Geologic and Stratigraphic Evaluation
Pixley Groundwater Banking Project
Tulare County, California

Prepared for:
South Valley Water Banking Project

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TECHNICAL MEMORANDUM

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1. Introduction
This technical memorandum presents results of a detailed examination of subsurface geologic conditions underlying the proposed Pixley Groundwater Banking Project. The Project would be implemented by the South Valley Water Banking Authority, a joint powers authority between Pixley Irrigation District (PID) and Delano-Earlimart Irrigation District (DEID). Project facilities would be would be located in Tulare County southeast of the community of Pixley between State Route 99 and the Friant-Kern Canal (see **Figure 1**).

The Project consists of a program of long-term groundwater banking in which up to 30,000 acre-feet per year (AFY) of surface water would be recharged to groundwater. The Project would provide opportunities for participants to bank water during wet years and recover water in normal and dry years. Banked water would be derived from surplus sources and, along with a 10-percent "leave-behind" fraction, would improve local groundwater conditions and partially offset overdraft.

1.1 Hydrogeologic Conceptualization
The findings in this technical memorandum are reflected in a conceptualization of hydrogeologic conditions that would govern recharge and recovery processes of the water bank. The conceptualization serves multiple purposes including understanding of the occurrence and nature of aquifer materials that are tapped locally and regionally for water supply, how bank recharge would be transmitted and stored, and the pathways through which pumping drawdown could be propagated during recovery operations. These purposes are analyzed in other parts of Appendix H through a numerical groundwater flow model and other methods of analysis.

The hydrogeologic conceptualization developed in this evaluation bridges the needs of the water bank and requirements of the state's 2014 Sustainable Groundwater Management Act (SGMA). Under SGMA, a hydrogeologic conceptualization is a required element of a Groundwater Sustainability Plan to implemented, with approval by the State Water Board, by local Groundwater Sustainability Agencies (GSAs). In the Project area, PID and DEID have been designated by the

Department of Water Resources (DWR) as exclusive GSAs for their respective service areas, which overlie the Tule Groundwater Subbasin (DWR Bulletin 118 Subbasin No. 5-22.13; Updates 2003 and 2016).

1.2 Stratigraphic Model

The form of the hydrogeologic conceptualization presented in this technical memorandum is a stratigraphic model. It is an extension of, and consistent with, a model constructed by Luhdorff & Scalmanini (2014) for the Tulare Lake Bed beneficial use archetype under Central Valley Salt Alternatives for Long-Term Sustainability program (CV-SALTS). The stratigraphic relationships reflect a regional model of freshwater aquifer sources in major groundwater subbasins of the Tulare Lake hydrologic region including the Tule Subbasin. The model delineates and distinguishes sand sequences and interbedded lake bed clays including the Corcoran Clay from fluvial and alluvial plain sediments deposited by drainages toward and into the Tulare Lake Bed.

1.3 Aquifer System

The stratigraphic model in this technical memorandum indicates that the subject groundwater banking Project facilities are situated east of the Corcoran Clay, a regionally extensive lacustrine formation that separates shallow and deep aquifers throughout a significant portion of the San Joaquin Valley. As such, the Project area is treated as a single aquifer system in modeling and analytic solutions used to predict impacts from the water banking project (see part H3 of this appendix).

2. Method

This evaluation is based on examination of well logs and construction of geologic cross sections to develop stratigraphic relationships of sand units that comprise the aquifer system in the Project area. Stratigraphic correlations were determined from electric geophysical logs (e-logs) based on the nature, character, and variation in geophysical signatures of geologic beds encountered in boreholes. Observations were made on the thickness and number of beds as well as electrical their resistivity values. Cross sections were constructed on regional and local scales to show the interpreted stratigraphy. Here, stratigraphy is defined as the grouping of stratified sediments, or rocks, according to sequence, composition, and distinction from adjacent units. The resultant stratigraphic correlations permit characterization of sand bed occurrence within depth intervals even where well control is lacking.

The cross-section locations constructed in this evaluation are shown on **Figure 1**. The location and well control for the cross sections are shown on **Plate 1**. Drillers reports obtained through DWR included those for agricultural, domestic, and other uses. E-logs provide the most precision in stratigraphic correlations while lithologic descriptions from water well drillers reports were employed as complementary sources. The lithologic descriptions from water well reports were found to be less reliable, at best, for delineation of beds for stratigraphic correlation. Even the presence of the lacustrine Corcoran Clay, notable for its blue or gray color, was often not discernable in water well reports due to the lack of color descriptors.

In general, higher resistivity values of beds on e-logs represent coarse-grained, sedimentary geologic material of sands and gravels, with the lowest resistivity values representing fine-grained, sedimentary material of silts and clays. In the southern San Joaquin Valley and elsewhere, water wells are screened in higher resistivity beds of sand and gravel beds, which have characteristics conducive to successful water supply development. Observations of resistivity values for individual beds, or the range of values for a series of beds, were also considered in developing stratigraphic relationships presented in this technical memorandum.

For each e-log shown on a cross section (see **Figures 2** to **5**), the 16-inch normal resistivity curve (short normal) from the log was reproduced on a working section based on a normalization to an original drawing scale of 0.10 inch to 10 ohm-meter^2/meter (the shorthand "ohms" is often used to express resistivity values). The final work section was then scanned and imported into AutoCAD to highlight stratigraphic relationships and add appropriate scales and labels. In this manner, the regional and local cross sections reflect the character of the geophysical log response from which the stratigraphy was interpreted.

