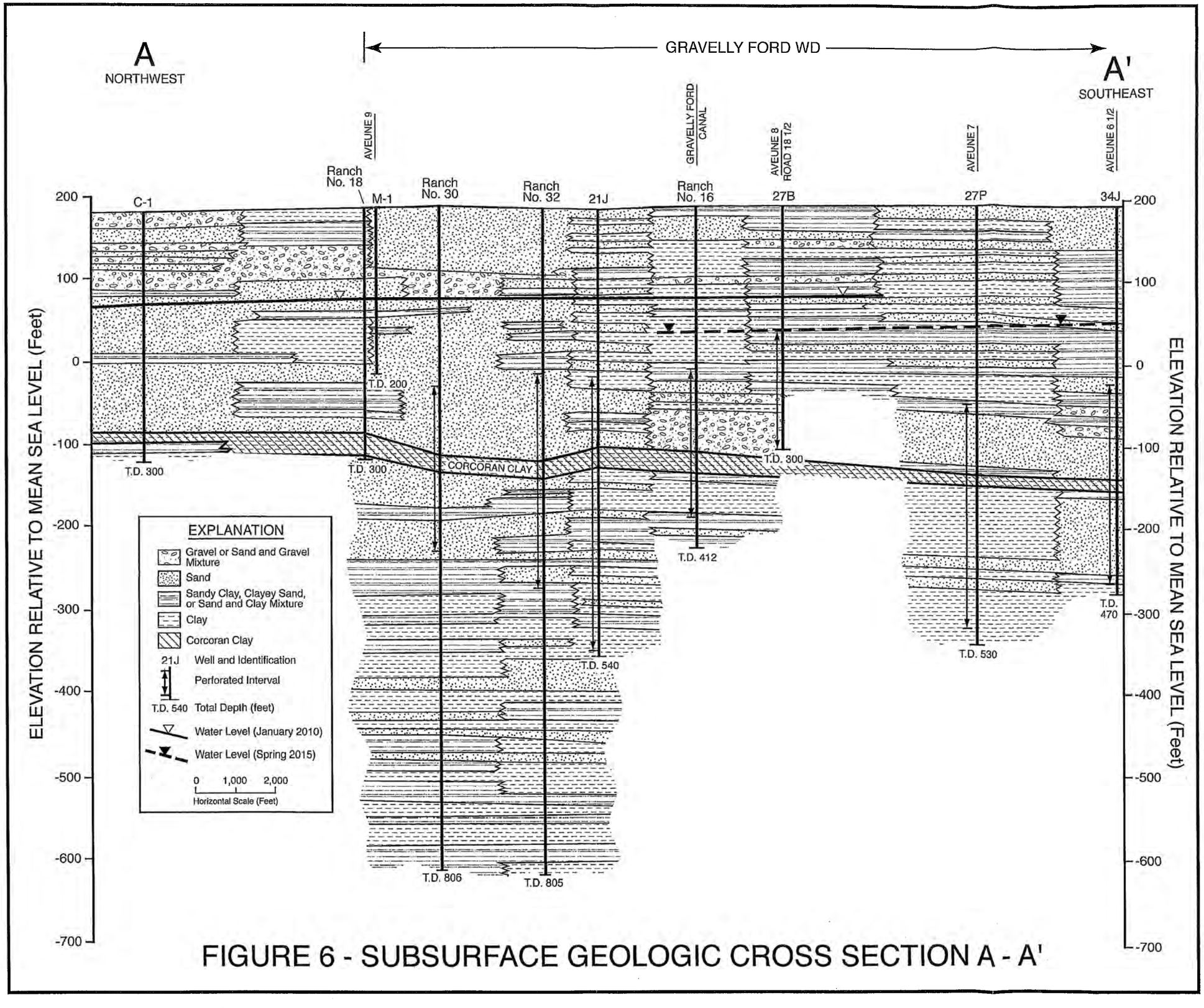
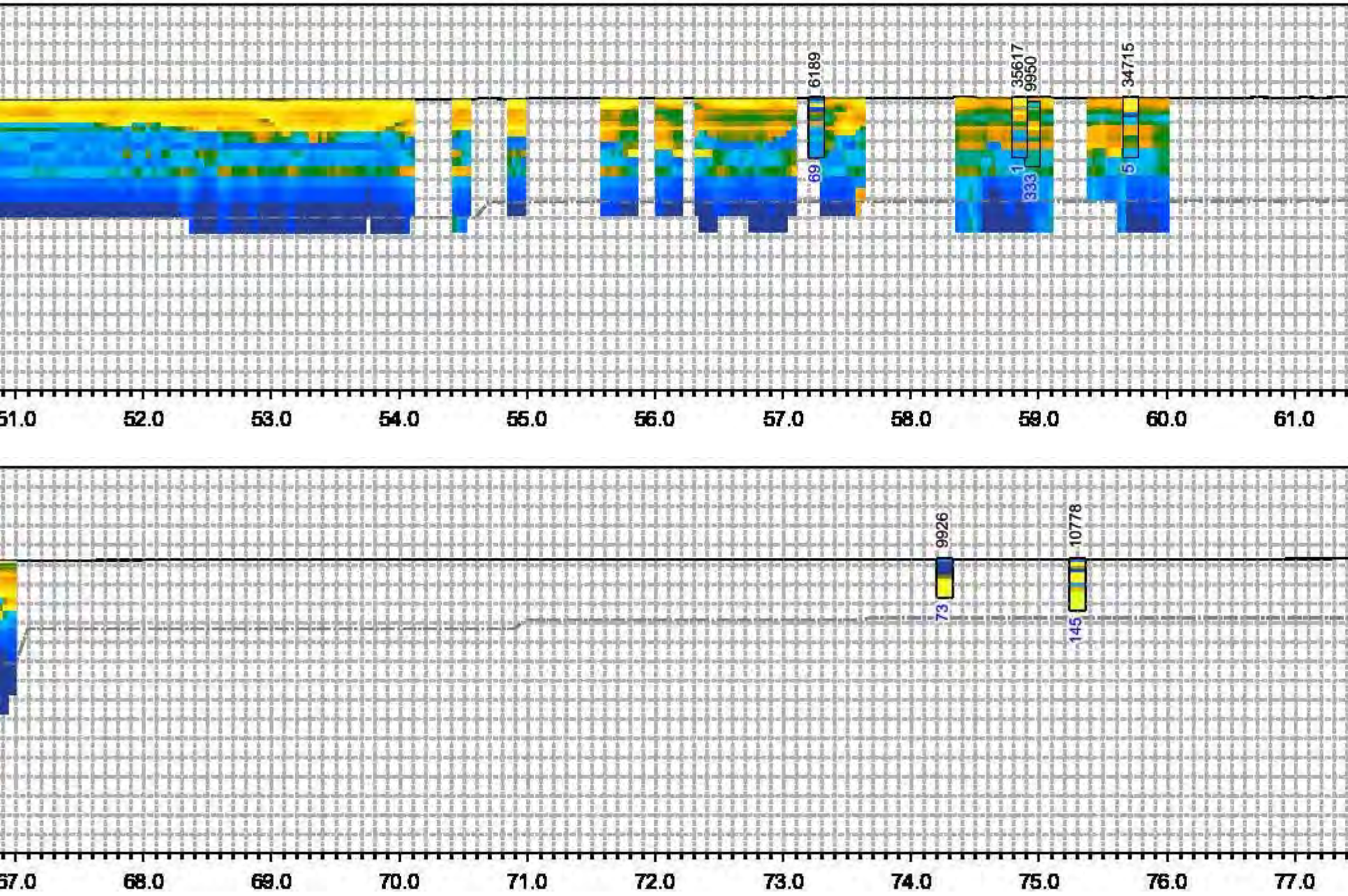


FIGURE 6 - SUBSURFACE GEOLOGIC CROSS SECTION A - A'

A - A' Nearest AEM Log



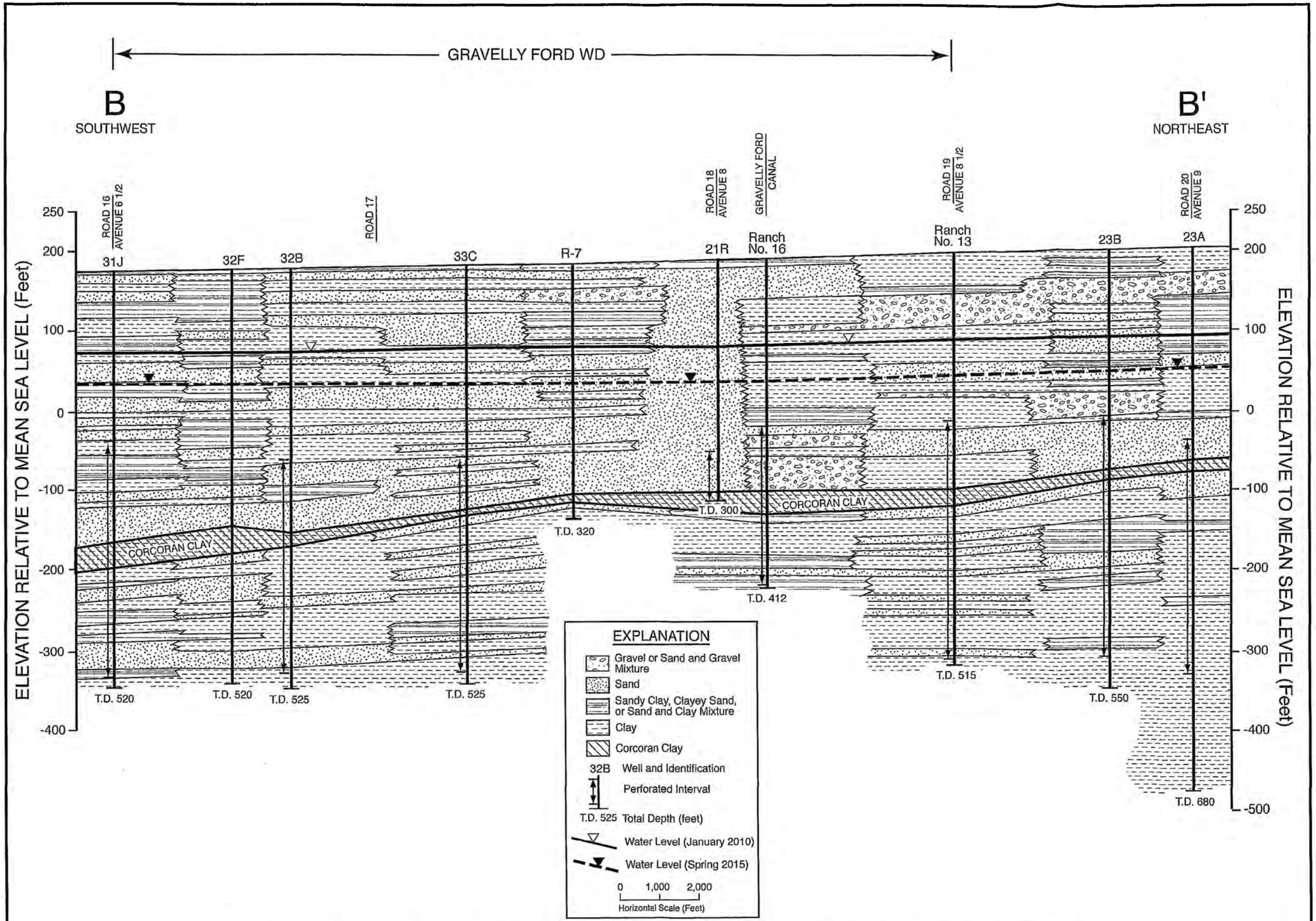
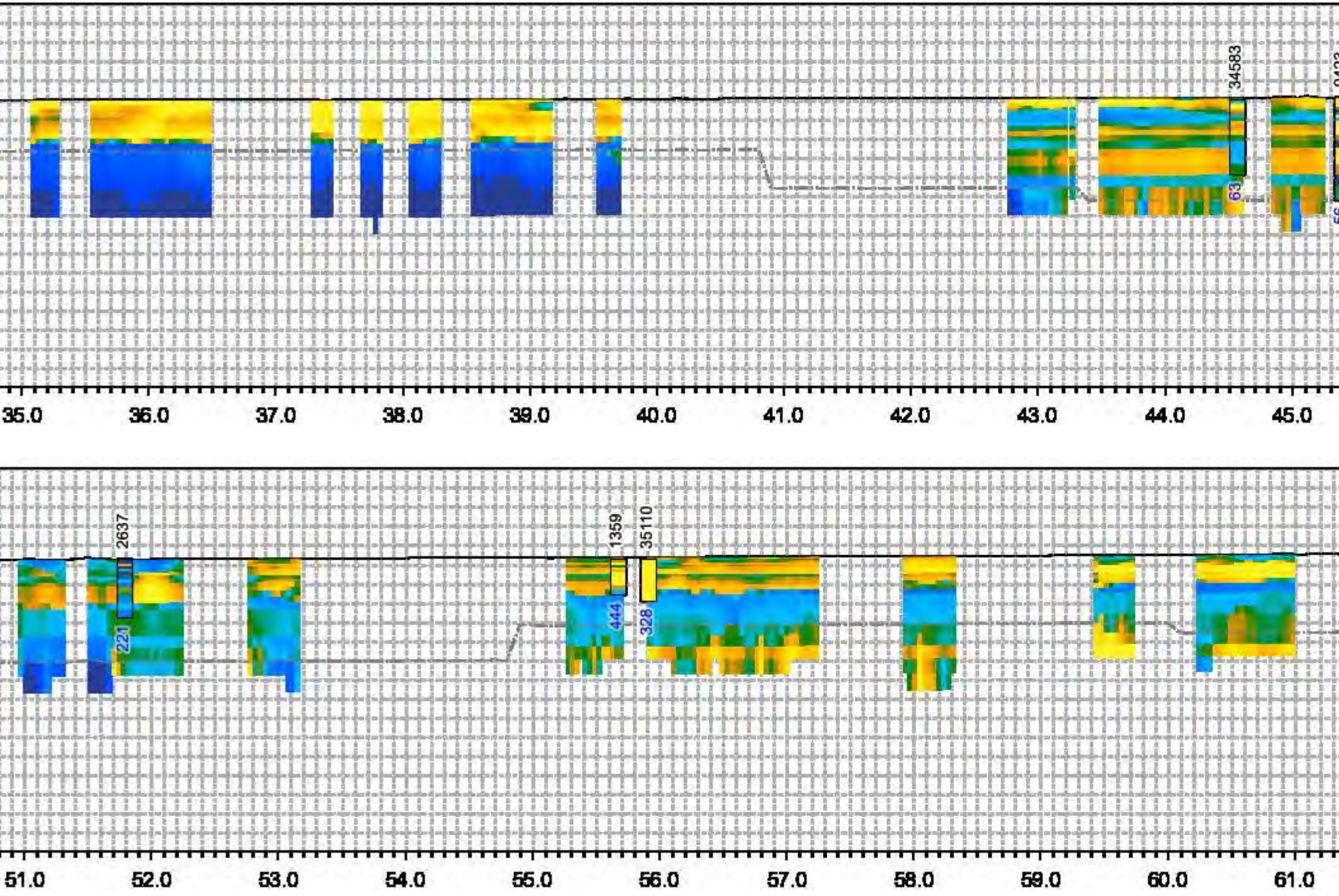


FIGURE 7 - SUBSURFACE GEOLOGIC CROSS SECTION B - B'

B - B' Nearest AEM Log



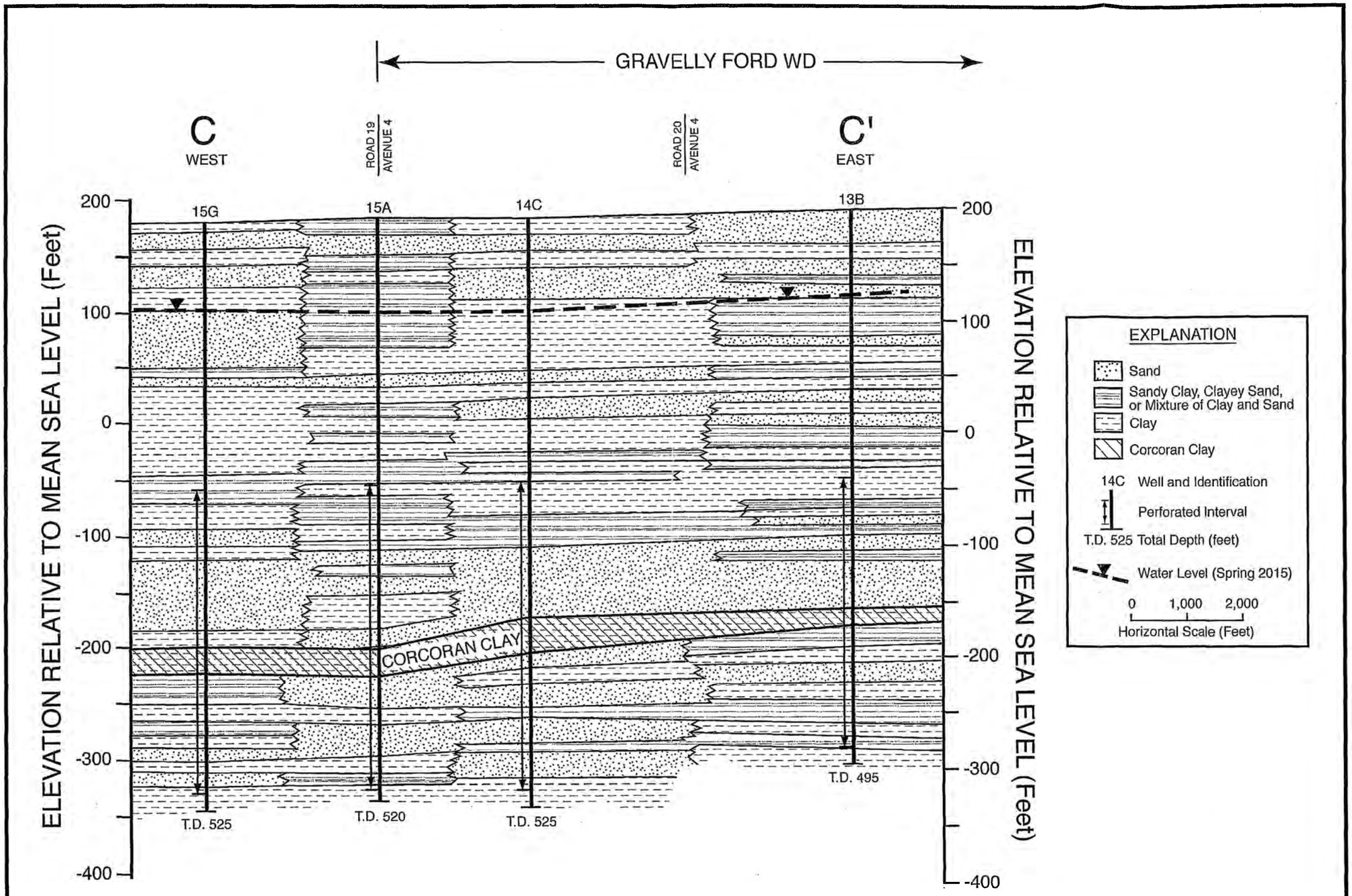


FIGURE 8 - SUBSURFACE GEOLOGIC CROSS SECTION C - C'

MADERA SUBBASIN

Sustainable Groundwater Management Act (SGMA)

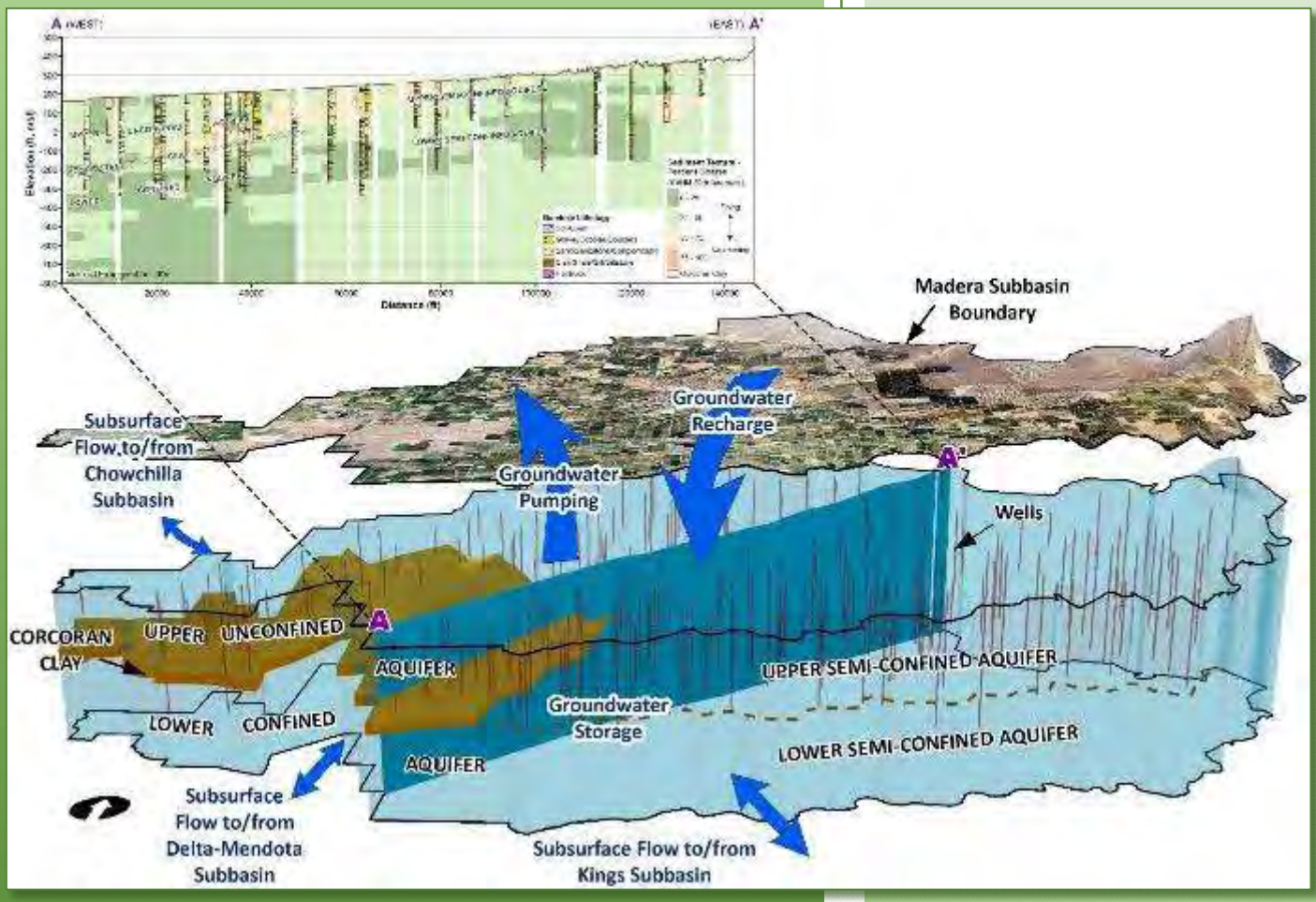
Joint Groundwater Sustainability Plan

City of Madera GSA
County of Madera GSA – Madera
Madera Irrigation District GSA
Madera Water District GSA

January 2020
Revised March 2023

Prepared by

Davids Engineering, Inc. *(Revised GSP Team)*
Luhdorff & Scalmanini *(Revised GSP Team)*
ERA Economics
Stillwater Sciences and
California State University, Sacramento



water level, and water quality data currently being collected as part of the 2019-2020 nested monitoring well program.

Maps of the depth to basement rock (**Figure 2-19**) and elevation of basement rock (**Figure 2-20**) show increasing depths (and decreasing elevations) to basement rock from northeast to southwest across the Subbasin. The depths to bedrock range from less than 500 feet (essentially zero at the eastern Subbasin boundary) to greater than 4,000 feet at the southwestern boundary of the Subbasin. In general, the aquifer base is controlled mostly by the base of fresh water provided in **Figure 2-18** except in the far eastern portions of the Subbasin. It should also be recognized that wells drilled and screened below the currently defined base of fresh water likely will still have a hydraulic connection with the overlying fresh water zone and are considered part of the Madera Subbasin.

2.2.1.3 Major Aquifers/Aquitards

Geologic cross-sections are a key element of the HCM required in a GSP under SGMA. Related work completed for this Joint GSP included review of existing literature to extract the available geologic cross-sections and construction of additional new geologic cross-sections based on data compiled for GSP efforts. This section of the GSP (and **Appendix 2.D**) provides a general description of the existing and new cross-sections, and documents the source of available existing geologic cross-sections along with details of how the new cross-sections were developed.

Existing Geologic Cross-Sections

The geologic cross-sections derived from previous reports are presented in **Appendix 2.D** and were described in a previous report (DE/LSCE, 2017). Two of these existing cross-sections are described below to provide overall regional context for the stratigraphy of the Subbasin (Davis et al.,1959; Page, 1986). The locations of these two existing geologic cross-sections are provided in **Figure 2-21**, and the individual cross-sections are provided in **Figures 2-22 and 2-23**. A summary of the two regional geologic cross-sections is provided below.

Davis' (1959) cross-section D-D' (**Figure 2-22**) runs from southwest to northeast through the center of the Madera Subbasin, and extends to a depth of about 800 feet below ground surface (bgs). The Corcoran Clay is indicated to be present at an approximate depth of 400 feet bgs at the western edge Madera County, with depth and thickness decreasing towards the northeast (to a depth of about 200 feet at the eastern edge of the clay layer). Sediments consist primarily of sands to sandy clay and silty clay to clay and shale. Layers of gravel are present in the upper 200 feet primarily in the center of Madera County.

Page (1986) cross-section B-B' (**Figure 2-23**) runs northwest to southeast through the western edge of the Madera Subbasin, and extends down to an elevation of 9,000 feet below mean sea level (msl). Within this portion of the Madera Subbasin, the Corcoran Clay is present throughout, at an elevation of approximately -200 feet msl. Thin deposits of Quaternary flood-plain deposits (Qb) are present at the surface, underlain by Quaternary continental rocks and deposits (QTcd). A layer of Tertiary marine rocks and deposits interfinger the QTcd layer. A layer of Pre-Tertiary and Tertiary continental and marine rocks and deposits underlies these units.

New Geologic Cross-Sections

New geologic cross-sections were developed during GSP preparation efforts utilizing data collected for the GSP. A location map for new geologic cross-sections is provided in **Figure 2-21**. The new geologic cross-sections include some that do not cross Madera Subbasin, but are included here because they occur within the Model Domain for the MCSim Model developed for Madera Subbasin. The CVHM well log dataset and DWR well log database developed for this project were reviewed to select logs for relatively deep wells that had fairly detailed descriptions of geologic units encountered. Locations for screened well

logs were plotted to selected representative well logs at a reasonable spacing along each geologic cross-section line.

New geologic cross-sections C-C', D-D', E-E', and F-F' (**Figures 2-26, 2-27, 2-28, and 2-29**) extend from southwest to northeast across Madera Subbasin towards (perpendicular to) the Sierra Nevada Mountains, with C-C' being furthest north and F-F' being furthest south. Each cross-section generally shows the ground surface, the lithology associated with each well log, the Spring 2014 unconfined groundwater level, the Corcoran Clay (from C2VSim), and the base of fresh water (from Page 1986). The well logs generally range from very close to section lines to one mile of offset from the section line. The cross-sections generally illustrate the interbedded and variable nature of fine- and coarse-grained sediments both laterally and vertically. In general terms, the cross-sections tend to show a greater percentage of coarse-grained sediments in the upper 200 to 400 feet (Upper Aquifer) as compared to greater depths (Lower Aquifer). This is particularly the case in the central to western portion of the cross-sections, as illustrated in D-D'. Overall, fine-grained sediments comprise a larger percentage of the subsurface than do coarse-grained sediments. Thus, it can be expected that vertical hydraulic conductivity (Kv) values will likely be orders of magnitude lower than horizontal hydraulic conductivity (Kh) values for a given aquifer. Geologic cross-sections C-C' through F-F' also illustrate the extent of Corcoran Clay is limited to the western portion of the Subbasin, although other clay layers are prominent throughout the Subbasin. New geologic cross-sections A-A' and B-B' (**Figures 2-24 and 2-25**) are included here but not described further as they do not cross Madera Subbasin.

New geologic cross-sections G-G' through K-K' (**Figures 2-30, 2-31, 2-32, 2-33, 2-34**) were constructed parallel to the Sierra Nevada Mountain front starting from the southwestern end of Madera Subbasin and progressing towards the northeast (i.e., cross-section G-G' furthest from and parallel to the Sierra Nevada Mountain front and K-K' is closest to the mountain front). These geologic cross-sections further demonstrate and confirm the features/characteristics described above for the cross-sections perpendicular the Sierra Nevada Mountains. In particular, this set of cross-sections illustrates that general trend of higher percentages of coarse-grained sediments in the upper 200 to 400 feet, and the variability in Page's (1986) map of base to freshwater. While it is challenging to reliably correlate coarse-grained units in these cross-sections, they do illustrate well the general distribution of coarse- and fine-grained sediments both laterally and vertically. The textural analysis described in a subsequent GSP chapter for input to the groundwater model attempts to capture the somewhat disconnected distribution of coarse-grained sediments reflected in the cross-sections.

Geologic Cross-Section Summary

The existing geologic cross-sections provided in Davis et al. (1959) and Page (1986) illustrate the vertical distribution of major geologic formations, but do not provide any detail on distribution of fine- and coarse-grained sediments of the major aquifer units. The new geologic cross-sections generally illustrate in a fairly detailed manner the lateral and vertical distribution of fine- and coarse-grained sediments throughout the Subbasin. It is apparent from these cross sections that the Upper Aquifer (generally the upper 200 to 400 feet) has a higher overall percentage of coarse-grained sediments compared to deeper intervals, although significant coarse-grained intervals are present to the full depths of most borings shown on the cross sections. These cross sections further demonstrate that Kv values are likely to be orders of magnitude less than Kh values.

Groundwater System Conceptualization

The Madera Subbasin is underlain by the Corcoran Clay over approximately the western one-third of the Subbasin area. The depth to top of Corcoran Clay varies from 100 to 150 feet at its northeastern extent to in excess of 300 feet in the southwestern portion of the Subbasin (**Figure 2-15**). Where the Corcoran Clay aquitard exists, the aquifer system is subdivided into an upper unconfined aquifer above the Corcoran

Clay and a lower confined aquifer below the Corcoran Clay (**Figure 2-35**). In the central and eastern portions of the Subbasin where the Corcoran Clay does not exist, the aquifer system is generally considered to be semi-confined with discontinuous clay layers interspersed with more permeable coarse-grained units (**Figure 2-35**). For discussion purposes, in the eastern part of the Subbasin, the semi-confined aquifer can be subdivided into an upper semi-confined aquifer and a lower semi-confined aquifer at a somewhat arbitrary depth that ranges from 200 to 400 feet bgs (generally corresponding to the depth of Corcoran Clay at its eastern extent).

In addition to the generally higher percentages of coarse-grained material in the Upper Aquifer, the available cross-sections described above and provided in **Appendix 2.D** generally indicate that approximately the upper 500 feet of the Lower Aquifer are comprised of a greater percentage of coarse-grained sediments as compared to deeper zones within the Lower Aquifer. Thus, it can be anticipated that most wells will obtain close to their maximum yield within approximately the upper 800 feet of sediments. The vast majority of water wells are constructed within the upper 1,000 feet because sediments generally become finer with depth and towards the center of the valley (Provost and Pritchard, 2014).

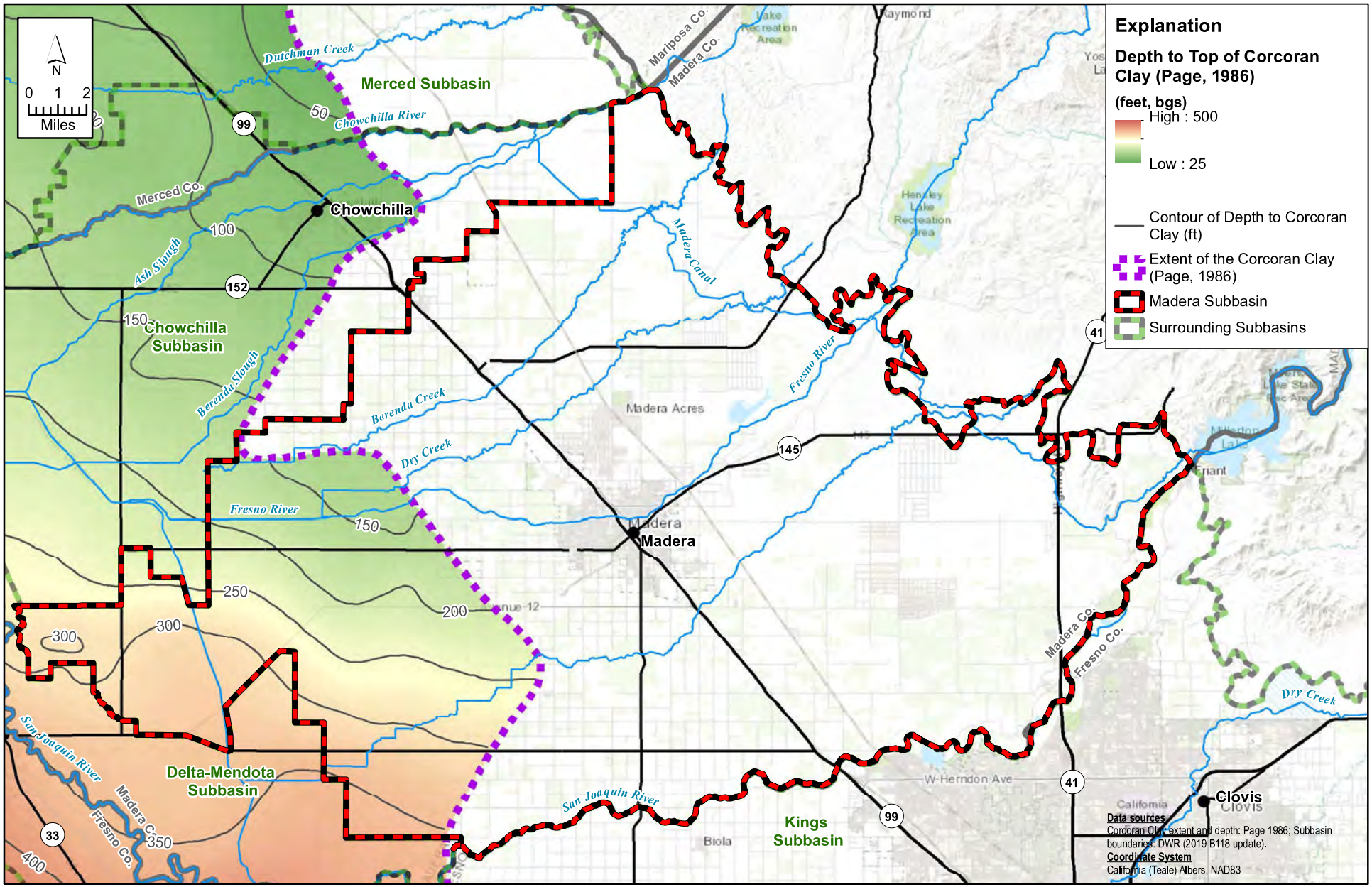
The general occurrence of higher percentages of coarse-grained sediments at shallower depths is further illustrated by the sediment texture model developed by the United States Geological Survey (USGS) for the Central Valley Hydrologic Model (CVHM). **Figures 2-36 and 2-37** illustrate the spatial distribution of coarse-grained sediments at 50-foot depth intervals from the ground surface to a total depth of 1,400 feet. These maps indicate percentages of coarse-grained sediments are noticeably greater in the upper 400 feet compared to deeper depths.

2.2.1.4 Aquifer Parameters

A detailed summary of aquifer parameter data derived from existing reports was presented in the Preliminary HCM and is included in **Appendix 2.D**. For Madera County as a whole, the Madera Regional Groundwater Management Plan indicates the Older Alluvium generally has transmissivity values ranging from about 20,000 to 250,000 gpd/ft. Well test data indicate that wells tapping a significant thickness of coarse-grained materials in the upper 500 feet tend to have the highest specific capacities. The underlying Continental Deposits are reported to have transmissivities ranging from 10,000 to 30,000 gpd/ft (Provost and Pritchard, 2014).

Specific yield (Sy) values for Madera County were evaluated in previous studies for use in groundwater storage change calculations (Provost and Pritchard, 2014; Todd, 2002). These county-wide studies used Sy values ranging from 0.10 to 0.13. A study specific to Madera Subbasin (DWR, 2004) cited a specific yield value of 0.104 for use in calculating total groundwater in storage. Given that sediments generally become finer grained with depth, it is possible that the Sy value from DWR (2004) being on the lower end of the county-wide range is due to evaluation of specific yield to a deeper depth than in the other studies.

As part of recent GSP efforts related to the HCM, DWR well completion reports (WCRs) were reviewed to obtain additional specific capacity data from various wells throughout Madera Subbasin and the greater model domain. The details of the specific wells, well construction data, and specific capacity data are summarized in **Appendix 2.D**. The specific capacity data were converted to transmissivity values based on methodology developed by Driscoll (1986). Maps of transmissivity (T) values were prepared for the Upper Aquifer (**Figure 2-38**), Lower Aquifer (**Figure 2-39**), and for composite wells screened in both aquifers (**Figure 2-40**). There are 14 transmissivity values displayed on the map for the Upper Aquifer (**Figure 2-38**) with seven of those wells in the central portion of the Subbasin, two wells in the northwestern part of the Subbasin, and five wells in the southwestern part of the Subbasin. Transmissivity values were quite variable ranging from 25,000 to greater than 100,000 gpd/ft in the central and northwestern Subbasin areas and from less than 25,000 to greater than 100,000 in the southwestern Subbasin area.



