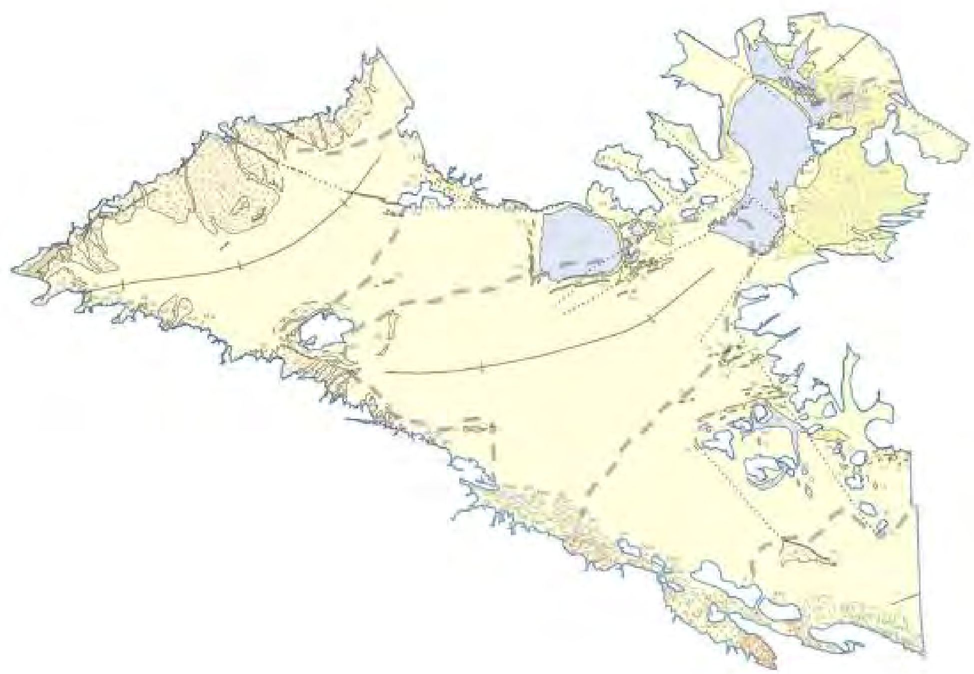
Summary Expert Report
Phase 3 – Basin Yield and Overdraft

Antelope Valley Area of Adjudication



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I. Introduction

Approximately ten years ago, Bolthouse Farms and Diamond Farming brought suit against the major public water suppliers located in the Antelope Valley, including Los Angeles County Waterworks District No. 40 and Palmdale Water District. By doing so, those agricultural entities sought to quiet title to their right to continue to produce water for their uses when compared in priority to the public water suppliers. Approximately five years later, Los Angeles County Waterworks District No. 40 filed suits in Los Angeles and Kern Counties, seeking an inter se adjudication among all persons pumping or claiming a right to pump water from the Antelope Valley Groundwater Basin and seeking the imposition of a court-administered physical solution on that pumping. Those complaints were coordinated with the earlier Bolthouse Farms and Diamond Farming case for joint processing.

A Phase 1 trial was conducted in the coordinated cases (Judicial Council Coordination Proceeding No. 4408; Los Angeles County Superior Court, Case No. BC 325 201), the result of which established the jurisdictional boundaries of the area to be adjudicated. The resultant boundaries of the Antelope Valley Area of Adjudication (AVAA) are described and illustrated in Chapter II. A subsequent Phase 2 trial was conducted in the coordinated cases, the result of which established that there were no hydrogeologically or otherwise separate basins or subbasins within the AVAA that would be separately treated in subsequent phases of the overall adjudication. A Phase 3 trial is scheduled to begin in late September 2010 to address the topics of basin yield and overdraft; this summary Report has been prepared for Phase 3.

1.1 Scope and Preparation of Summary Report

This Summary Report on Overall Basin Conditions in the Antelope Valley is the joint effort of six experts retained by eight of the parties to the Antelope Valley Groundwater Cases. It was prepared to summarize their collective, integrated efforts to describe the geology, occurrence of groundwater, and overall conditions in the Valley as related to historical and current land uses, water-requirements, surface and groundwater supplies, including natural and supplemental sources of groundwater recharge, resultant groundwater basin yield, extent of groundwater use, and resultant groundwater basin conditions. The report also summarizes the treatment, utilization and disposal of recycled water in the Valley.

Strictly speaking, the geographic area that is the focus of this report, while called the Antelope Valley for convenience, is not exactly the Antelope Valley as might be commonly referenced or understood. Rather, it is properly the Antelope Valley Area of Adjudication which derived from the Phase 1 trial introduced above; the definitive boundaries are illustrated and generally described in Chapter 2 of this report.

This Summary Report has been co-prepared by the authors listed on the cover and in Appendix A, primarily to document the descriptions and analyses included herein, and to serve as a summary of information intended to be presented by some or all of them in the Phase 3 trial on groundwater basin yield and conditions.

1.2 Organization of Summary Report

This Summary Report on Overall Basin Conditions in the Antelope Valley is organized to include this Introduction; a brief description of the Antelope Valley and the Area of Adjudication to which the report is applicable (Chapter 2); a summary description of the geologic setting and occurrence of groundwater (Chapter 3); summaries of the various detailed analyses of water resources, water requirements, and water supplies in the Antelope Valley, ultimately focused on groundwater basin yield and groundwater conditions relative to basin yield, with reference to expanded reports on those topics in the appendices of this report (Chapter 4); and conclusions relating historical and current groundwater pumping to the sustainable yield of the basin and also summarizing the net effects of imbalance between pumping and sustainable yield on groundwater levels, storage, and land subsidence.

II. Antelope Valley

2.1 Physical Setting

The Antelope Valley is located in the southwest portion of the Mojave Desert in southern California about 40 miles north of the city of Los Angeles. Approximately two-thirds of the Valley area is located in northern Los Angeles County and the remainder occupies adjacent southeastern Kern County. The Valley is bounded on the south and west by the San Gabriel and Tehachapi Mountains, respectively; on the north by the Rosamond and Bissell Hills; and on the east by the buttes and alluvial fans of the Hi Vista area. Adjacent to the Antelope Valley are the Fremont Valley to the north and the Victor Valley to the east.

The Antelope Valley is a closed basin, approximately 1,390 square miles area, comprised of relatively flat valley land and dry lake beds with coalescing alluvial fans and scattered buttes around the periphery. Surface elevations in the Valley range from about 2,300 feet to nearly 3,500 feet above mean sea level (MSL). Several creeks, most notably perennial Big Rock and Little Rock Creeks, drain the surrounding mountains, cross the alluvial fans, and typically become dry washes. The Los Angeles Aqueduct traverses the western end of the Valley and the California Aqueduct runs along the Valley’s southern edge, flanking the San Gabriel Mountains.

Urban centers in the Antelope Valley include the cities of Lancaster, Palmdale, and Rosamond along State Highway 14, as well as a large portion of Edwards Air Force Base (Edwards AFB) in the Valley’s northeast corner. The population in the Palmdale/Lancaster urbanized area has increased rapidly since the 1980's and is currently above 300,000. Agricultural lands occupy various parts of the area near the cities and Edwards AFB, historically exceeding 60,000 acres and currently comprising approximately 25,000 acres. For several decades, into the 1980’s, the predominant agricultural land use was for alfalfa farming. In recent years, cropping patterns have been more diverse, including alfalfa, grain, carrots and onions, with some deciduous orchards and small areas of sugar beets, melons, squash, potatoes, and grape vineyards.