3. Regional Geologic Setting

The study area occurs in the southern San Joaquin Valley east of Highway 99 and south of the community of Pixley in Tulare County (see **Figure 1**). The San Joaquin Valley, a portion of the larger Great Valley, or Central Valley, geologic province of California, is a tectonically formed structural basin filled with Mesozoic (pre-63 m.y.[1]) and Cenozoic (post 63 m.y.) sedimentary deposits. The youngest non-marine, unconsolidated sedimentary deposits are up to 3,000 feet in thickness and contain freshwater targeted for water supply in the region.

Regional geologic relationships are best shown on the Bakersfield Sheet of the Geologic Map of California (Smith, 1964) and the Cenozoic evaluation of the San Joaquin Valley, California (Bartow, 1991). Other geologic and groundwater reports relevant to the area include Croft (1972), Page (1986), and Williamson, et al. (1989). Numerous other reports have been published concerning local geology and groundwater occurrence.

East of the San Joaquin Valley is the Sierra Nevada geologic province composed largely of intrusive igneous rocks of granitic character with minor metamorphic rocks of Mesozoic and older

[1] m.y. = million years

age. The Sierra Nevada is a large west-sloping, tilted block uplifted by faulting along the eastern edge in late Cenozoic time.

On the western side of the San Joaquin Valley occurs the Coastal Range geologic province, which here consists of Mesozoic and older Cenozoic (Tertiary 63 to 5 m.y.) sedimentary deposits of marine and non-marine origin, which are consolidated to weakly consolidated. The Coastal Range has been highly deformed by folding and faulting, and uplift in the later Cenozoic. The rocks exposed in the Coastal Range extend at great depth eastward below the San Joaquin Valley to a structural relationship with the rocks exposed in the Sierra Nevada province (Bartow, 1991). West of the Coastal Range adjacent to the San Joaquin Valley occurs the major strike-slip San Andreas Fault system, a major structural feature of the region.

In the southern San Joaquin Valley, a marine embayment occurred through much of earlier Tertiary time connected to the Pacific Ocean to the west. In late Tertiary time (mid-Pliocene 3 to 4 m.y.), the San Andreas Fault system isolated the embayment from the ocean. The isolated water apparently transformed into a freshwater lake and, with continued subsidence to present day, resulted in up to 3,000 feet of lake bed silt and clay deposition beneath Tulare Lake (Bartow, 1991). Streams draining into the lake from the north and east interfingered with the lake beds as five distinct stratigraphic units. Along the lake margin, thick, clean sands were deposited as deltas or beach deposits. Similar deposits appear to occur farther south formed by the Kern River draining into the southern San Joaquin Valley, which extended northward as the lake receded.

The stratigraphic model of interbedded sands and lake bed clays for CV-SALTS was extended to encompass surrounding groundwater subbasins. Informal stratigraphic divisions of lower, middle, and upper lake beds based on the relationship with five lake margin sand sequences (informally named 1st through 5th in ascending order). Each younger sand sequence extends further into the lake beds. This is prominent to the north of Tulare Lake and less so from the east. The first four sand sequences consist of several hundred feet of thick, massive, fine-grained sand beds near the lake edge that are thought to be delta, beach, and possibly Aeolian dune deposits. A zone of thick sand beds occurs to the north of these deposits believed to be distributary stream channel deposits. Further north and northeast, sand beds are thinner and are interbedded with finer-grained beds believed to be fluvial, flood plain and alluvial fan/plain deposits. Tentatively, the top of the 2nd sand sequence is believed to mark the beginning of the Quaternary period (Pleistocene 2.5 to 0.01 m.y.) when glaciers carved the high Sierra Nevada.

With the onset of upper Tulare Lake Bed deposition, the upper half of the 4th and 5th sand sequences became thinner bedded and interfingered with thin lake bed clays. The extent of the lake beds extended north northeastward, and eastward and were termed the A through F clays in descending order by Croft and Gordon (1968) and Croft (1972). The most extensive of these clay beds is the

E-Clay, or Corcoran Clay, which extends from northern Kern County all the way to the City of Tracy in the San Joaquin Delta. The E-Clay was formed when a lake occurred in most of the San Joaquin Valley, which is delineated by the presence of this formation. A volcanic ash deposit above the E-Clay is dated as late Pleistocene about 600,000 years before present. The E-Clay has been long recognized as a major confining bed in much of the San Joaquin Valley separating two major aquifers: a shallow unconfined aquifer and a confined to semi-confined lower aquifer. The extent of a two-aquifer system east of Tulare Lake Bed is an important aspect of water banking processes of recharge and recovery pumping in proposed Pixley Groundwater Banking Project.

4. Local Geologic Setting

The proposed Pixley Groundwater Banking Project site is located along the eastern alluvial plain from the Sierra Nevada and east of the Tulare Lake Bed. Two regional Cross Sections H-H'' a K-K'' (**Figures 2** and **3**; two sheets each) reflect the stratigraphy described above. Oil and gas electric logs obtained from the state Division of Division of Oil Gas and Geothermal Resources (DOGGR) are the primary source delineating the occurrence and nature of sand sequences below and above the E-Clay. Electric logs from wells in DEID's Turnipseed Water Bank (see **Figure 1**) project also provided control in the southern portion of the current study area as reflected in cross sections K-K" (**Figure 3**) and 1-1' (**Figure 5**).

The majority electric logs sourced from oil and gas exploratory boreholes mostly record the depths below the surface at several hundred feet or greater, and may not record the E-Clay and shallower features. Along with the electric logs, approximately 450 DWR water well drillers reports were reviewed in Tulare and Kings counties to evaluate number, depths, and distribution of water wells in the study area (see **Plate 1**). Unfortunately, few electric logs are available for these water well boreholes. In addition, most driller's reports fail to describe the color of the clay beds that would delineate the blue or gray coloration of the E-Clay by deposition below the lake waters. The extent of the E-Clay shown on the cross-sections is from the Page (1986) map. The well control examined for this study did not provide evidence expanding that delineation.