X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-15 Madera Subbasin Extent and Depth of Corcoran Clay.mxd

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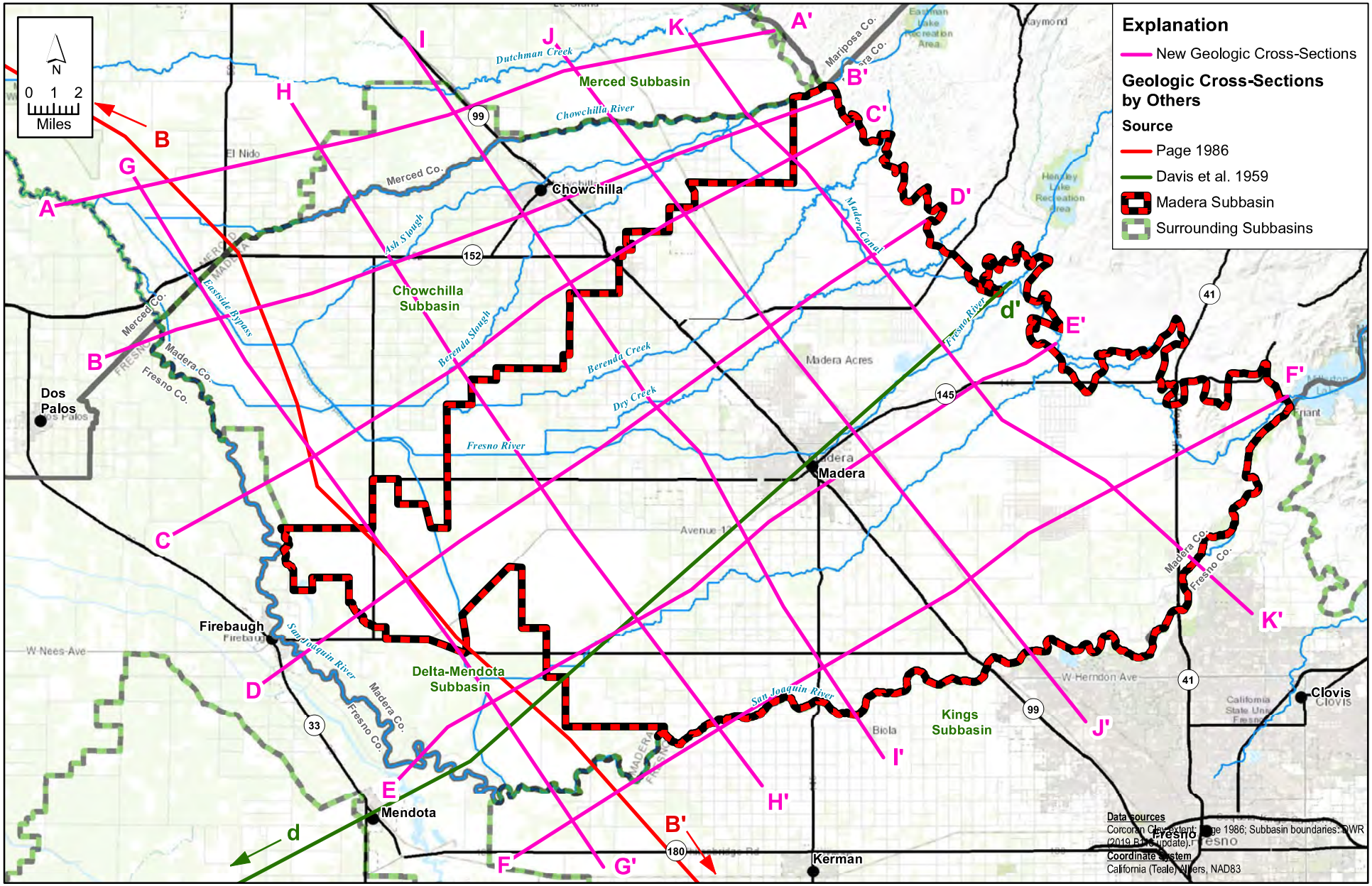
FIGURE 2-15
Extent and Depth of the Corcoran Clay: After Page (1986)

Madera Subbasin
Groundwater Sustainability Plan



X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-21 Madera Subbasin Cross Section Location Map.mxd

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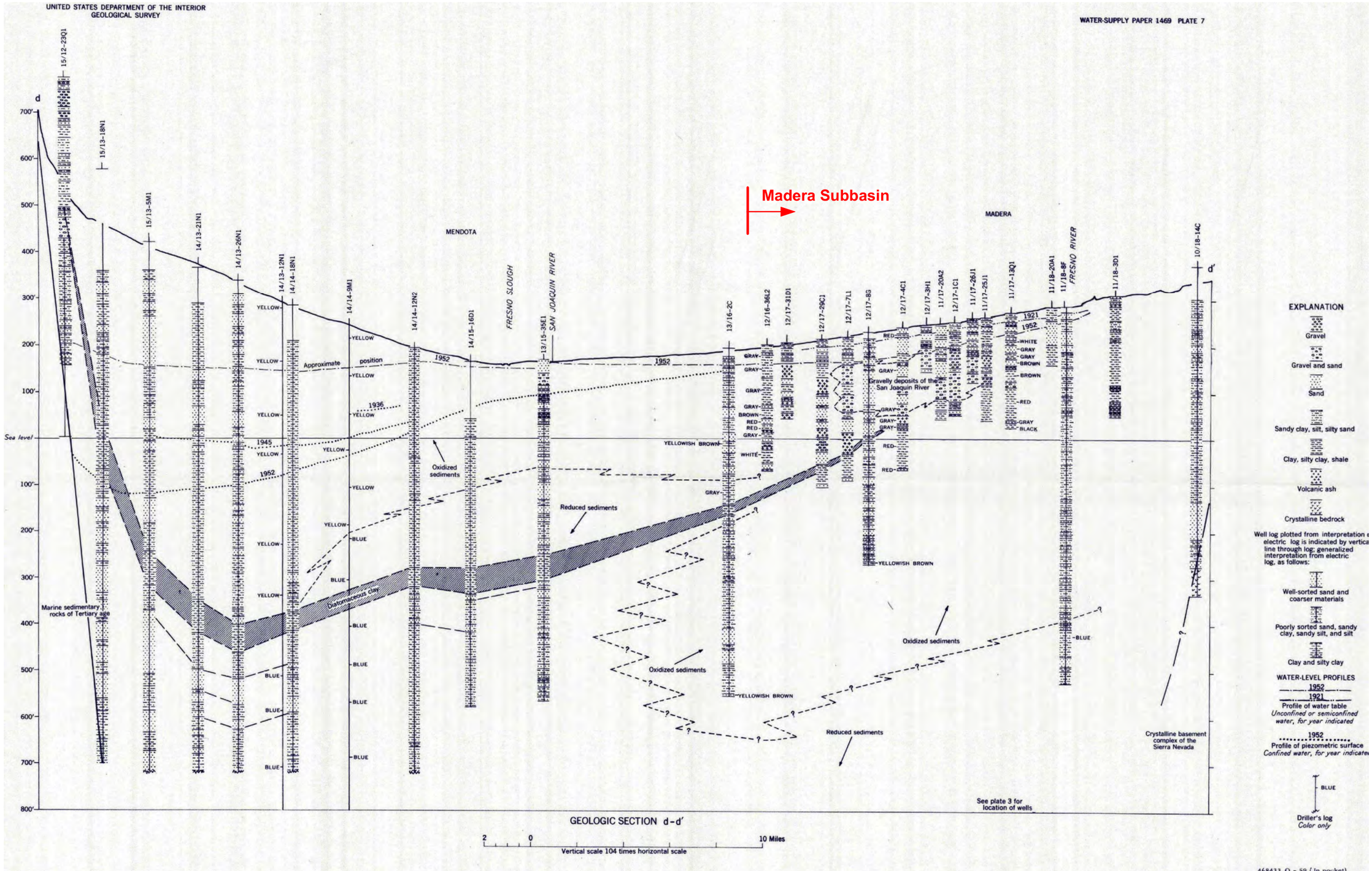
FIGURE 2-21

Geologic Cross-Section Location Map

Madera Subbasin
Groundwater Sustainability Plan

Madera Subbasin



GEOLOGIC SECTION d-d'

2 0 10 Miles
Vertical scale 104 times horizontal scale

EXPLANATION

- Gravel
- Gravel and sand
- Sand
- Sandy clay, silt, silty sand
- Clay, silty clay, shale
- Volcanic ash
- Crystalline bedrock

Well log plotted from interpretation of electric log is indicated by vertical line through log; generalized interpretation from electric log, as follows:

- Well-sorted sand and coarser materials
- Poorly sorted sand, sandy clay, sandy silt, and silt
- Clay and silty clay

WATER-LEVEL PROFILES

- 1952 / 1921 — Profile of water table. *Unconfined or semiconfined water, for year indicated*
- 1952 — Profile of piezometric surface. *Confined water, for year indicated*

BLUE — Driller's log. *Color only*

468433 O - 59 (In pocket)

X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-22 CrossSection_Davis1959_d.mxd

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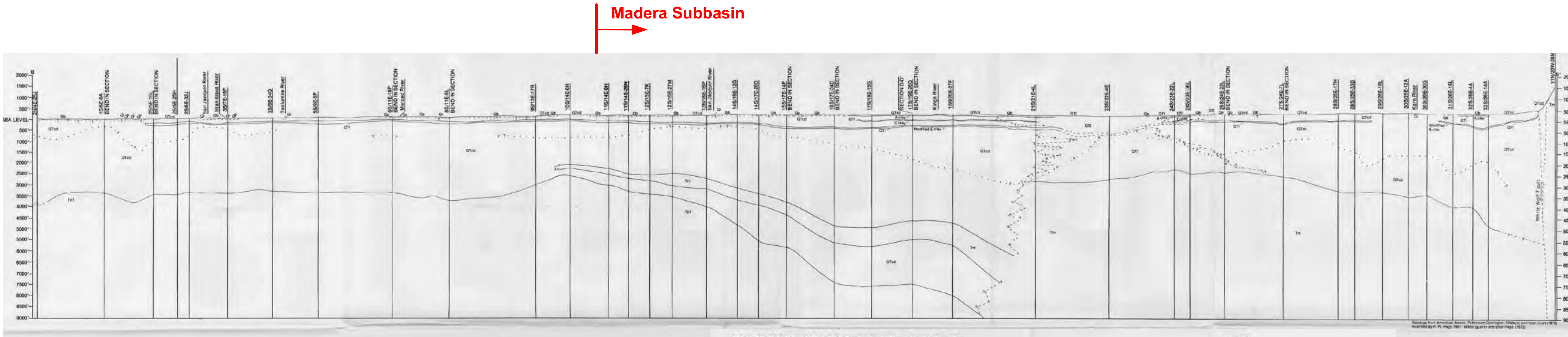
FIGURE 2-22
Geologic Cross-Section: Davis et al. (1959) Section D-D'

Madera Subbasin
Groundwater Sustainability Plan

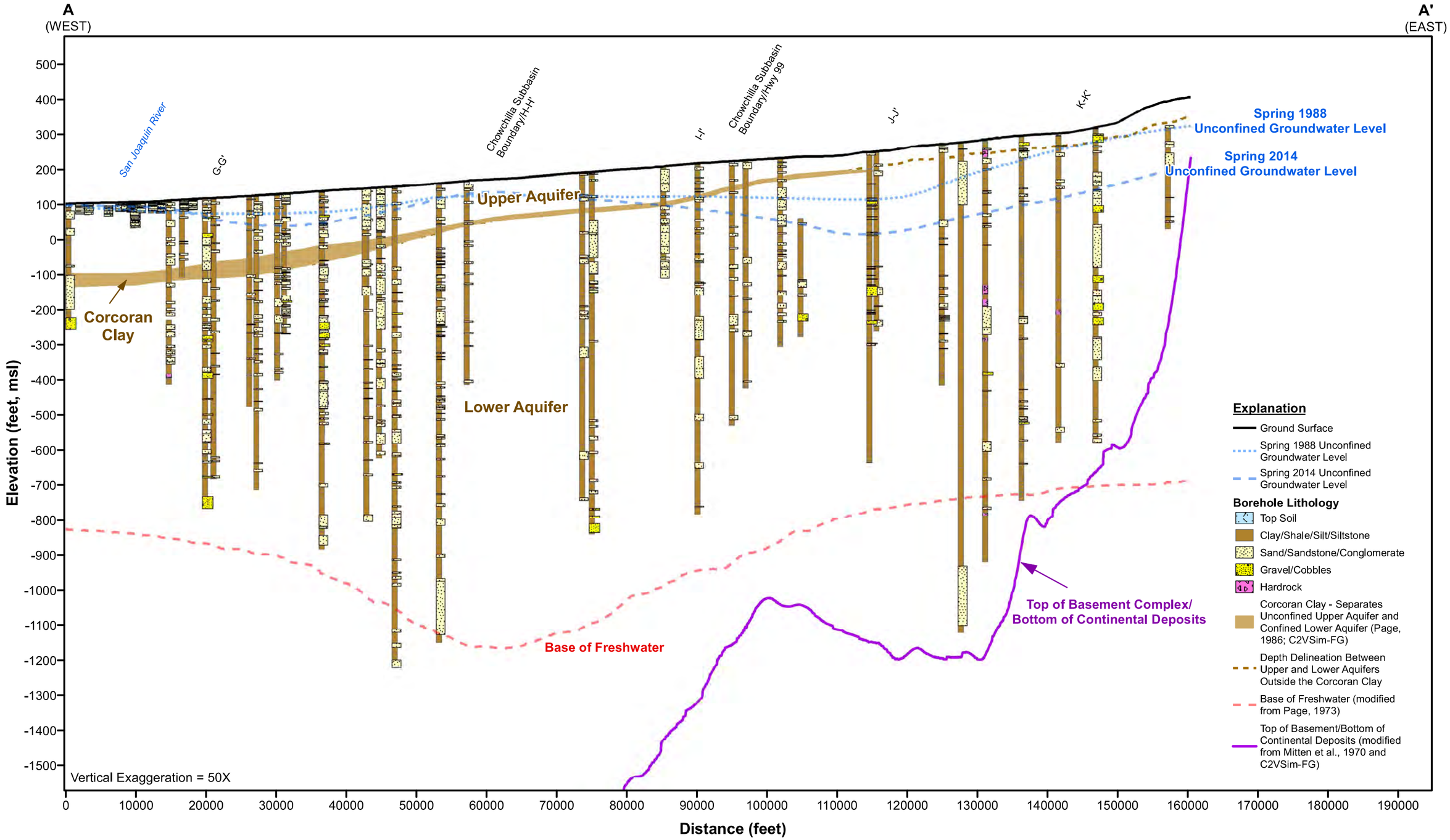


SAN JOAQUIN VALLEY SECTION B - B' and D - D'		B - B'
Qs	**Sand dunes (Holocene)** Windblown sand and dune sand	Description at left
Qb	**Flood-basin deposits (Holocene)** Clay, silt, and some sand;	Near northern end of section consist of muck, peat, and other organic soils
Qr	**River deposits (Holocene)** Gravel, sand, silt, and minor amounts of clay; deposited along channels, flood plains, and natural levees of main streams.	Description at left
QTl	**Lacustrine and marsh deposits (Pliocene to Holocene)** Clay, silt, and some sand; in subsurface include three widespread clays: A clay (Pleistocene and Holocene?), C clay (Pleistocene); and modified E clay (Pleistocene), includes Corcoran Clay Member of Tulare Formation	Description at left
QTcd	**Continental rocks and deposits (Oligocene to Holocene)** Hetero-generous mix of generally poorly sorted clay, silt, sand, and gravel, some beds of claystone, siltstone, sandstone, and conglomerate...	On this section, principal unit, continental rocks and deposits (Miocene to Holocene): in northern part of section may include continental rocks and deposits (Miocene and Pliocene)–mostly Mehrten Formation or an equivalent, and continental rocks and deposits (Oligocene and Miocene) -mostly Valley Springs Formation or an equivalent. Include continental rocks and deposits (Miocene and Pliocene)--chiefly the Chanac Formation (Miocene) at extreme southern end of section, and the Zilch Formation of informal subsurface usage, which is considered to be the continental equivalent of the Marine Temblor Formation (Oligocene and Miocene)
Tm	**Marine rocks and deposits (Eocene, Oligocene, Miocene, and Pliocene)** Sand, clay, silt, sandstone, shale, mudstone, and siltstone. On these section include marine rocks and deposits of Miocene and Pliocene age only	Description at left
TpT	**Continental and marine rocks and deposits (Pre-Tertiary to Oligocene)** Continental rocks and deposits of clay, shale, sand, sandstone and conglomerate; marine rocks and deposits of clay, shale, sandstone, and conglomerate...	On this section include marine rocks and deposits of Eocene and Oligocene age, also include some Paleocene marine rocks. Include continental rocks and deposits (Eocene to Miocene)-- chiefly Walker Formation (Eocene to Miocene) at depths off the section - greater than 13,000ft, where the Walker Formation underlies Eocene, marine sediments. Include marine rocks (Pre-Tertiary)
pTgm	**Granitic and metamorphic rocks (Pre-Tertiary)** Granitic rocks with some mafic intrusive rocks, and metasedimentary and metavolcanic rocks. Include granitic rocks (Pre-Tertiary) and metamorphic rocks (Pre-Tertiary)	Not present

X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-23 CrossSection_Page1986_B.mxd

FIGURE 2-23
Geologic Cross-Section:
Page (1986) Section B-B'

Madera Subbasin
Groundwater Sustainability Plan



X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-24 CrossSection_LSCE_A.mxd

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FIGURE 2-24

Madera County Geologic Cross-Section A

Madera Subbasin
Groundwater Sustainability Plan

B
(WEST)

B'
(EAST)

Elevation (feet, msl)

600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400
-1500

San Joaquin River
Chowchilla Subbasin Boundary
G-G'
East Side Bypass
Ash Slough
H-H'
I-I'
Hwy 99
J-J'
Madera Canal
K-K'
Chowchilla/Madera Subbasin Boundary

Upper Aquifer
Corcoran Clay
Lower Aquifer

Spring 1988 Unconfined Groundwater Level
Spring 2014 Unconfined Groundwater Level

Base of Freshwater

Top of Basement Complex/
Bottom of Continental Deposits

Vertical Exaggeration = 50X

0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
140000
150000
160000
170000
180000
190000

Distance (feet)

Explanation

- Ground Surface
- Spring 1988 Unconfined Groundwater Level
- Spring 2014 Unconfined Groundwater Level

Borehole Lithology

- Top Soil
- Clay/Shale/Silt/Siltstone
- Sand/Sandstone/Conglomerate
- Gravel/Cobbles
- Hardrock
- Corcoran Clay - Separates Unconfined Upper Aquifer and Confined Lower Aquifer (Page, 1986; C2VSim-FG)
- Depth Delineation Between Upper and Lower Aquifers Outside the Corcoran Clay
- Base of Freshwater (modified from Page, 1973)
- Top of Basement/Bottom of Continental Deposits (modified from Mitten et al., 1970 and C2VSim-FG)

X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-25 CrossSection_LSCE_B.mxd

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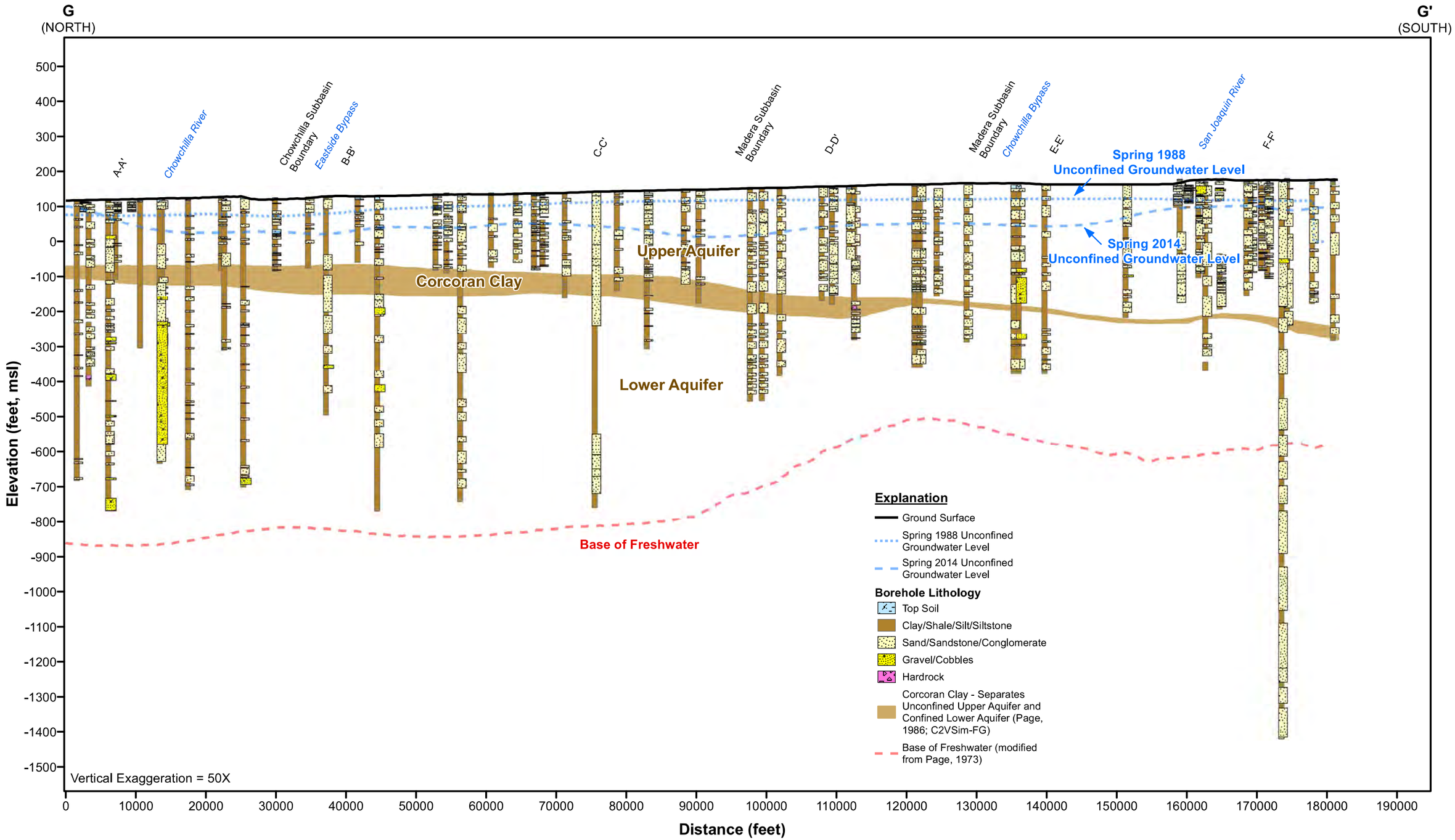
FIGURE 2-25

Madera County Geologic Cross-Section B

Madera Subbasin
Groundwater Sustainability Plan



X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-30 CrossSection_LSCE_G.mxd

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FIGURE 2-30

Madera County Geologic Cross-Section G

Madera Subbasin
Groundwater Sustainability Plan

H (NORTH)

H' (SOUTH)

Chowchilla Subbasin Boundary/A-A'

Chowchilla River

B-B' Ash Slough

C-C' Berenda Slough

Madera Subbasin Boundary

Fresno Bypass

D-D'

E-E' Cottonwood Creek

San Joaquin River

Madera Subbasin Boundary F-F'

Spring 1988 Unconfined Groundwater Level

Spring 2014 Unconfined Groundwater Level

Upper Aquifer

Corcoran Clay

Lower Aquifer

Base of Freshwater

Vertical Exaggeration = 50X

Elevation (feet, msl)

400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400
-1500
-1600

0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
140000
150000
160000
170000
180000
190000

Distance (feet)

Explanation

- Ground Surface
- Spring 1988 Unconfined Groundwater Level
- Spring 2014 Unconfined Groundwater Level

Borehole Lithology

- Top Soil
- Clay/Shale/Silt/Siltstone
- Sand/Sandstone/Conglomerate
- Gravel/Cobbles
- Hardrock
- Corcoran Clay - Separates Unconfined Upper Aquifer and Confined Lower Aquifer (Page, 1986; C2VSim-FG)
- Depth Delineation Between Upper and Lower Aquifers Outside the Corcoran Clay
- Base of Freshwater (modified from Page, 1973)

X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-31 CrossSection_LSCE_H.mxd

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FIGURE 2-31

Madera County Geologic Cross-Section H

Madera Subbasin
Groundwater Sustainability Plan

I (NORTH)

I' (SOUTH)

Chowchilla Subbasin Boundary

Deadman Creek

A-A'

Chowchilla River

Ash Slough

B-B'

Berenda Slough

C-C'

Chowchilla/Madera Subbasin Boundary

Berenda Creek

Dry Creek

D-D'

Fresno River

E-E'

Cottonwood Creek

F-F'

San Joaquin River

Madera Subbasin Boundary

Spring 1988 Unconfined Groundwater Level

Upper Aquifer

Corcoran Clay

Spring 2014 Unconfined Groundwater Level

Lower Aquifer

Base of Freshwater

Top of Basement Complex/ Bottom of Continental Deposits

Vertical Exaggeration = 50X

Elevation (feet, msl)

500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400
-1500

0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
140000
150000
160000
170000
180000
190000

Distance (feet)

Explanation

- Ground Surface
- Spring 1988 Unconfined Groundwater Level
- Spring 2014 Unconfined Groundwater Level

Borehole Lithology

- Top Soil
- Clay/Shale/Silt/Siltstone
- Sand/Sandstone/Conglomerate
- Gravel/Cobbles
- Hardrock
- Corcoran Clay - Separates Upper Aquifer and Lower Aquifer (Page, 1986; C2VSim-FG)
- Depth Delineation Between Upper and Lower Aquifers Outside the Corcoran Clay
- Base of Freshwater (modified from Page, 1973)
- Top of Basement/Bottom of Continental Deposits (modified from Mitten et al., 1970 and C2VSim-FG)

X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-32 CrossSection_LSCE_I.mxd

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FIGURE 2-32

Madera County Geologic Cross-Section I

Madera Subbasin
Groundwater Sustainability Plan

J
(NORTH)

J'
(SOUTH)

Deadman Creek
A-A'
Chowchilla River
Chowchilla Subbasin Boundary
B-B'
Ash Slough/ Berenda Slough
C-C'
Chowchilla/Madera Subbasin Boundary
Berenda Creek
D-D'
Dry Creek
Fresno River
E-E'
Cottonwood Creek
F-F'
San Joaquin River
Madera Subbasin Boundary

Spring 1988 Unconfined Groundwater Level

Spring 2014 Unconfined Groundwater Level

Upper Aquifer

Lower Aquifer

Base of Freshwater

Top of Basement Complex/ Bottom of Continental Deposits

Vertical Exaggeration = 50X

Elevation (feet, msl)

600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400

0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
140000
150000
160000
170000
180000
190000

Distance (feet)

Explanation

- Ground Surface
- Spring 1988 Unconfined Groundwater Level
- Spring 2014 Unconfined Groundwater Level

Borehole Lithology

- Top Soil
- Clay/Shale/Silt/Siltstone
- Sand/Sandstone/Conglomerate
- Gravel/Cobbles
- Hardrock

- Base of Freshwater (modified from Page, 1973)
- Depth Delineation Between Upper and Lower Aquifers Outside the Corcoran Clay
- Top of Basement/Bottom of Continental Deposits (modified from Mitten et al., 1970 and C2VSim-FG)

X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-33 CrossSection_LSCE_J.mxd

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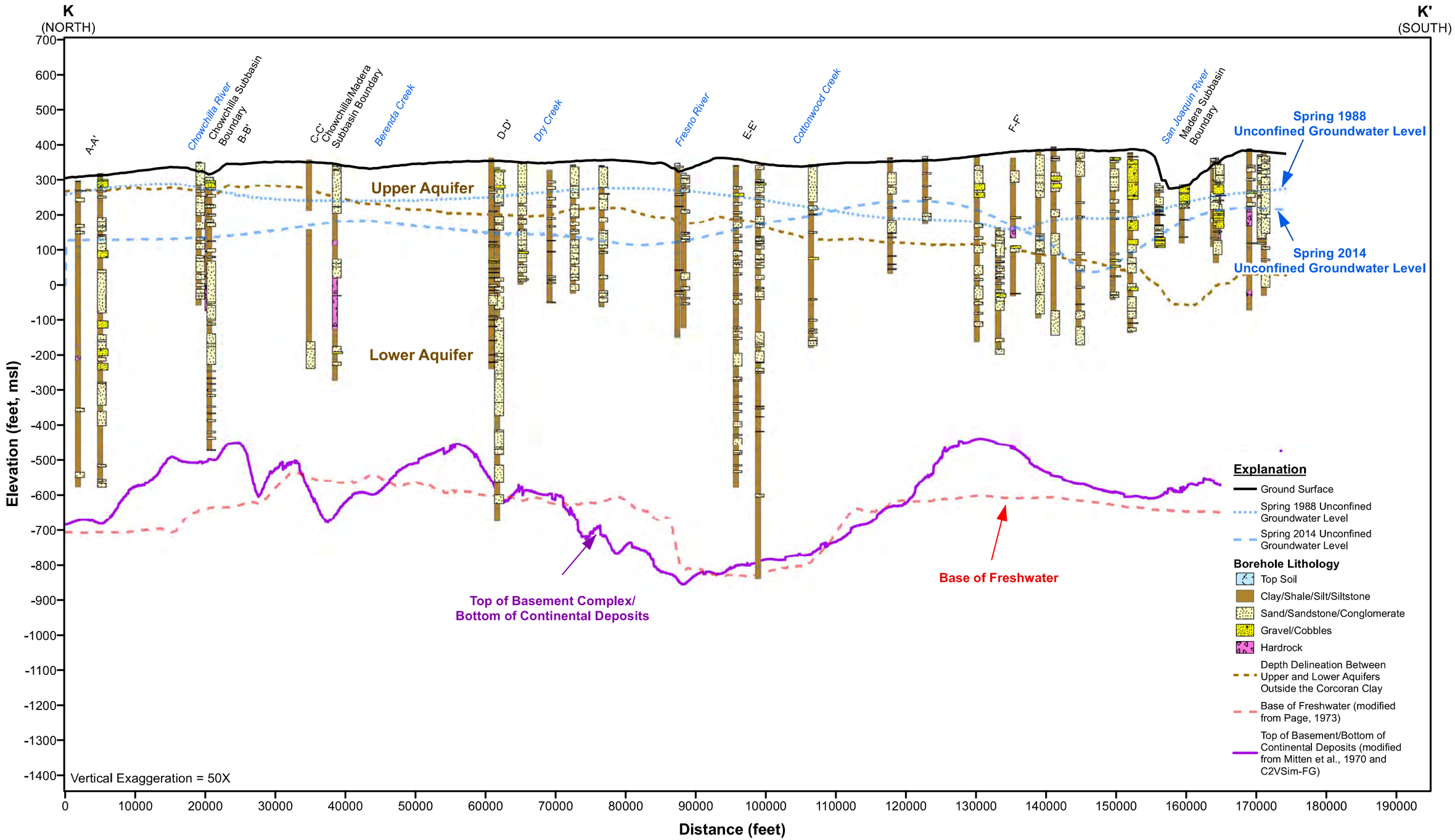
FIGURE 2-33

Madera County Geologic Cross-Section J

Madera Subbasin
Groundwater Sustainability Plan



X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-34 CrossSection_LSCE_K.mxd

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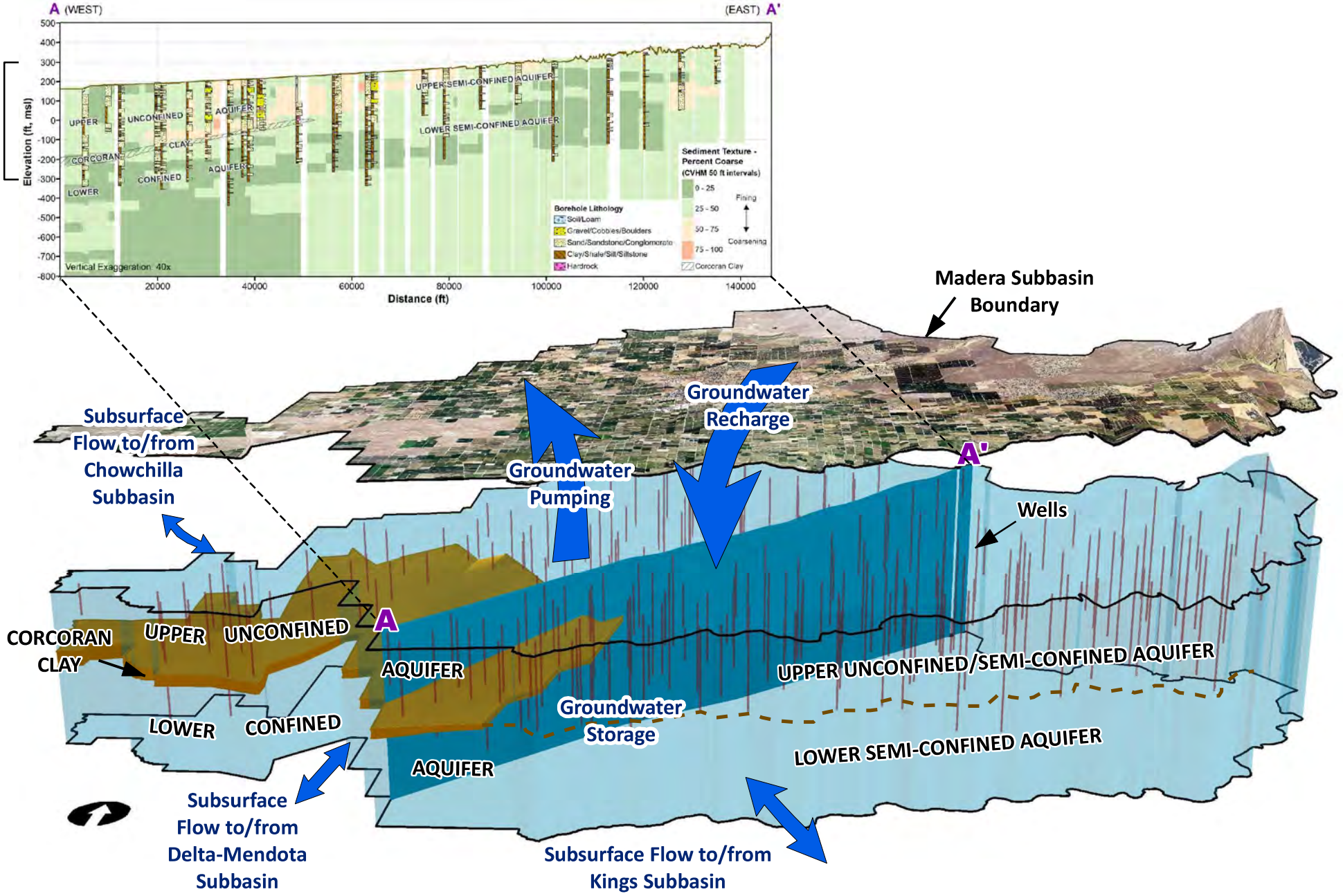
FIGURE 2-34

Madera County Geologic Cross-Section K

Madera Subbasin
Groundwater Sustainability Plan



X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-35 Madera Subbasin Hydrogeologic Conceptual Diagram.mxd

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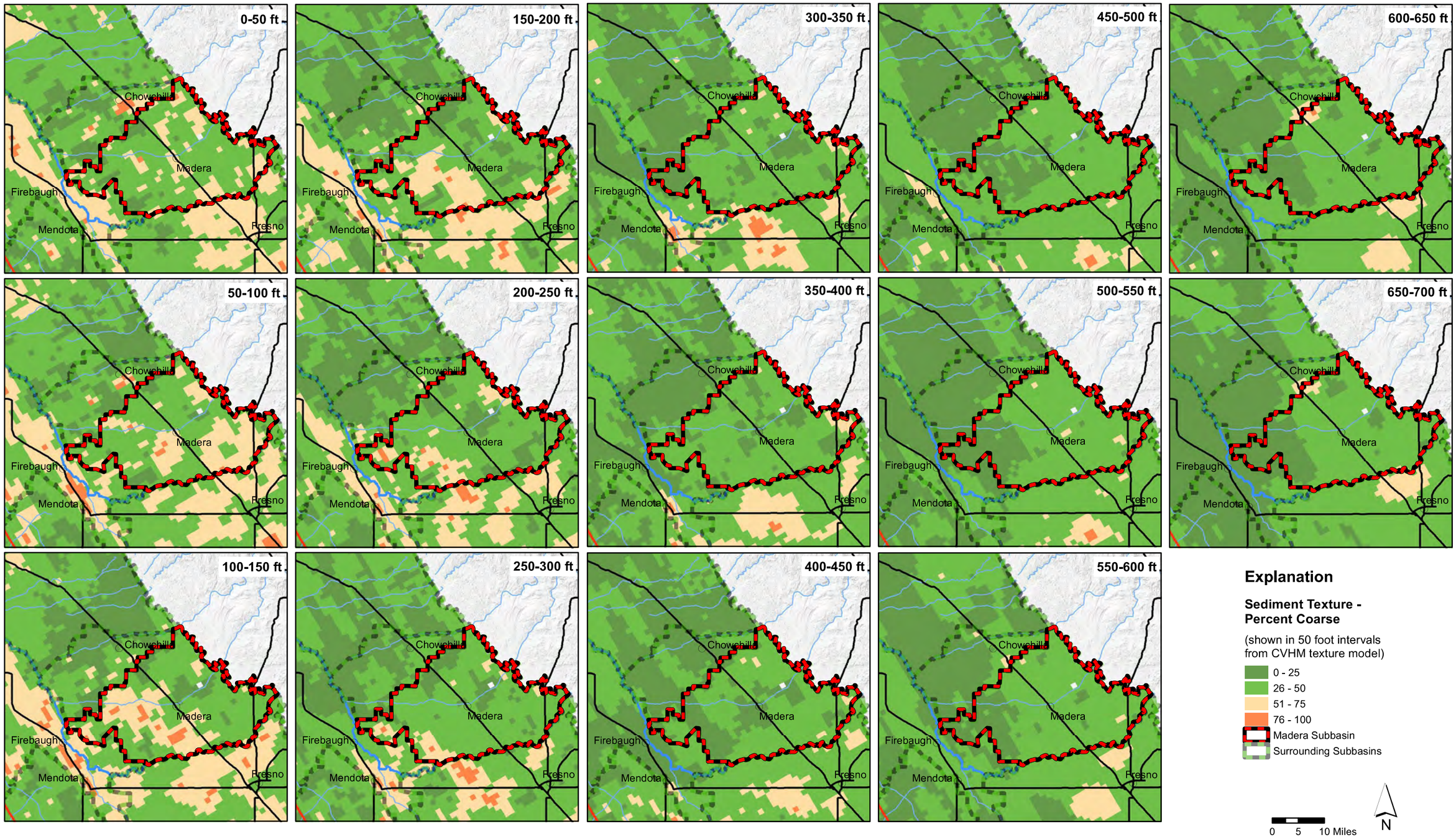
FIGURE 2-35

Conceptual Hydrogeologic System

Madera Subbasin
Groundwater Sustainability Plan



X:\2017\17-113 Madera Subbasin GSP Development\GIS\Map Files\REPORT map files\Chapter 2\Figure 2-36 CVHM Sediment Texture Model 0 to 700.mxd