The climate in the Valley is dry with typically less than 10 inches of average rainfall annually, while the surrounding mountains receive upwards of 18 inches annually. The seasonal variation in rainfall is pronounced, with the great majority occurring during the winter months from November through March. Temperatures in the Valley vary greatly by season, with average monthly temperatures ranging from 44° F in January to 88° F in August. The daily temperatures vary widely as well, and they commonly exceed 100° F in the summer months and usually drop below freezing during winter nights. As a result, the average length of the growing season for most of the Valley is 215 to 245 days per year, generally from April through October. High wind velocities constitute an additional challenge, creating erosion problems of blowing soil and accumulation of wind-driven sand on irrigated lands, as well as circulating drier air and contributing to higher evaporation.

2.2 Area of Adjudication

At the completion of Phase 1 of the overall Antelope Valley Groundwater Cases, the Court concluded in its Order dated November 3, 2006 that the alluvial basin as described in California Department of Water Resources Bulletin 118-2003 should be the basic jurisdictional boundary for purposes of the litigation. The Court noted that, in addition to the alluvial basin, the adjacent valleys also may have conductivity and potentially some impact on the aquifer. However, the Court further noted that the evidence before the Court at that time was that the amount of flow in those valleys at the present time and historically has been nominal and in some cases virtually nil, and will likely remain so for the indefinite future. Thus, the court excluded the adjacent valleys from the Area of Adjudication jurisdictional boundaries but left open the opportunity for any party may seek leave to have particular parties in those areas joined if it believes that there is measurable impact on the aquifer. Since no change has occurred to date, the Area of Adjudication for this Summary Report reflects the description in the Court's order, and thus excludes the adjacent valleys.

The Area of Adjudication for the Antelope Valley Groundwater Adjudication is illustrated in Figure 2-1. The illustrated area is generally described as follows.

Beginning in the southeast corner of the basin (where "basin" is intended to mean adjudication area for purposes of this report), and proceeding clockwise around the area, the southerly boundary is largely comprised of the mapped extent of bedrock contact to the north of, and generally parallel to the San Andreas Fault. Along the entire southerly boundary, it cuts across two locations, at the mouth of Soledad Canyon and the mouth of Leona Valley, where surface drainage occurs above alluvium that is narrowly connected to the main Antelope Valley and/or is known or thought to be very thin or limited in extent. Thus, that alluvium is neither significantly productive nor conductive of significant groundwater flow into the main valley.

From the southwesterly corner of the basin, the westerly boundary is entirely comprised of the mapped extent of bedrock contact to the southeast of, and roughly parallel to the Garlock Fault complex. The northwesterly corner of the basin is along that bedrock contact near the mouth of Oak Creek Canyon. From that northwesterly corner, the basin is bounded on the north by a southeasterly trending line to Middle Butte; the basin boundary follows the westerly side of that bedrock contact and then crosses an alluvial gap to bedrock outcrop of Gem Hill and the Rosamond Hills, which it then follows to the northwest corner of the dry Rosamond Lake bed. From the northwest corner of Rosamond Lake (dry), the basin predominately follows bedrock contact along the Rosamond and Bissell Hills, generally on the west side of Edwards Air Force Base, to the Muroc Fault where it follows the Fault/bedrock contact. The boundary arbitrarily crosses some narrow gaps between rock outcrops in the Rosamond and Bissell Hills, where the gaps represent small connections with the Fremont Valley Groundwater Basin to the west. Similarly, to the north of Edwards AFB and on the east side of Rogers Dry Lake, the boundary arbitrarily crosses some narrow gaps between rock outcrops, the most notable of which is a narrow neck that isolates the Peerless Valley to the north.

On the east side of the Antelope Valley, the basin is bounded by bedrock contacts along the entire so-called Hi-Vista area of bedrock outcrops. Where that contact reaches the Los Angeles-San Bernardino County line along the southeast side of the basin, the groundwater basin is arbitrarily bounded by the County line, which is recognized to be the western boundary of the adjudicated Mojave Water Agency area in San Bernardino County.