From the regional cross sections, H-H'' and K-K'' (**Figures 2** and **3**), the lower and middle lake beds appear to extend further to the southeast to nearer the edge of the valley. The 1st sand sequence does not appear to have a thick lake margin zone, and is hard to differentiate from older nonmarine deposits. The entire post-Pliocene marine deposits thin eastward towards the edge of the Sierra Nevada and the uplift of the older geologic units. In addition, all the deposits have similar bedding characteristics from the common depositional setting of basin marginal fluvial and alluvial plain.

The 2nd sand sequence appears to be somewhat better defined and may have a thick-sand lake margin deposits several miles west of Highway 99. Further east, the 2nd sand sequence becomes indistinguishable from the rest of the deposits due to lack of stratigraphic markers.

The 3rd and 4th sequences extend much further west to about five miles west of Highway 43 where they interbed with lake bed clays. To the south, these sequences appear to merge with similar sand sequences that are sourced from the south. These sand sequences appear to be somewhat less distinctive and thinner than near-lake shore units on the north and northeast sides of Tulare lake Bed and appear to thin eastward to the edge of the valley. This may be attributable to a lack of large streams and sediment inflow compared to drainages further to the north. It may also be attributable to structural uplift. These sequences can be traced to several miles east of Highway 99 where separation becomes difficult as they thin. The 3rd and 4th sand sequences are composed of thin to occasional rare thick sand beds interbedded with clays, and represent deposition on fluvial and alluvial plains.

The youngest, uppermost 5th sand sequence occurs above the E-Clay. To the west near Highway 43, the unit may be 400 feet thick with interbeds of lake clays. The unit thins eastward to about 200 feet near the mapped edge of the E-Clay, and the interbeds of lake clays have pinched out. East of the mapped edge of the E-Clay, the 5th sequence thins further, and consists of thin sand beds and clays of fluvial/alluvium plain deposits. Separation from the underlying 4th sequence is difficult to discern.

The north-south cross section 1-1' (see **Figure 4**) was constructed at a regional scale to cross-correlate between the two regional cross sections H-H" and K-K" (**Figures 2** and **3**) to the project site area. This cross section has some lack of well control, but is also oblique to the stratigraphic and structural trends of the valley.

The detailed cross-section 2-2' (see **Figure 5**) was constructed in an east-west orientation to examine the project site area. The regional stratigraphic relationships and correlations from the regional cross-sections H-H" and K-K", and carried into the project site area by cross-section 1-1', were used to interpret the local detailed area of the Project site. The mapped extent of the E-Clay (Page, 1986) is about 2 miles east of the site at a depth of about 200 feet. The 5th sand sequence, above the E-Clay, is relatively thin at 200 feet or less, and thins eastward for about 2 miles. Water well drillers reports indicate that the 5th sequence consists of thin to rarely thick sand beds with interbedded finer-grained beds of fluvial/alluvial plain origin. Exploratory bore holes on the site (Provost & Pritchard, 2011) indicated similar materials to a depth of 100 feet. One boring to 150 feet encountered a thick clay between about 100 to 140 feet. However, water well logs do not indicate a thick clay surrounding the site and the occurrence appears to be anomalous. The 4th sequence below the site extends to a depth of about 600 feet (-300 feet elevation). This unit consists of thin to locally thick sand interbedded with fine grained clay/silt beds. The depositional setting again appears to be fluvial/alluvial plain environment with most wells in the project vicinity completed in the 4th sequence. The 3rd sequence occurs to a depth of about 900 feet (-600 feet elevation). The apparent thickness for this sequence at about 300 feet is somewhat less than encountered further west. The deepest water wells in the area appear to terminate largely in the 3rd sequence.

The 2nd sequence occurs to a depth of about 1,500 feet (-1,200 feet elevation). To the west, this sequence appears to increase in number and thickness of sand beds. This pattern of sand appears to indicate that the edge of the 2nd sand sequence ends at a lake margin west of Highway 99. East of the project site, the 2nd sequence decreases in sand bed content and becomes difficult to distinguish. Few driller's logs or water wells of record appear to extend into the 2nd sequence.

Below the 2nd sequence, the 1st sequence is difficult to delineate. Thin sand beds with interbedded clays appear to interfinger with lake beds to the west. Because of the thin nature of the sand beds, this sequence appears to be a questionable target for water wells. Below the 1st sequence, are older Tertiary (Pliocene and older) nonmarine deposits. These appear to have few thin sand beds with many interbeds of thick clays. Water quality in these deeper deposits is not clear and may be brackish to possibly saline. The Tertiary (Miocene) Santa Margarita sandstone at depth has definite saline water from the character of the electric log signatures.

5. Conclusions

The conceptualization of the aquifer system in the Project area is of a single aquifer system consisting of sands and interbedded clays typical of fluvial/alluvial plain deposition. Successful water well development would target the upper 4th and 3rd sand sequences, while the 5th sequence is too shallow in the project area to support high capacity supply wells. Sand beds in the deepest 2nd and 1st sequences have not historically been targeted for water supply. While the 2nd sequence appears to have favorable sand beds, the deepest 1st sequence would likely not offer viable targets for water supply in the Project area.

From its configuration, the aquifer system is expected to be heterogenous and leaky with impedance to vertical flow of varying degrees. With respect to water banking, direct recharge would follow vertical and horizontal pathways and accrue to groundwater storage such as in the manner that streamflow from the Sierra Nevada and irrigation conveyances recharge the underlying aquifer system on local and regional scales. This conceptualization is reflected in numerical modeling used to evaluate benefits of recharge and the 10-percent leave-behind components of the Project (see part H3 of this appendix).