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FIGURE 2-36

CVHM Sediment Texture Model: 0 to 700 feet

Madera Subbasin
Groundwater Sustainability Plan

New Stone Water District

Groundwater Sustainability Agency

Revised

Groundwater Sustainability Plan

in compliance with the

Sustainable Groundwater Management Act

Adopted

December 23, 2019

Revised March 2023

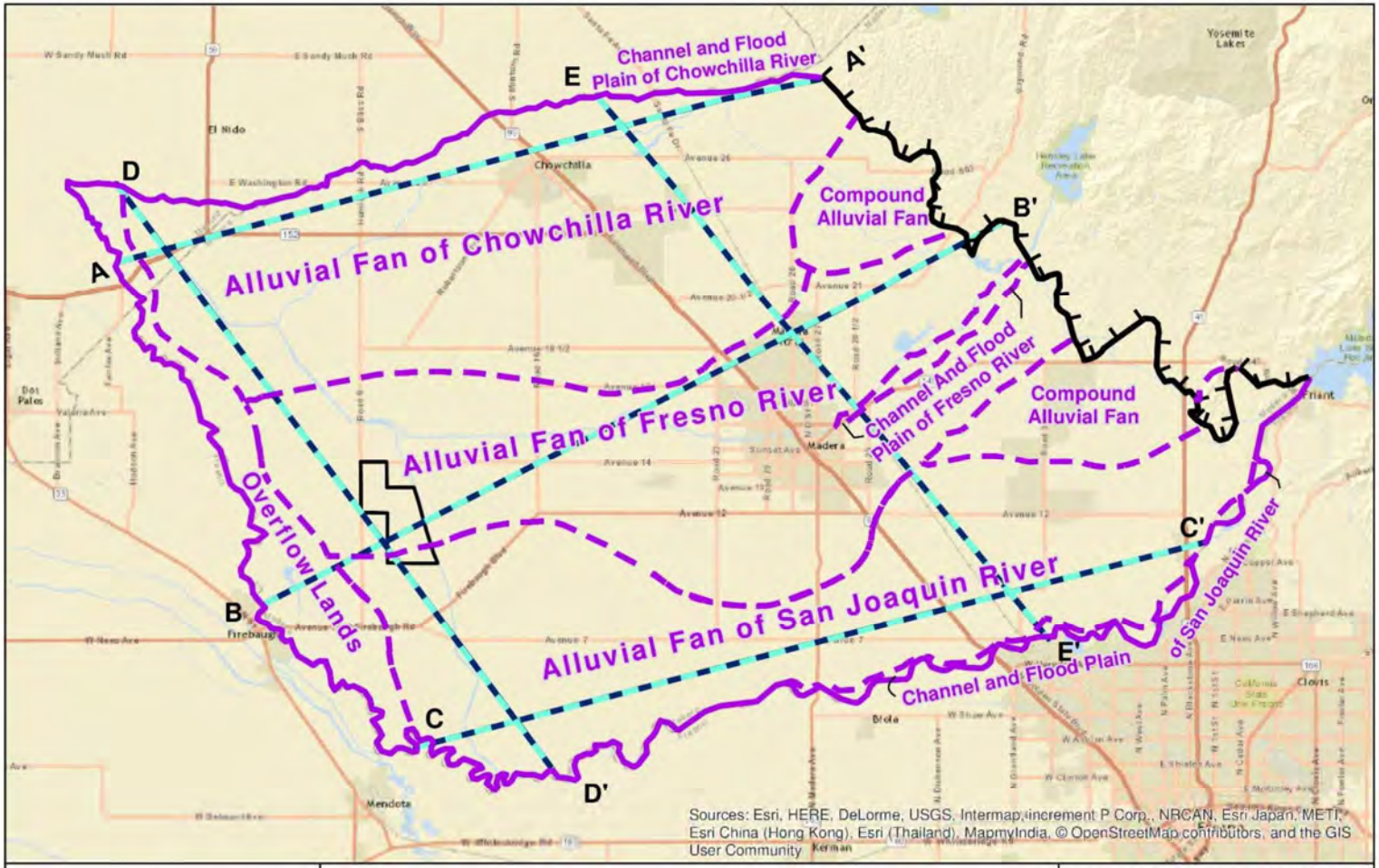
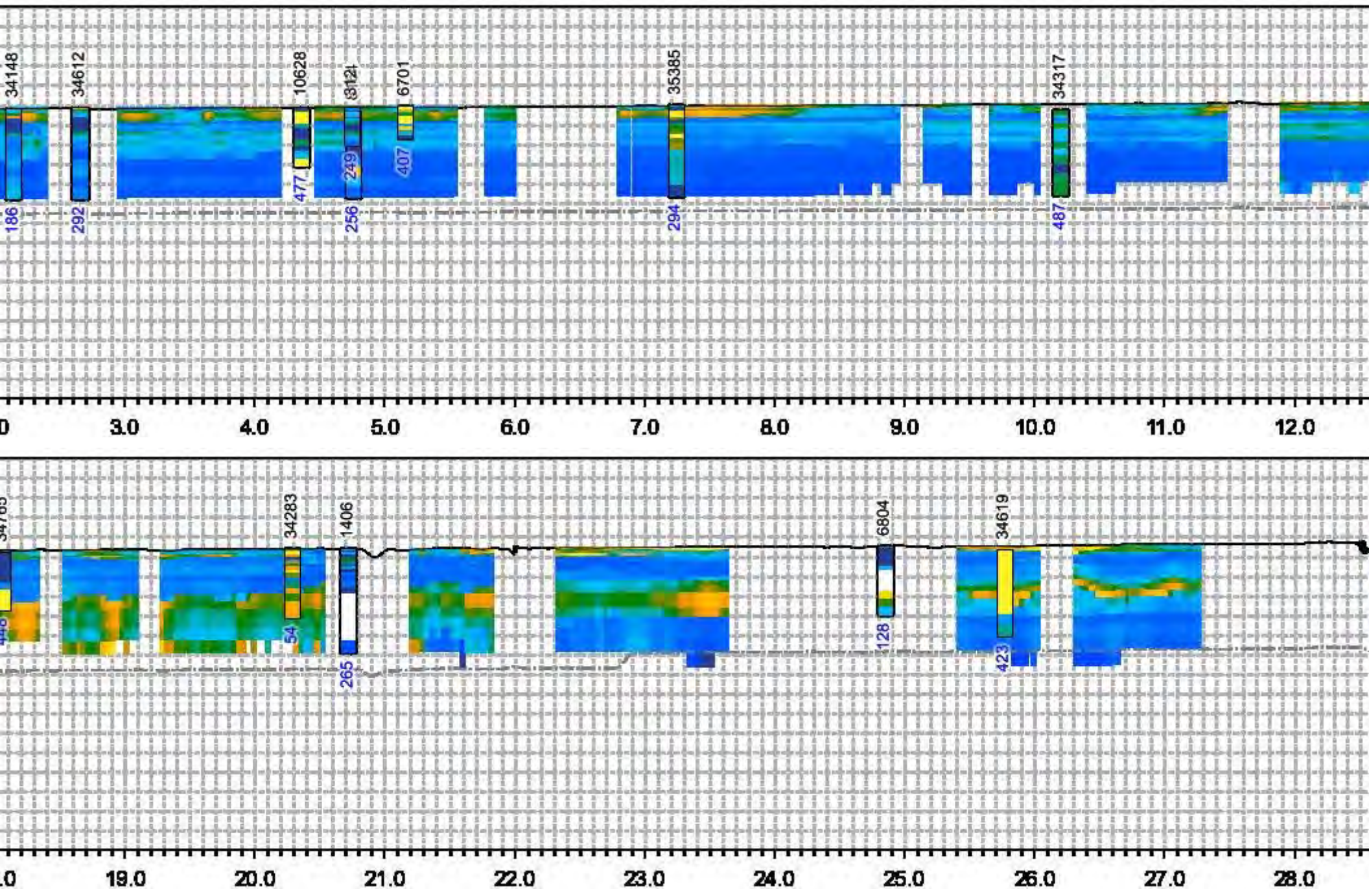
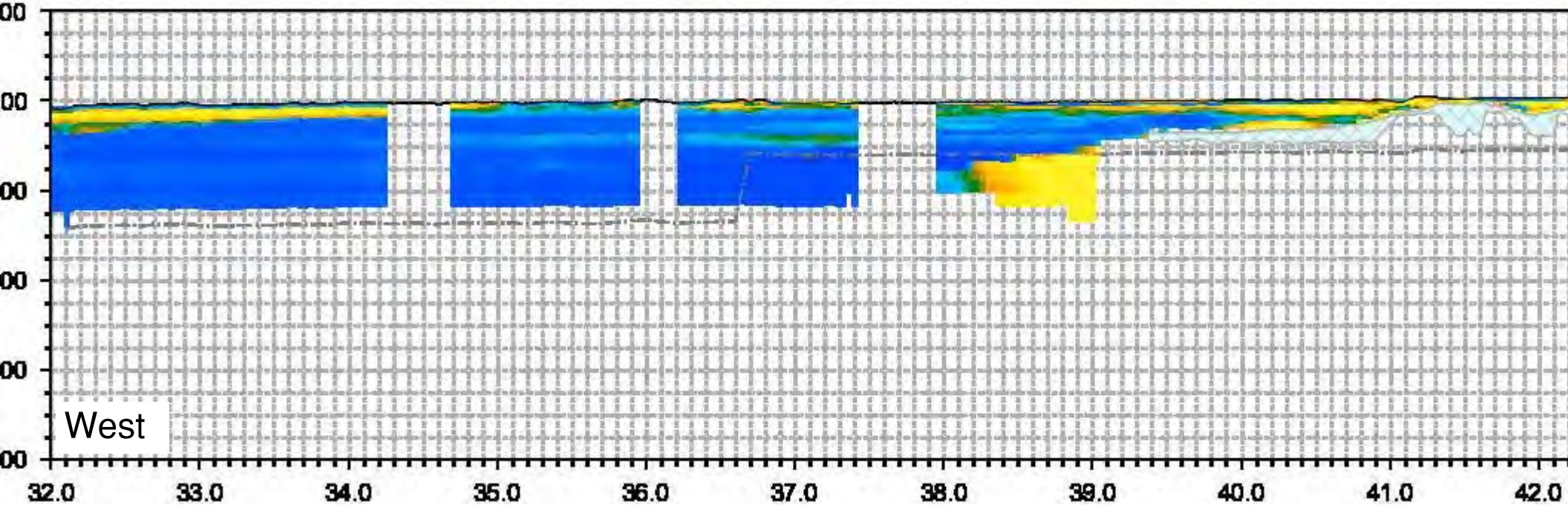


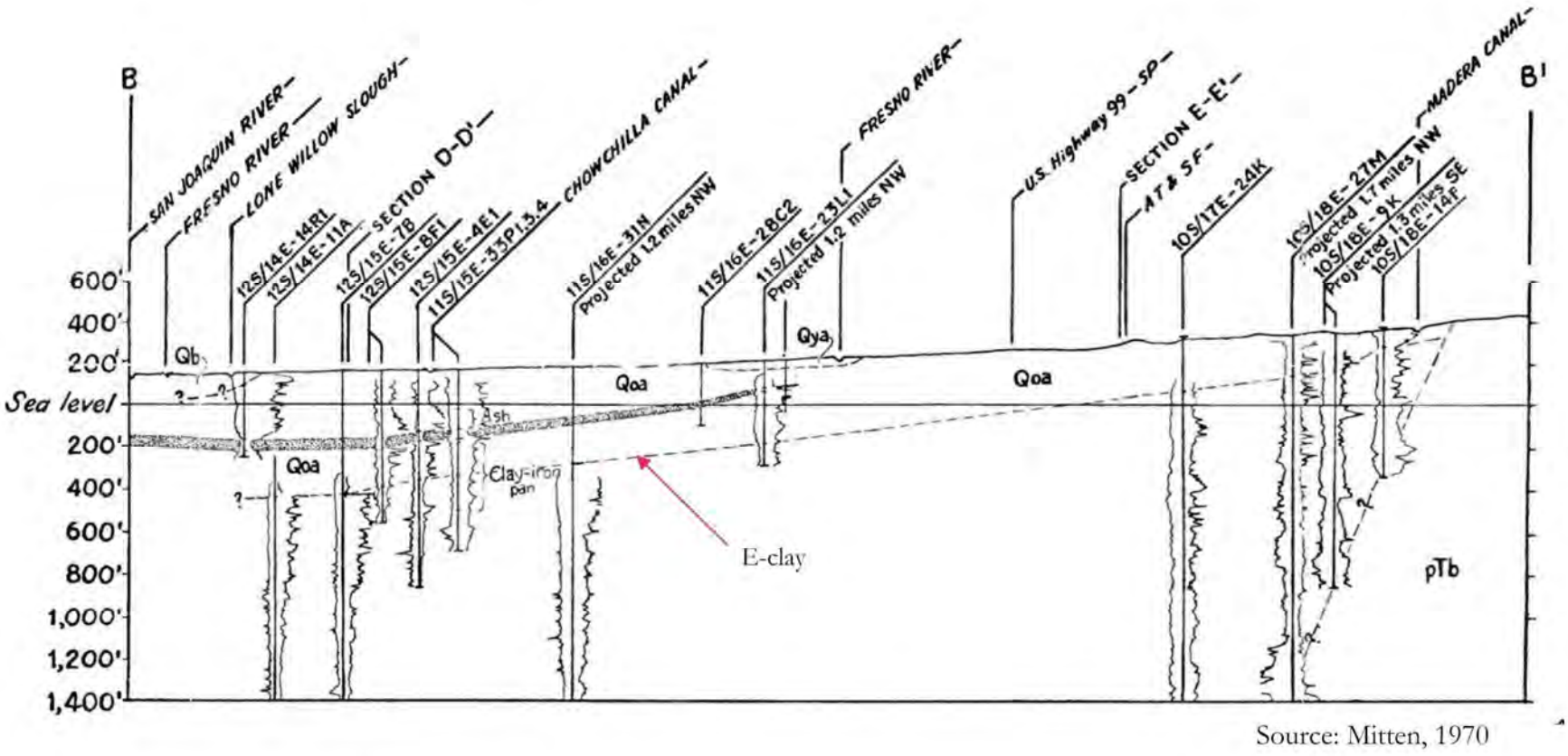
Figure 3-9 Regional Geologic Cross-section Traverses

A - A' Nearest AEM Logs



A - A' Nearest AEM Logs

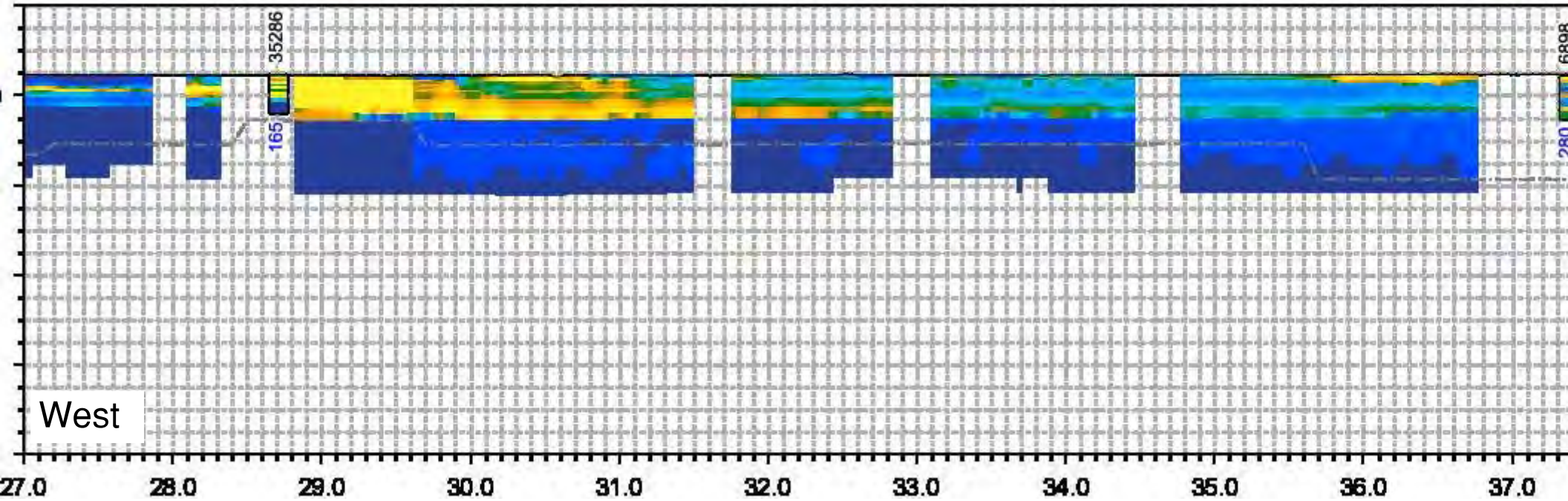


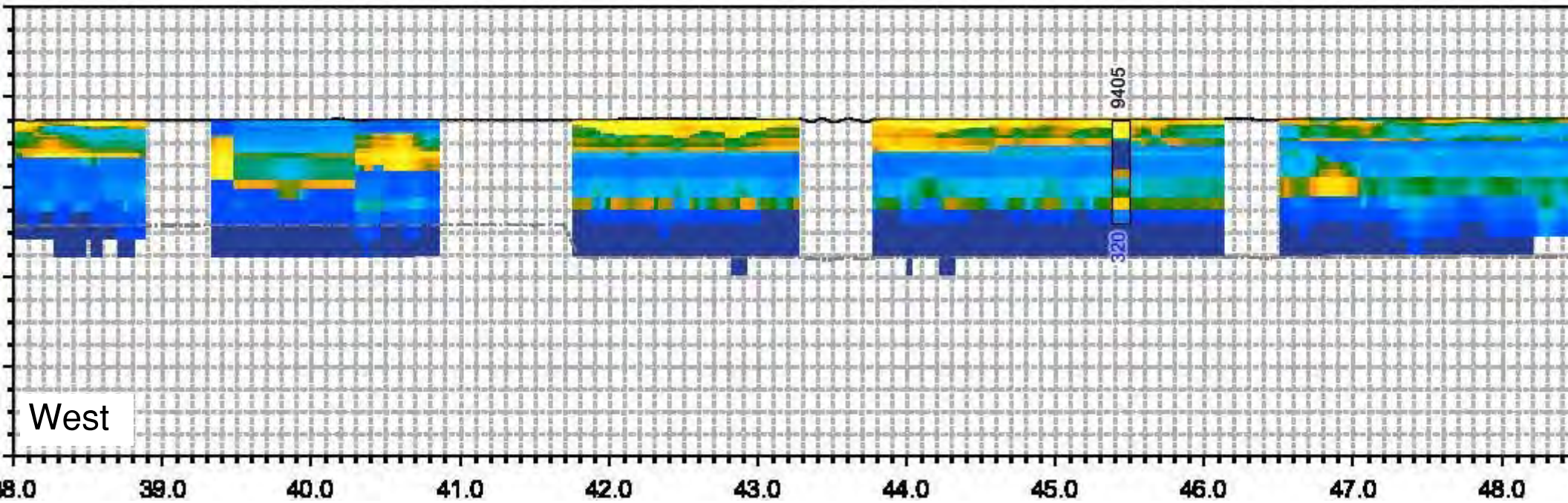


Source: Mitten, 1970

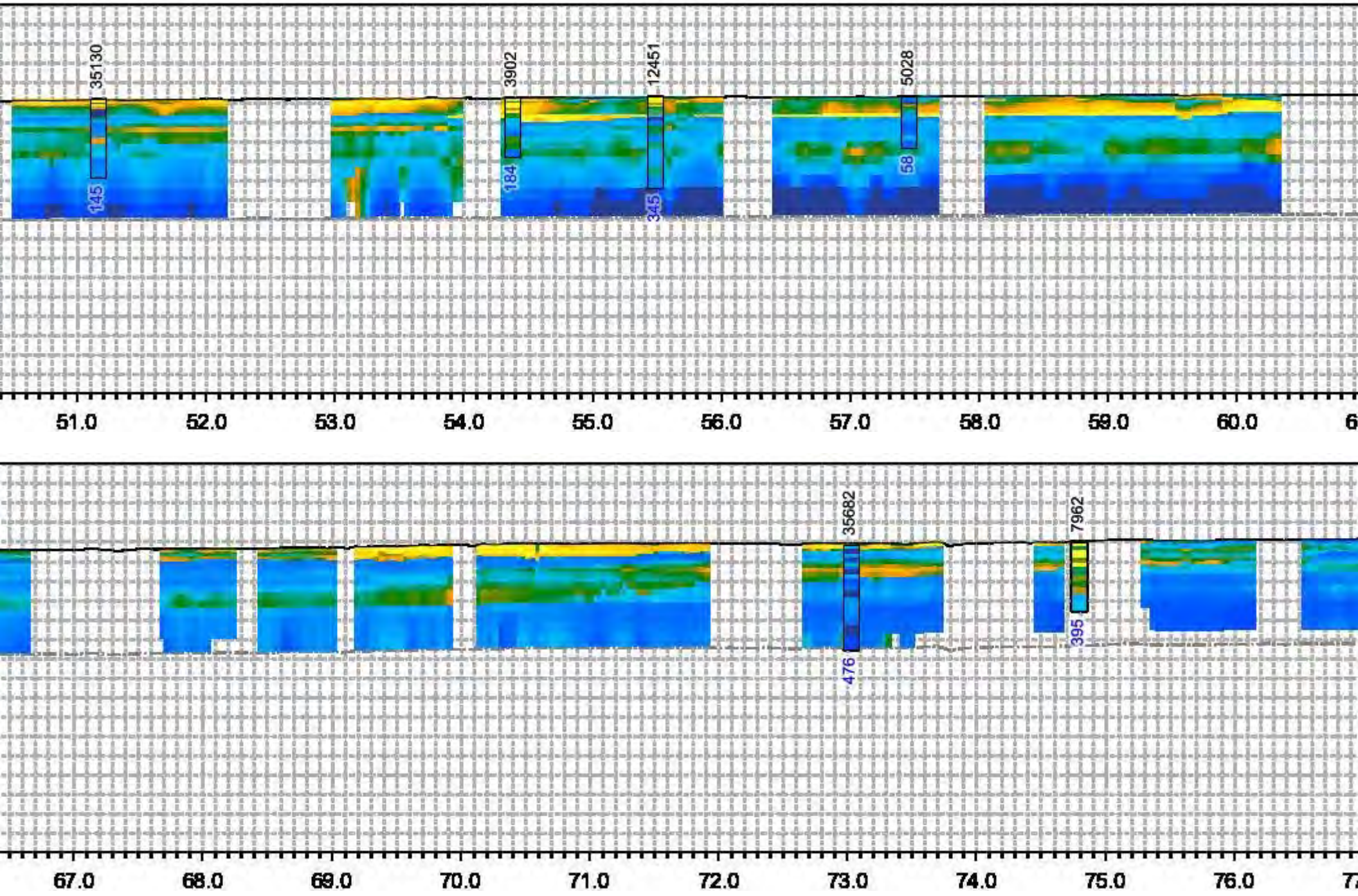
Figure 3-10 Regional Cross-Section B-B'

B - B' Nearest AEM Logs





B - B' Nearest AEM Logs



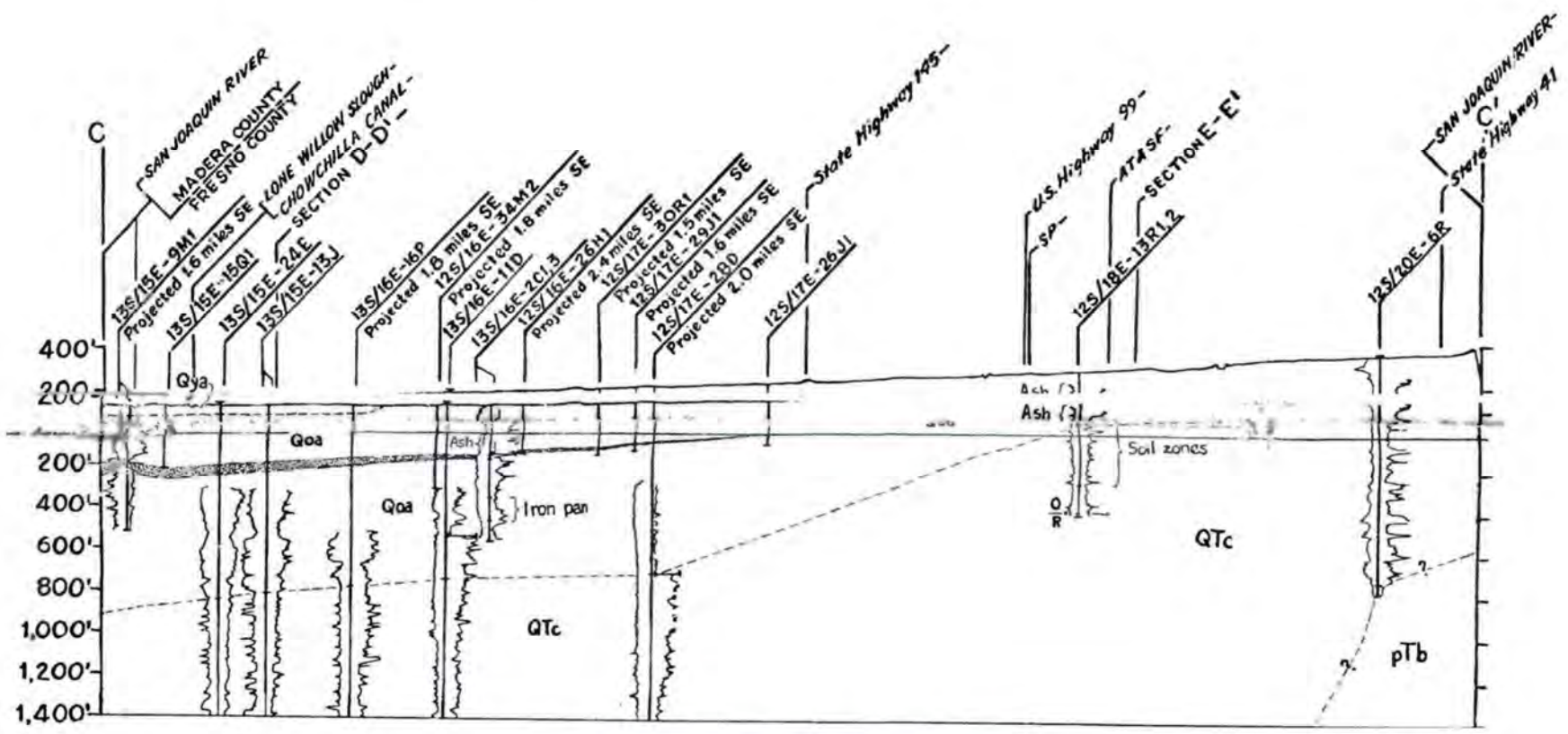
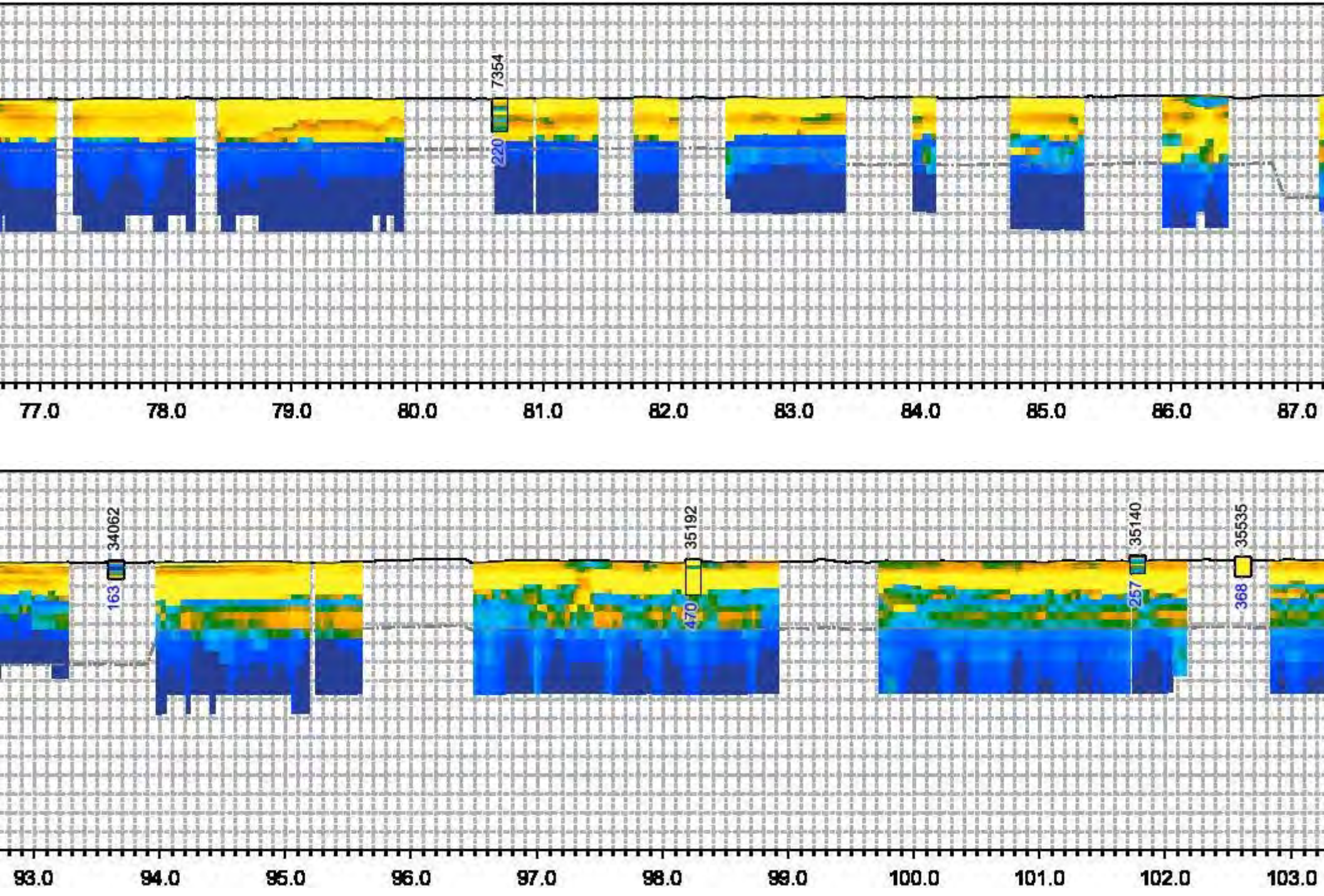


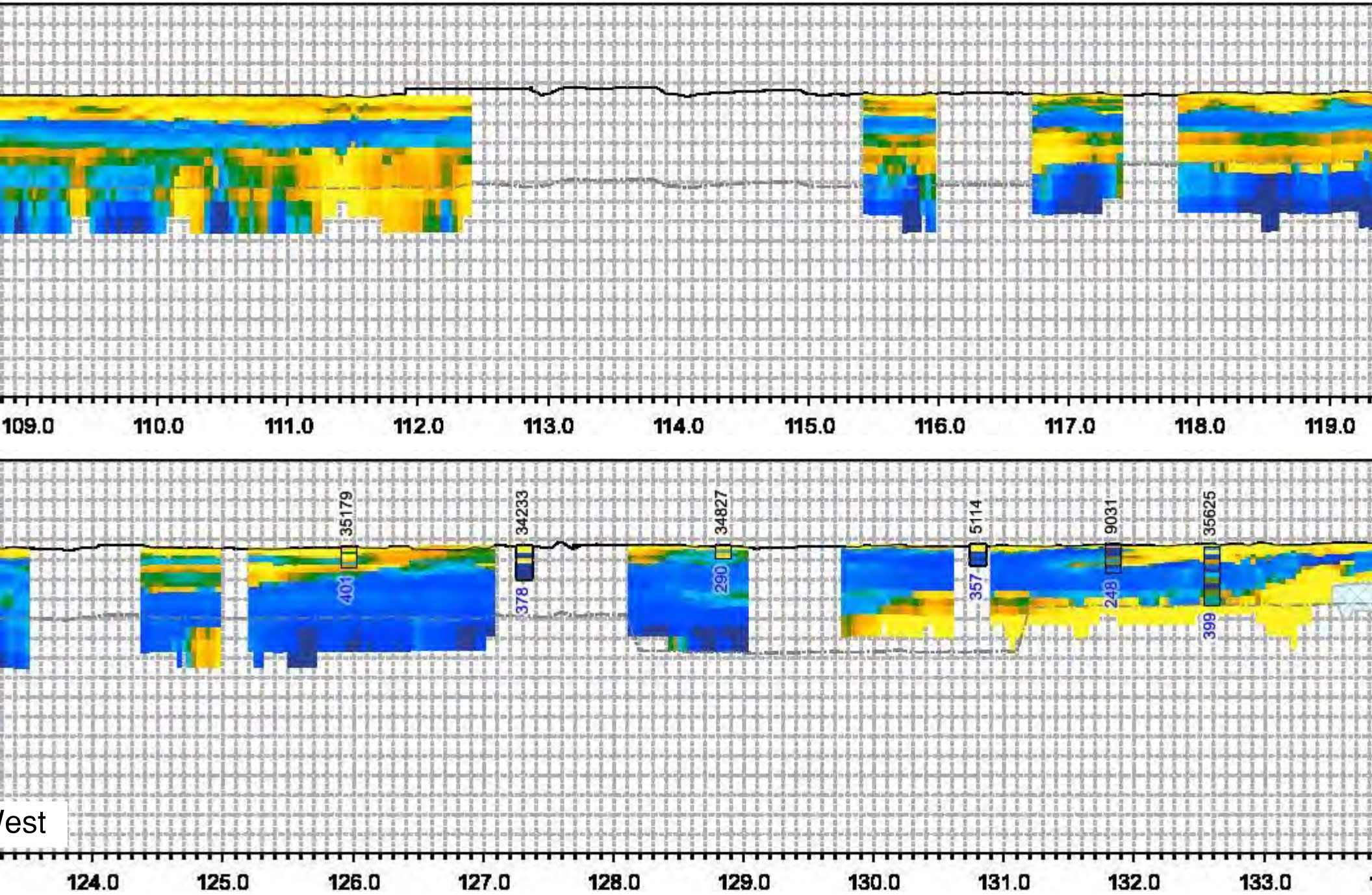
Figure 3-11 Regional Cross-Section C-C'

Source: Mitten, 1970

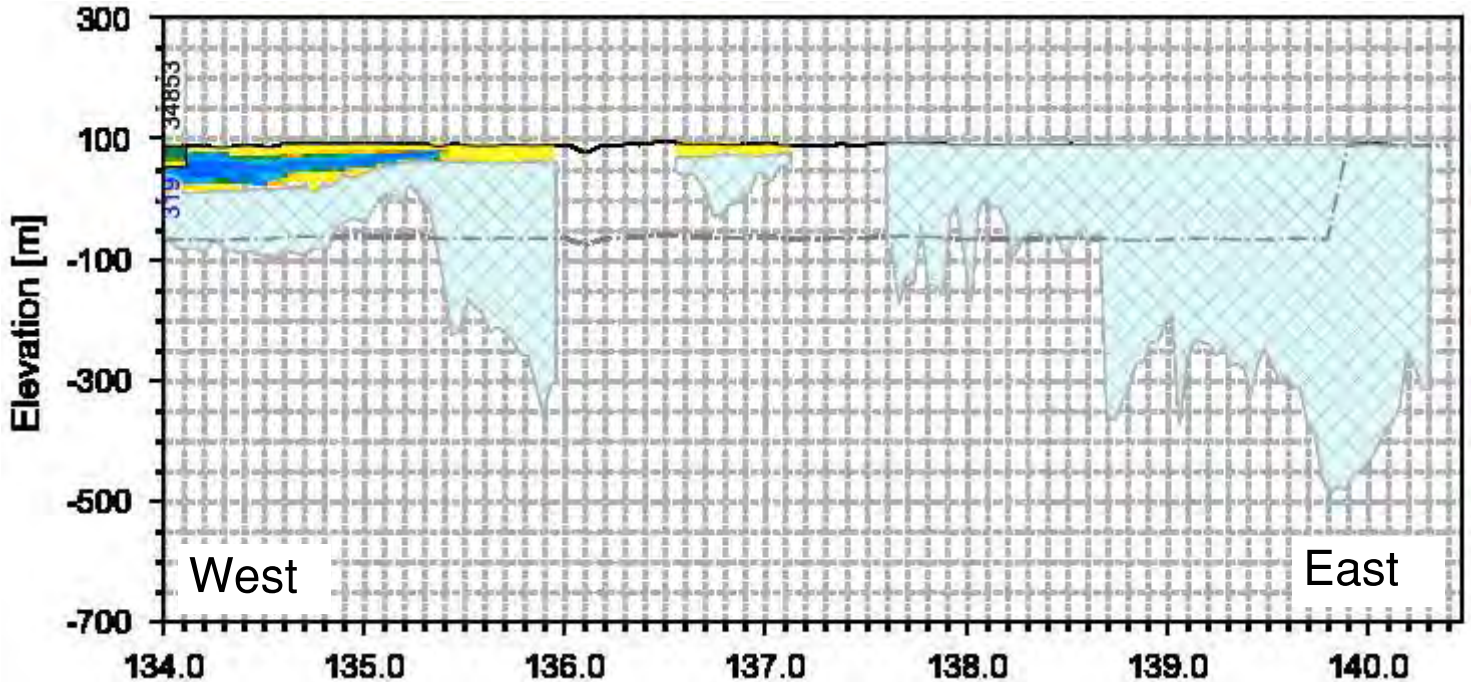
C - C' Nearest AEM Logs



C - C' Nearest AEM Logs



C - C' Nearest AEM Logs



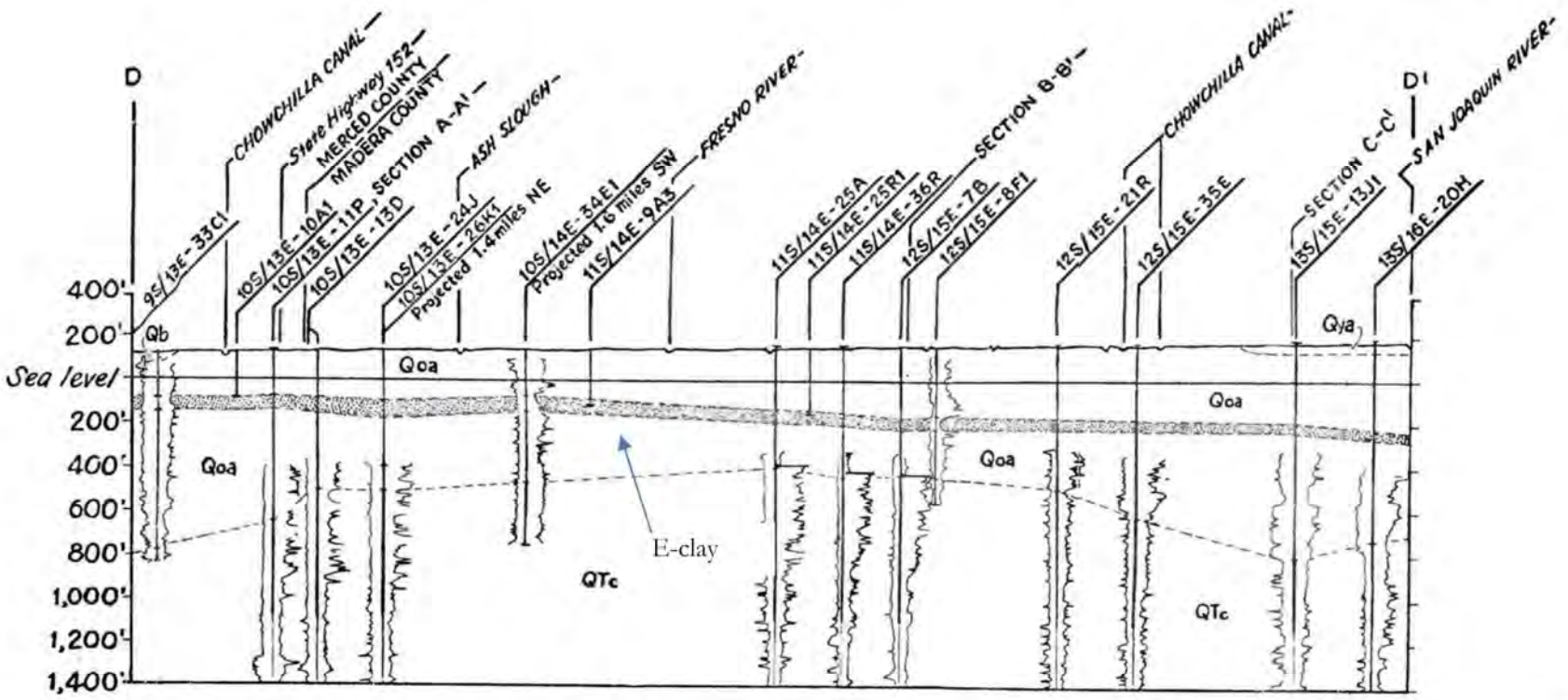
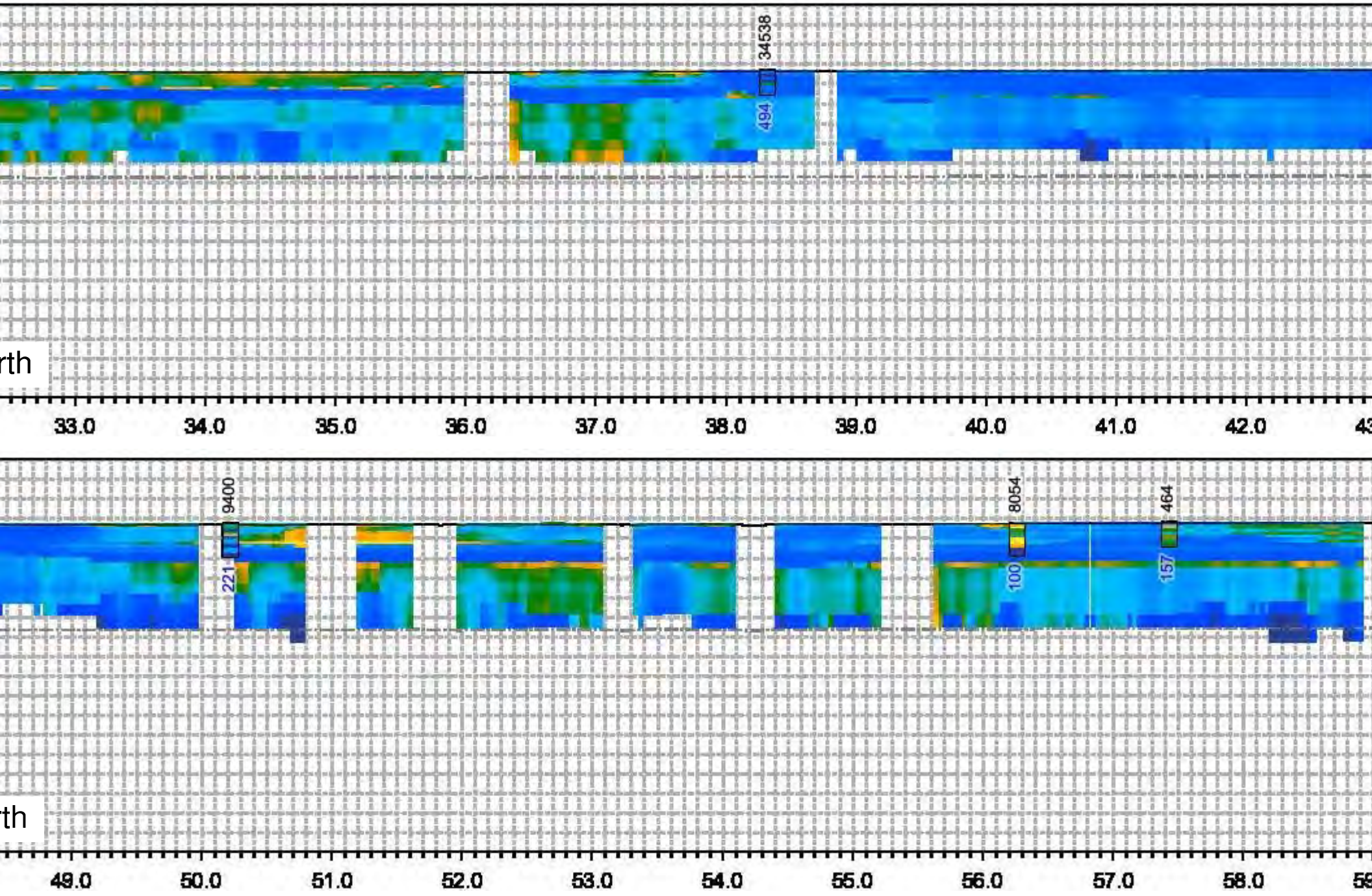