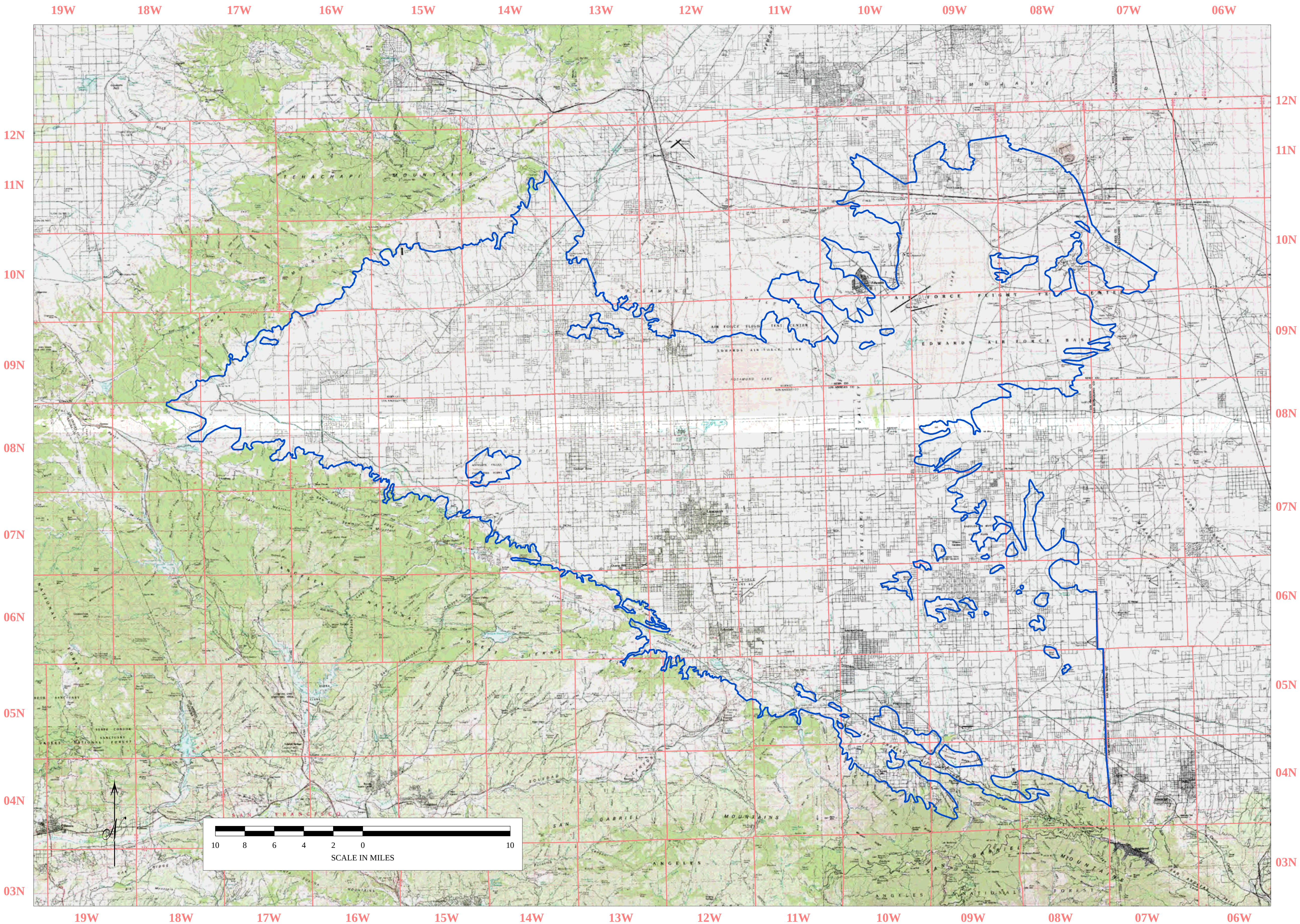

Figure 2-1
Jurisdictional Boundary
Antelope Valley Groundwater Adjudication

III. Geology and the Occurrence of Groundwater

3.1 Introduction

The Antelope Valley Area of Adjudication (AVAA) is in the western-most area of the Mojave Desert geologic province of California. The boundaries of the western Mojave Desert are the northeast trending Garlock Fault Zone to the west and the San Andreas Fault Zone to the south (Figure 3-1). The three major geologic units present are: Pre-Cenozoic crystalline rocks; older Cenozoic, Tertiary volcanic and sedimentary rocks; and younger Cenozoic, Quaternary sedimentary deposits.

The AVAA is a west pointing, crudely wedge-shaped or arrowhead-shaped area. The AVAA boundaries are defined as approximately the contact between the Quaternary sedimentary deposits and the older geologic units (Figure 3-1). Where necessary, the AVAA boundary was drawn to limit the extent based on hydrologic divides, across narrow valley areas, and along the San Bernadino County line, the western boundary of the adjacent Mojave River Adjudication Area.

The majority of groundwater production is extracted from aquifer materials to maximum depths of about 1,000 to 1,500 feet in the AVAA, and appears to be primarily from the Quaternary sedimentary deposits, and possibly the uppermost Tertiary units. While the major (Garlock and San Andreas Fault Zones) and secondary faults in the AVAA have had major effects on the structure and history of the geologic units, the presence of four Cenozoic sedimentary basins have influenced the deposition of the Tertiary and Quaternary sedimentary units. These four sedimentary basins are: the West Antelope Valley basin, the East Antelope Valley basin, the Cajon basin, and the Kramer basin (Figure 3-1). The West and East Antelope Valley sedimentary basins lie largely within the AVAA. Only the southern portion of the Kramer sedimentary basin and the western-most portion of the Cajon sedimentary basin lie within the AVAA. As they subsided, these sedimentary basins have been filled with Cenozoic volcanic and sedimentary deposits with thicknesses of about 8,000 feet in the West Antelope Valley basin, and 10,000 feet or more in the East Antelope Valley basin. The portions of the Kramer and Cajon sedimentary basins beneath the AVAA are not as well known, but appear to contain at least several thousand feet of Cenozoic deposits. The nature and water-bearing characteristics of these deep deposits in the sedimentary basins are not well known. Because these deposits occur well below the depths of groundwater production, these units have not been examined in detail.

3.2 Methodology

The primary intent of this chapter is to first describe the geology of the area, and then describe the nature and extent of subsurface materials, primarily as they relate to the occurrence of groundwater. The description of geology is derived primarily from available geologic reports and mapping. The description and illustration of subsurface materials, on the other hand, is primarily based on interpretation of borehole data lithologic logs and geophysical (electrical) logs, as sequentially collected and analyzed as follows.

The initial data set consisted of wells of record compiled by the U.S. Geological Survey (USGS) and published by Department of Water Resources (DWR) in five volumes of Bulletin No. 91 (91-4, 6, 11, 12, and 16). Within the AVAA, these Bulletins contain records of about 2,500 wells, of which approximately 800 have lithologic descriptions of materials encountered (i.e. "driller's logs"). A second data set consisted of driller's logs, water well drillers reports, and a few geophysical logs from the files of the major municipal water suppliers. A third data set consisted of lithologic logs and geophysical logs from published reports of monitoring wells installed by the U.S. Geological Survey.

Based on review of reports, the distribution of available subsurface data, and the configuration of the AVAA, a network of work cross-sections was constructed to examine the groundwater geology; ultimately, because of the large areal extent of the AVAA, a total of 21 work cross-sections was prepared (Figure 3-2). During construction of these cross-sections, some additional local work cross-sections were prepared to examine localized configurations.

A fourth data set of water well drillers reports and geophysical logs was made available by the State Department of Water Resources after completion of the initial set of work cross-sections. This data set consisted of about 3,000 items, of which 2,000 to 2,500 represented additional wells, excluding duplicates from the previous data sets, well abandonment reports, and shallow monitoring wells. Where this new data occurred in gaps along existing work cross-sections, or extended to greater depths, selected well profiles were added as appropriate to aid definition in the cross-sections.

Where appropriate, working structure-contour maps were made in selected areas where Pre-Cenozoic crystalline or older Tertiary rocks were encountered in boreholes to evaluate the subsurface elevation configuration of these rocks. Derivative maps were also made from boreholes, where 'blue or gray' clay was encountered, and where the elevation and thickness of the clay were noted. In the East Antelope Valley area, a working structure-contour map was constructed to show the elevation contours on the top of the 'blue clay' lake beds. In selected areas, derivative maps were prepared to show reported well usage (i.e. public supply, domestic, industrial, and irrigation) and the well drilling method (i.e. cable-tool or rotary).

Ultimately, the configuration and nature of the aquifer system in the Antelope Valley basin were derived from the work cross sections and various maps. The latter parts of this chapter describe and illustrate the aquifer system, and include selected cross sections from the overall set of work cross-sections as noted on Figure 3-2. The balance of the work sections are included for reference in Appendix B.

3.3 Older Regional Geologic Units

The two older regional geologic units in the AVAA are composed of Pre-Cenozoic crystalline rocks, and Tertiary volcanic and sedimentary rocks. The following descriptions of the older geologic units are largely based on the geologic mapping by T.W. Dibblee, Jr. (see reference list), and in particular his summary reports (Dibblee, 1967, and 1980 a, b,c).

3.3.1 Pre-Cenozoic Crystalline Rocks

The Pre-Cenozoic crystalline rocks are the oldest (pre-63 million years, or my) in the region. They are divisible into three main types: granitic rocks, metasedimentary rocks, and the Pelona Schist (Figure 3-1). These rocks occur in the mountains and low hills surrounding the AVAA; they also exist below as much as 10,000 feet of younger geologic units beneath the surface of the AVAA. Many of the isolated buttes and knobs, particularly to the southeast, are composed of the crystalline rocks.

The Pre-Cenozoic rocks are generally considered 'non-water bearing' because of their crystalline nature. However, a limited number of wells located in these rocks indicate that small quantities of groundwater, sufficient for individual domestic or stock watering purposes, can be developed from fractures and weathered zones within the rocks. Additional data and discussion of permeability and well yields in fractured crystalline bedrock are provided in Section 3.6.5.