Chief among the important findings is that available well control supports location of the edge of the E-Clay, or Corcoran Clay, west of the Project. No evidence was found in drillers logs indicating an extension of the E-Clay, or other continuous lake bed clay, into the Project area. The nature of sand and clay sequences is one of aerially discontinuous units typical of fluvial/alluvial deposition.

From the stratigraphic model, high capacity supply wells including the Project recovery wells would target aquifer units to about 1,200 feet below ground surface with few viable aquifer units at greater depths. Bank operations would occur within the main aquifer system tapped by other groundwater users including adjacent landowners and recharge would be expected to accrue within the PID service area via laterally and vertically connected sand beds.

The Project includes implementation of a groundwater monitoring program of which the stratigraphic model and hydrogeologic conceptualization provides a basis for preliminary planning including design of dedicated observation wells.

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Figures

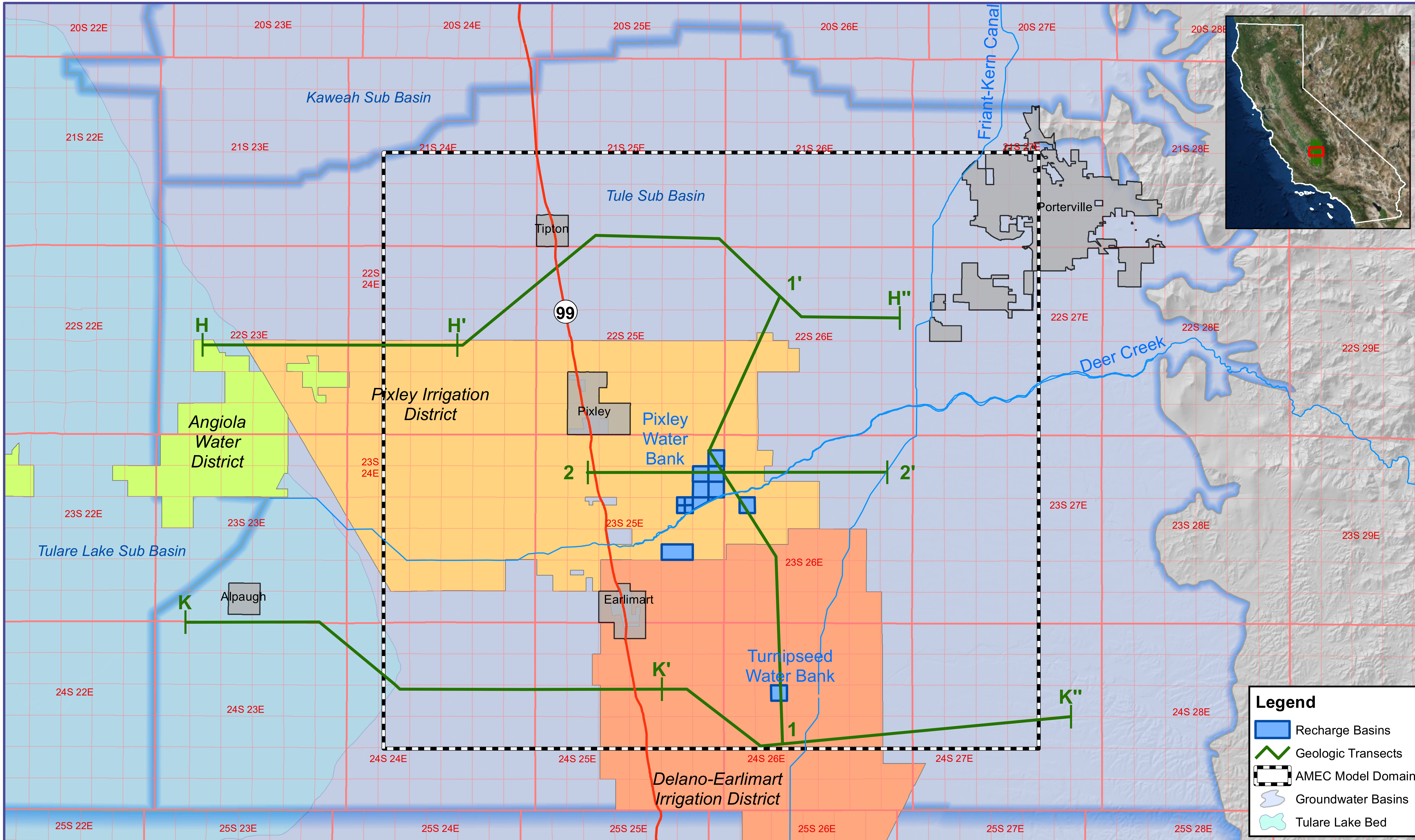

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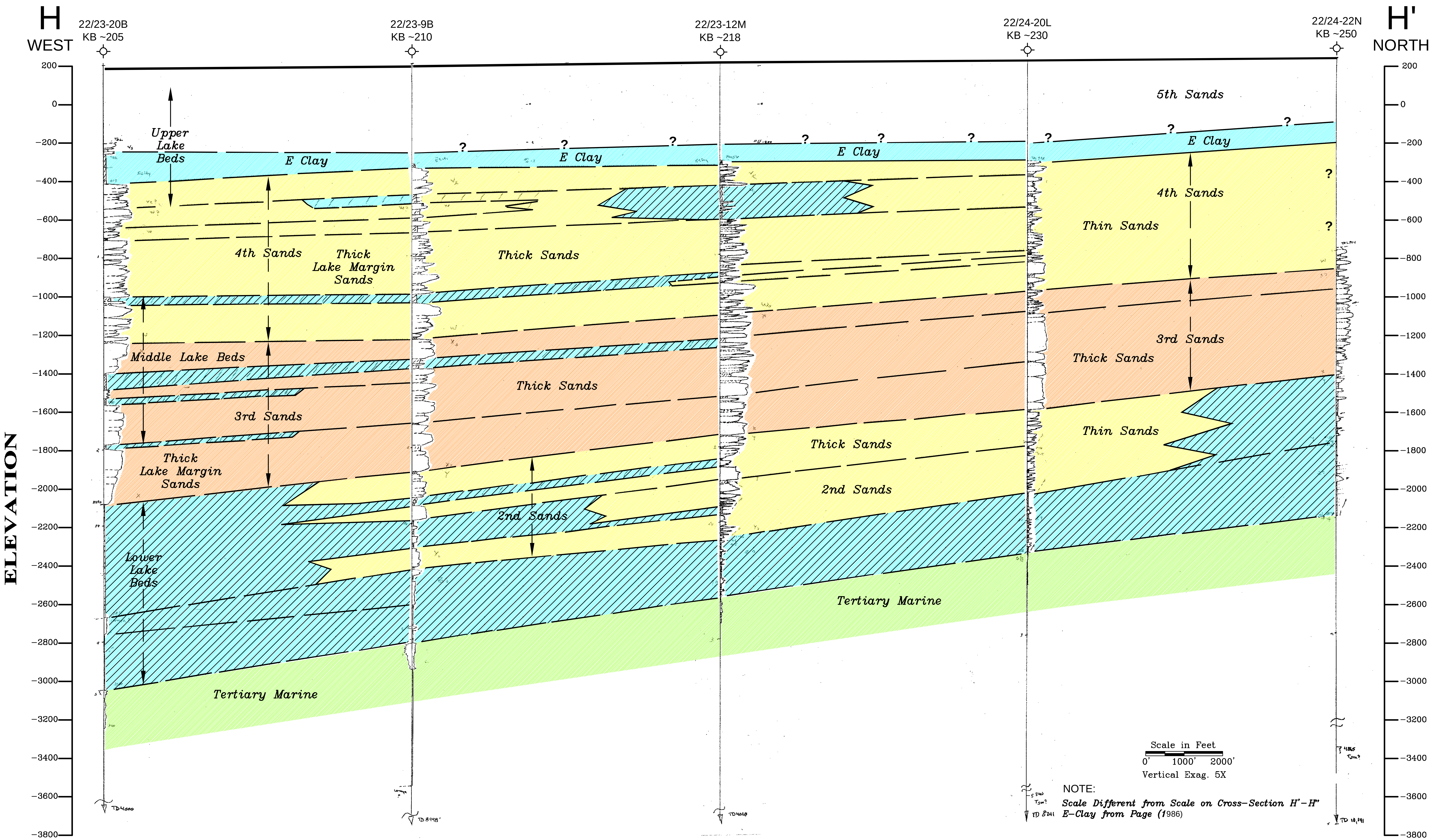
Figure 1: Location Map
Pixley Groundwater Banking Project



Sheet 1 of 2

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Figure 2a: Geologic Cross Section H-H'
Pixley Groundwater Banking Project