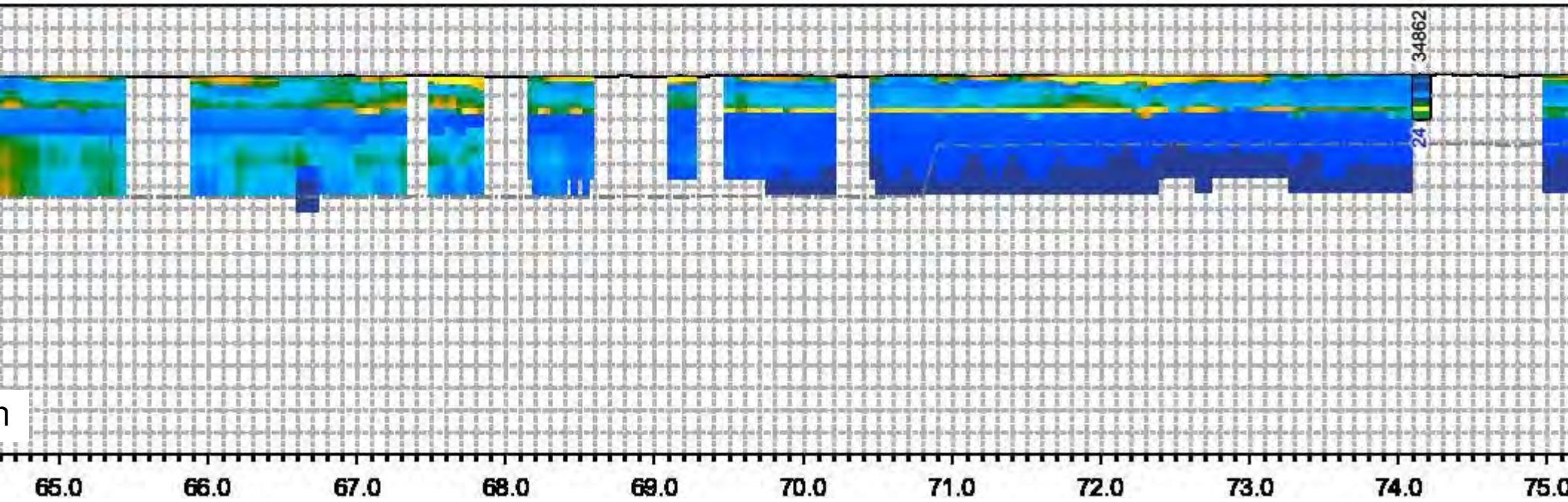
Figure 3-12 Regional Cross-Section D-D'

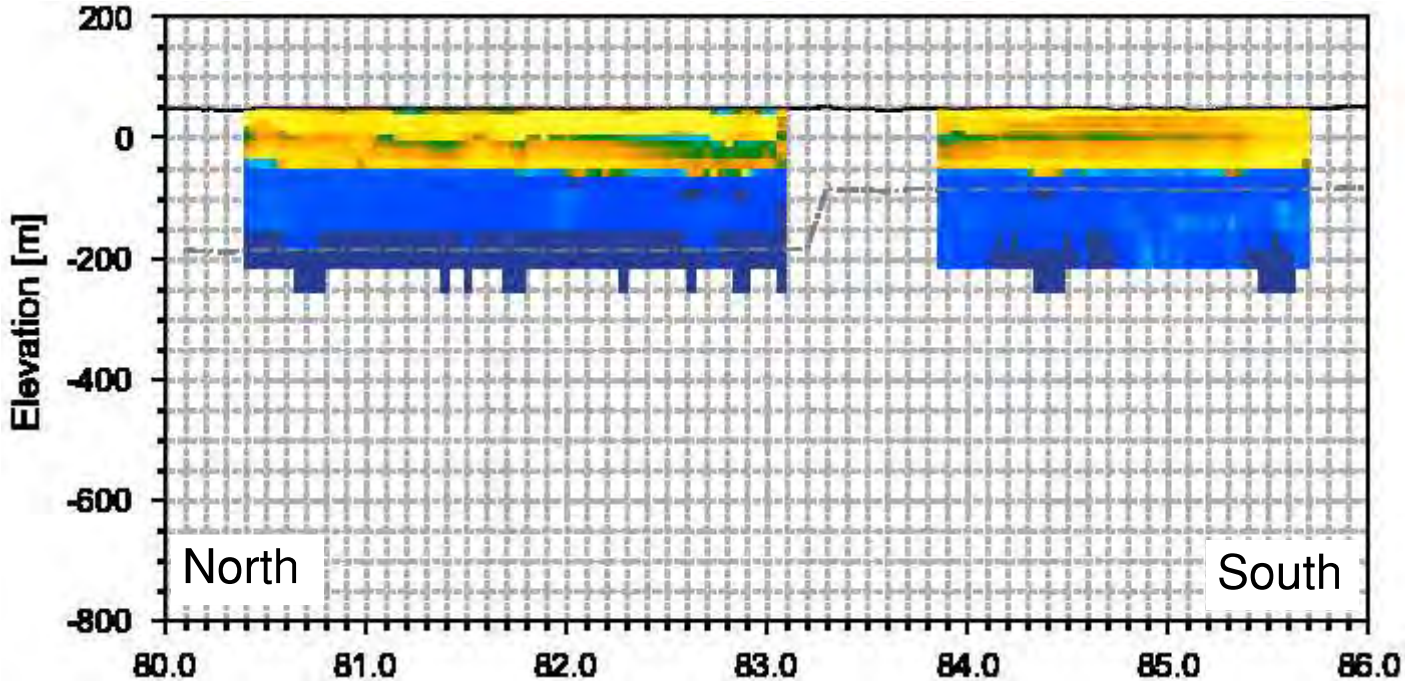
Source: Mitten, 1970

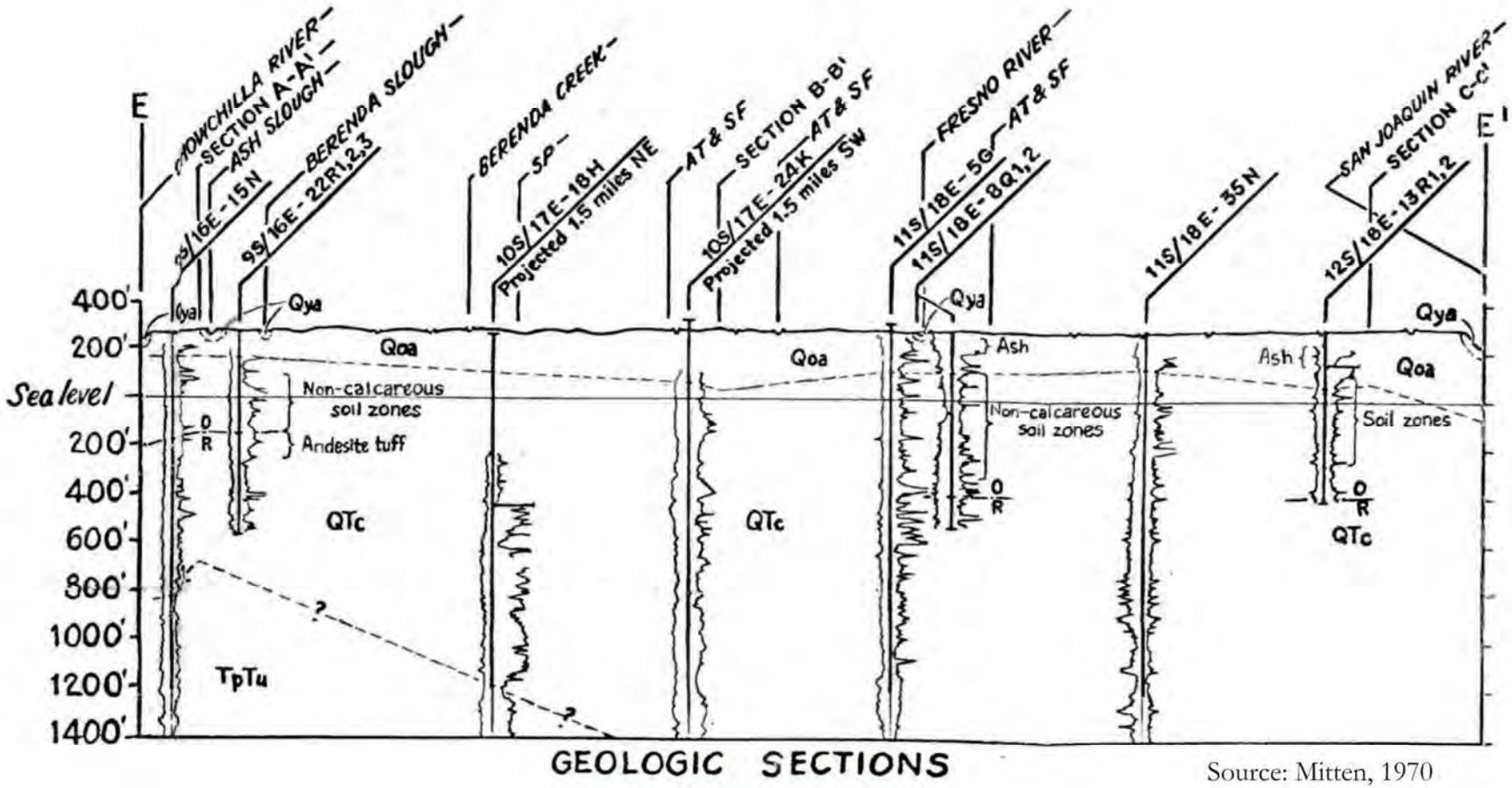
D - D' Nearest AEM Logs



D - D' Nearest AEM Logs



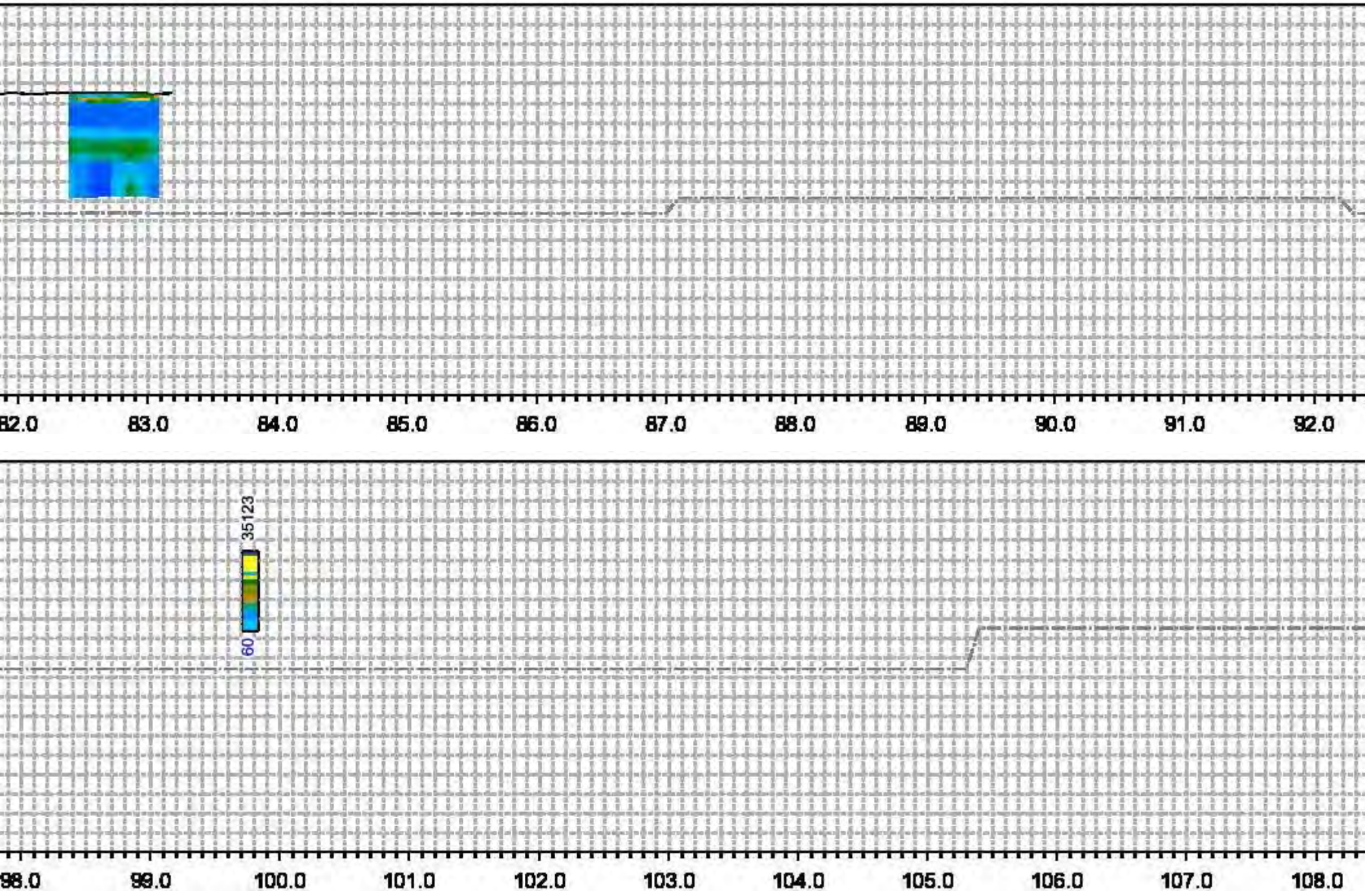




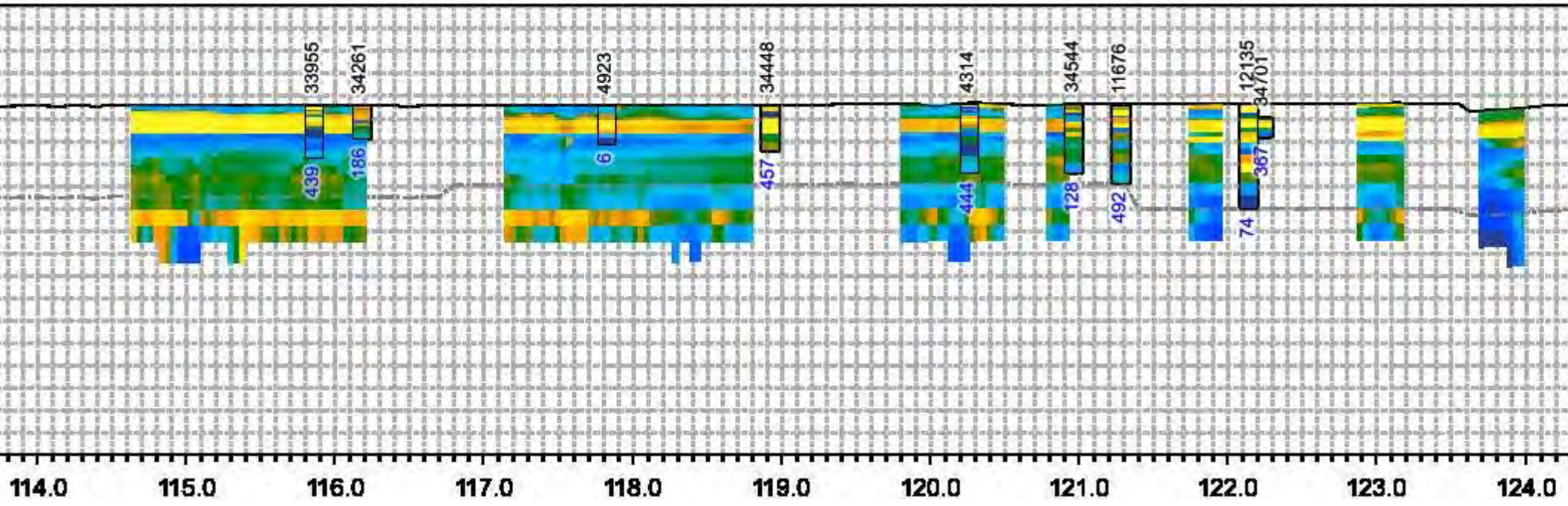
Source: Mitten, 1970

Figure 3-13 Regional Cross-Section E-E'

E - E' Nearest AEM Logs



E - E' Nearest AEM Logs



Cross-section E-E' is approximately parallel to and east of Highway 99, several miles to the east of the NSWDGSA. It shows shallow bands of Qoa ranging from a depth of approximately 250 feet below msl where it intersects with the San Joaquin River in the south, to approximately 200 feet above ground surface to the north near the Chowchilla River. Small bands of Qya lie along cross-section E-E' where it intersects the Ash Slough, Berenda Slough, Fresno River, and the San Joaquin River. QTc directly underlies Qoa along cross-section E-E' and typically remains above sea level.

3.1.8 Aquifer System

Regulation Requirement:

§354.14(b)(4) The hydrogeologic conceptual model shall be summarized in a written description that includes the principal aquifers and aquitards.

§354.14(b)(4)(c) Structural properties of the basin that restrict groundwater flow within the principal aquifers, including information regarding stratigraphic changes, truncation of units, or other features.

The NSWDGSA encompasses a small portion of the western-most Madera Groundwater Subbasin. The subbasin aquifer system consists of unconsolidated continental deposits of older series Tertiary (66 to 2.6 million years ago) and Quaternary (2.6 million years ago to the present) age sediments overlain by younger series deposits of Quaternary age. The Quaternary age deposits are divided into older alluvium (Qoa), lacustrine (lake) and marsh deposits, terrace deposits, younger alluvium (Qya), and flood-basin deposits (Mitten et al., 1970). Lacustrine and marsh deposits do not crop out in the Madera Groundwater Subbasin but tend to underlie the western portion of the subbasin (DWR, 2006).

Mitten, et al. (1970) states that subsurface water-bearing characteristics of the Qoa deposits are highly variable due to changes in lithology. These deposits consist mostly of interbedded layers of silts, silty/sandy clays, clay lenses, clayey and silty sands, sands, gravels, and cobbles. It contains much of the water that occurs in the unconfined aquifers in the Madera Subbasin.

A fine-grained lacustrine and marsh deposit, known as the E-clay or Corcoran Clay, acts as a confining layer separating the upper unconfined aquifer from the lower confined aquifer for much of the subbasin. The Corcoran Clay is approximately 100 feet below msl at the northeastern portion of the Madera Groundwater Subbasin and gradually gets deeper as it traverses south-southwest to the San Joaquin River and thicker as it traverses west-southwest. The Corcoran Clay confining layer is shown by cross-section D-D' to exist at a depth of approximately 150 to 200 feet below msl along the western section of the Madera Groundwater Subbasin. Cross-sections B-B' and C-C' show the Corcoran Clay as it crosses the Madera Subbasin from east to west. To the north, cross-section B-B' shows the Corcoran Clay at the San Joaquin River to the west at a depth of approximately 150 feet below msl and 50 feet thick. The Corcoran Clay layer thins to approximately 20 feet and appears to terminate approximately 100 feet above msl (100 feet bgs) to the east, a few miles before the cross-section bisects the Fresno River. Cross-section C-C' lies further south of cross-section B-B' and extends from west to east becoming gradually shallower and thinner as it reaches sea level. The Corcoran Clay from C-C' begins approximately 200 feet below msl and is approximately 50 feet thick. It terminates approximately 25 miles to the east near Highway 145.

The Corcoran Clay is present below the entirety of NSWDGSA. Below the NSWDGSA, the top of the Corcoran Clay lies between 200 to 350 feet bgs as shown in **Figure 3-14**. The Corcoran Clay under NSWDGSA is between 40 and 60 feet thick (Plate 5 of Page, 1986). See **Figure 3-15** for thickness of Corcoran Clay layer.

Where present, the Corcoran Clay is known to have confined groundwater conditions beneath it. It should be noted that newer supply wells are often sealed off from the quaternary alluvium and tap into confined

groundwater. Within the Madera Groundwater Subbasin, less extensive confining units, known as the A-clay, exist at shallower depths; however, this confining unit is not mapped and is assumed to occur only in the southwestern portion of the subbasin. The A-clay does not extend under the NSWDGSA.

3.1.8.1 Geologic Formations

Regulation Requirement:

§354.14(b)(4)(a) Formation names, if defined.

Marchand's report (1976) contains a set of geologic maps of the Madera area. The area of NSWDGSA is mapped as Modesto Formation, primarily the lower member but with small areas of the upper member. Both the upper and lower members are described as locally derived, arkosic, alluvial sand, silt, and clay of interdistributary areas, lower fans, and flood basins that are commonly stratified (Marchand, 1976; Marchand & Allwardt, 1981). The lower member is 80 feet or thicker and is underlain by the Riverbank Formation (Marchand & Allwardt, 1981).

3.1.8.2 Aquifer Characteristics and Properties

Regulation Requirement:

§354.14(b)(3) The hydrogeologic conceptual model shall be summarized in a written description that includes the definable bottom of the basin.

§354.14(b)(4)(b) Physical properties of aquifers and aquitards, including the vertical and lateral extent, hydraulic conductivity, and storativity, which may be based on existing technical studies or other best available information.

Vertical Extent

The vertical extent (i.e., depth) of the aquifer system of the Madera Subbasin is comprised of two separate boundary types and has been mapped by Page (1973, 1986) and Mitten et al. (1970). As shown in **Figure 3-7**, the eastern most boundary of the Madera Subbasin aquifer system is defined vertically by the top of the basement complex. The depth to the basement complex is zero along foothills where valley alluvium pinches out. Cross-section B-B' shows the basement complex recedes steeply from the foothills and is approximately 350 feet below msl approximately two-miles to the west. The depth to the basement complex continues to increase until it is undetectable on the cross-section after approximately five miles from the base of the foothills.

The vertical aquifer boundary for the NSWDGSA (western portion of the Madera Subbasin) is the base of freshwater, which for the purposes of this HCM, is defined as groundwater with total dissolved solids (TDS) content of less than 2,000 milligrams per liter (mg/L). As shown on **Figure 3-16**, the saltwater/freshwater interface below NSWDGSA is located at approximate depths ranging from 600 to 950 feet below msl according to Mitten et al. (1970). The base of freshwater is located below the Qoa bottom within the QTc (Mitten et al., 1970). Page (1973) includes a contour map based on EC values of 3,000 µmhos/cm, a comparable value to 2,000 mg/L for TDS. Page (1973) indicates the base of freshwater under NSWDGSA is approximately 400 to 800 feet below msl.

Aquifer Characteristics

Aquifer characteristics of importance to the NSWDGSA are mainly transmissivity, hydraulic conductivity, and storativity. Storativity relates to how much space is available in the aquifer system for storage of groundwater. More specifically, storativity is the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in head (Fetter, 1994). In unconfined aquifers, the storativity is approximately equal to the specific yield. Therefore, as most of the published sources consulted for this

HCM provide information on specific yield this portion of the report discusses specific yield as a close approximation of storativity in the unconfined aquifer.

Hydraulic conductivity is the rate at which water can move through a permeable medium, and the transmissivity is the amount of water that can be transmitted horizontally by the full saturated thickness of the aquifer under a hydraulic gradient of one. These two properties are related in that transmissivity is the hydraulic conductivity multiplied by saturated aquifer thickness, thus the following discussion focuses on transmissivity values alone as a representation of both these characteristics.

Specific Yield of the Deposits

The water storage capacity or specific yield in the Madera Subbasin area are related to soil textures which are determined by geomorphic units. Davis et al. (1959), DWR (2006), and Mitten et al. (1970) provide estimates of specific yields in the Madera area based on texture of the deposits. These estimates of specific yield are based on deposit descriptions (texture), electric logs, laboratory analysis of soils samples, and a relatively simple and transparent methodology.

Davis et al. (1959) sorted classification of materials from drillers logs into five major groups and assigned specific yields to each based on results of previous studies conducted on samples collected in California. The assigned specific yield values range from 3% for clay deposits to 25% for medium to coarse sand and gravel deposits. For the San Joaquin River storage unit, including the San Joaquin River alluvial plain and the valley plain west of Madera, the average specific yield from 10 to 200 feet bgs is 11.9% (Davis et al., 1959). Davis et al. (1959) also includes a table of estimated groundwater storage capacity units, by township subunits, sorted by depths of 10 to 50, 50 to 100, and 100 to 200 feet. NSWDGSA spans two townships: T11S R15E and T12S R15E. From shallow to deep, both townships have specific yields of 8.3%, 13.3% and 14.8% listed. These values are summarized in **Table 3-1**.

Mitten et al. (1970) report water bearing properties based on USGS laboratory analyses of surface samples of both older and younger alluvium in their Madera study area. The results show that specific yields are highly variable in the older alluvium and the younger alluvium is more permeable. Specific yields for older alluvium ranged from 0.5% to 22.4% in silts and 14.0% to 23.4% in sands. In the younger alluvium specific yields were higher, ranging from 18.8% to 32.8% in silts and 17.7% to 39.0% in sands. DWR (2006) estimates the average specific yield of the Madera Groundwater Subbasin is 10.4%. Davis et al. (1959) estimated specific yield for three depths by Township, which for the District area (Townships T11S and 12S, Range 15E). Williamson et al. (1989) also estimated specific yield for deeper than 150 feet to greater than 600 feet. From his study specific yield for the District area for a depth range of 200 feet to 300 feet can be estimated at 11.0%. Specific yield values at the depths of groundwater fluctuation in the NSWD are as summarized in **Table 3-1**.

Table 3-1 Summary of Specific Yield Estimates from Davis et al. (1959) & Williamson et al. (1989)

Township	Estimated Specific Yield (percent)				
	10-50 feet	50-100 feet	100-200 feet	200-300 feet	All zones
T11S R15E	8.3%	13.3%	14.8%	10-11%	13.0%
T12S R15E	8.3%	13.3%	14.8%		13.0%

Transmissivity

Estimates of and transmissivity are available from published sources including Davis, Lofgren and Mack (1964) and Provost & Pritchard (2008). Davis et al. (1964) provide information for numerous short-term pump tests in the area and provide specific capacity (discharge in gallons per minute [gpm] divided by drawdown) by township. Thomasson et al. (1960) developed an empirical relationship between specific capacity and transmissivity, which is also discussed by Driscoll (1986) and more recently by Abbott (2015).

Transmissivity can be approximated by multiplying specific capacity by a factor of 1,500 for unconfined aquifers and 2,000 for confined aquifers. At the time that these studies were done, it is likely that most wells in the San Joaquin Valley were shallow and open bottom, and the resultant transmissivities are probably more valid for the shallower portion of the aquifer comprised of the Older Alluvium. In general, transmissivity values are higher for the older alluvium than the underlying deposits. Transmissivity values can also be high in paleo channel deposits and low in deposits dominated by floodplain clays.

Short-term pump tests performed by PG&E in the San Joaquin Valley have been compiled by the USGS (Davis et al., 1964). For the two townships NSWDGSA falls within, the average discharge rate and specific capacity for T11S/R15E was 1,176 gpm and 81 gpm per foot (gpm/ft) respectively, and for T12S/R15E the discharge was 1,813 gpm with a specific capacity of 104 gpm/ft. Using the common conversion factor of 1,500 for unconfined aquifer conditions, the aquifer transmissivities would be 121,500 gallons per day per foot (gpd/ft) and 156,000 gpd/ft for T11S/R15E and T12S/R15E, respectively. These are likely pump tests of wells screened above the Corcoran Clay. These are relatively high numbers commonly found in the better portions of the aquifers of the San Joaquin Valley.

Pump tests conducted on wells within NSWDGSA were used to produce specific capacity and transmissivity values (Provost & Pritchard, 2008). With 26 wells tested, specific capacities ranged from 15 to 123 gpm/ft with an average of 41 gpm/ft. Transmissivity values ranged from 22,500 to 184,400 gpd/ft with an average of 44,000 gpd/ft. The wells are generally screened above the Corcoran Clay in the Older Alluvium. Summaries of the characteristics of the wells analyzed by Provost & Pritchard (2008) are in **Table 3-2** and estimated transmissivities in **Table 3-3.**

Table 3-2 NSWDGSA Well Characteristics and Pump Test Results (Provost & Pritchard, 2008)

Description	Units	Range	Average
Groundwater Depth	feet	51 - 110	76
Well Depth	feet	210 - 597	365
Well Diameter	inches	14 - 16	16
Pump Depth	feet	120 - 242	181
Pump Power	horse power	40 - 125	78
Specific Capacity	gpm/ft	15 - 123	41
Transmissivity	gpd/ft	22,500 - 184,400	44,000

Table 3-3 Summary of Transmissivity Estimates

Publication	Estimate of Transmissivity (gpd/ft)	Description/Notes
Davis et al. (1964)	121,500 156,000	Averages for T11S/R15E and T12S/R15E, respectively.
Provost & Pritchard (2008)	44,000	Average based on pump tests conducted on NSWDGSA wells.

MERCED SGMA

Merced Groundwater Subbasin

GROUNDWATER SUSTAINABILITY PLAN

Image courtesy: Veronica Adrover/UC Merced

November 2019
Revised July 2022

Four additional cross sections were developed by Page (1977) more specifically for the City of Merced-City of Atwater area. The locations of these cross-sections are shown on Figure 2-18, with the cross sections shown on Figure 2-19 through Figure 2-22.