3.3.1.1 Granitic Rocks

The most-widely exposed crystalline rocks in the region, and the youngest, are the Mesozoic intrusive granitic rocks. The most common is quartz monzonite of about 90 million years age. A variety of other granitic rock types occur, but are of limited extent and not discussed further. The granitic rocks are exposed in the Tehachapi Mountains to the west and in the Rosamond and Bissell Hills to the north of the AVAA (Figure 3-1). Several small exposures of granitic rock occur as isolated knobs in Hospital Ridge on the Edwards Air Force Base, and a very small exposure near the center of northern Rogers Lake (Dibblee, 1960). The granitic rocks occur along the high ridges to the east of Rogers Lake, merging into the Hi Vista area to the south (Figure 3-1). All of the isolated buttes and knobs in the southeast part of the AVAA towards the San Bernadino County line are granitic rocks. A series of small areas of granitic rock occurs southeast of Palmdale along the San Andreas Fault Zone. The San Gabriel Mountains south of San Andreas Fault Zone consist largely of pre-Cenozoic granitic rocks. Further west, north of the San Andreas Fault Zone, a larger exposure of granitic rocks occurs in the western Portal Ridge. Just to the north of the Portal Ridge, granitic rocks are present in Antelope Buttes and on a small knob southwest of Little Buttes (Figure 3-1).

The granitic rocks were formed by large intrusive magma bodies (plutons), which were generated by the collision and subduction of the Pacific Oceanic Plate beneath the North

American Continental Plate. The magma chambers fed an overlying volcanic mountain chain. The area was uplifted and the overlying volcanic and metamorphic rocks were removed by erosion to eventually expose the granitic rocks.

3.3.1.2 Metasedimentary Rocks

The least exposed crystalline rocks are low-grade metamorphosed, sedimentary rocks of marine origin consisting originally of shales, sandstones and limestones. Believed to range from Paleozoic (?) (pre-245 my) to Mesozoic (pre-63 my), the rocks were deposited along the edge of the North American Continental Plate and then deformed, metamorphosed, and intruded by the granitic rocks as subduction occurred.

In the AVAA region, only a few small bands of the metasedimentary rocks occur along the eastern edge of the Tehachapi mountains, which are either un-named to the south, or named the Bean Canyon Formation to the north (Figure 3-1). To the southeast of Palmdale, a thin band of metasedimentary rocks occurs in the knobs of granitic rocks along the San Andreas Fault.

3.3.1.3 Pelona Schist

Slightly more widespread are the rocks of the more highly metamorphosed Pelona Schist and other similar schists, with nearly all exposures occurring along the Garlock and San Andreas Fault Zones (Figure 3-1). The largest areas of Pelona Schist are in eastern Portal Ridge and Quartz Hill in the AVAA, and south of the San Andreas Fault Zone outside the AVAA. Other exposures of schist occur in the Tehachapi Mountains along the Garlock Fault Zone. Originally sedimentary in origin, the schist is so highly deformed and metamorphosed that its history is poorly known and has been assigned ages from Paleozoic (?) to late Mesozoic.

3.3.2 Tertiary Volcanic and Sedimentary Rocks

Following the long period of deformation, uplift, and erosion which extended into the Cenozoic, the next major geologic event in the AVAA was Tertiary volcanism and sedimentation. Rocks from this event are divisible into two types: older Miocene (23.7 – 5.3 my) volcanic and sedimentary rocks, and younger Pliocene (5.3 – 1.77 my) sedimentary rocks.

3.3.2.1 Miocene Volcanic and Sedimentary Rocks

The Miocene volcanic and sedimentary rocks occur along the western Antelope Valley area in the western tip, northeastward in the Rosamond Hills, and into the Kramer sedimentary basin to the north (Figure 3-1). The oldest Miocene rocks appear to be the Neenach Volcanic Formation (24-21 my?) on the southwest edge of the AVAA (Figure 3-1) composed of at least 1,500 feet of volcanic flows and tuffs. The distinctive volcanic stratigraphy of the Neenach Volcanic Formation has been correlated to a similar sequence in the Pinnacles Volcanic area west of the

San Andreas Fault Zone in central California, as evidence of strike-slip fault displacement of about 200 miles (Crowell, 2003).

Overlying the Neenach Volcanic Formation is a sequence of marine shale, sandstone, and conglomerate termed the Quail Lake Formation. The Oso Canyon Formation of non-marine sandstones and conglomerates interfingers and overlies the Quail Lake Formation. Both formations are believed to be of late Miocene age (11.2 – 5.3 my), with maximum thicknesses of 2,400 feet for the Quail Lake Formation and 5,500 feet for the Oso Canyon Formation.

To the north, the Miocene volcanic and sedimentary rocks are collectively known as the Tropico Group, with local formational names applied in different areas. In the southern Rosamond Hills and Antelope Buttes areas (Figure 3-1), the lower unit is named the Gem Hill Formation, consisting of volcanic tuff, tuff breccias, and tuffaeous sandstone. In the Antelope Buttes, about 1,250 feet is exposed and dips westward. At Little Buttes, about 800 feet of Gem Hill Formation occurs and dips eastward. In the south Rosamond Hills area, the Gem Hill Formation is about 1,300 feet thick, and complexly faulted and folded.

At Willow Springs Mountain, Tropico Hill, Middle Buttes, Soledad Mountain, and along the southern edge of Rosamond Hills (Figure 3-1), intrusive volcanic rocks are present. These rocks are named the Bobtail Quartz Latite Member of the Gem Hill Formation. The rocks were formed by the cooling of magma in the volcanic vents from which the tuff deposits of the Gem Hill Formation were erupted. Because of the crystalline nature of these volcanic rocks, they are more resistant to erosion, and occur as steep buttes.

Overlying the Gem Hill Formation in the western Antelope Valley area, a reddish brown, coarse fanglomerate of boulders to pebbles of tuffaceous and granitic rocks is named the Fiss Fanglomerate. The unit is about 900 feet thick in the southern Rosamond Hill area, and up to 1,700 feet thick at the Fairmont Butte (Figure 3-1). These coarse-grained deposits were formed by alluvial fans from erosion of uplifted Gem Hill Formation and granitic bedrock.

Further north in the Bissell Hills, a small syncline preserves a similar stratigraphic sequence of Miocene rocks (Figure 3-1). A thin section of Gem Hill Formation is overlain by about 760 feet of carbonate, shale, claystone, and sandstone, which Dibblee named the Bissell Formation of the Tropico Group. The fine-grained deposits (carbonate and shales) were formed in a lake environment. The sandstone and claystone deposits are believed to have been laid down by streams. The Bissell Formation is considered correlative to the Gem Hill Formation and Fiss Fanglomerate.

At the northern edge of the AVAA, a thick sequence of Miocene Tropico Group occurs in the Kramer sedimentary basin (Figure 3-1). The lower part consists of nearly 2,000 feet of volcanic and sedimentary rocks, with some interbedded basalt lava flows. A middle section consists of basalt lava flows up to at least 400 feet thick, and named the Saddleback Basalt. Exposures of the Saddleback Basalt as small knobs and buttes in the Muroc Hills and Stone House Hills are used to define the northern AVAA boundary. An upper part of the Tropico Group occurs to the north and east of the AVAA, ranging up to 2,500 feet thick. The Saddleback Basalt and upper Tropico Group in the Kramer basin may extend into Pliocene time. The lower, middle, and some upper Tropico Group may occur southward to near the northern edge of Rogers Lake at depths below 1,000 feet.