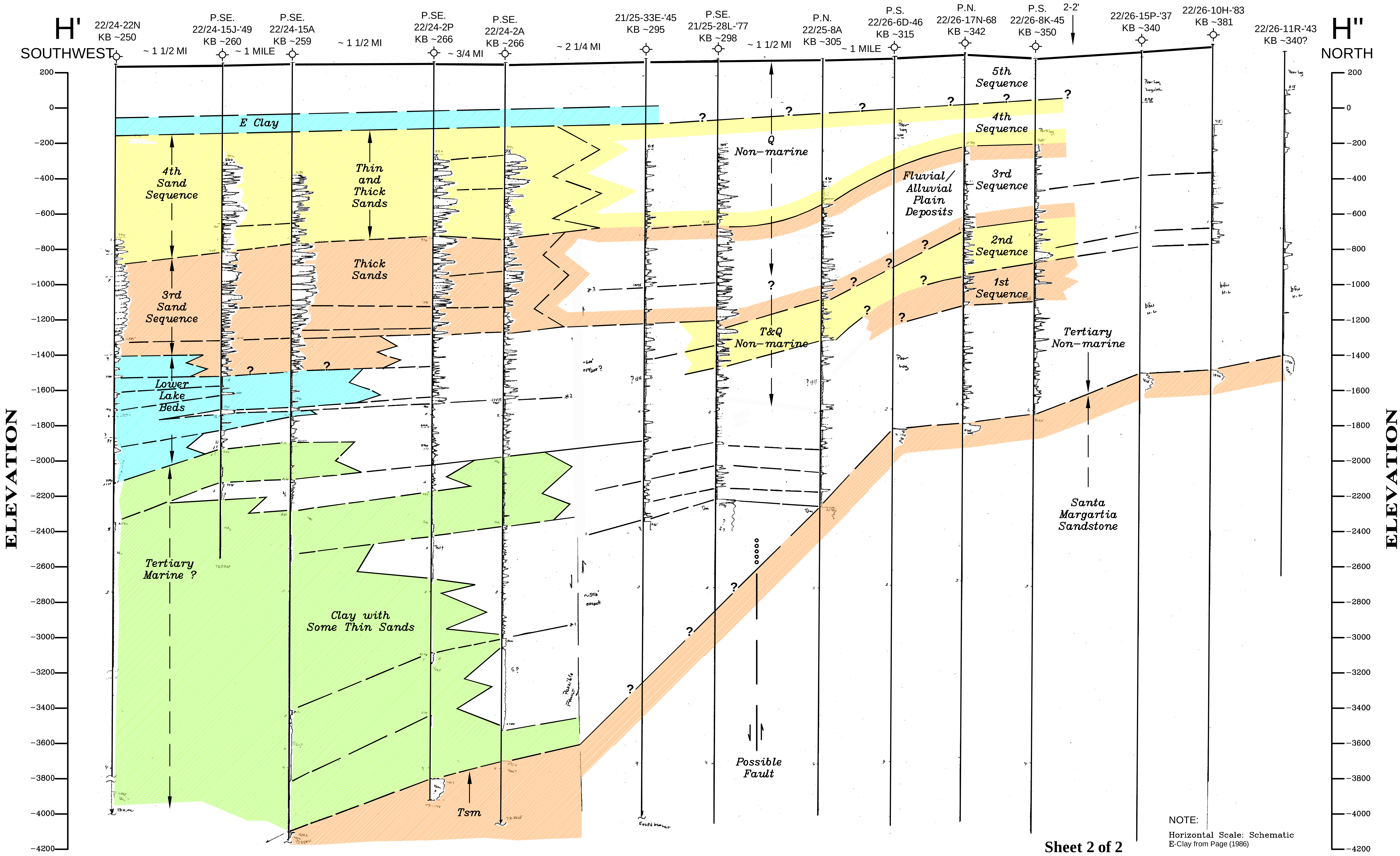

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Figure 2b: Geologic Cross Section H'-H''
Pixley Groundwater Banking Project

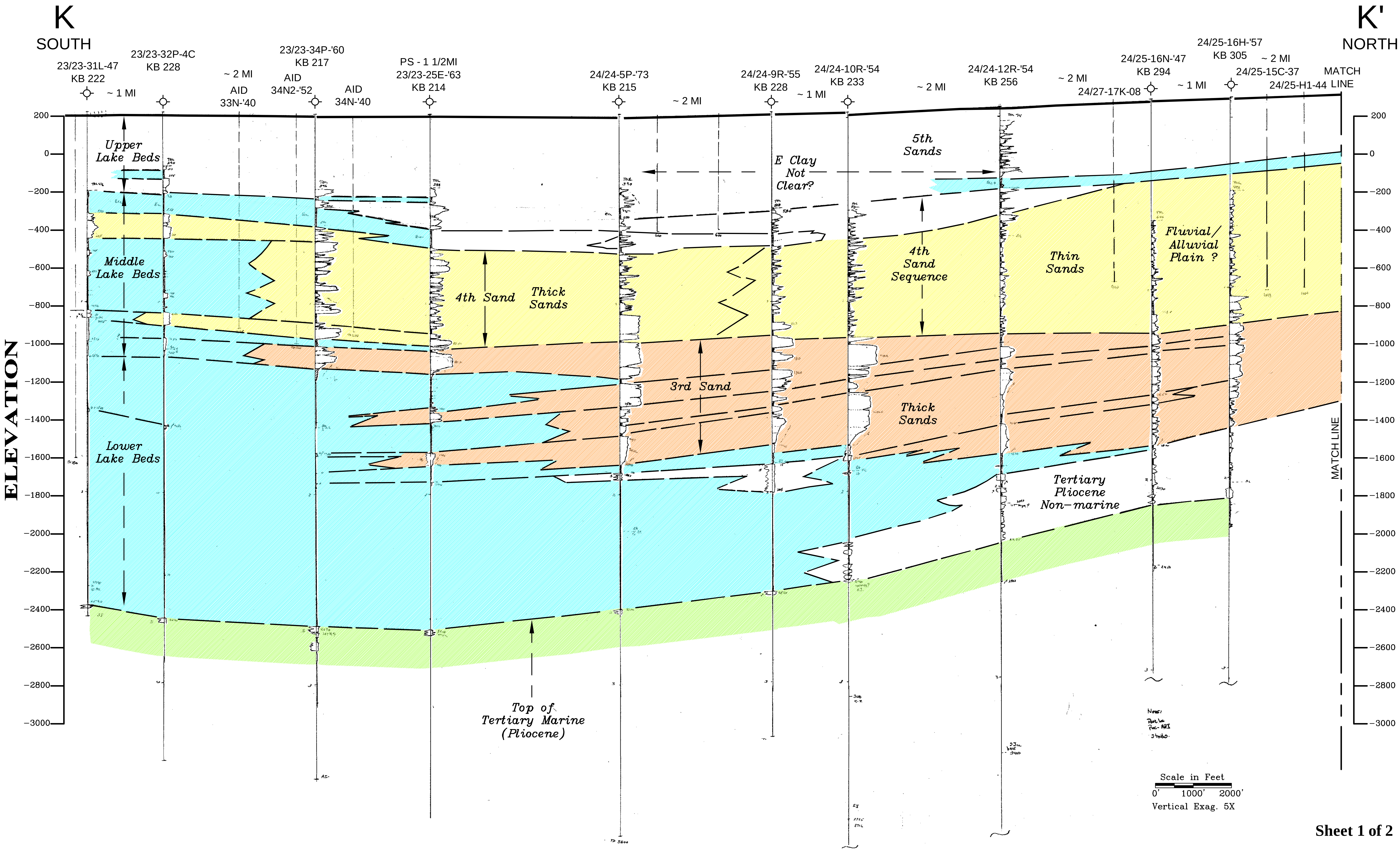

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Figure 3a: Geologic Cross Section K-K'
Pixley Groundwater Banking Project