Figure 2-12: Location of Geologic Cross Sections (Page & Balding 1973)

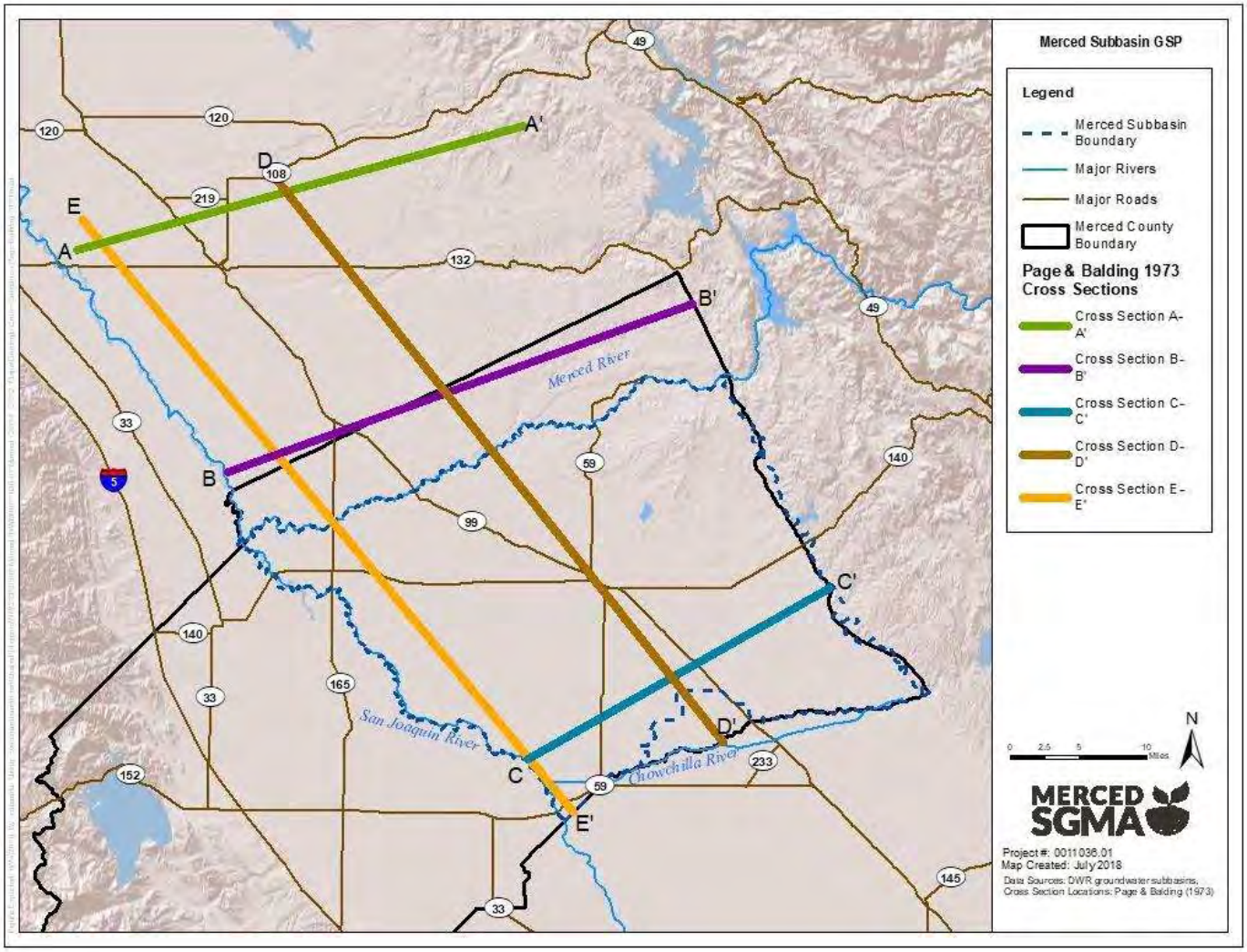
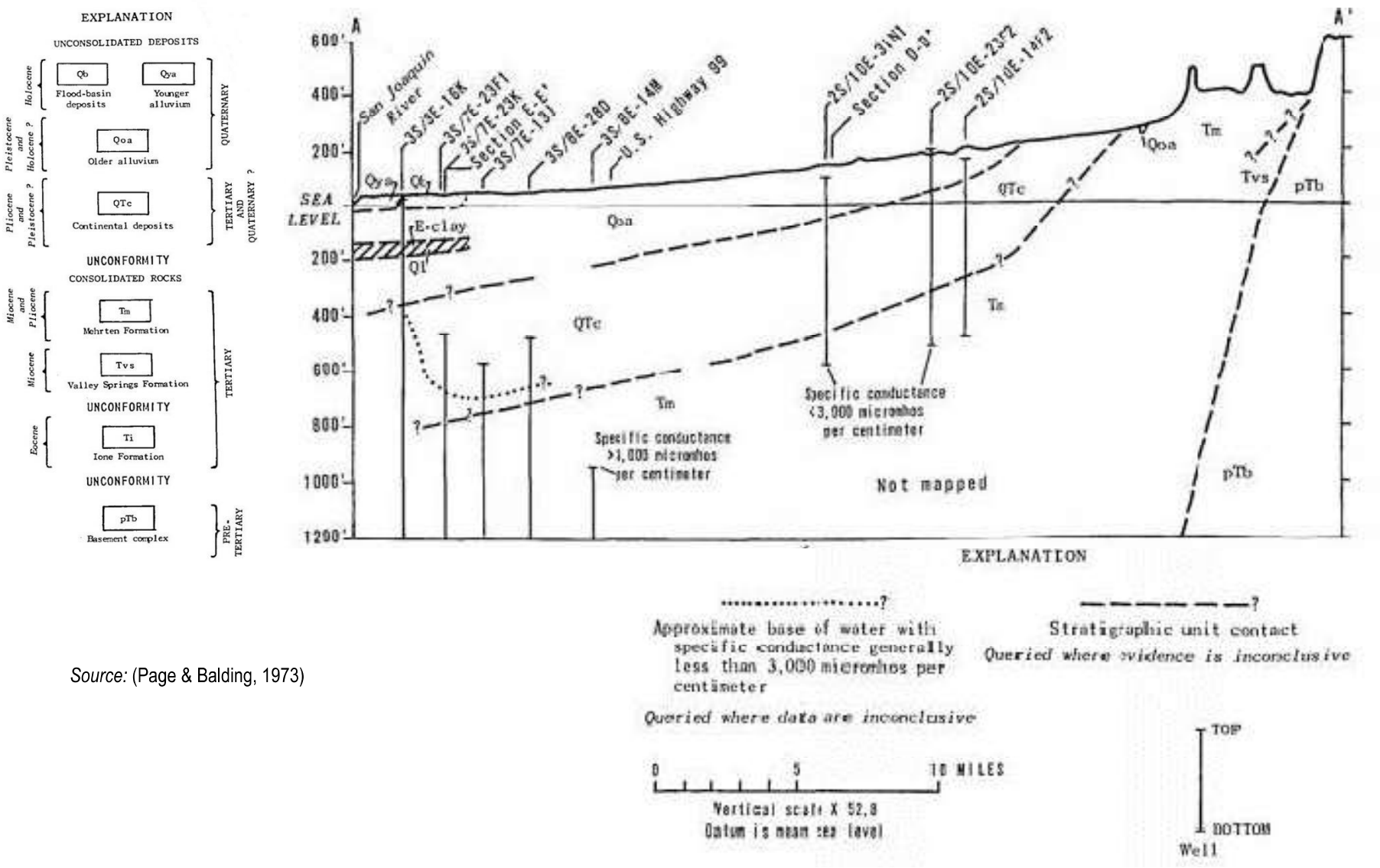
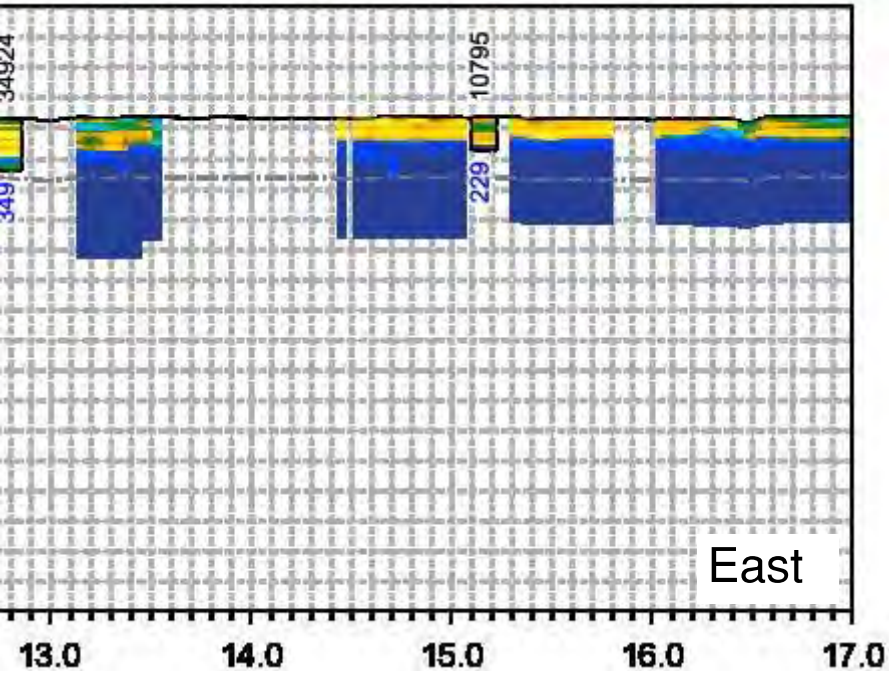


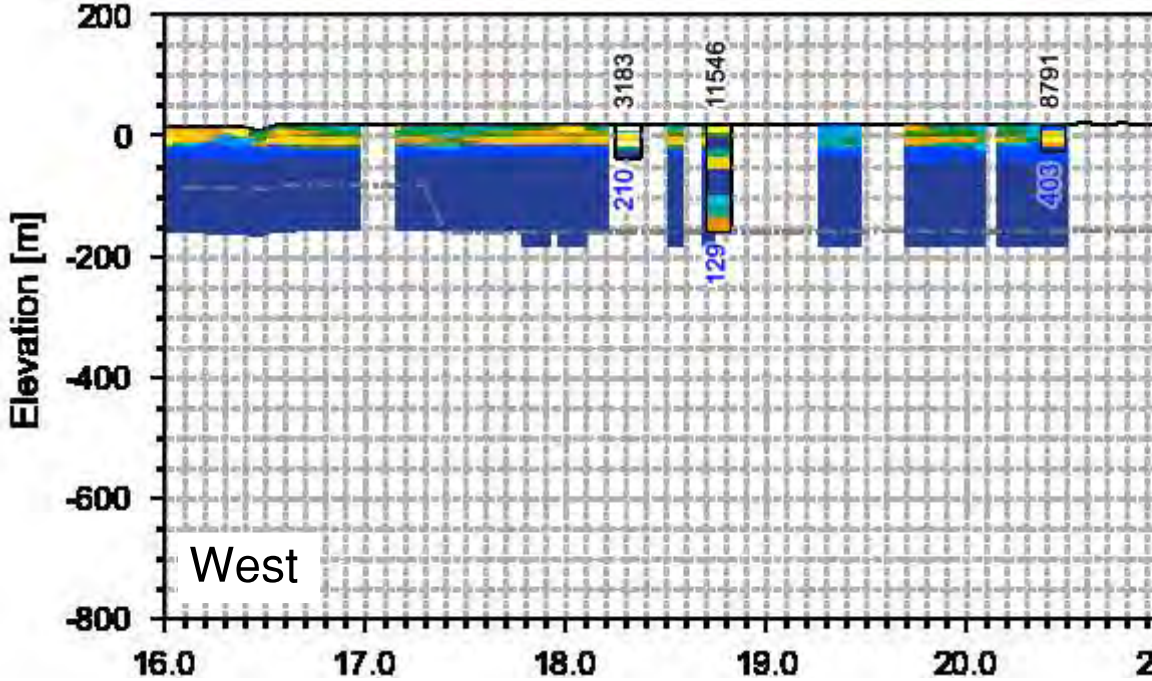
Figure 2-13: Geologic Cross-Section A (Page & Balding 1973)

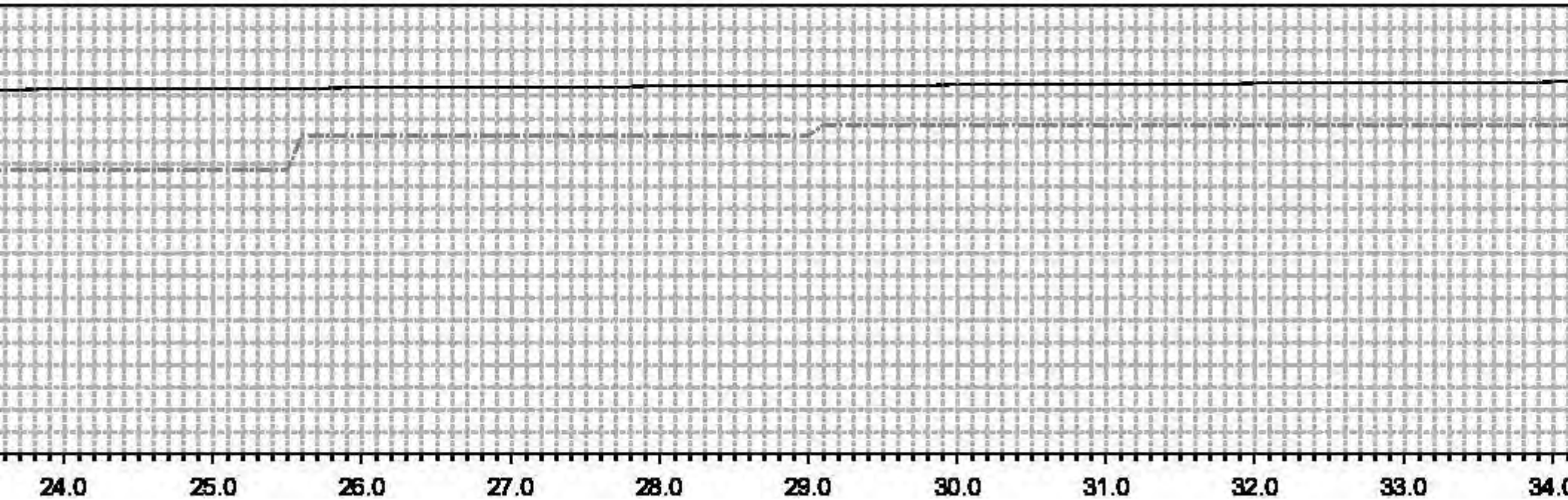


Source: (Page & Balding, 1973)

A - A' Nearest AEM Logs







A - A' Nearest AEM Logs

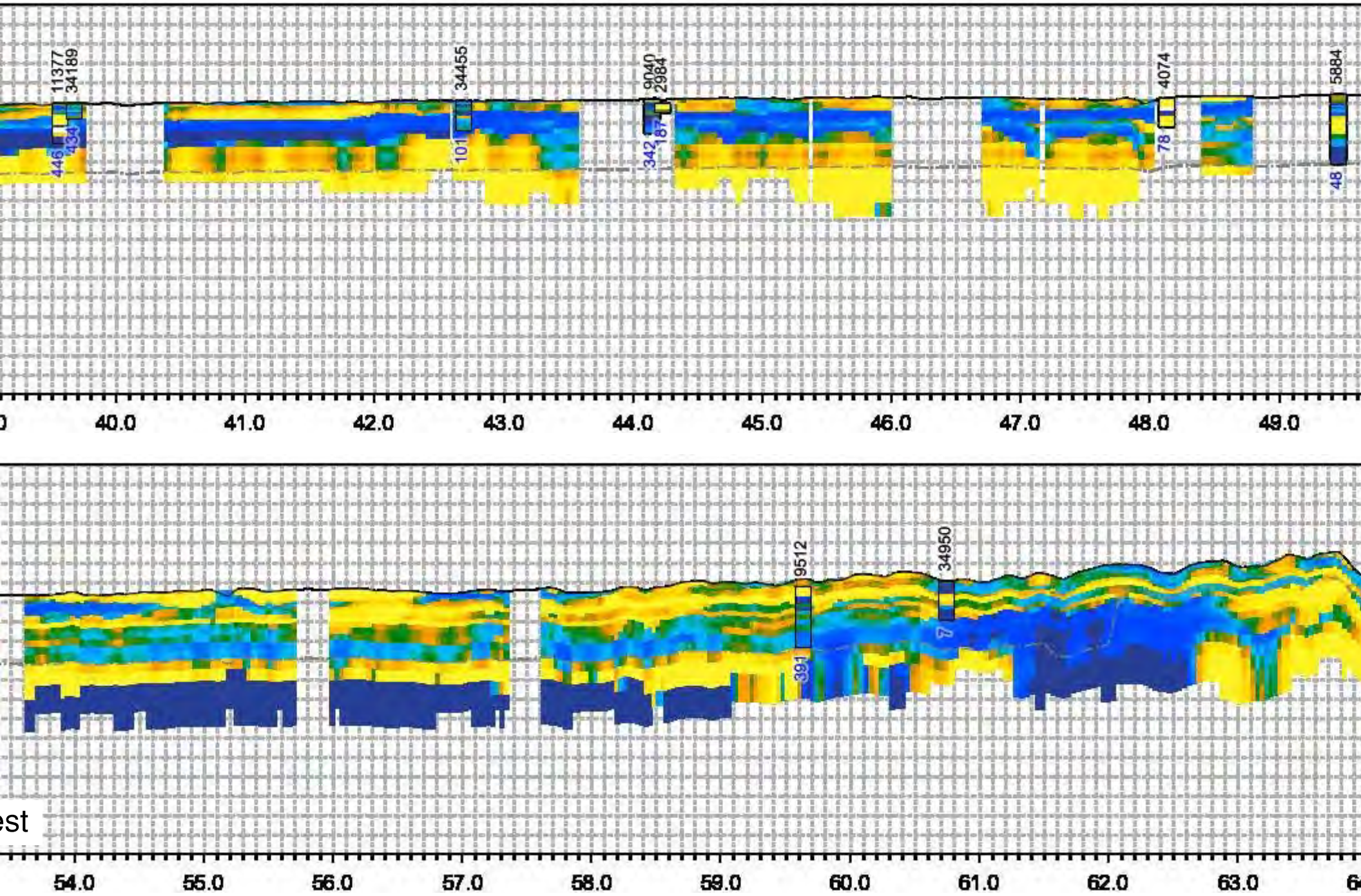
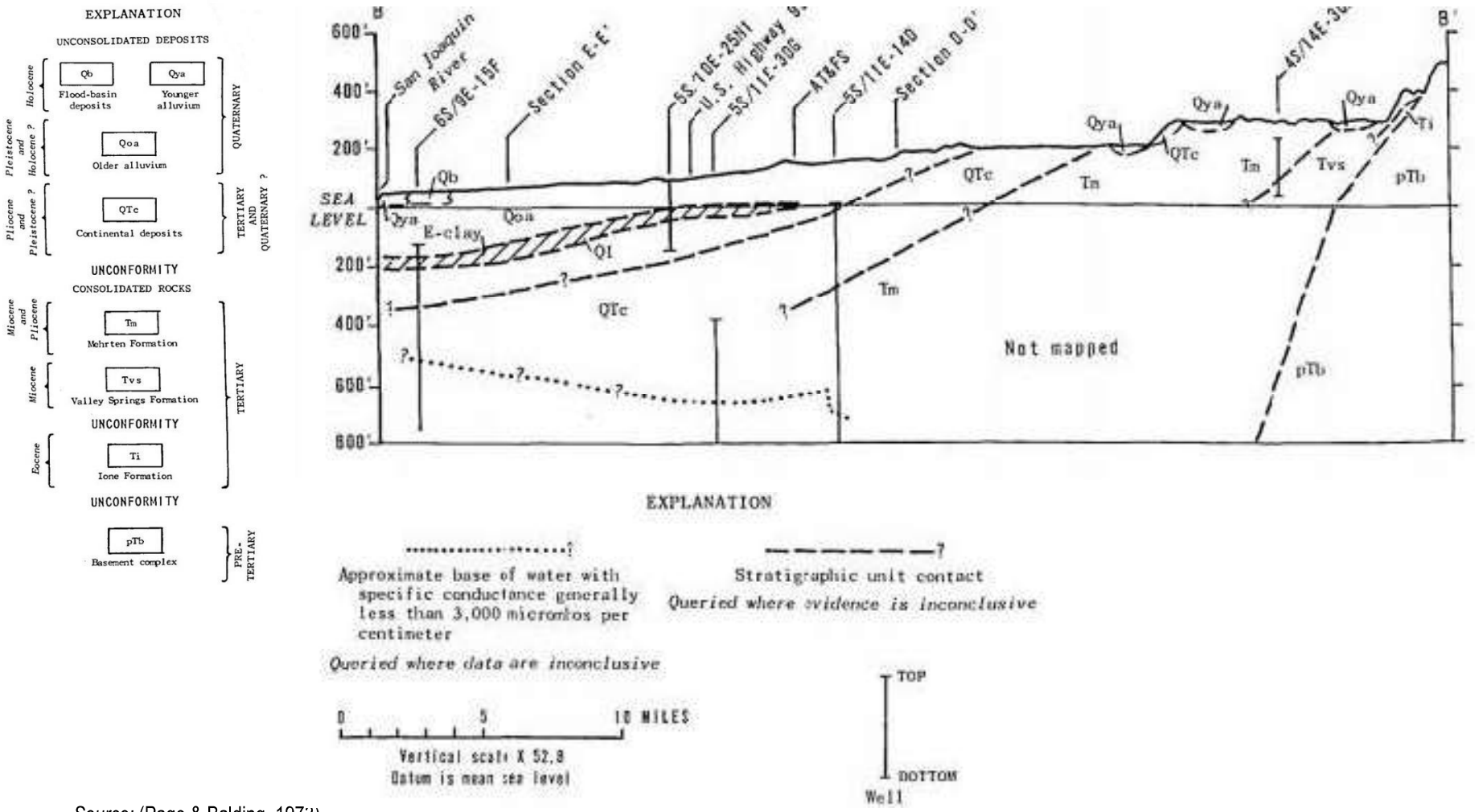
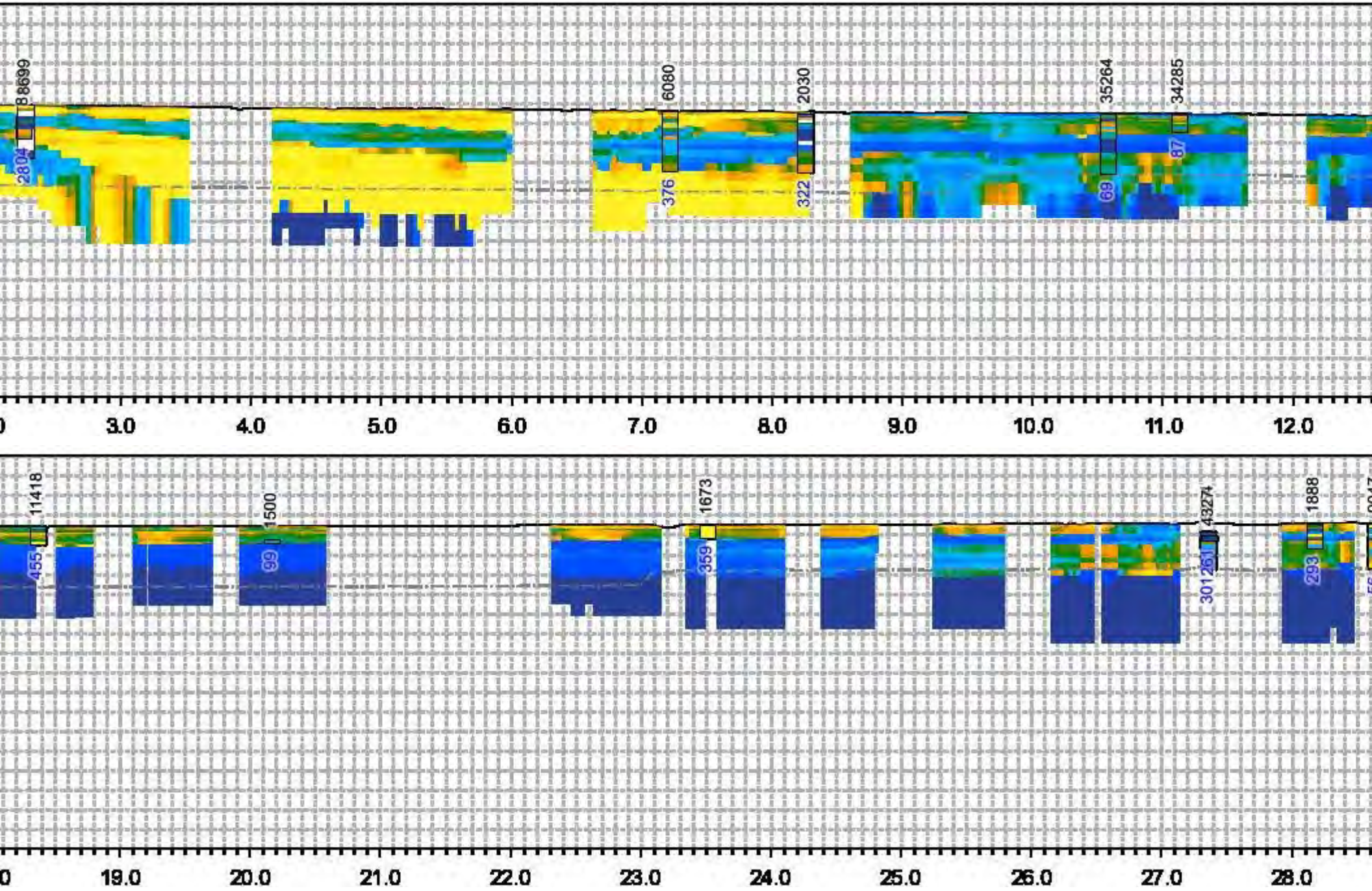


Figure 2-14: Geologic Cross-Section B (Page & Balding 1973)

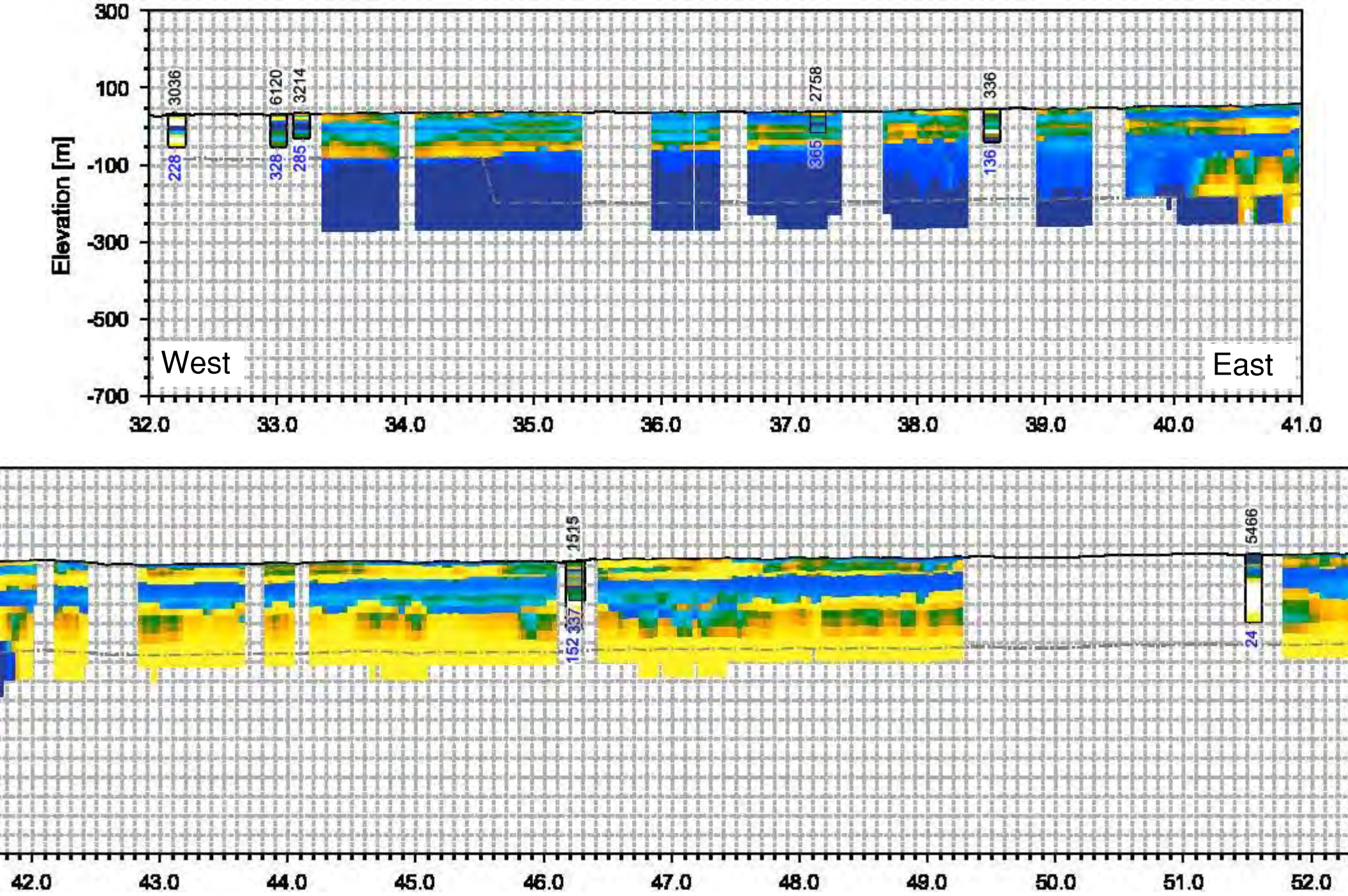


Source: (Page & Balding, 1973)

B - B' Nearest AEM Logs



B - B' Nearest AEM Logs



B - B' Nearest AEM Logs

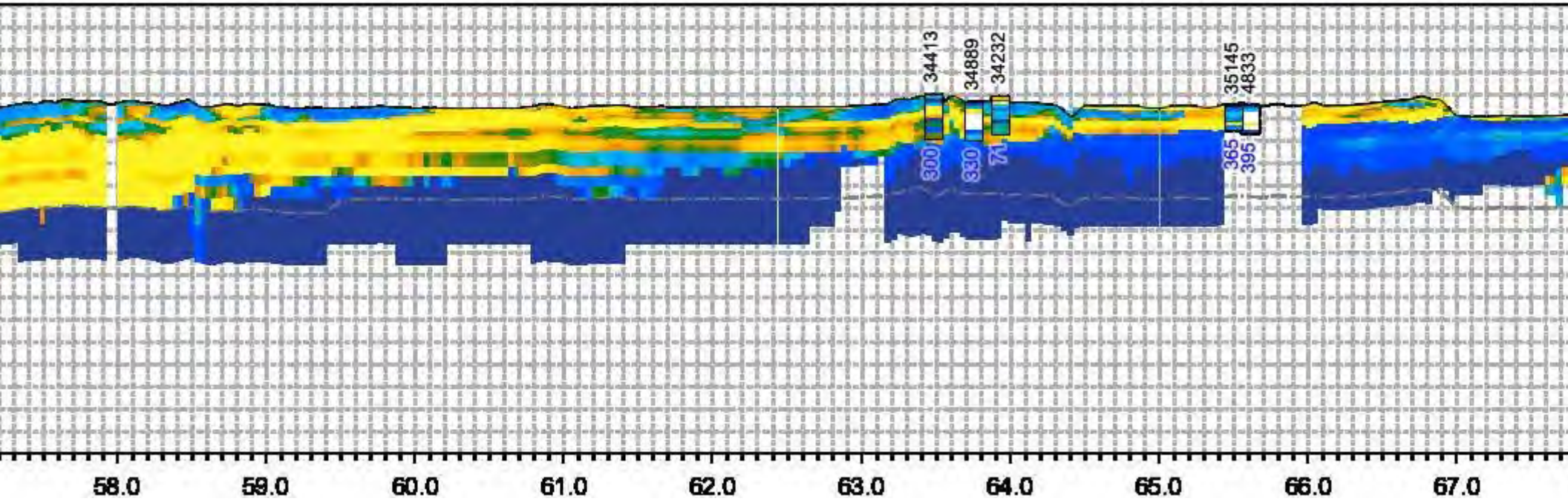
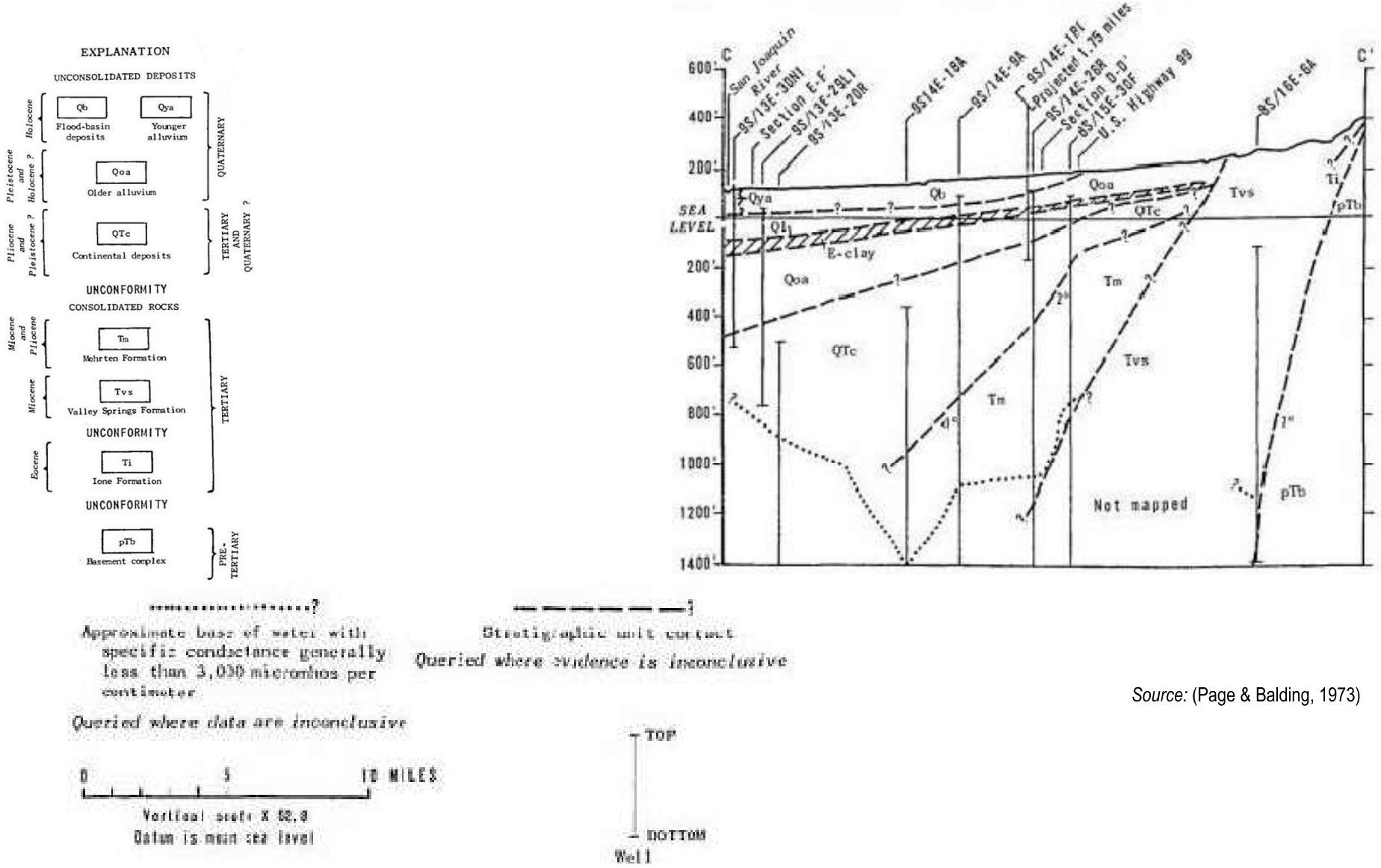
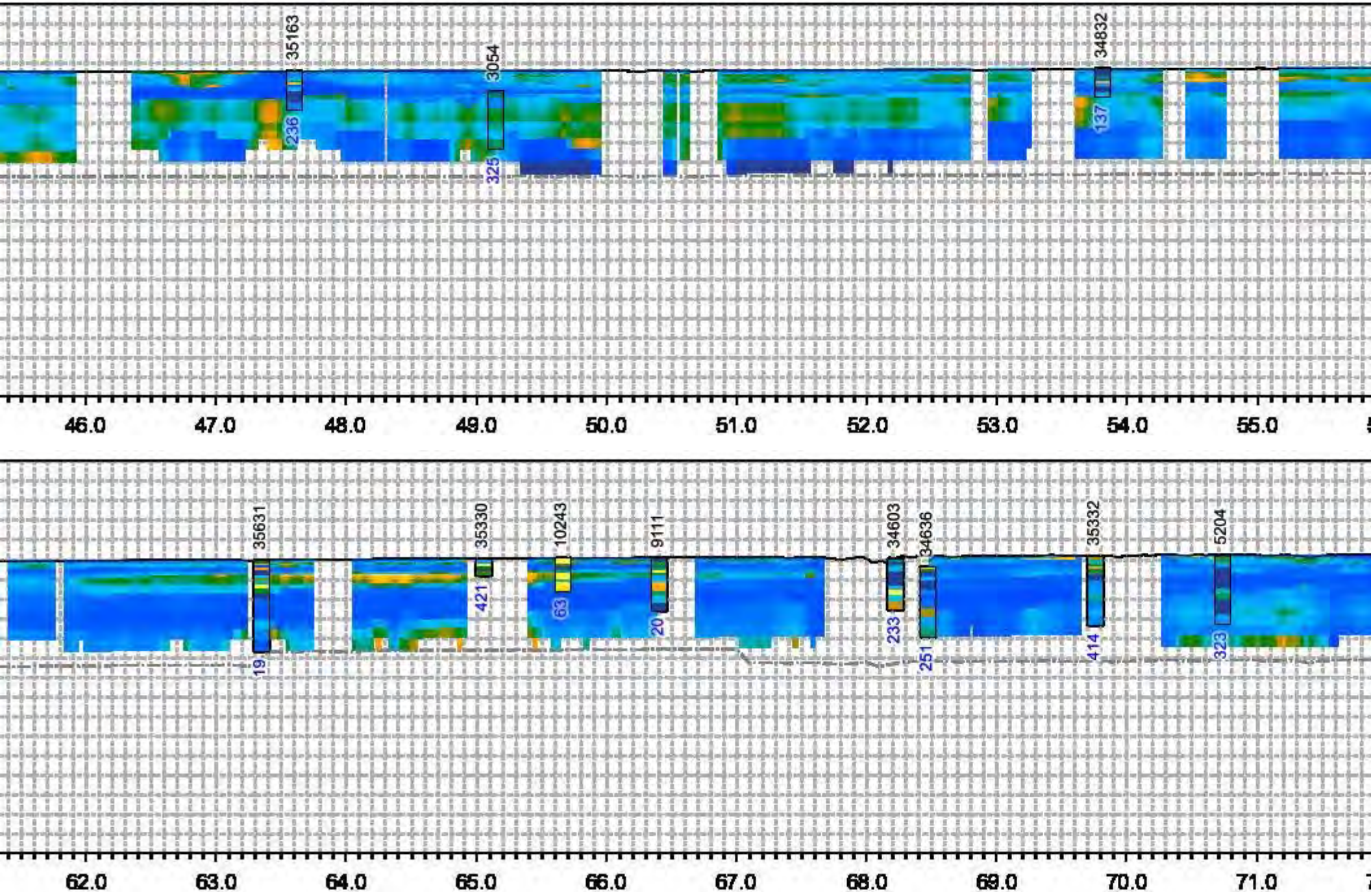


Figure 2-15: Geologic Cross-Section C (Page & Balding 1973)



Source: (Page & Balding, 1973)