In the rest of the AVAA, Miocene rocks are absent. A small volcanic intrusive plug occurs at Haystack Butte east of Rogers Lake (Figure 3-1). Two small knobs of fanglomerate west of Buckhorn Lake were mapped by Ward and Dixon (2002) as Fiss Fanglomerate, although Dibblee (1967) had mapped them as Quaternary fanglomerate. Small, scattered exposures of Miocene sedimentary rocks occur in the San Andreas Fault Zone along the southern AVAA boundary.

3.3.2.2 Pliocene Sedimentary Rocks

Overlying the older rocks are late Tertiary, Pliocene (5.3-1.77 my) sedimentary deposits. Exposed in only a few small areas, the Pliocene deposits are believed to be present in the subsurface in the West Antelope Valley, East Antelope Valley, and the Cajon sedimentary basins (Dibblee, 1967). In the Kramer sedimentary basin, the Saddleback Basalt and upper Tropico Group may extend into Pliocene time, but are largely north of the AVAA.

In the westernmost tip of the AVAA is a 1,500 foot thick sequence of non-marine, fluvial and lacustrine sedimentary deposits named the Meeke Mine Formation (Figure 3-1). The formation consists of two weakly consolidated gravel units separated by a lacustrine clay sequence. A similar unit occurs slightly northeast, and consists of about 1,650 feet of sandstone and conglomerate with thin clay to shale beds.

In the southeastern corner of AVAA, there is a Pliocene sequence of fluvial sedimentary deposits termed the Crowder Formation (Figure 3-1). About 1,000 feet thick and dipping gently northward, the unit is composed of weakly consolidated, gray to white sandstones and conglomerates. The Crowder Formation appears to thin to the west, and is part of the western-most Cajon sedimentary basin.

Between Big Rock Creek and Amargosa Creek along the San Andreas Fault Zone, a Pliocene non-marine sedimentary sequence is named the Anaverde Formation (Figure 3-1). The unit is comprised of fluvial sandstones and lacustrine clays, with thin beds of gypsum evaporites. The Anaverde Formation is about 1,500 feet thick, and is strongly deformed by faulting.

While exposures of Pliocene deposits are relatively limited in the AVAA, Dibblee (1967, 1980 b, c) clearly believed that unexposed Pliocene deposits exist in the subsurface in the sedimentary basins. In addition, he believed that deposition was continuous from Pliocene into Quaternary time in the sedimentary basins (Dibblee 1967).

3.3.2.3 Tertiary Sedimentary Rocks South of San Andreas Fault Zone

South of the San Andreas Fault Zone, largely outside the AVAA, occurs a complex sequence of Tertiary sedimentary rocks. These rocks formed in a variety of depositional settings and sedimentary basins different from those north of the Fault Zone. The area south of the San Andreas Fault Zone has been transported by strike-slip fault movement since early (?) Pliocene, northward about 150 miles from their point of origin in southern California near the present day Salton Sea. Because of the small size and complexity of this area within AVAA, these deposits are not summarized here. A recent summary of this area south of the San Andreas Fault Zone is contained in Crowell, ed. (2003).

3.4 Quaternary Deposits

The Quaternary Period began at the end of the Tertiary's Pliocene Epoch; it is divided into the Pleistocene (1.77 my – 10,000 yrs.) and Holocene (post 10,000 yrs. to present). In the AVAA, Dibblee (1967) separated the Quaternary deposits into older alluvium, younger alluvium, and other surficial deposits (Figure 3-1). He mapped these units based on the amount of deformation, the degree of erosional dissection, relative stratigraphic positions, grain-size, and surficial features (i.e. sand dune, playa lake, etc.). Most subsequent reports have generally followed Dibblee's mapping, with some minor variations.

3.4.1 Detailed Mapping

Ponti and Burke (1980), and Ponti and others (1981), collectively referenced as Ponti and others, attempted to unravel the complexities of the Quaternary deposits by detailed stratigraphic mapping, grain-size analyses (i.e. gravel, sand, silt & clay), topographic position, and soil development. They subdivided the alluvium into seven numbered sequences from Q1 to Q7 from oldest to youngest (Figure 3-3). Each sequence was further differentiated by grain-size observations into very coarse, coarse, medium, and fine textures (e.g. Q6vc, Q6c, Q6m, Q6f). Very coarse texture is composed of boulder (10 inch to 3 feet) gravel. The spaces between the boulders are filled with a matrix of cobble and pebble gravel, sand, and silt. Lacking the boulder size, the coarse texture is composed of either pebble gravel, or very-coarse sand with a prominent gravel fraction, and a matrix of finer-grained sand and silt. The medium texture largely consists of fine to medium sand with a matrix, or thin interbeds, of silt and clay. The fine texture is composed of mostly silt and clay, with lesser amounts of fine to very fine sand mixed in the finer-grained material, or as thin interbeds.

Texture subdivisions of the numbered sequences are not all exposed at the surface. Sequences Q1, Q2, and Q3 are exposed only as very coarse and coarse textures. These sequences are also mapped together in areas of poor exposure as Q1-Q2, Q2-Q3, or Q1-Q3, where differentiation was not possible. Sequences Q4 and Q5 are exposed only as very coarse, coarse, and medium textures. Sequence Q6 has all textures exposed. Sequence Q7 has all textures exposed, but has the most limited area of exposure of all the sequences. Q7f corresponds to the playa lake deposits.

Ponti and others (1980, 1981) also mapped some Quaternary deposits outside of the numbered sequences (Figure 3-3). The largest of these is the surficial (pluvial or perennial) lake bed deposits surrounding Rosamond Lake for several miles to the south and west. Smaller areas were mapped as caliche (calcium carbonate) cemented nearshore alluvium formed by evaporation of fluctuating groundwater along the edge of the surficial lake bed deposits. Other mapped areas consisted of sand dunes and active streambed sands and gravels (only some shown, Figure 3-3).

Unfortunately, the detailed mapping by Ponti and others (1980, 1981) does not cover all of the AVAA (Figure 3-3). The westernmost end of the valley was not mapped. A portion of the AVAA north of Willow Springs Fault was also not mapped. While most of the eastern Antelope Valley to the San Bernardino County line is covered by the mapping, nearly all of the Rogers Lake Valley and east of Rosamond Lake is not covered by the mapping (Figure 3-3). For this report, tentative Quaternary sequences are projected into the unmapped areas of Ponti and others (Figure 3-3). These projections are based on stratigraphic relationships, topographic expression, and other available geologic mapping. These projected sequences are shown with a question mark on Figure 3-3.

In general, sequences Q1 to Q3 correspond to the older alluvium of Dibblee (compare Figure 3-1 to 3-3). However, some areas mapped by Dibblee as older alluvium were mapped by Ponti and others as younger sequences, mostly sequences Q4 and Q5. In addition, some areas mapped as younger alluvium by Dibblee were mapped by Ponti and others as sequences Q1 to Q3 (Figure 3-3). These areas of mapping conflicts are annotated with sequence number on Figure 3-3.