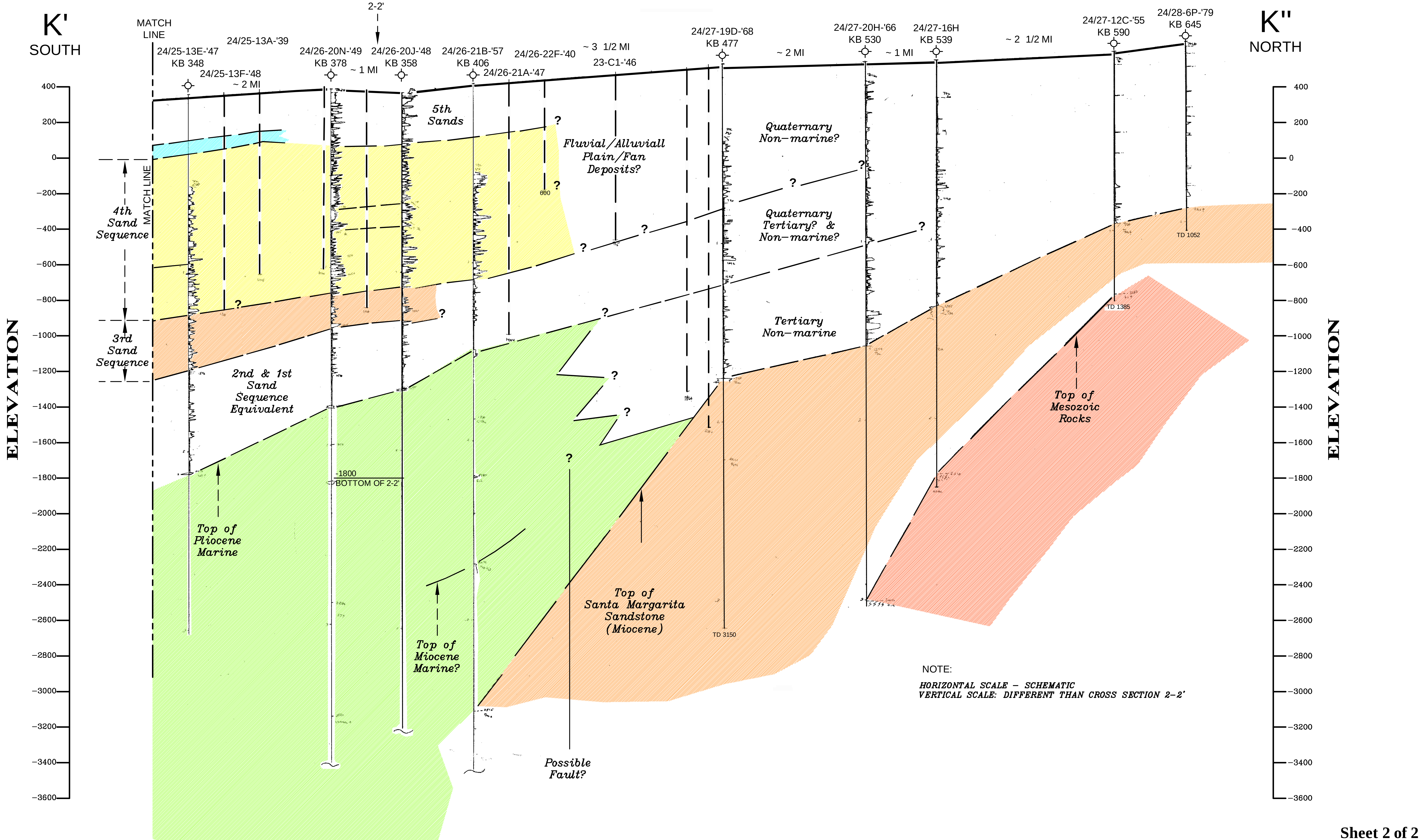

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Figure 3b: Geologic Cross Section K'-K"
Pixley Groundwater Banking Project