C - C' Nearest AEM Logs



C - C' Nearest AEM Logs

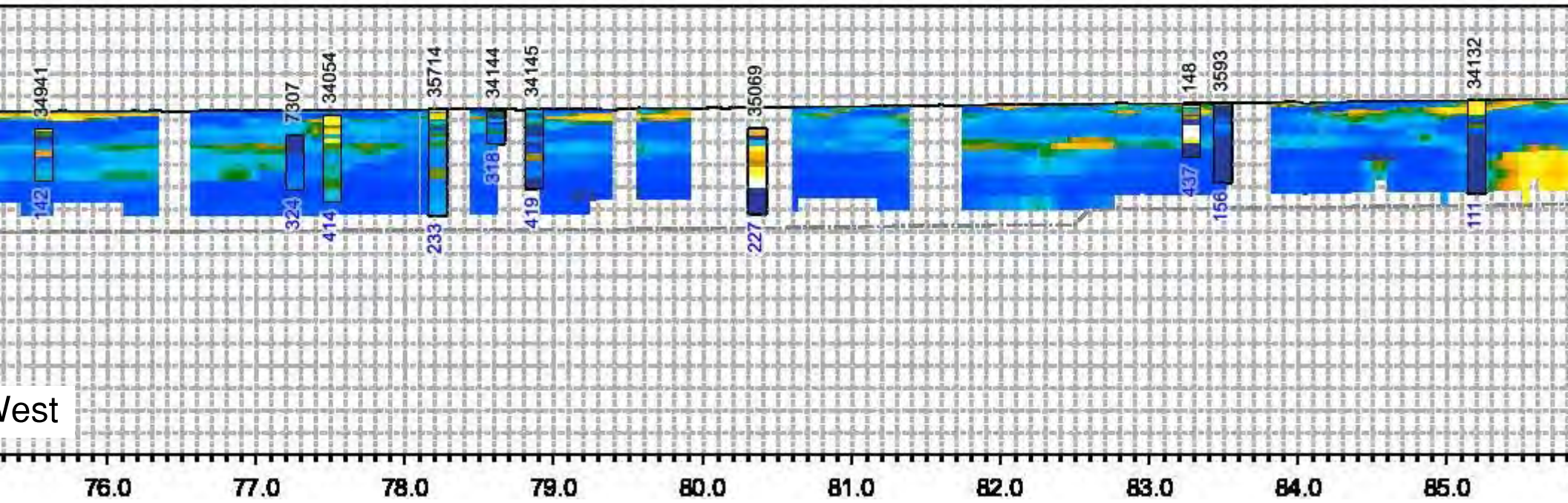
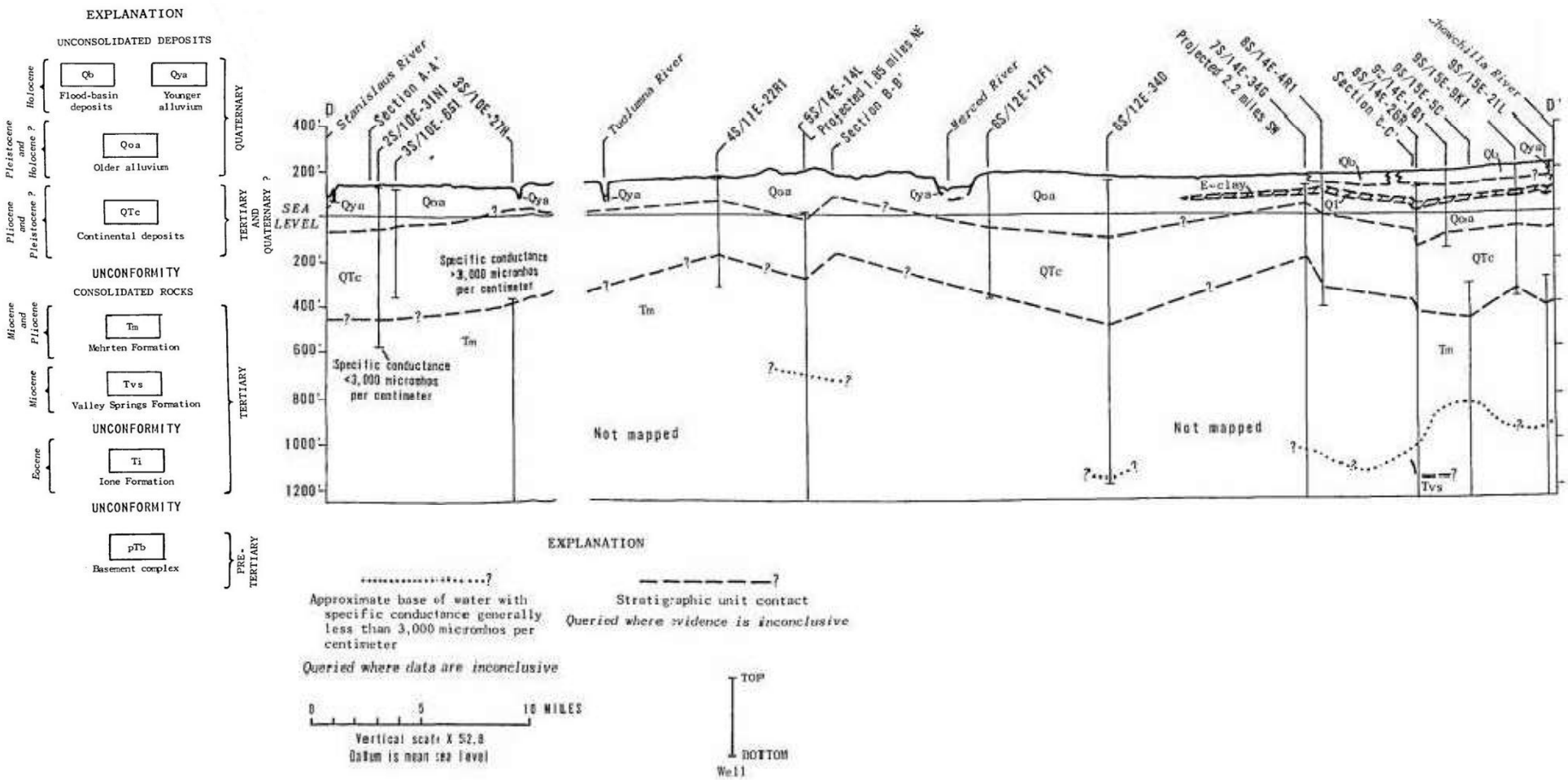
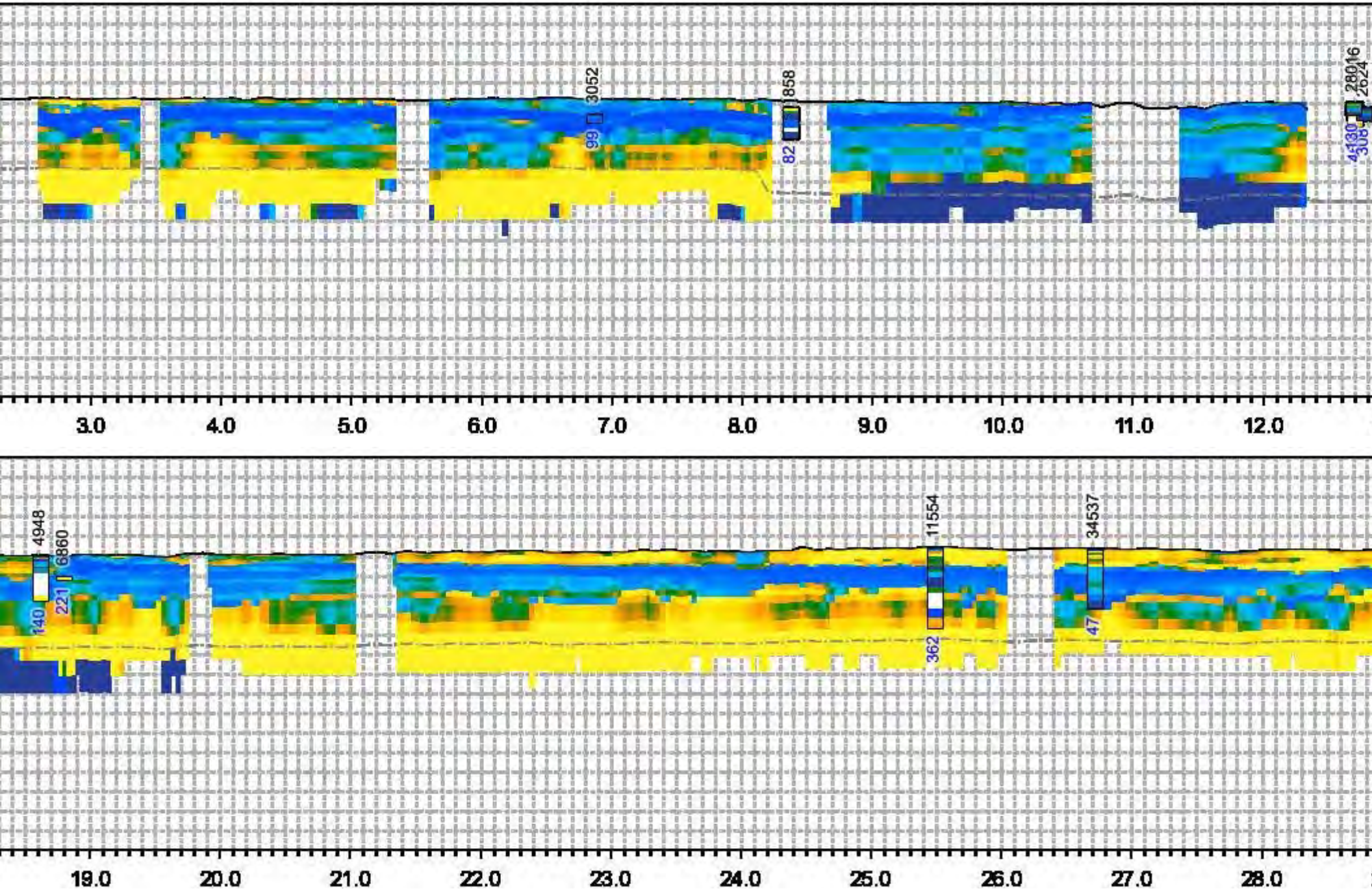


Figure 2-16: Geologic Cross-Section D (Page & Balding 1973)

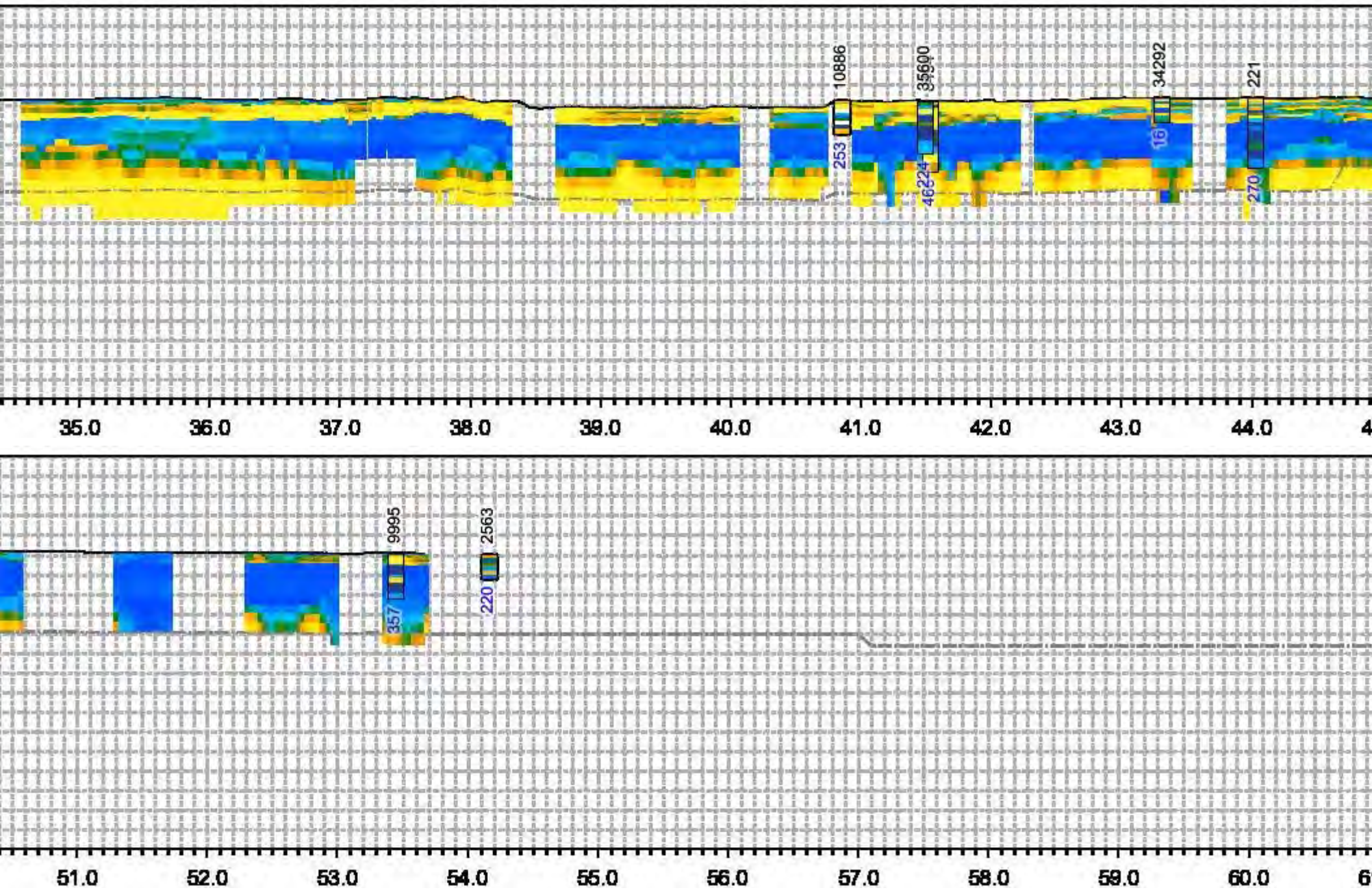


Source: (Page & Balding, 1973)

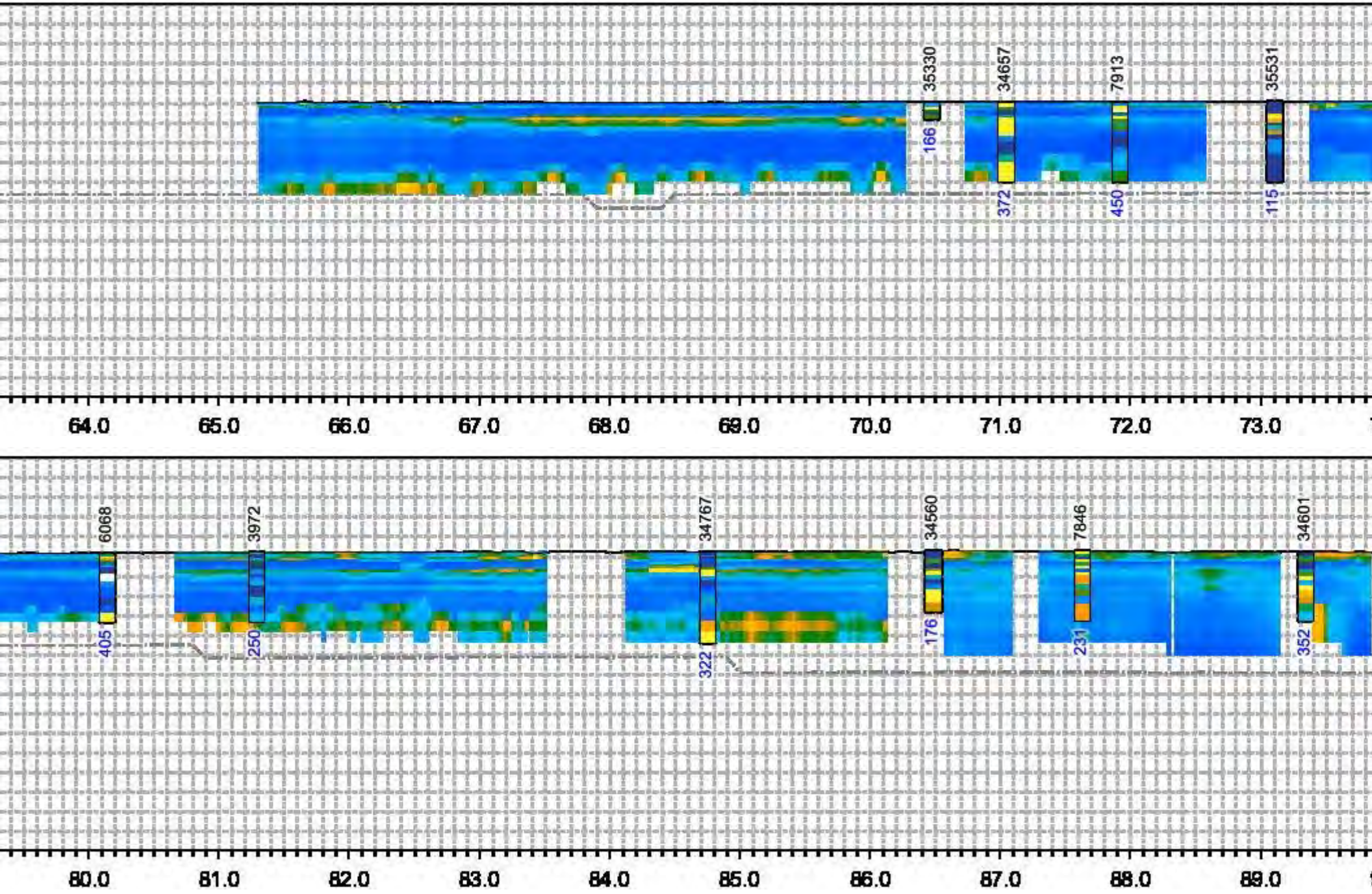
D - D' Nearest AEM Logs



D - D' Nearest AEM Logs

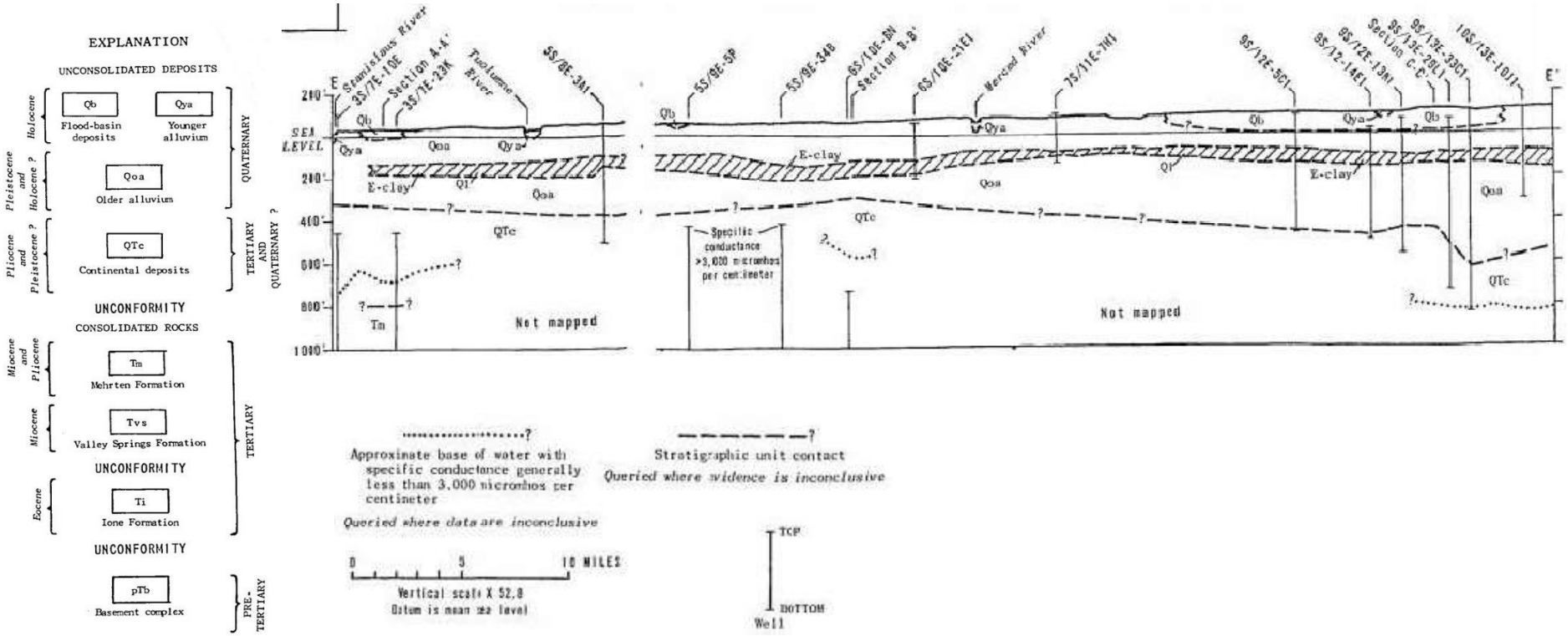


D - D' Nearest AEM Logs



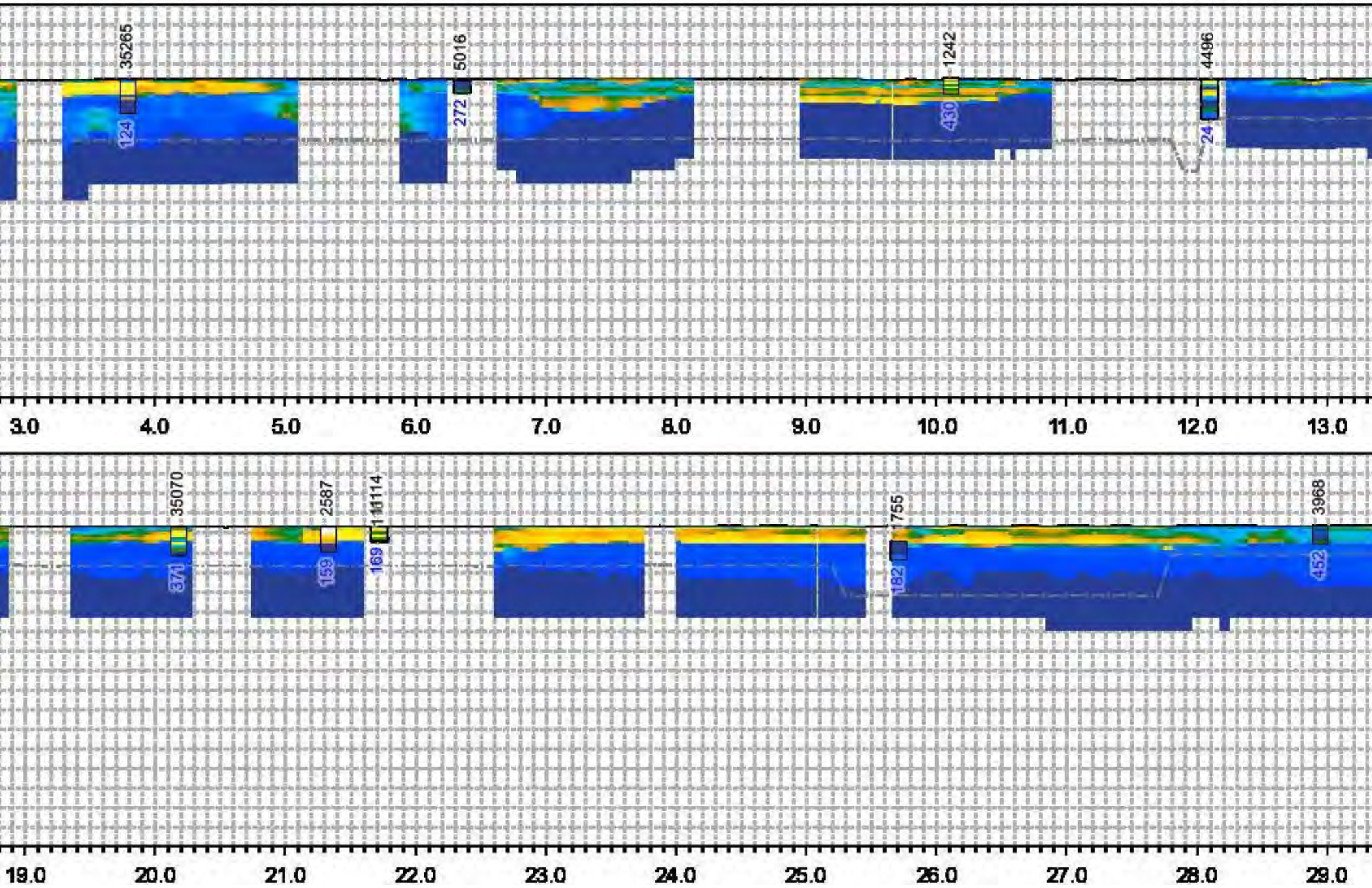
D - D' AEM Log is NOT continuous with previous AEM Log.

Figure 2-17: Geologic Cross-Section E (Page & Balding 1973)

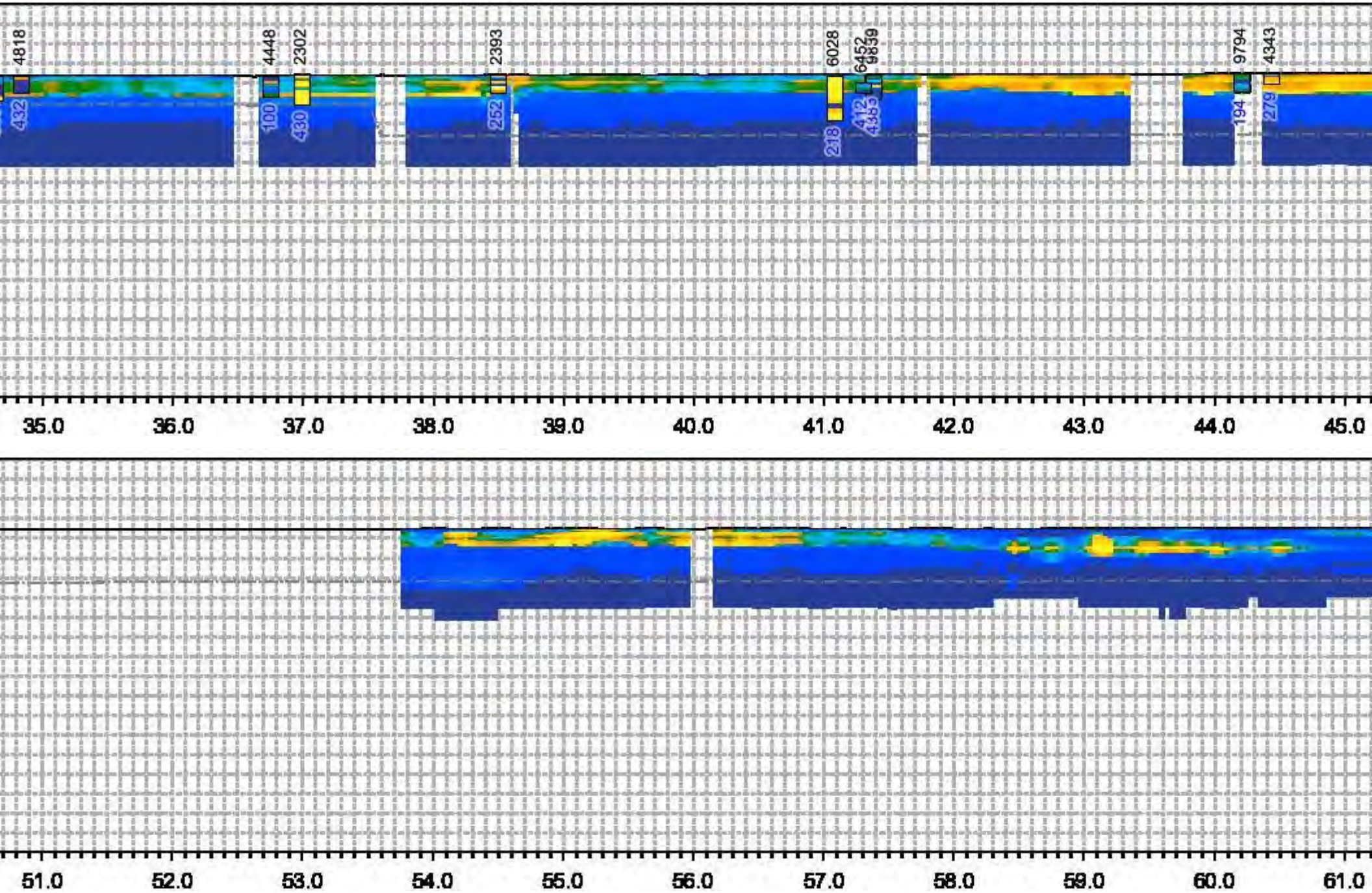


Source: (Page & Balding, 1973)

E - E' Nearest AEM Logs



E - E' Nearest AEM Logs



E - E' Nearest AEM Logs

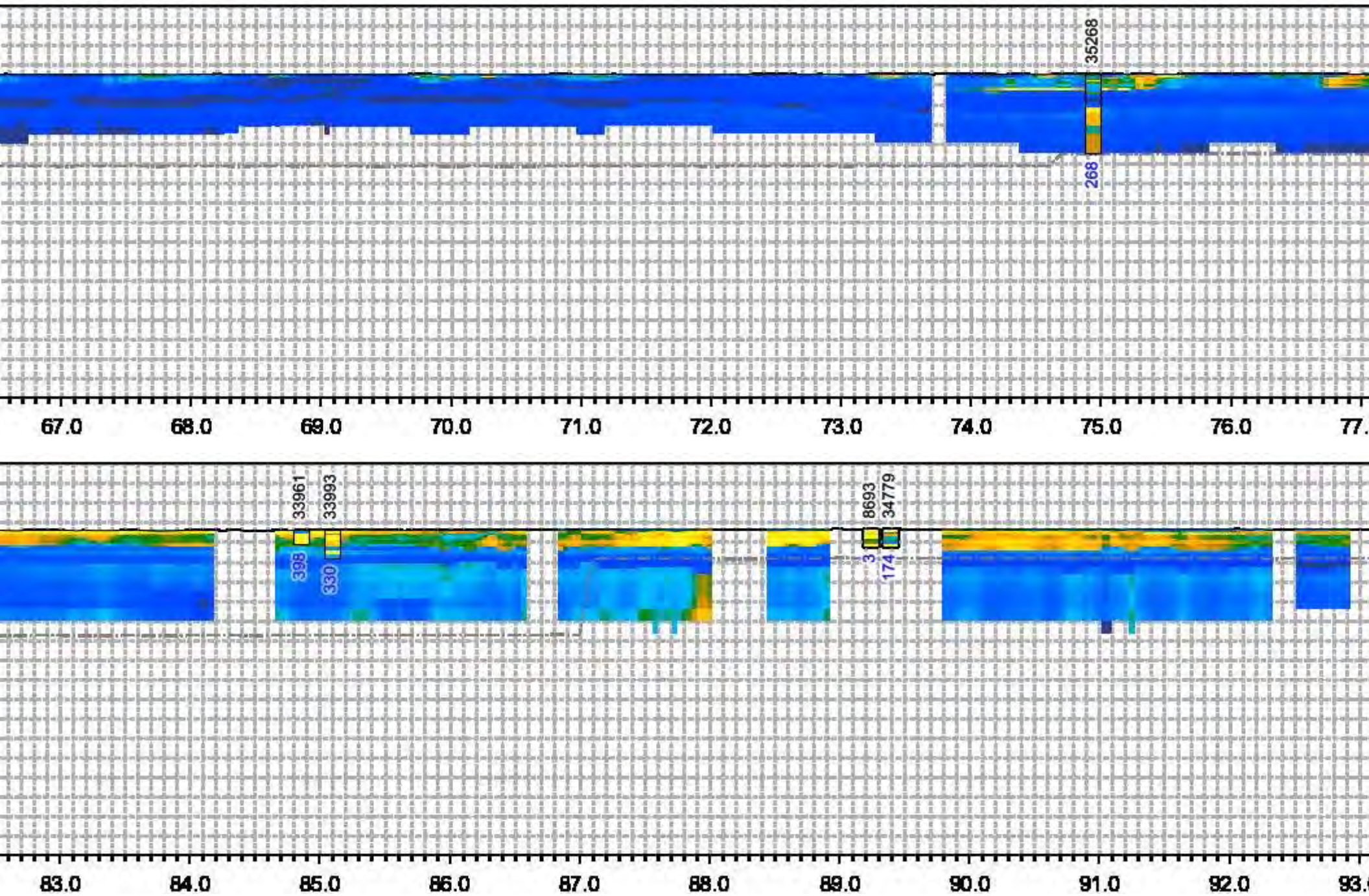


Figure 2-18: Location of Geologic Cross Sections (Page 1977)

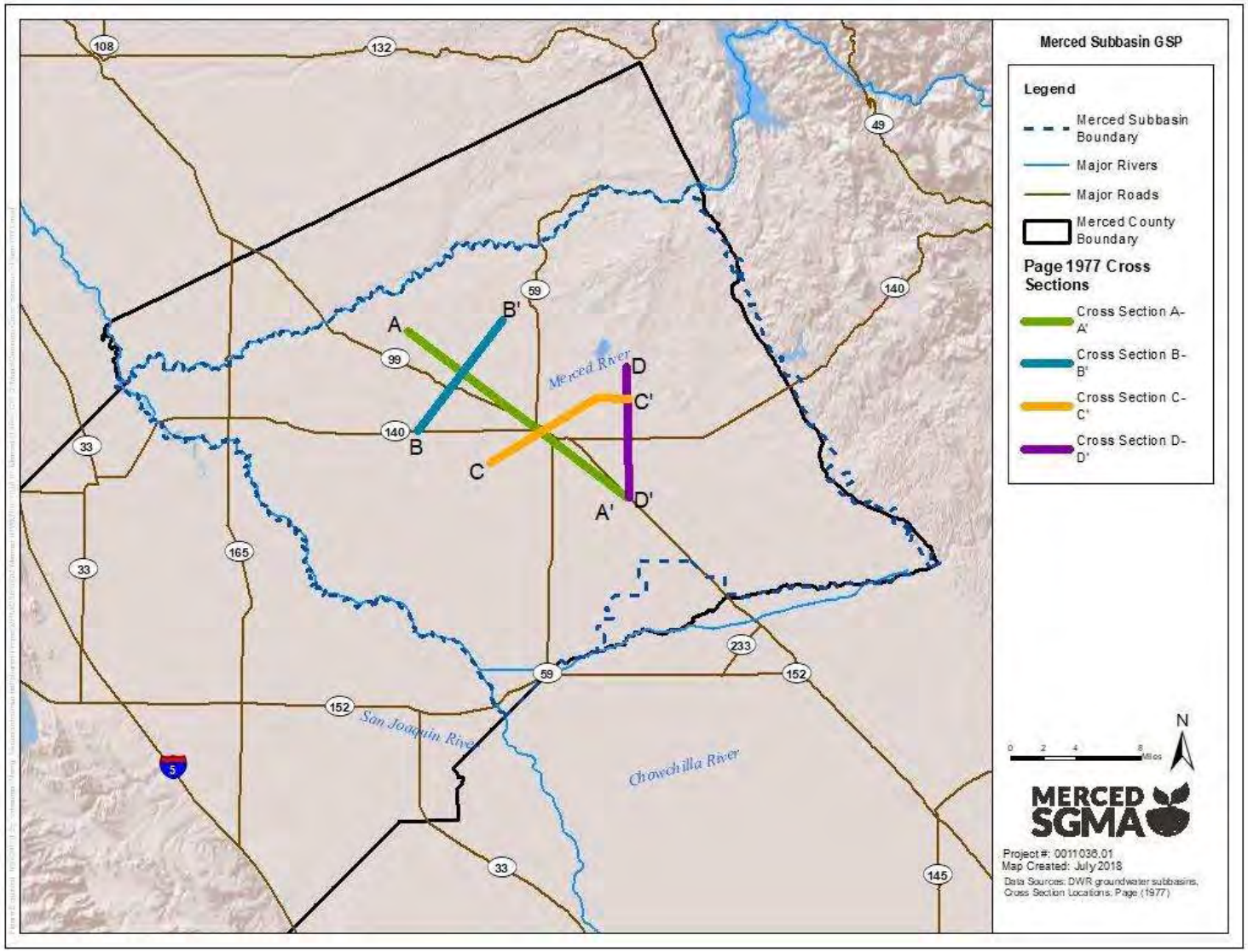
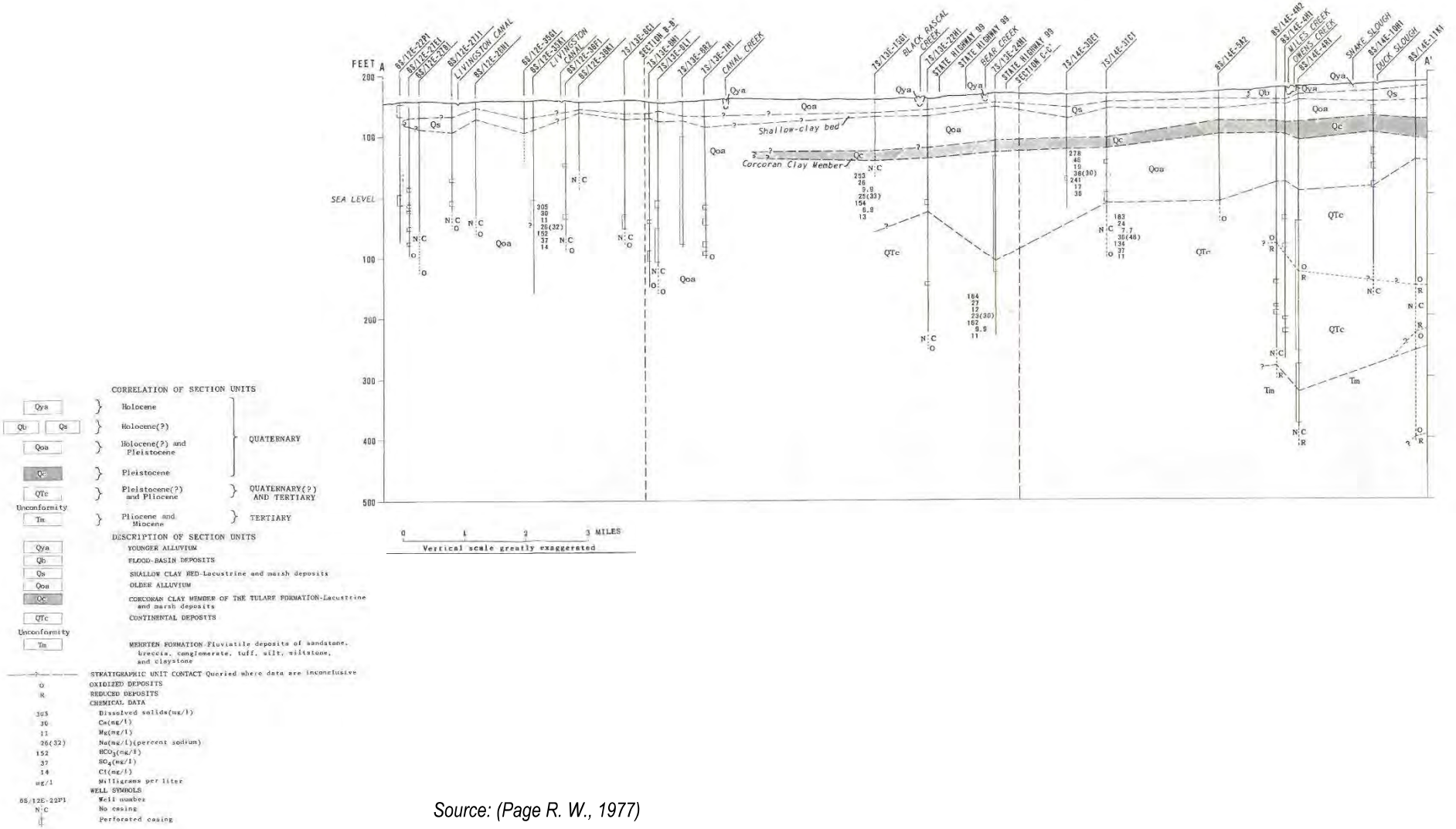
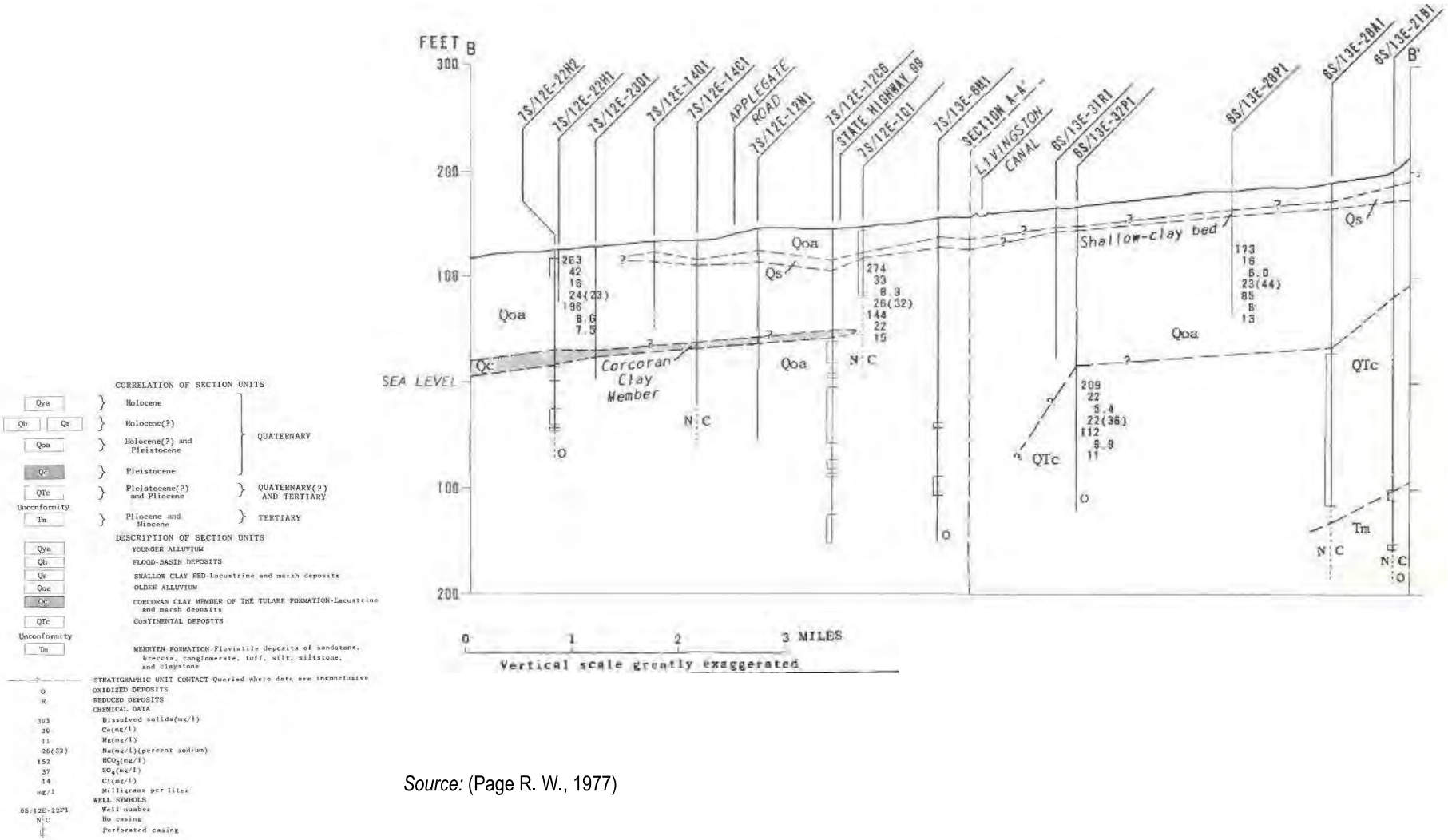