Sequences Q4 and Q5 (shown combined on Figure 3-3) encompass large areas which Dibblee mapped as younger alluvium. This is especially the case in western Antelope Valley and along the southern AVAA boundary. Several areas of older alluvium of Dibblee were mapped as sequences Q4 and Q5 by Ponti and others. These areas of mapping conflicts are annotated with sequence numbers on Figure 3-3.

Sequence Q6 encompasses most of the remaining areas of Dibblee’s younger alluvium (Figure 3-3). The sequence is most widespread in the eastern Antelope Valley. The sequence’s coarse texture has distinctive lobate, upper alluvial fan expressions emanating from the south. Downslope occur broad alluvial plains of medium texture which transitions into the fine texture to the north (Figure 3-3).

Sequence Q7 is the remainder of the younger alluvium of Dibblee, and is more restrictive in extent. Only the coarse texture upper alluvial fan areas, and fine texture of the playa lakes are shown on Figure 3-3. Small areas of Q7 occur elsewhere, mostly along present wash channels, but are too small to show.

The surficial lake bed deposits of Ponti and others (1980, 1981) in part correspond to Dibblee's earlier (1960, 1963) map unit of playa clay covered with small sand dunes. The surficial lake bed deposits encompass the lakeshore lines mapped by Dibblee, and extend beyond them to the west and south (Figure 3-3).

3.4.2 Possible Ages

The early mapping of the Mojave Desert by Dibblee occurred prior to, or in the infancy of, geologic age-dating techniques. His mapping was based on relative ages based on visible physical features of the Quaternary deposits, such as degree of consolidation, amount of deformation, degree of erosion, and topographic expression. He considered his older alluvium to be early to late Pleistocene in age, and the younger alluvium to be late Pleistocene and Holocene in age.

Ponti and others (1980, 1981) attempted to correlate their detailed soil-based numbered sequences to similar mapping done in the San Joaquin Valley, which had age-dated deposits. They concluded that their sequences were post-500,000 years and Holocene in age (late Quaternary). Sequences Q1, Q2, and Q3 were believed to range from about 450,000 to 140,000 years. Sequences Q4 and Q5 were considered to be about 90,000 to 17,000 years. Sequence Q6 was considered to range from about 14,000 to 4,000 years. Sequence Q7 was considered to be from 4,000 years to present. The surficial lake bed deposits were considered associated with the last pluvial lake until about 12,000 years ago (late Pleistocene).

Recent studies in the Mojave River area just to the east were summarized by Cox and Owens (2003). These studies indicate that strata equivalent to part of the older alluvium in the southeast of AVAA (Qco, Harold Formation, Shoemaker Gravels, sequences Q1 & Q2, Figure 3-3) range in age from about 1.7 million years to 780,000 years (early Pleistocene). This is considerably older than the post-500,000 years considered by Ponti and others for their sequences Q1 to Q3.

Unfortunately, geologic datable material in AVAA has not been found, or has not been studied. In a borehole south of Lancaster, the USGS (Fram and others, 2002) described a paleomagnetic polarity reversal between the 350 and 450 foot depths, which they related to a date of 780,000 years (early to middle Pleistocene boundary). Because of the uncertainty of the absolute age of the Quaternary alluvium, this report has used stratigraphic relationships, both surficial (Figure 3-3) and subsurface, for relative age relationships. The older alluvium is considered early and middle Pleistocene (sequences Q1 and Q2) and middle Pleistocene (sequence Q3). The lower younger alluvium is considered middle to late Pleistocene (sequences Q4 and Q5). The upper younger alluvium is considered late Pleistocene (part of sequence Q6 and surficial lake bed deposits, Qpl) and Holocene (remainder Q6, sequence Q7, and surficial playa lake deposits, Ql/Q7f). The following sections describe these units in greater detail.

3.4.3 Older Alluvium

Dibblee (1967) mapped uplifted and/or erosionally dissected alluvial fan deposits of gravel and sand around the edge of the AVAA as the older alluvium. He subdivided the deposits into the Harold Formation, the older fanglomerate, and undifferentiated older alluvium. He believed the first two were older than the remaining older alluvium.

3.4.3.1 Harold Formation

Originally named by Noble (1953), the Harold Formation appears to be the oldest Quaternary unit exposed in AVAA. The unit is composed of 100 to 200 feet of alluvial sand and gravel, and the lower portion has a distinctive greenish coloration. The Harold Formation occurs in the extreme southeast corner of AVAA, and westward for several miles along the San Andreas Fault Zone (Figure 3-1). Vertebrate fossils in the Harold Formation indicate an imprecise age of 0.6 – 0.45 my, which was the age used by Ponti and others (1980, 1981). They did not map the Harold Formation separately, but included it in a Tertiary-Quaternary continental sediments unit which also included the Pliocene Anaverde and Meeke Mine Formations. Their age range for this unit was 5 to 0.45 million years; however, more recent work in the Mojave River Area, summarized by Cox and Owen (2003), indicates an older age for the Harold Formation of about 1.7 to about 1.2 (?) my (early Pleistocene).

3.4.3.2 Older Fanglomerate

Overlying the Harold Formation in the southeast is a thick sequence of coarse (boulders and cobbles) alluvial fan deposits which Dibblee termed the older fanglomerate (Figure 3-1). Earlier mapping by Noble (1953, 1954) had named these and similar deposits along the San Andreas Fault Zone as the Shoemaker Gravel and the Nadeau Gravel. Ponti and Burke (1980) showed these deposits as sequences Q1, Q2 and Q3, as very coarse and coarse textures (Figures 3-1, 3-3). Cox and Owen (2003) indicate an age of about 1.5 to 0.78 my for these deposits to the east.

Elsewhere in the AVAA, Diblee mapped older fanglomerate in relatively small exposures. A band of small exposures occurs along the southern margin of the Rosamond Hills, mapped by Ponti and others (1981) as sequence Q1-Q3 (Figure 3-3). Two small knobs on the western side of Buckhorn Lake were mapped by Dibblee as older fanglomerate (Figure 3-1). However, Ward and Dixon (2002) mapped these as Miocene Fiss Fanglomerate. Dibblee mapped some small areas of older fanglomerate north of Rogers Lake, largely outside of the AVAA. A final larger area of older fanglomerate was mapped by Dibblee east of the south end of Rogers Lake, in the Jackrabbit Hill area (Figure 3-3). Unfortunately, these areas in the Rogers Lake Valley area are not covered by the detailed mapping of Ponti and Burke (1980).

3.4.3.3 Older Alluvium, Undifferentiated

Dibblee (1967) mapped uplifted and/or erosionaly dissected alluvial fan deposits of gravel and sand around the edge of the AVAA as older alluvium, undifferentiated (Figure 3-1). Dibblee believed these deposits were younger than the Harold Formation and his older fanglomerate.