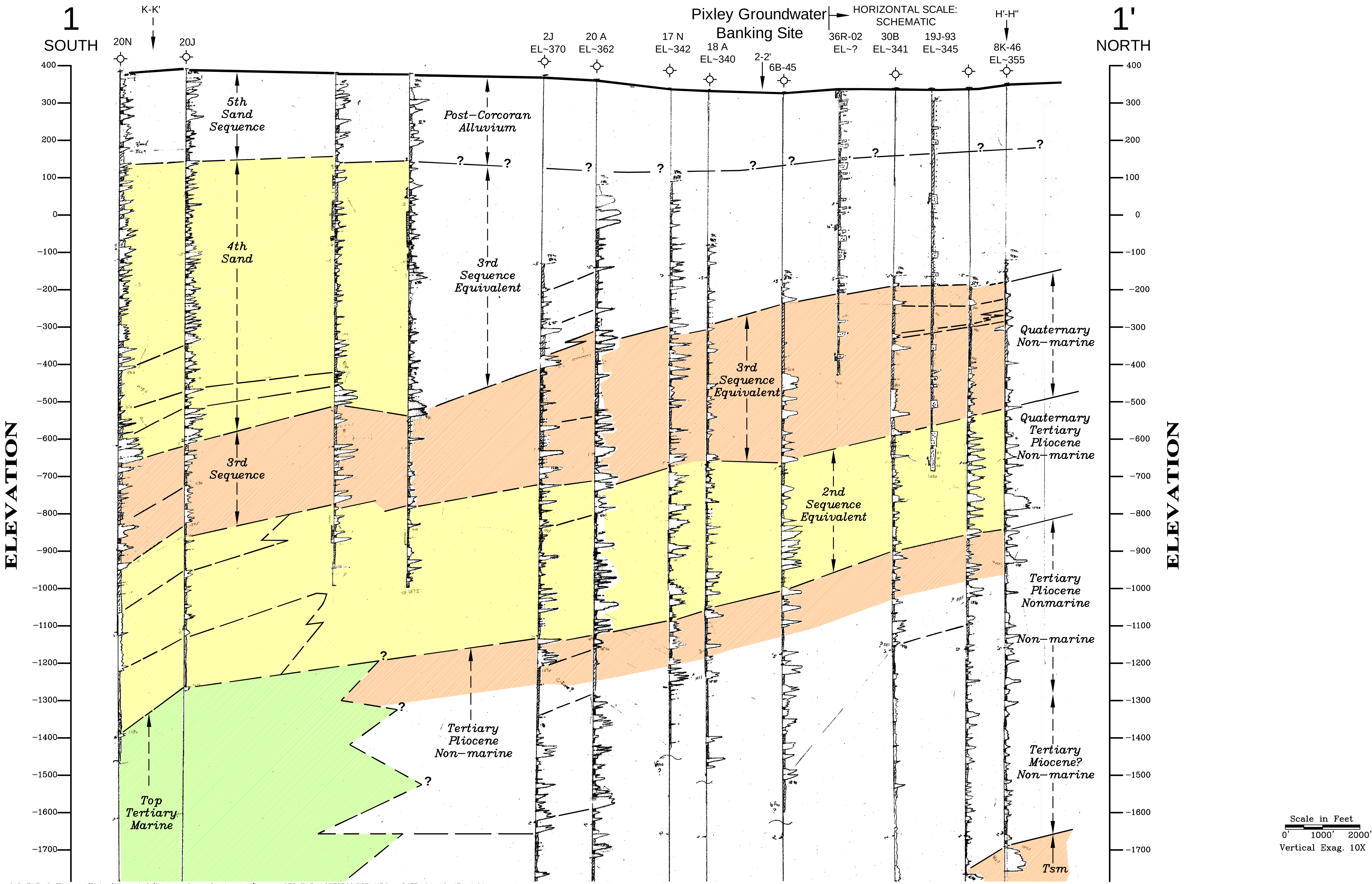

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Figure 4: Geologic Cross Section 1-1'
Pixley Groundwater Banking Project

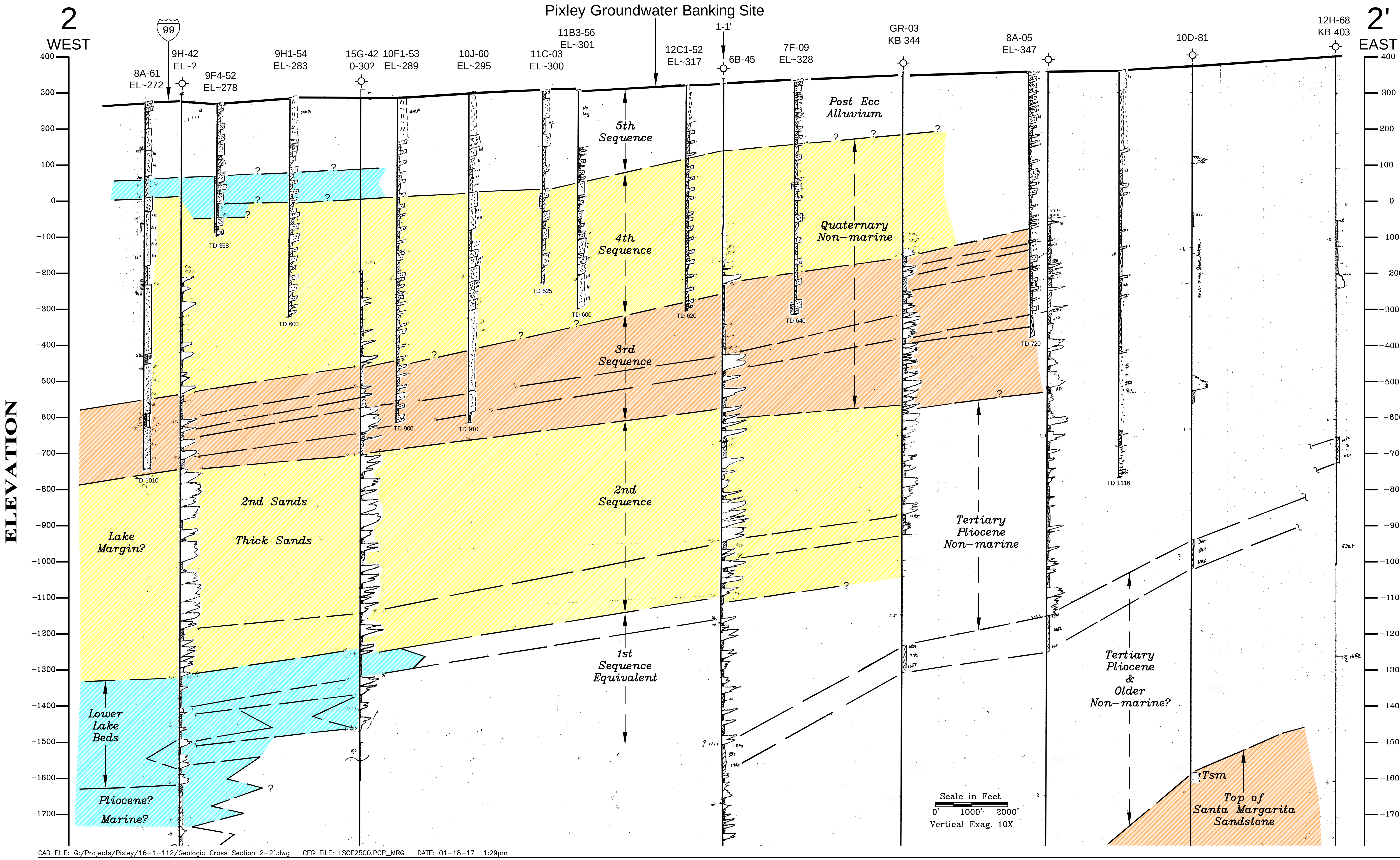

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Figure: 5 Geologic Cross Section 2-2'
Pixley Groundwater Banking Project

Plate 1

Well and Cross Section Locations Map