Figure 2-19: Geologic Cross-Section A (Page 1977)



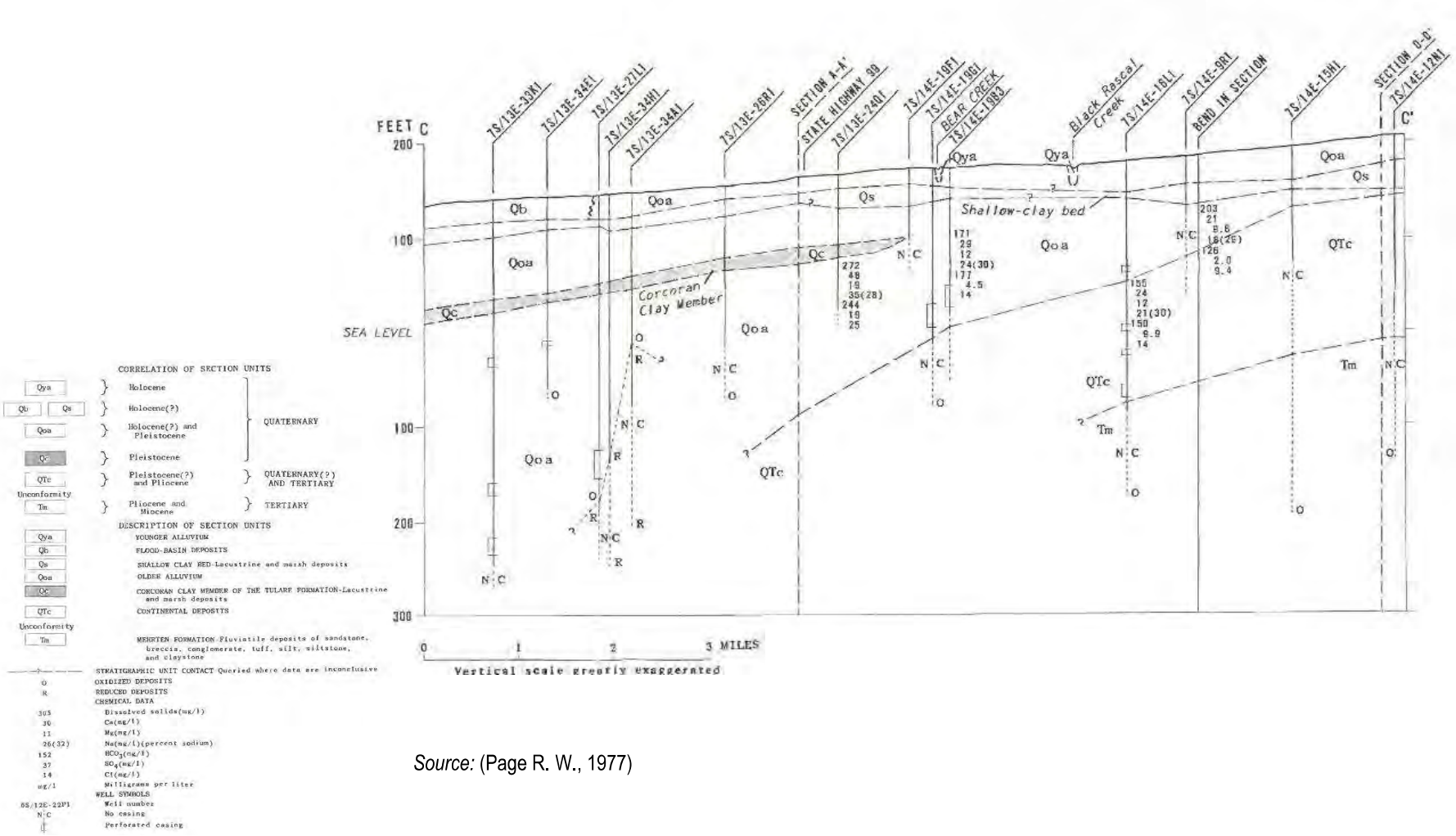
Source: (Page R. W., 1977)

Figure 2-20: Geologic Cross-Section B (Page 1977)



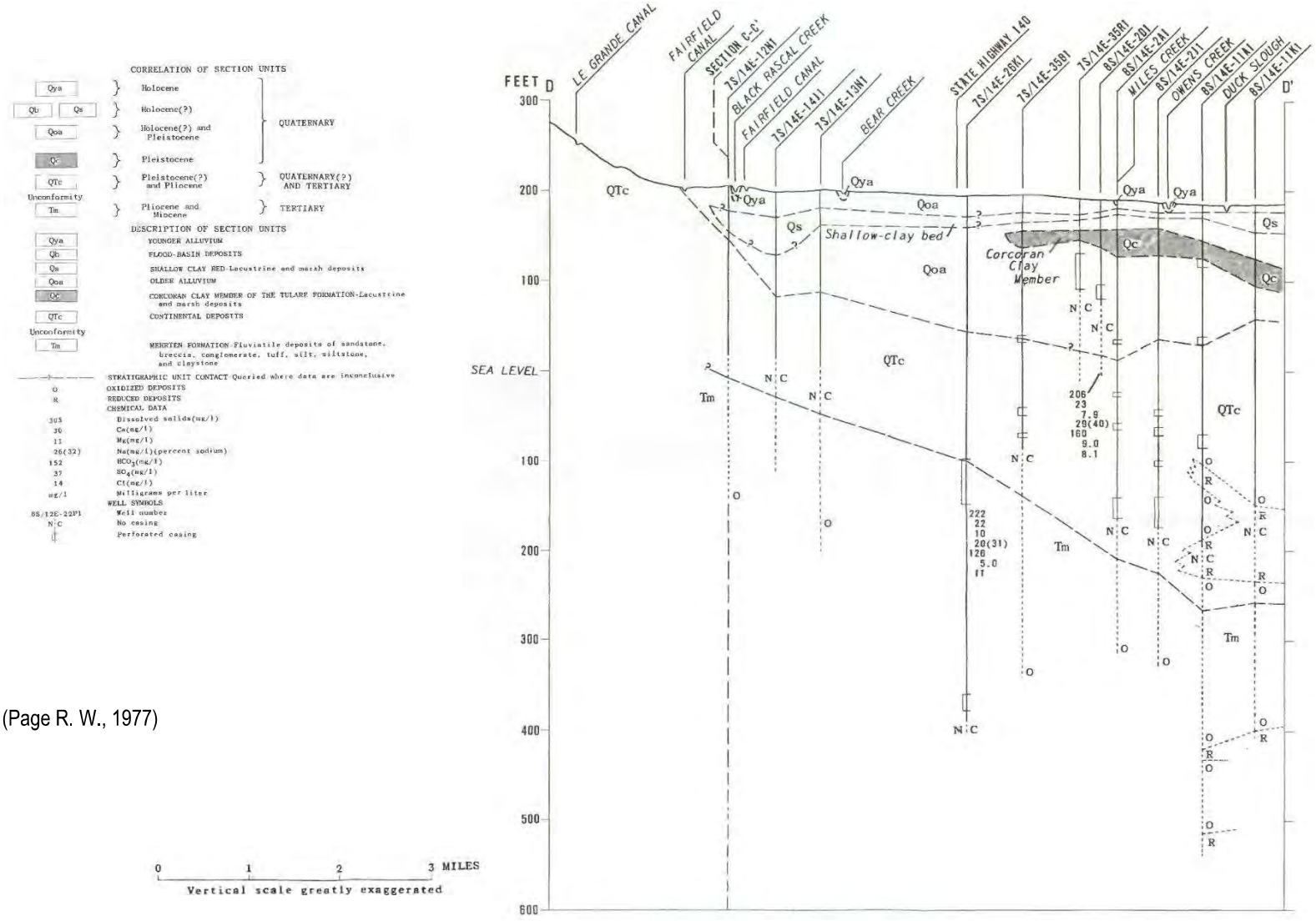
Source: (Page R. W., 1977)

Figure 2-21: Geologic Cross-Section C (Page 1977)



Source: (Page R. W., 1977)

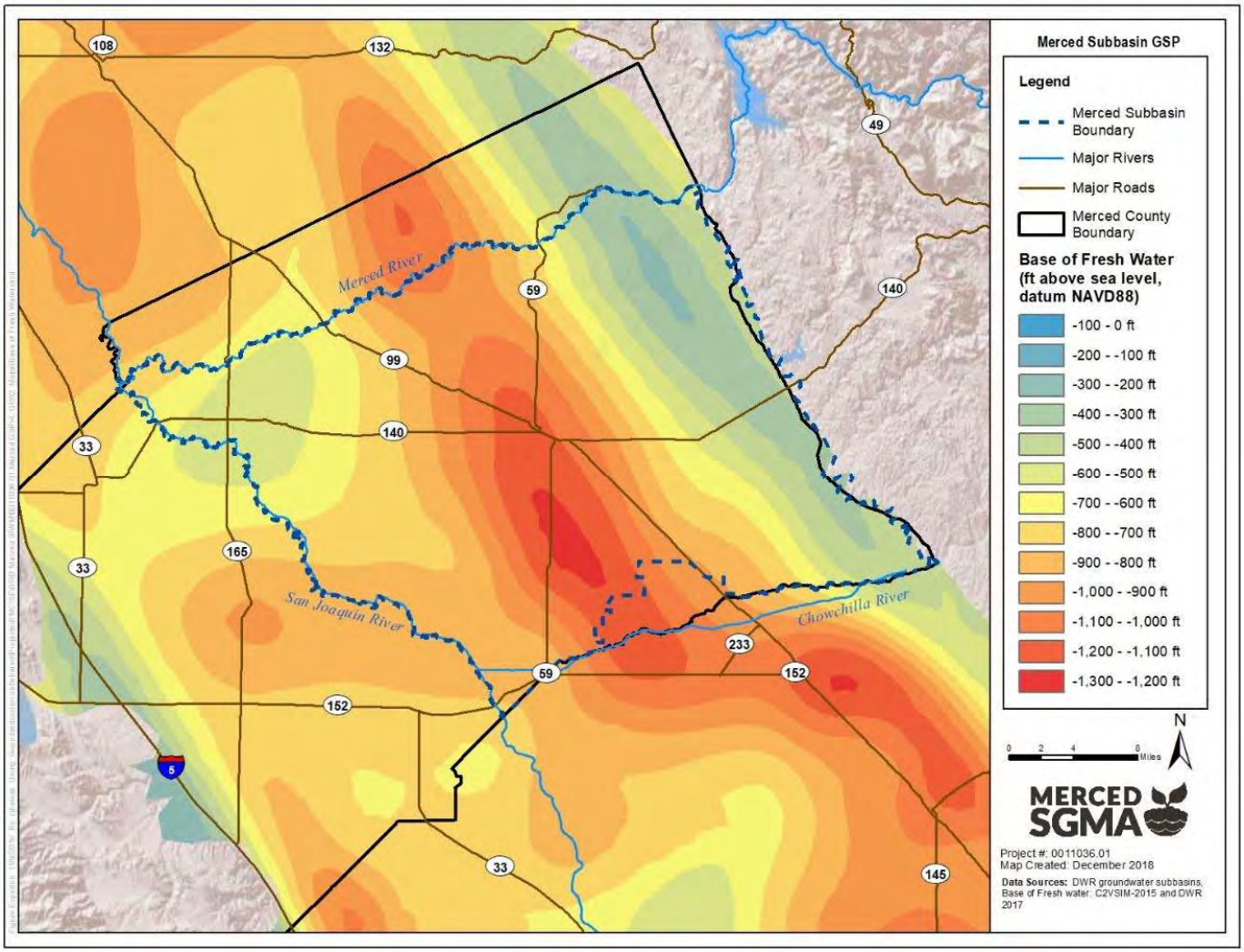
Figure 2-22: Geologic Cross-Section D (Page 1977)



Source: (Page R. W., 1977)

A well depth analysis completed in March 2018 found that, based on information in Merced County's well permit database, 56 wells (approximately 4% of wells with data) extended below the bottom of the basin as defined above, primarily located along the central portion of the County just east of the San Joaquin River (Woodard & Curran, 2018b). The quality of water produced from these wells is not known, and no data are available to show that the wells are actively used.

Figure 2-28: Base of Fresh Water



2.1.7 Principal Aquifers and Aquitards

There are five different aquifer systems identified in the Subbasin based on their differing geologic history and hydrogeologic characteristics. These systems have been modeled in the MercedWRM. The systems interact with each other throughout the Subbasin but are separated in some areas by the presence of the confining Corcoran Clay layer. Based on these interactions and for the practical purpose of developing and implementing this GSP, the five aquifer systems have been combined into three pertinent Principal Aquifers and are described further in the sections below.

2.1.7.1 Aquifer Systems in the Basin

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

In addition to the descriptive information from the Merced Groundwater Management Plan, the MercedWRM (see Appendix D) provides information on aquifer characteristics by aggregating available data and calibrating selected characteristics to closely match observed and simulated groundwater elevation and streamflows. The model uses five distinct fresh-water aquifer layers, one saline aquifer, and two confining units. The fresh water aquifer layers correspond closely with the aquifer formations described below from the Merced Groundwater Management Plan.

Hydraulic conductivity, specific storage, and specific yield are three aquifer parameters that describe physical characteristics of aquifers that are important for groundwater modeling.

Hydraulic conductivity is defined and mapped separately for each aquifer layer (Figure 2-29 through Figure 2-33

). Hydraulic conductivity is a numeric characteristic of an aquifer that describes the ease with which groundwater moves through pore spaces or fractures in soil or rock.

During a sensitivity analysis in which changes in aquifer parameters were compared against modeled groundwater level outputs, specific storage (Figure 2-34) and specific yield (Figure 2-35) were determined to not vary significantly between aquifer layers and thus are defined across the entire Subbasin for all aquifer layers (Woodard & Curran, 2019). Specific storage describes the unit volume of water released or taken into storage per unit change in hydraulic head. It is a unitless quantity. Specific storage is a more important characteristic for unconfined aquifers (i.e., above the Corcoran Clay) and has less importance for confined aquifers (i.e., below the Corcoran Clay). Specific yield describes the unit volume released from the aquifer per unit change in head under the force of gravity.

These five aquifer systems are described from deepest to shallowest, and the following Section 2.1.7.2 describes the three principal aquifers to be used in this GSP based on the interactions of the five systems described below. Table 2-7 shows the relationship between MercedWRM layer, formation name, and principal aquifer name.

Fractured Bedrock - Along the eastern edge of the Merced Subbasin, wells have been completed within the Valley Springs and Ione Formations (Page & Balding, 1973), (Page R. W., 1977). The Ione Formation unconformably overlies the Sierra Nevada bedrock complex and is composed of marine to non-marine clay, sand, sandstone, and conglomerate. The Valley Springs Formation is composed of a fluvial sequence of rhyolitic ash, sandy clay, and siliceous gravel in a clay matrix. Wells in this system appear to be completed in fractured bedrock with limited and variable yields. Because of the limited extent (and poor yields) of the fractured bedrock aquifer, the fractured aquifer is not a significant source of water in the Merced Subbasin (AMEC, 2008).

Hydraulic conductivity is shown in Figure 2-29 as part of the MercedWRM Layer 5 which contains both the Valley Springs Formation portion of the Fractured Bedrock system where it underlies the Mehrten Formation as well as the Mehrten Formation itself (described below).

The Mehrten Formation - The Mehrten Formation outcrops over a large area in the Merced Subbasin. It is composed of fluvial deposits of sandstone, breccia, conglomerate, luff, siltstone and claystone. It contains a large amount of andesitic material, making it easy to distinguish. Many water supply wells in the eastern portion of the Merced Subbasin penetrate the formation, and it is a significant source of groundwater. Where the Mehrten occurs beneath the Corcoran Clay, it is considered a confined aquifer. Where the Mehrten does not underlie the Corcoran Clay, there is insufficient data to determine the degree of confinement of the formation (AMEC, 2008).

Laboratory and field tests made by the United States Army Corps of Engineers (USACOE) and DWR in other areas indicate a range in hydraulic conductivity in the Mehrten Formation range from 0.01 to about 67 ft/day. Yields from the Mehrten, therefore, can be expected to differ greatly from place to place and at different depths. Based on another DWR regional study, the Mehrten formation has a yield of about 1,000 gallons per minute (gpm) and a horizontal transmissivity of about 9,100 ft^2/day (Page & Balding, 1973).

Hydraulic conductivity is shown in Figure 2-29 as part of the MercedWRM Layer 5 which contains both the Mehrten Formation and the Valley Springs Formation portion of the Fractured Bedrock system (described above).

Confined Aquifer - The confined aquifer occurs in older alluvium (and Mehrten Formation) deposits that underlie the Corcoran Clay (Figure 2-37). The older alluvium consists of a heterogeneous mixture of poorly sorted gravel, sand, silt and clay up to 400 feet thick derived primarily from the Sierra Nevada. Many water supply wells in the western portion of the Merced Subbasin penetrate the Corcoran Clay into the confined aquifer, and it is a significant source of groundwater (AMEC, 2008).

In the older alluvium, yields to wells were as large as 4,450 gpm with an average 1,900 gpm. The specific capacity of 101 sampled wells ranged from 8.2 gpm/ft to 134.6 gpm/ft with a mean of 41.9 gpm/ft and a median of 36.7 gpm/ft. Specific capacities in the eastern part of the area, where wells penetrate older rocks and deposits, were generally smaller than those in the west. Because specific capacity is a rough indicator of transmissivity, the pattern indicates smaller transmissivities in the eastern part of the area near where the consolidated rocks crop out (Page & Balding, 1973).

The Confined Aquifer's hydraulic conductivity is shown in both Figure 2-30 and Figure 2-31 as part of the MercedWRM Layers 3 and 4 which together describe the Confined Aquifer. Layer 3 consists of older alluvium while layer 4 consists of continental deposits.

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

The intermediate leaky-aquifer is the most extensively developed aquifer in the Merced Subbasin. Measured well yields within the Merced Subbasin range from 670 to 4,000 gpm (Page & Balding, 1973). Estimates of specific capacity of supply wells throughout the Merced Subbasin range from about 20 to 40 gpm/ft of drawdown and indicate that the specific capacity increases from east to west.

Hydraulic conductivity is shown in Figure 2-32 as part of the MercedWRM Layer 2.

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

Hydraulic conductivity is shown in Figure 2-33 as part of the MercedWRM Layer 1.

The sixth layer of the model (not mapped) consists of saline water below the base of fresh water (described in 2.1.6.2) and was implemented as a refinement to the water quality model and for the potential use of scenario development for the simulation of deep well production (Woodard & Curran, 2019).

Table 2-7: Formation, Aquifer Name, and MercedWRM Layer Number Lookup

Formation/Aquifer Name	Principal Aquifer for GSP	MercedWRM Layer Number
Ione Formation	N/A	6
Valley Springs Formation	Outside Corcoran Clay	5
Mehrten Formation (outside of Corcoran Clay extent)	Outside Corcoran Clay	5
Mehrten Formation (within Corcoran Clay extent)	Below Corcoran Clay	5
Confined Aquifer	Below Corcoran Clay	4 (continental deposits)
	Below Corcoran Clay	3 (older alluvium)
Intermediate Leaky-Aquifer (within Corcoran Clay extent)	Above Corcoran Clay	2
Intermediate Leaky-Aquifer (outside of Corcoran Clay extent)	Outside Corcoran Clay	2
Shallow Unconfined Aquifer (outside of Corcoran Clay extent)	Outside Corcoran Clay	1
Shallow Unconfined Aquifer (within Corcoran Clay extent)	Above Corcoran Clay	1

January 2022

Modesto Subbasin

Groundwater Sustainability Plan

Stanislaus and Tuolumne Rivers Groundwater Basin Association (STRGBA) Groundwater Sustainability Agency

&

County of Tuolumne Groundwater Sustainability Agency

Three principal aquifers were defined in the Modesto Subbasin for future groundwater management under SGMA. The Corcoran Clay, underlying the western Subbasin, is the primary aquitard in the Subbasin and used to demarcate the three principal aquifers: the Western Upper Principal Aquifer is the unconfined aquifer above the Corcoran Clay, the Western Lower Principal Aquifer is the confined aquifer below the Corcoran Clay and the Eastern Principal Aquifer is the unconfined to semi-confined aquifer system east of the Corcoran Clay.

Cross sections were developed for the GSP based on geologic textures that illustrate the distribution of coarse- and fine-grained deposits within the Subbasin and the westerly dipping and thickening Corcoran Clay. Simplified cross sections were also developed to represent the geologic formations within the Subbasin. A conceptual cross section on Figure ES-6 is provided to illustrate subsurface conditions across the Subbasin including the principal aquifers, the Corcoran Clay, the westerly dipping formations, offsets caused by two interpreted geologic faults in the central and eastern Subbasin, and the base of fresh water which represents the bottom of the basin. The bottom of the basin is about -550 feet msl along the eastern Subbasin boundary, dips to about -1,000 feet msl in the center of the Subbasin and then rises to about -700 feet msl along the western Subbasin boundary.

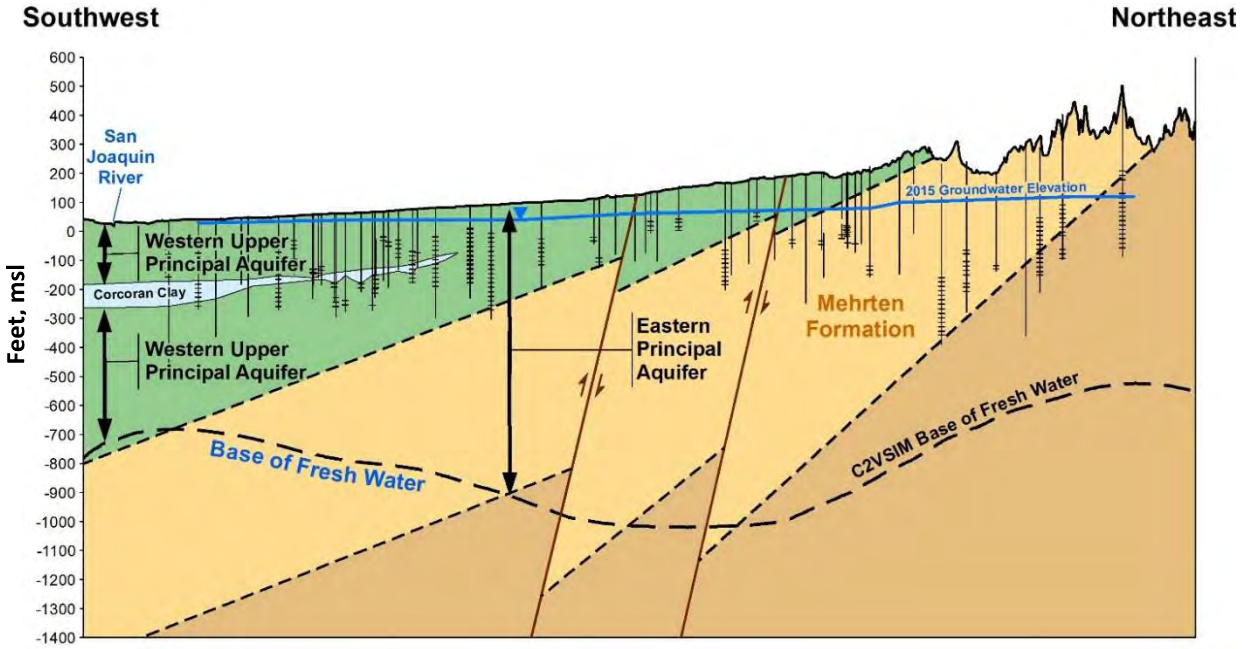


Figure ES-6 Cross Section of Hydrogeologic Framework

The cross section also depicts the shallow groundwater elevation across the Subbasin in Fall 2015 (blue line near top of section). As indicated on Figure ES-6, the water table is shallow in the western Subbasin and deepens to the east with the rising ground surface elevation. A small area of lowered water levels is indicated in the eastern Subbasin, reflecting an area with ongoing water level declines, although data in that area are sparse.

downward flow of groundwater in the western Subbasin where artesian conditions were historically documented. Downward gradients are apparently created from pumping beneath the Corcoran Clay, including areas on the west side of the San Joaquin River (Burow et al., 2004).

Other sources of recharge include deep percolation of precipitation, underflow from the foothills, Modesto Reservoir leakage, leakage from unlined canals, and seepage from rivers and streams. Modesto Reservoir leakage was estimated by Modesto Irrigation District to be approximately 24,000 acre-feet per year (Phillips et al., 2015). Other sources of discharge include flow into the downstream (western) reaches of the Stanislaus and Tuolumne rivers, flow into the San Joaquin River, underflow beneath the western Subbasin boundary, flow out of subsurface drains and consumption by riparian vegetation.

3.1.4. Principal Aquifers and Aquitards

As mentioned previously, the Corcoran Clay represents the primary aquitard in the Subbasin and separates the alluvial aquifers above and below the clay, creating confined conditions at depth in the western Subbasin where the Corcoran Clay occurs. The Corcoran Clay does not extend into the eastern Subbasin, and no additional regional aquitard has been defined in this area. Accordingly, the Corcoran Clay defines two aquifer systems in the western Subbasin, but aquifers are more hydraulically connected in the eastern Subbasin where the regional clay is absent.

Recognizing these conditions, , three principal aquifers are defined in the Subbasin for the purposes of this GSP and future management of groundwater under SGMA. These three aquifers are defined as follows:

- Western Upper Principal Aquifer – unconfined aquifer above the Corcoran Clay.
- Western Lower Principal Aquifer – confined aquifer below the Corcoran Clay.
- Eastern Principal Aquifer – unconfined to semi-confined aquifer system east of the extent of the Corcoran Clay.

The definition of these three Principal Aquifers is consistent with the Principal Aquifer definitions for the Turlock Subbasin GSP, allowing for consistent interpretations along the shared Tuolumne River boundary. The Principal Aquifers in the Eastern San Joaquin Subbasin are different because the Corcoran Clay is only found in the southwest corner of the Subbasin. The Eastern San Joaquin GSP defines one principal aquifer the provides water from three production zones: a Shallow Zone, Intermediate Zone and Deep Zone.

The Western Upper Principal Aquifer and the Eastern Principal Aquifer are composed of Plio-Pleistocene- to Holocene- age alluvial sediments of the Modesto, Riverbank, Turlock Lake formations, and younger alluvium (where saturated). Not all of these alluvial sediments are present everywhere within the Eastern Principal Aquifer due to erosion or non-deposition. The base of the Western Principal Aquifer is the Corcoran Clay. The Eastern

Principal Aquifer (east of the Corcoran Clay) also includes the Laguna, Mehrten and older formations that extend to the operational bottom of the Subbasin (i.e., base of fresh water).

The Modesto, Riverbank and Turlock Lake formations form sequences of overlapping terrace and alluvial fan deposits in response to cycles of alluviation, soil formation and channel incision influenced by changes in climate and glacial stages in the Sierra Nevada (Jurgens et al., 2008). The Modesto Formation forms a thin veneer at the surface, approximately 20 feet thick (Jurgens et al., 2008) throughout most of the western Subbasin (Burow et al., 2004). The Modesto Formation is composed of fluvially-deposited arkosic sand, gravel and silt and its lithology is similar to the underlying Riverbank, Turlock Lake, and Laguna formations (Burow et al., 2004). Where saturated, the Modesto Formation yields moderate amounts of water (Burow et al., 2004).

The Riverbank Formation is also composed of fluvial arkosic sand, gravel and silt and varies in thickness from approximately 150 to 250 feet (Burow et al., 2004). Its depositional dip is slightly steeper than the Modesto Formation, resulting in westward thickening of the deposits. The formation yields moderate quantities of water.

The Turlock Lake Formation is the most developed aquifer in the western Subbasin, both within the Western Upper Principal Aquifer and the Eastern Principal Aquifer, yielding up to 2,000 gallons per minute (gpm) from gravel and sand units (Burow et al., 2004). Similar to the Modesto and Riverbank formations, the Turlock Lake Formation is composed of a coarsening-upward sequence of silt, arkosic sand, and gravel layers (Burow et al., 2004).

The Western Lower Principal Aquifer consists of the Turlock Lake Formation below the Corcoran Clay, the Laguna Formation and the underlying Mehrten Formation. Both the Western Lower Principal Aquifer and the Eastern Principal Aquifer extend to the base of fresh water, which is located within or below the Mehrten Formation, respectively.

The Laguna Formation is composed of alluvial deposits of gravel, sand, and silt in at least two coarsening-upwards sequences (Burow et al., 2004). Laguna Formation sediments are more consolidated than the younger overlying formations (Jurgens et al., 2008) and yield variable amounts of water (Burow et al., 2004). The Laguna Formation is commonly mapped as part of the Turlock Lake Formation in the Modesto area (Burow et al., 2004). The Laguna Formation is not clearly identifiable from adjacent units in areas to the east where it crops out at the surface (Burow et al., 2004).

USGS indicates that the Eastern Principal Aquifer is unconfined and becomes semi-confined with depth due to numerous discontinuous clay lenses and extensive paleosols (Burow et al., 2004). In addition, the Mehrten Formation is more consolidated than the overlying formations and the sand beds are generally thin, so the degree of hydraulic connection between the Mehrten and overlying deposits is not well understood (Burow et al., 2004). However, many wells in the Eastern Principal Aquifer are screened in both the Mehrten Formation and overlying younger formations, where present, providing for some hydraulic connection in wells. Further, these wells provide average water levels across these zones

and would represent a combined aquifer system for managing water levels. In the absence of a defined aquitard, it is likely that there is hydraulic connection among the formations, especially where the shallow formations thin to the east.

The Corcoran Clay is defined in this GSP as the only principal aquitard, which delineates the base of the Western Upper Principal Aquifer and the top of the Western Lower Principal Aquifer. The eastern edge of the Corcoran Clay is oriented from northwest to southeast, approximately parallel to the axis of the Valley (Burow et al., 2004). Where present, the blue lacustrine Corcoran Clay is up to 100 feet thick and occurs at depths ranging from 80 to 210 feet (Burow et al., 2004). The Corcoran Clay is generally well sorted clay to silty clay but becomes siltier and grades into coarser textures along the edges (Burow et al., 2004).

The Corcoran Clay surface from the C2VSim Model within the Modesto Subbasin was replaced with the Corcoran Clay surface from the USGS MERSTAN model (Phillips et al., 2015). During analysis for this GSP, it was discovered that the top of the Corcoran Clay surface from C2VSim suggested a mounded area in the western Subbasin where the top of the clay was higher than anticipated and not supported by well logs or USGS texture data. This anomaly was discussed with DWR staff, who supported revision of the surface in the model. The Corcoran Clay surface used in the USGS MERSTAN model (Phillips et al., 2015) is based on USGS hydrogeologic characterization of the Modesto Area (Burow et al., 2004) and represents the most detailed mapping of the Corcoran Clay in the Modesto Subbasin.

The elevation contours of the top and base of the revised Corcoran Clay surface within the Modesto Subbasin is shown on **Figures 3-9 and 3-10**, respectively. The Corcoran Clay generally dips to the west, with some irregularities. The eastern edge of the top of the Corcoran Clay slopes from an elevation of approximately -70 ft msl along the southern Subbasin boundary to -110 ft msl along the northern Subbasin boundary. The top of the Corcoran Clay is deepest in the northwestern Subbasin, at an elevation of approximately -210 ft msl. The elevation contours of the base of the Corcoran Clay generally mimic the top surface, ranging in elevation from approximately -120 to -140 ft msl along its eastern boundary to -260 ft msl in the northwestern Subbasin.

3.1.4.1. Cross Section Development

Five hydrogeologic cross sections (A through E) were developed to illustrate the hydrostratigraphy of the principal aquifers in the Modesto Subbasin, with a focus on aquifer textures and geometry. Cross section locations are shown on **Figures 3-11**. Cross section A-A' extends from southwest to northeast along the length of the Subbasin, cross sections B-B', C-C', and D-D' are perpendicular to A-A', oriented northwest to southeast. Cross section E-E' is a local cross section parallel to A-A' in the vicinity of Oakdale and along the Stanislaus River.

Cross sections were developed based on USGS texture data, DWR well completion reports, California Department of Oil, Gas and Geothermal Resources (DOGGR) geophysical logs, and localized cross sections in the City of Modesto as part of a previous study (Todd, 2016). Cross sections are presented on **Figures 3-12** through **3-18**.

Legend

- USGS Texture Data Wells
- Cross Section Well
- DOGGR Geophysical Log
- Section Line
- Rivers
- Basin Boundary
- Corcoran Clay Extent (Burow et al., 2004)
- County Line

N

0 1.5 3

Miles

A A' B B' C C' D D' E E'

Path: C:\Projects\Modesto GSP 7430\GIS\Figures\Section 3\Figure 3-11 Cross-Section Lines.mxd

April 2020

TODD GROUNDWATER

Figure 3-11
Cross Section Locations

Southwest

Northeast

A

A'

B-B'

C-C'

D-D'

City of Modesto
H-H'

Western Basin Boundary

Eastern Basin Boundary

San Joaquin River

Elevation (feet msl)

500
400
300
200
100
0
-100
-200
-300
-400
-500
-600

374481 E0126128 799940 e0223215 326897 145649 381772 781541 476388 374447 476389 370469 340961 547523 168904 582961 582970 71022 516492 426314 488254 22677 304030 33 96157 25 264 58 259 75791 260 54 168954 718322 325398 791023 946031 26580 495243 129575 16656 965680 789376 926300 52129 40469 409168 994502 426391 53695 46452 129606 29043 370429 529989 E0253458 83085 242804 994562 955618 912374 515495 117773 E0114877 994014

Western Upper Principal Aquifer

Corcoran Clay

Western Lower Principal Aquifer

Mehrten Formation

Eastern Principal Aquifer

?

?

?