Along the southern boundary of the AVAA, westward from Big Rock Creek, only small patches of older alluvium are exposed, largely along the San Andreas Fault Zone (Figure 3-1). One exception to this trend is the ‘island’ of older alluvium exposed in the Llano area, bound by the Llano fault to the north (Figure 3-1). Ponti and Burke (1980) mapped this area as sequences Q2 and Q3 (Figure 3-3). A second exception is south of Palmdale where older alluvium was mapped by Ponti and others (1981) as sequences Q2 and Q3 (Figure 3-3).

West of Amargosa Creek, only a few small patches of older alluvium occur and were mapped as sequences Q2 and Q3. South of Antelope Buttes, a large area of older alluvium was mapped by Dibblee (1967) (Figures 3-1, 3-3). Ponti and others (1981) mapped smaller areas as sequences Q1 to Q3, very coarse to coarse textures, and overlain by younger sequence Q4. In this area, they also mapped a few small exposures of continental sediments. The nature and correlation of these deposits is not known.

Just west of the adjacent Fairmont Butte, an area of older alluvium of Dibblee (1967) was mapped by Ponti and others (1981) as a small area of sequence Q1-Q3 coarse texture, but mostly as younger alluvium, sequence Q4-medium texture (Figure 3-3). Further west, only a few poorly exposed areas of older alluvium occur which Ponti and others (1981) mapped as sequences Q1 to Q3. Older alluvium mapped by Dibblee (1967) near the western edge of Ponti and others (1981) appears to be sequence Q4 (?) alluvium (Figure 3-3). At the southwestern tip of AVAA, the older alluvium of Dibblee (1967) is projected to be sequence Q3 (?) (Figure 3-3).

The largest area of exposed older alluvium occurs northeastward along the edge of the Tehachapi Mountains (Figure 3-1). Portions of this area are uplifted and deeply eroded. Dibblee (1967) estimated the older alluvium in this area to be as much as 1,000 feet in thickness. A small, uplifted anticline associated with a fault in the Sand Hills exposes an upper 400 feet of coarse alluvial gravel, and a lower 500 feet of finer gravel with interbedded reddish to greenish-gray silt and sand (Figure 3-1). Earlier, Dibblee (1963) speculated that coarse sand exposed in the center of this anticline might be of late Pliocene age. Ponti and others (1981) mapped this small area as continental sediments of Pliocene to Pleistocene age (5.0 – to 0.45 my).

With their detailed mapping, Ponti and others (1981) subdivided the older alluvium along the Tehachapi Mountains into their sequences Q1, Q2, and Q3 (Figure 3-3). Each sequence was represented by very coarse and coarse textures. The larger area between Sacatara Creek north to Tylerhorse Canyon (Figure 3-3) was mapped as sequence Q1, very coarse and coarse textures.

The smaller areas of older alluvium south of Sacatara Creek and northeast of Tylerhorse Canyon, were mapped as sequence Q1 to the west, with sequences Q2 and Q3 progressively east and downslope.

There are few exposures of older alluvium around the northern and eastern AVAA boundary, except for the older fanglomerate mentioned previously. Ponti and others (1981) mapped an area of sequence Q1-Q3 alluvium just south of Willow Springs Mountain (Figure 3-3). Extensive older alluvium was mapped by Dibblee to the north outside of the AVAA. Ponti and Burke (1980) mapped a number of small areas of sequence Q1- Q3 along the tributary canyons marginal to the Hi Vista area (not shown on Figure 3-3).

3.4.4 Younger Alluvium

Dibblee (1967) mapped the surface of the vast majority of the AVAA as younger alluvium of late Pleistocene and Holocene age (Figure 3-1). This alluvium is relatively undissected, and composed of unconsolidated sediments carried downslope by streams draining the adjacent highlands. Dibblee mentions various forms of the younger alluvium as alluvial fan alluvium, and valley alluvium. Other deposits of most recent age which he mentions are eolian sand dunes and sand fields, and playa lake clays.

Ponti and others (1980, 1981) show a more complex nature with their detailed mapping of soil types. Their mapping subdivides the younger alluvium into sequences Q4 and Q5 alluvium, sequence Q6 alluvium, surficial lake bed deposits (Qpl), sequence Q7 alluvium and other recent deposits (Figure 3-3).

3.4.4.1 Sequence Q4 & Q5 Alluvium

Middle and late Pleistocene alluvial deposits of sequence Q4 and Q5 occur downslope of older alluvium along the Tehachapi Mountain front over extensive areas (Figure 3-3, Q5 not shown separately). Coarse, and medium textures of both sequences are exposed. Small patches of sequence Q4-Q5 occur along the edges of the Rosamond Hills east to Rosamond. In the southwest tip of the AVAA, extensive areas of sequences Q4 (?) and Q5 (?) are believed to exist to the north and south of the central wash (Figure 3-3), outside of mapping by Ponti and others (1981). Eastward along the southern AVAA boundary to Fairmont Butte, sequence Q4 alluvium was mapped over large areas, mostly of medium texture. Around Antelope Buttes and extending to Amargosa Creek, extensive areas of sequence Q4 alluvium, coarse and medium textures occur (Figure 3-3). From Amargosa Creek to southeast of Palmdale, sequence Q4 alluvium, coarse and medium textures occur (Figure 3-3). Along the remainder of the southern AVAA boundary, only small areas of sequence Q4-Q5 occur (Figure 3-3).

Along the AVAA boundary in the Hi Vista area, no sequences Q4 and Q5 alluvium were mapped. In the Rogers Lake valley area, based on available geologic maps and topographic relationships, it is believed that sequences Q4 (?) and Q5 (?) alluvium may exist, partially covered by younger sequence Q6 (?) alluvium and eolian sand fields (Figure 3-3).

3.4.4.2 Sequence Q6 Alluvium

Sequence Q6 alluvium is the most extensive of the younger alluvium deposits, and is considered very late Pleistocene and Holocene in age (14,000-4,000 yrs). The very coarse texture Q6 deposits are largely restricted to incised wash channels along the western margin of the AVAA. The coarse texture overlies older alluvial deposits as fan shaped lobes, and transitions within a mile or two into more widespread medium texture deposits, covering most of the valley floor. The medium texture Q6 extends eastward, both north and south of Little Buttes. It appears to transition into and in part overlie the surficial lake beds deposits (Figure 3-3). No fine texture sequence Q6 was mapped along this area.

In the southwest tip of the AVAA, sequence Q6 (?) alluvium occurs along the central wash area of the valley floor. The sequence Q6 alluvium appears to extend eastward in a narrow band overlying sequences Q4 and Q5 (Figure 3-3), in turn overlain in part by younger sequence Q7. Along the southern AVAA boundary, to Amargosa Creek, sequence Q6 alluvium (not shown on Figure 3-3) extents from small washes and overlies sequence Q4 alluvium.

In the southeast, large areas of coarse texture sequence Q6 alluvium emerge from the canyons and creeks, and are spread downslope as alluvial fans for several miles (Figure 3-3). The Q6 alluvium then transitions into medium texture and extends northwest surrounding and just past the various bedrock buttes. Small washes draining from the Hi Vista area to the north have discharged largely medium texture sequence Q6 alluvium (Figure 3-3).

Similar sequence Q6 alluvium emerges from across the San Andreas Fault Zone from Little Rock Creek to Amargosa Creek. This area has coarse texture sequence Q6 alluvial lobes and blends northward into the medium texture sequence Q6 plain (Figure 3-3). To the north, the medium texture sequence Q6 alluvium transitions into fine texture (Q6f) alluvium that appears to transition into and overlie the surficial lake bed deposits (Qpl, Figure 3-3).