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

Miles

Approximate Fault Location
Inferred Fault Motion
Estimated Top of Mehrten Formation

Coarse-Grained Material
Blue Clay
Black Sands

Fine-Grained Material

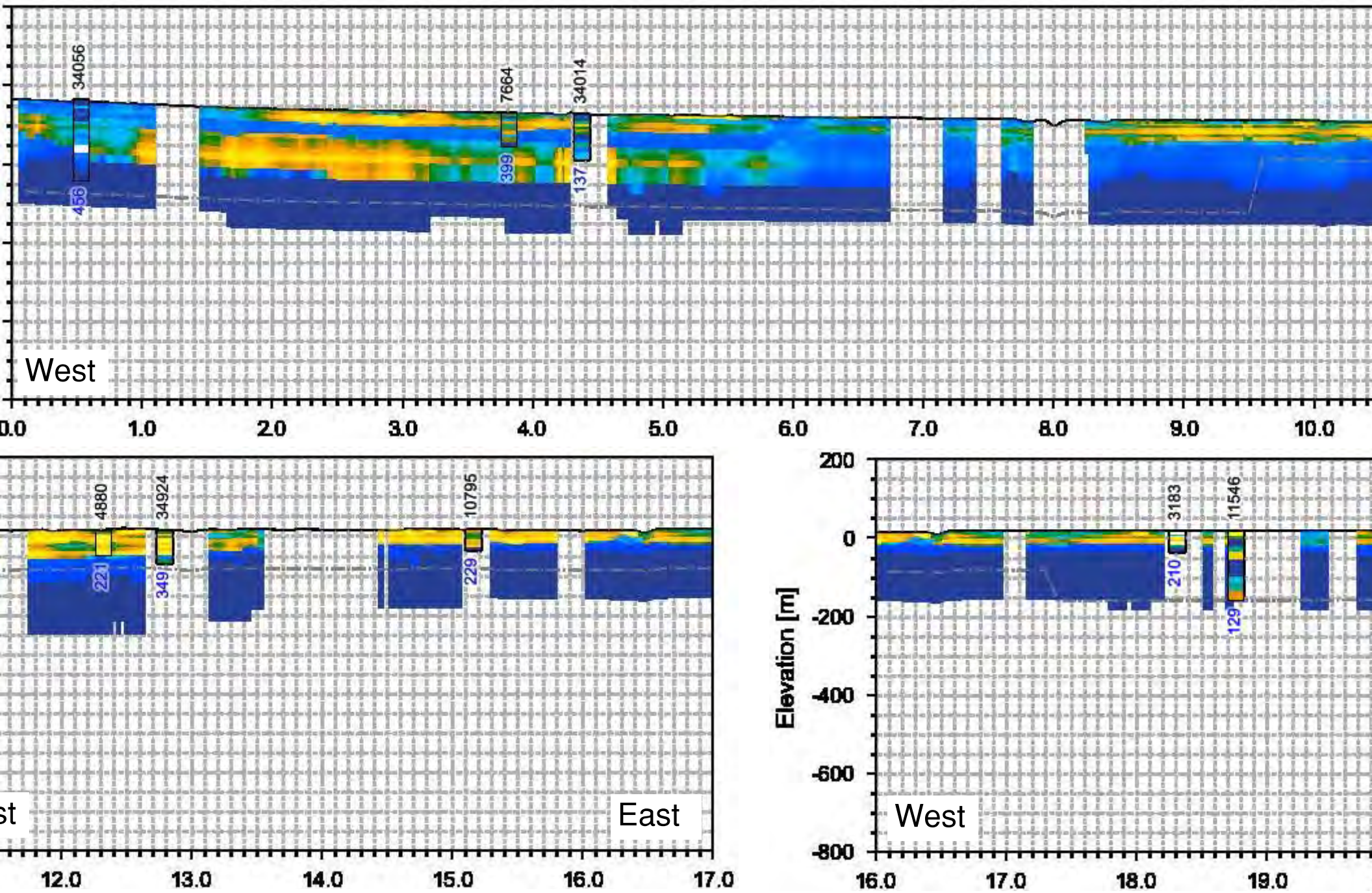
May 2020

TODD GROUNDWATER

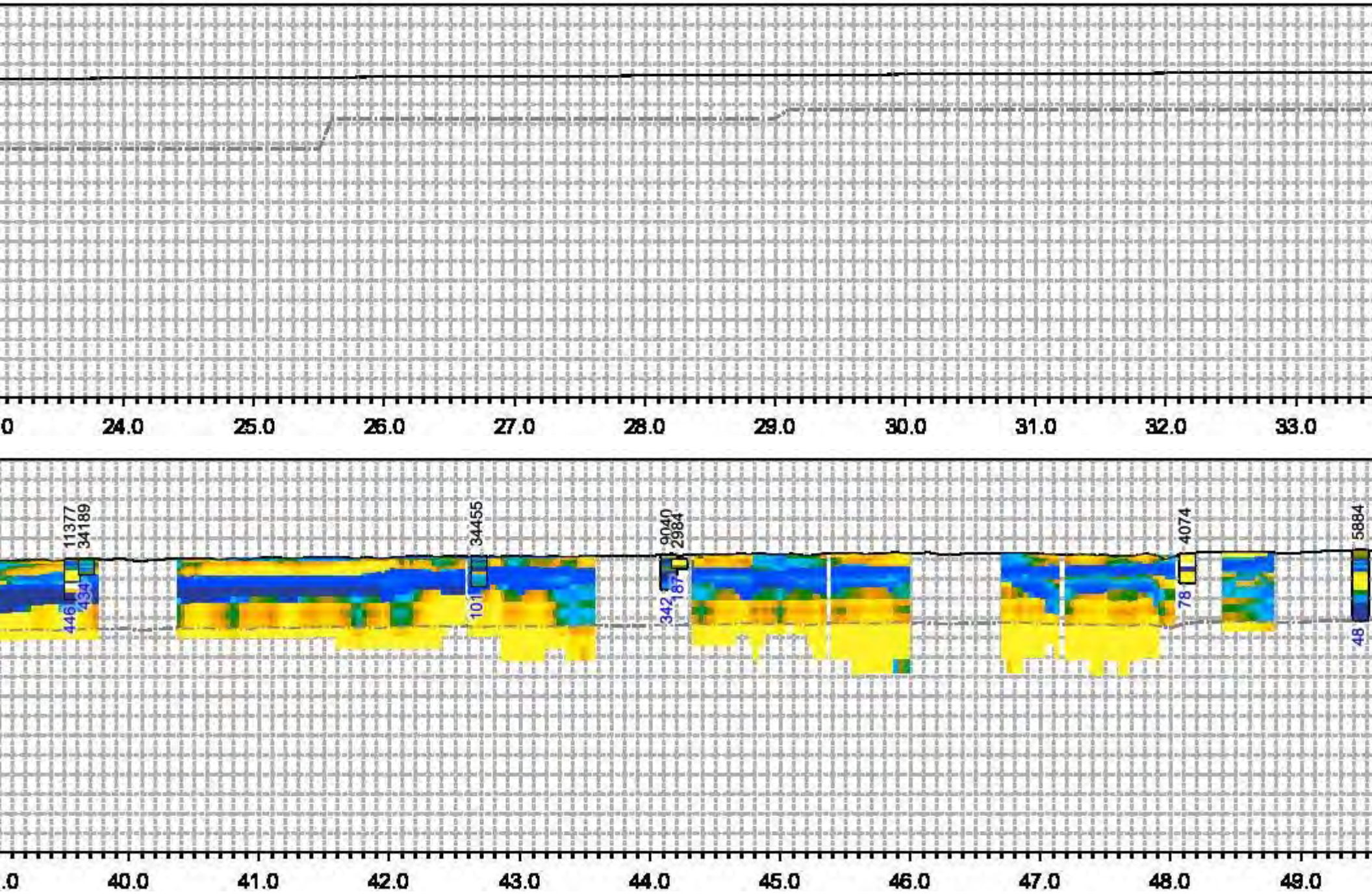
Figure 3-12
Cross Section A-A'

Path: C:\Projects\Modesto GSP 7430\5\GIS\Figures\Section 3\Figure 3-12 Cross-Section A-A'.mxd

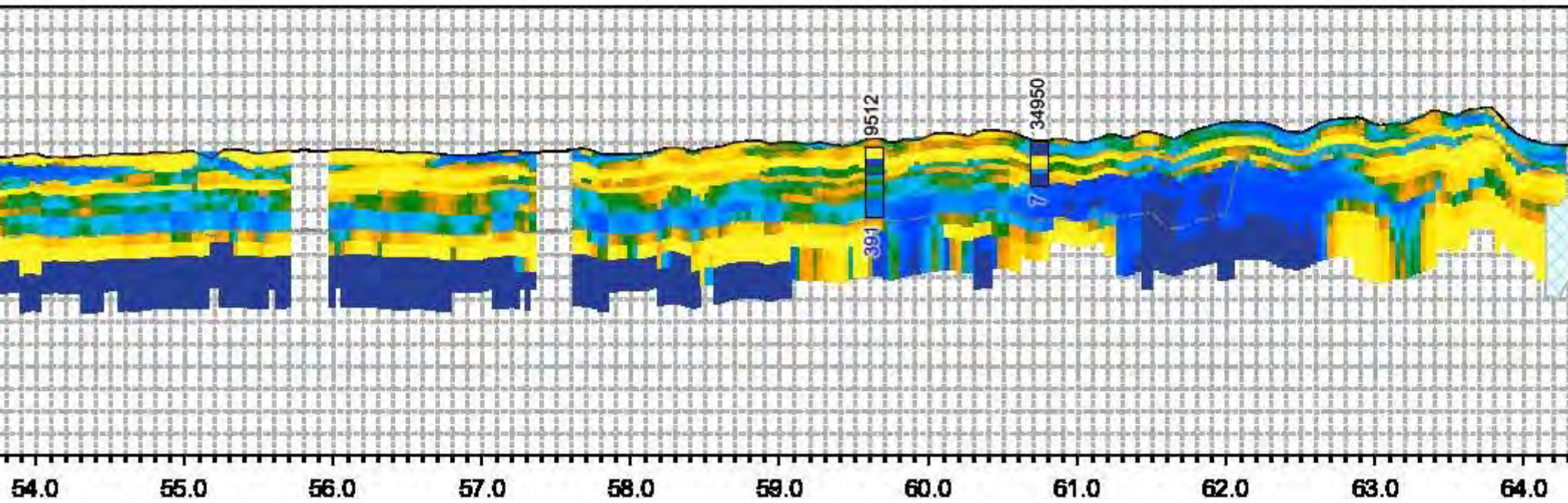
A - A' Nearest AEM Logs

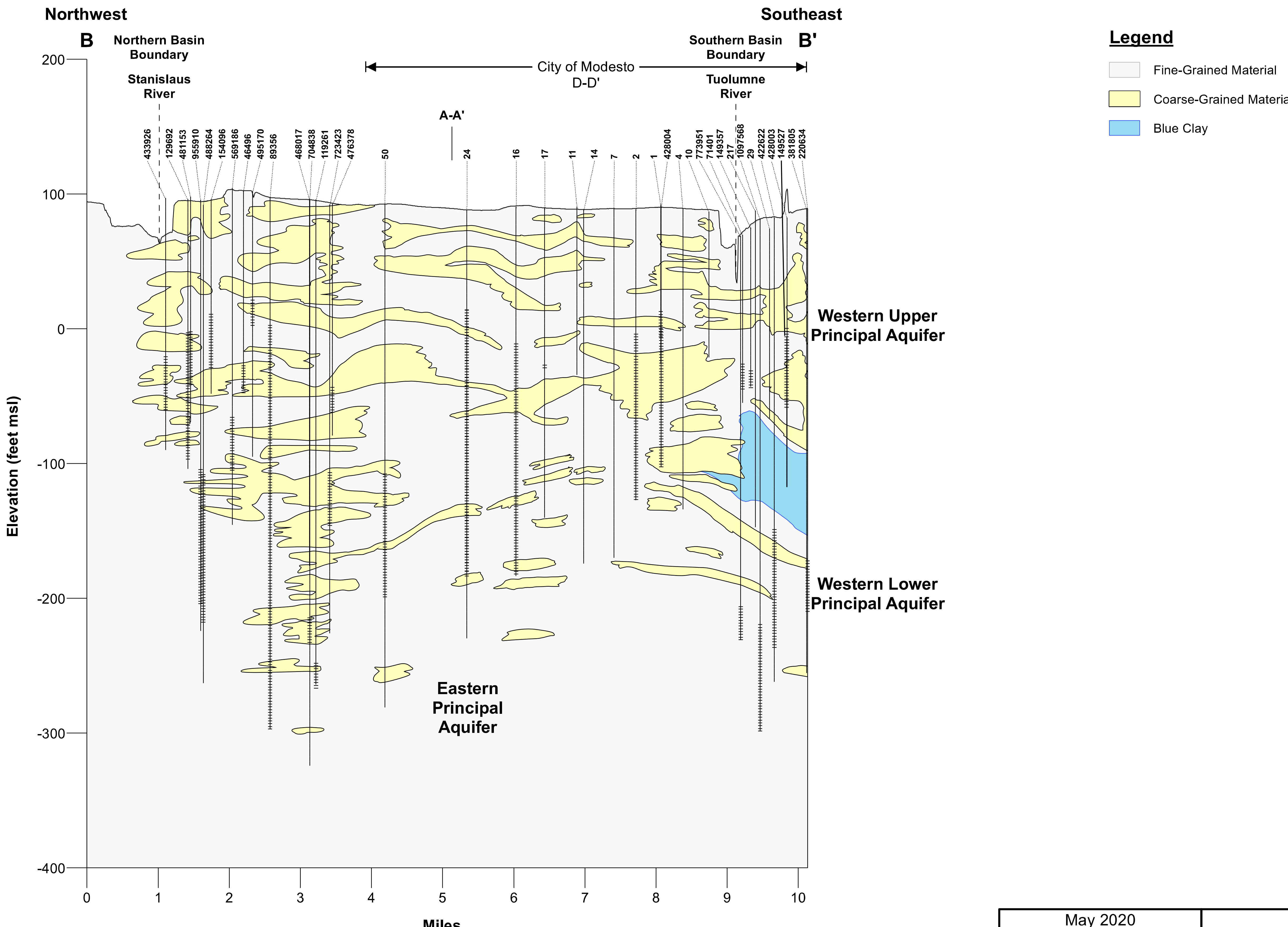


A - A' Nearest AEM Logs



A - A' Nearest AEM Logs



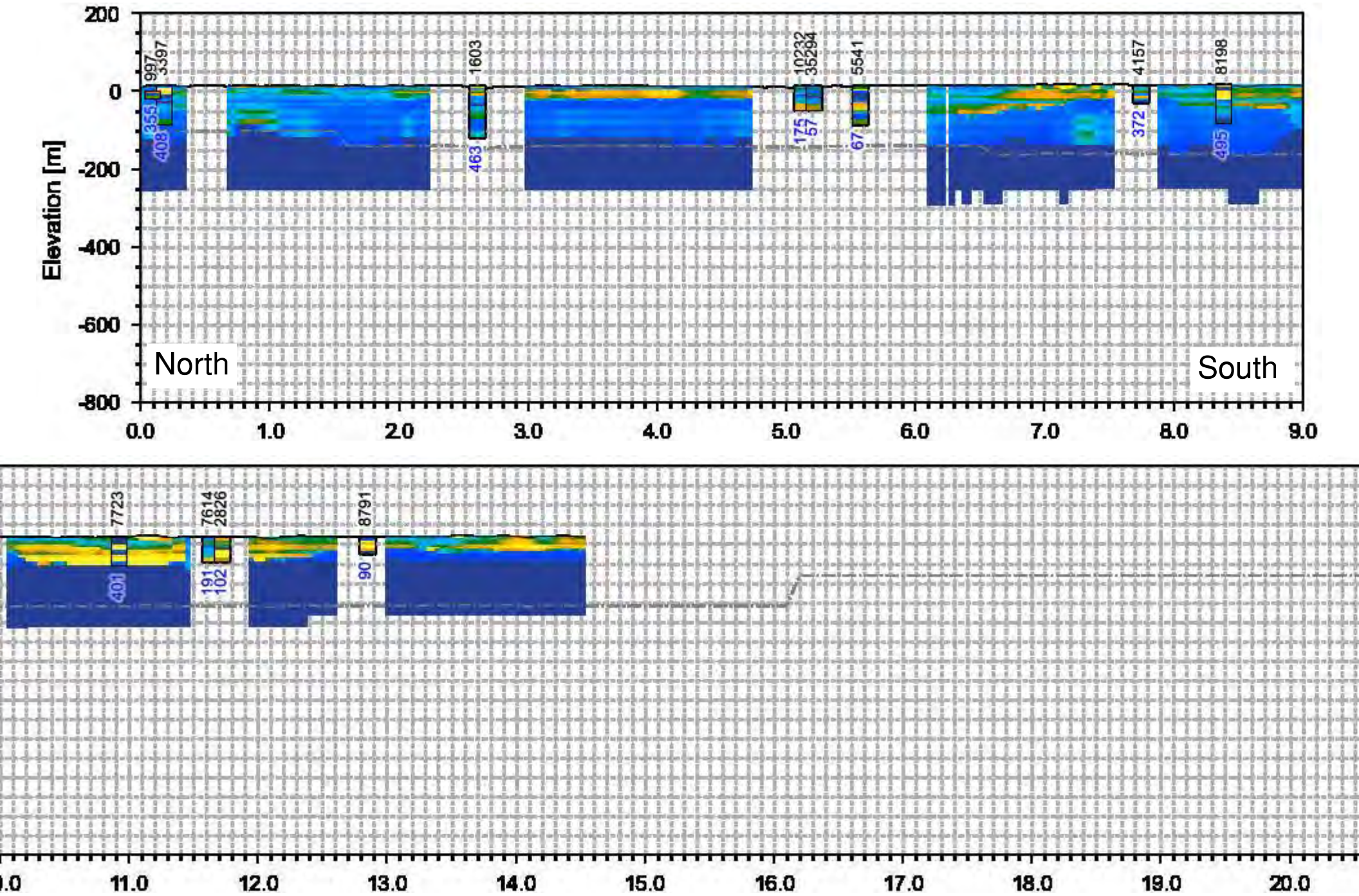


May 2020

TODD GROUNDWATER

Figure 3-13
Cross Section B-B'

B - B' Nearest AEM Logs

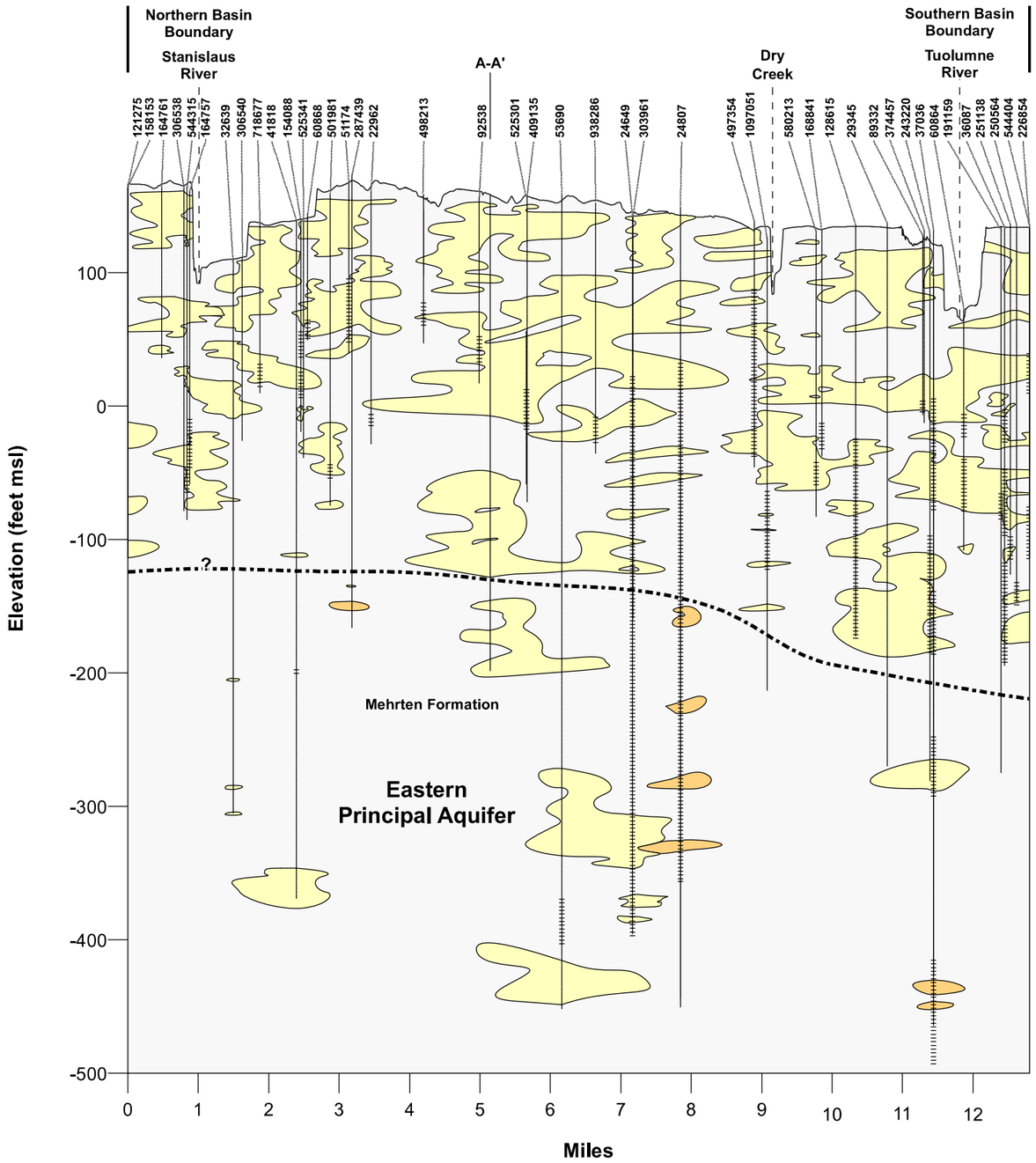


Northwest

C

Southeast

C'



Legend

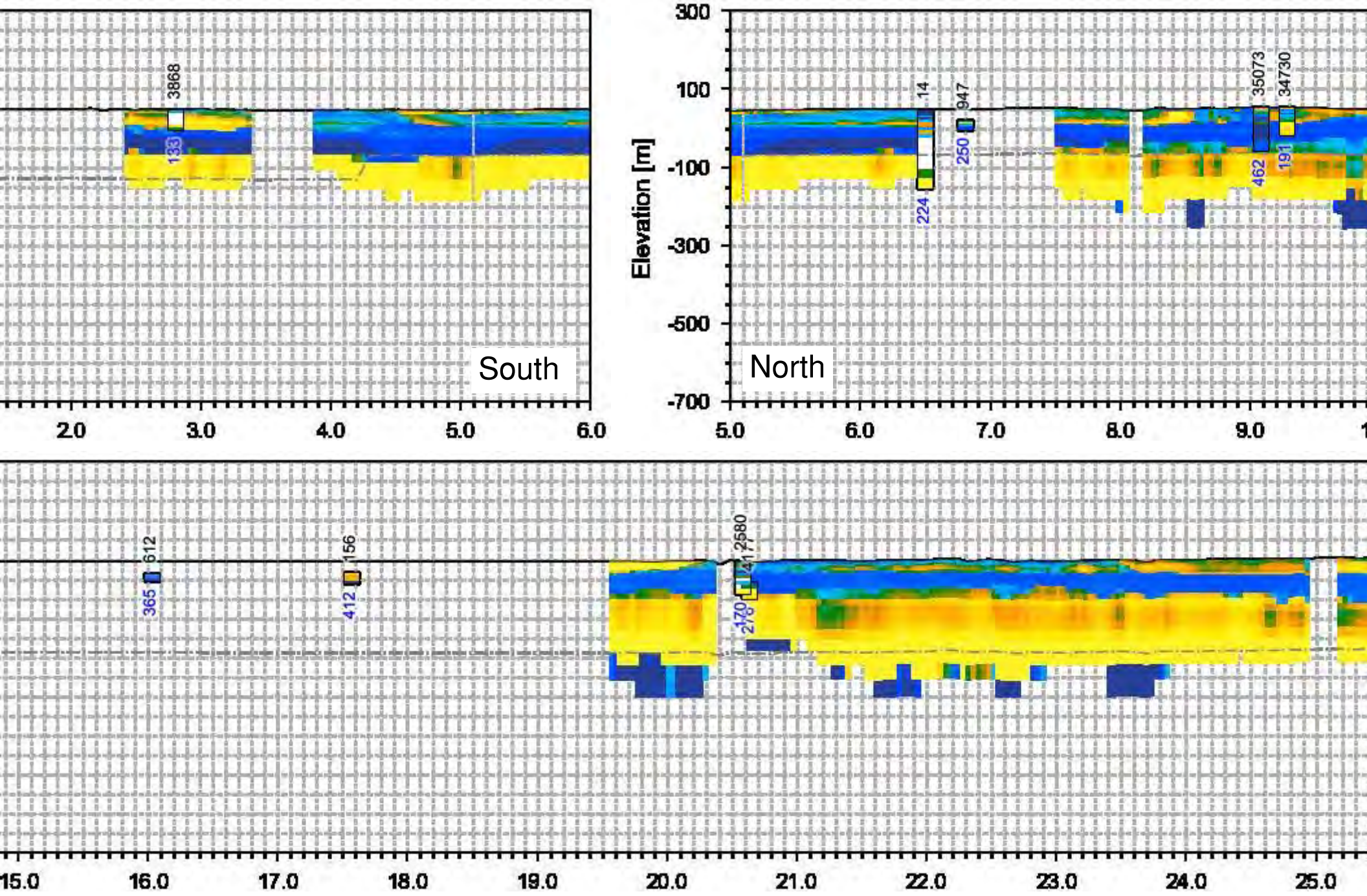
- Esimated Top of Mehrten Formation
- Fine-Grained Material
- Coarse-Grained Material
- Black Sands

May 2020

TODD GROUNDWATER

Figure 3-14
Cross Section C-C'

C - C' Nearest AEM Logs



Northwest

D

Southeast

D'

Northern Basin Boundary

Stanislaus River

Dry Creek

Modesto Reservoir

Southern Basin Boundary

Tuolumne River

A-A'

e0256752
e0162496
995114
190808
e0250577
e0187445
e0147907
994068
994067
993831
515495
117773
947882
947881
956988
1097538
706223
955556
465239
96056
994356
76517
40471
111237
111238
290064
733016

Mehrten Formation

Eastern Principal Aquifer

Elevation (feet msl)

500
400
300
200
100
0
-100
-200
-300
-400

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Miles

Legend

- Estimated Top of Mehrten Formation
- Fine-Grained Material
- Coarse-Grained Material
- Black Sands

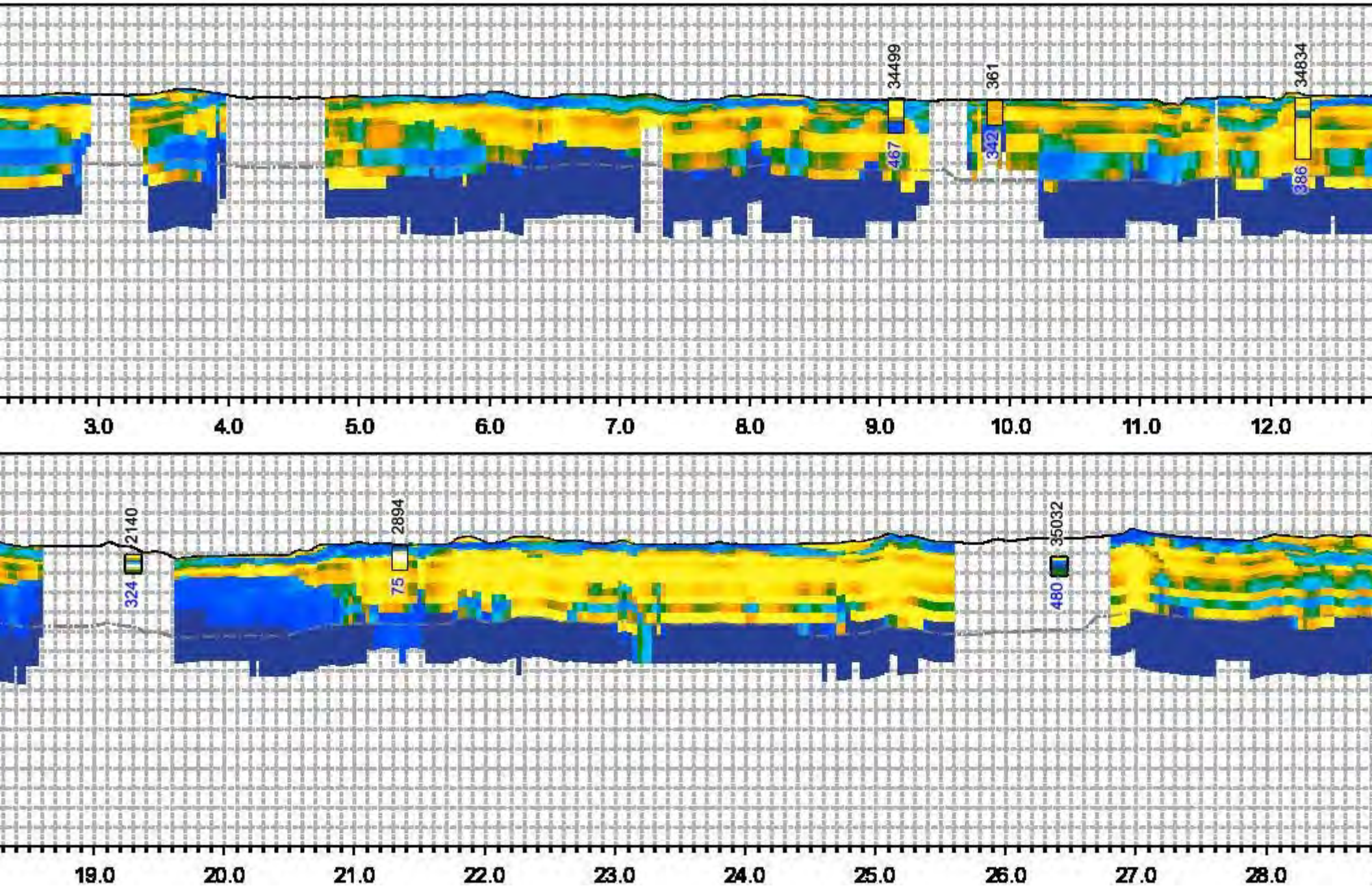
May 2020

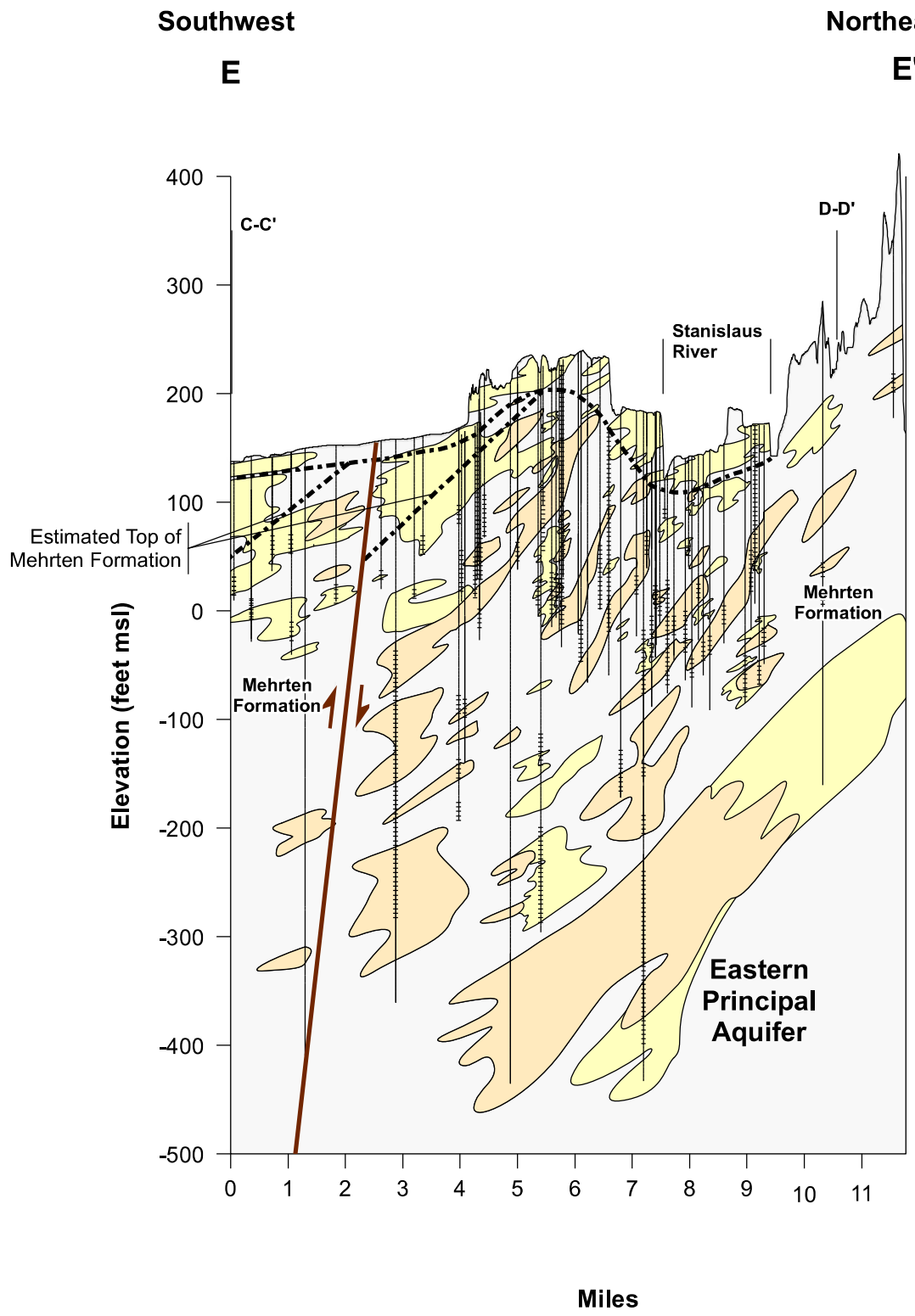
TODD GROUNDWATER

Figure 3-15
Cross Section D-D'

John C:\Projects\Modesto GSP- 7400\GIS\Figures\Section 3\Figure 3-15 Cross Section D-D'.mxd

D - D' Nearest AEM Logs





Legend

- Fine-Grained Material
- Coarse-Grained Material
- Black Sands
- Approximate Fault Location
- Inferred Fault Motion

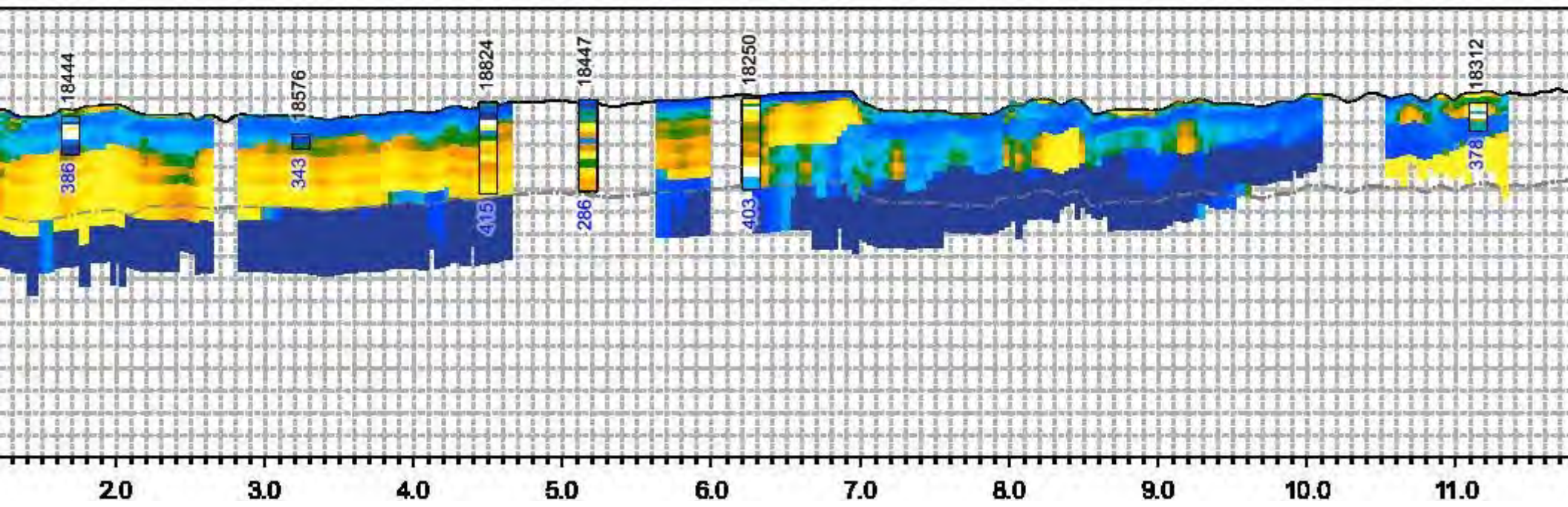
May 2020

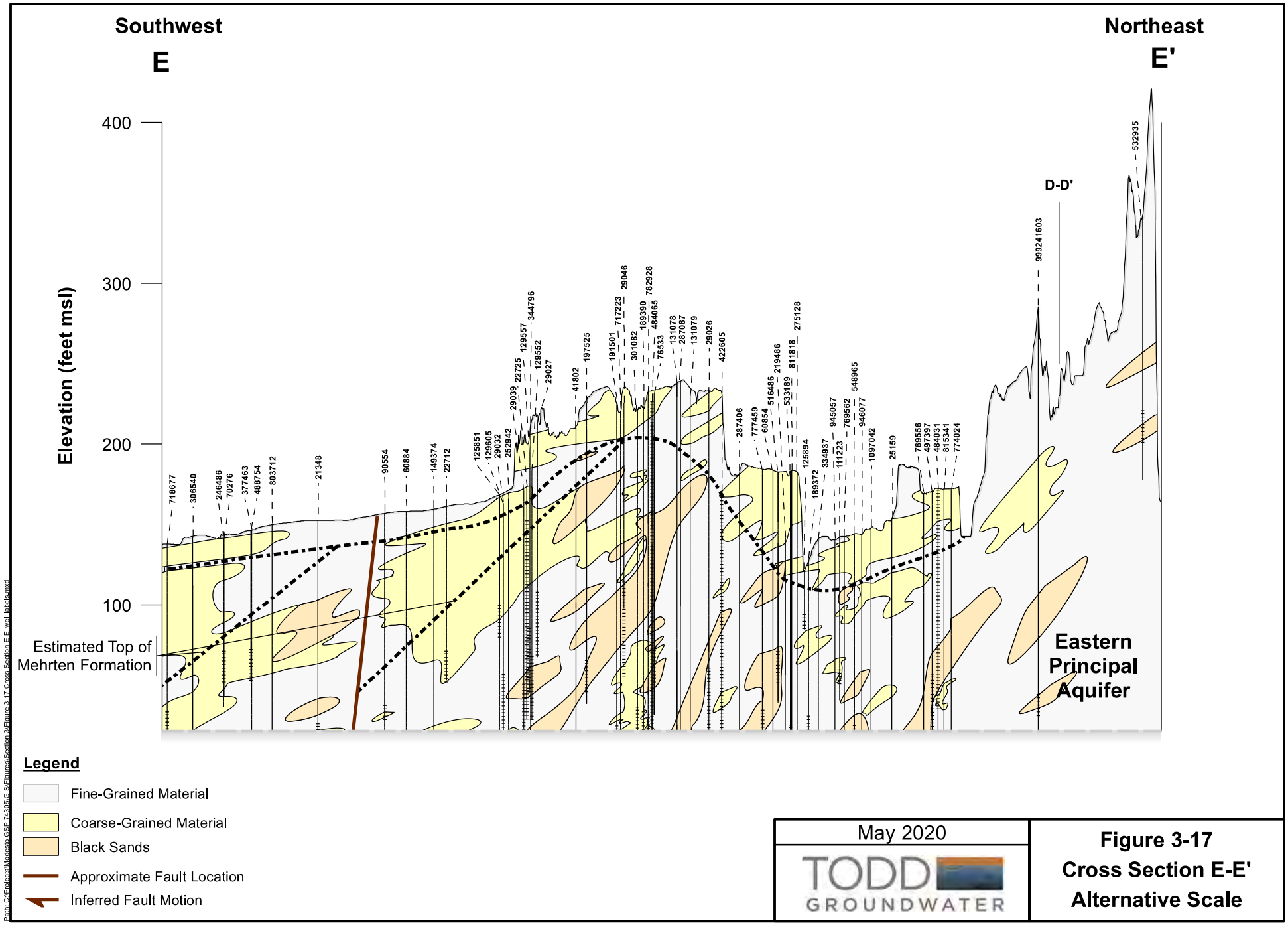
TODD GROUNDWATER

Figure 3-16
Cross Section E-E'

Path: C:\Projects\Modesto GSP 7430\5\GIS\Figures\Section 3\Figure 3-16 Cross-Section E-E'.mxd

E - E' Nearest AEM Logs




Southwest
E
Northeast
E'
Elevation (feet msl)
400
300
200
100
Estimated Top of Mehrten Formation
D-D'
Eastern Principal Aquifer
718677
306540
246486
70276
377463
488754
803712
21348
90554
60884
149374
22712
125851
129605
29032
252942
29039
22725
129557
344796
129552
29027
41802
197525
191501
717223
29046
301082
189390
782928
484065
76533
131078
287087
131079
29026
422605
287406
777459
60854
516486
219486
533189
811818
275128
125894
189372
334937
945057
111223
769562
548965
946077
1097042
25159
769556
497397
484031
815341
774024
999241603
532935
Legend
Fine-Grained Material
Coarse-Grained Material
Black Sands
Approximate Fault Location
Inferred Fault Motion
May 2020
TODD GROUNDWATER
Figure 3-17
Cross Section E-E'
Alternative Scale
Path: C:\Projects\Modesto GSP 7430\GIS\Figures\Section 3\Figure 3-17 Cross Section E-E' wellLabels.mxd

Southwest

A

Northeast

A'

Western Basin Boundary

B-B'

C-C'

D-D'

Eastern Basin Boundary

San Joaquin River

374481 126128 799940 223215 326897 145649 381772 476388 781541 374447 476389 370469 340961 547523 168904 582961 582970 71022 516492 426314 488254 22677 304030 33 96157 25 264 58 259 75791 260 54 168954 718322 325398 791023 946031 26580 495243 129575 16656 965680 926300 789376 52129 40469 409168 994502 426391 53695 46452 29043 370429 129606 529989 253458 83085 242804 994562 955618 912374 515495 117773 114877 994014

Western Upper Principal Aquifer

Western Lower Principal Aquifer

Eastern Principal Aquifer

Corcoran Clay

Undifferentiated Modesto, Riverbank, and Turlock Lake Formations

Mehrten Formation

Mehrten Formation

Mehrten Formation

Undifferentiated Continental and Marine Sediments

Undifferentiated Continental and Marine Sediments

Undifferentiated Continental and Marine Sediments

C2VSIM Base of Fresh Water

600 500 400 300 200 100 0 -100 -200 -300 -400 -500 -600 -700 -800 -900 -1000 -1100 -1200 -1300 -1400

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

Approximate Fault Location

Inferred Fault Motion

Approximate Formation Boundary

Approximate Base of Mehrten Formation Inferred from DOGGR Geophysical Log

Groundwater Elevation October 2015

Path: C:\Projects\Modesto GSP 7430\GIS\Figures\Section 3\Figure 3-18 Cross-Section A-A' (2.mxd

May 2020

TODD GROUNDWATER

Figure 3-18
Hydrogeologic Framework
Cross Section A-A'