3.4.4.3 Surficial Lake Bed Deposits

Ponti and others (1980, 1981) mapped surficial (pluvial) lake bed deposits of clay and silt west and south of Rosamond Lake (Figure 3-3). They characterized these as well stratified, light-colored silt and clay with minor sand and gravel. Soil development is limited, and salt is present in the material. Small areas of younger alluvium occur on top of the surficial lake bed deposits, and larger areas are covered by wind-blown sand and dunes. A series of coarser-grained lakeshore sand bars overlies the surficial lake bed near Rosamond Lake. The surficial lake bed deposits encompass the lake shorelines mapped by Dibblee (1967) at about 2,325 foot elevation to the east, west, and south of Rosamond and Buckhorn Lakes (Figure 3-3). The surficial lake bed deposits extend to about the 2,375 foot elevation. They extend south to the Lancaster area. Between Lancaster and Rosamond Lake, Dibblee (1963) had mapped playa lake clay covered with small sand dunes, which generally coincides with the limits of the surficial lake bed deposits.

The surficial lake bed deposits are believed to represent the last Pleistocene (until about 12,000 yrs) pluvial lake (Lake Thompson) in the AVAA. Dibblee (1967) showed the extent of Lake Thompson to his lake shoreline features at the 2,325 foot elevation. The surficial lake bed deposits extend further west to about the 2,375 foot elevation. Dibblee (1963) mentions a possible older lake shoreline near the 2,400 foot elevation from near Rosamond to Tropico Hill. This shoreline and the extent of the surficial lake bed deposits may represent an initial high stand of Lake Thompson. The lake may then have receded because of drier climates to the 2,325 foot elevation of the lake shoreline, and finally to the sand bars near Rosamond Lake at about 2,290 foot elevation (Figure 3-3). Because of the size and length of these sand bars, this final stage of Lake Thompson may have persisted for a considerable period. Finally, with continued drier and warmer climates, the lake evolved into the present playa lakes of Rosamond, Buckhorn, and Rogers Lakes.

Dibblee (1967) believed that Lake Thompson extended up the Rogers Lake valley based on the presence of lakeshore sand bars, lake shoreline features, and fine grained deposits. Unfortunately, Ponti and others did not map the Rogers Lake valley area. Based on Dibblee’s mapping (1960, 1967) and mapping by Dixon and Ward (2002), the surficial lake bed deposits were projected in the Rogers Lake area (Figure 3-3). It appears the surficial lake bed deposits extend east from Rosamond Lake and northward up the Rogers Lake valley. In the southern region, these deposits appear to be partially covered by younger playa lake clays, sand dunes, and sequences Q6 and Q7 alluvium. Northward up the Rogers Lake valley, clayey deposits marginal to the playa lake bed may represent surficial lake bed deposits (Figure 3-3).

The prominent lakeshore sand bars enclosing Rogers Lake to the north occur at about the 2,300 foot elevation (Figure 3-3). North of these sand bars are clayey deposits which may represent surficial lake bed deposits of a higher stand of Lake Thompson. These deposits appear to be partially covered by younger sand dunes, playa lake clays, and sequences Q6 and Q7 alluvium (Dibblee, 1958). These surficial lake bed deposits may extend to near the north AVAA boundary (Figure 3-3).

3.4.4.4 Caliche-Cemented Nearshore Alluvium

Ponti and others (1980, 1981) mapped several areas along the west and south margins of the surficial lake bed deposits as caliche-cemented nearshore alluvium (Figure 3-3). They attributed the compact and well lithified nature of these deposits to the formation and cementation of calcium carbonate (caliche) from evaporation of fluctuating groundwater levels. The caliche formation has destroyed the soil and sedimentary features of the alluvium, which they believed to have been medium texture, sequences Q4, Q5 and Q6 alluvium.

Dixon and Ward (2002) noted the presence of caliche in alluvium adjacent to lake deposits in the Rogers Lake area. They related these deposits to caliche-cemented nearshore alluvium of Ponti and others (1980, 1981). These deposits are not differentiated on Figure 3-3.

3.4.4.5 Sequence Q7 Alluvium

Ponti and others (1980 1981) mapped unconsolidated alluvium with minimal soil development as sequence Q7. While all textures are present in the AVAA, only the coarse texture alluvial fan lobes and the fine texture playa lake beds are shown on Figure 3-3. The remainder of the sequence Q7 alluvium occurs largely along present wash channels and smaller areas too limited in extent to show on Figure 3-3. Ponti and others (1980, 1981) assigned a Holocene age of 4,000 years to present for sequence Q7 alluvium.

3.4.4.6 Other Surficial Deposits

Ponti and others (1980, 1981) mapped small areas of active stream channel sand and gravels, which are too small to show on Figure 3-3. Larger areas of eolian sand dunes and fields were also mapped overlying the other alluvium. Composed of well-sorted fine to medium sand, some dunes are actively shifting while others are stabilized by vegetation. No soil development has occurred on the sand dune areas. Ponti and others (1980, 1981) considered them to have formed since the drying of pluvial Lake Thompson (i.e. post about 12,000 years). Only some of the sand dune areas are shown on Figure 3-3.

3.5 Occurrence of Groundwater

3.5.1 General Occurrence and Records

Beginning with early exploration, settlement, and study in the Antelope Valley, groundwater was known to occur at shallow depths in the Valley. The pioneering study by Johnson (1911) noted the occurrence of a number of natural springs, and a large central area of flowing artesian wells. [ck.] Continued development of agriculture and the associated drilling of wells for irrigation supply in the 1900’s resulted in a long history of declining groundwater levels to several hundred feet below much of the valley.

Since the early 1950’s, intensive and continuous studies have been made of groundwater levels and conditions. Beginning as inventories of wells and general hydrogeologic investigations, they continued as studies of groundwater level changes through time. Study emphasis gradually shifted to groundwater modeling. More recently, studies have focused on potential groundwater recharge and land subsidence caused by groundwater extraction.

Groundwater in the AVAA is produced from wells generally less than 1,000 feet deep with the deepest wells extending to a maximum of about 1,500 feet. It appears that most groundwater is being extracted from the Quaternary (Pleistocene) sedimentary deposits. Some of the deeper wells may be producing, in part, from Tertiary (Pliocene) sedimentary deposits.

As introduced in Section 3.2 above, there are about 5,000 to 6,000 wells of record in the AVAA; about half of those records are in the original well inventories (DWR Bulletins 91) and thus predate about 1967, and the remainder are in DWR well log files. Less than half of all wells of record have a lithologic log of some type. Less than 100 have a known geophysical log (electrical logs). The period of construction for the wells of record ranges from 1890 to about 2006. Uses of the wells include irrigation supply, municipal water supply, small water system supply, industrial supply and individual domestic supply.

3.5.2 Groundwater Geology

Groundwater geology examines the geologic nature, configuration and history of the sedimentary deposits through which groundwater flows in the subsurface. As noted above, it appears that most groundwater extracted in the AVAA is from Quaternary deposits and possibly later Tertiary (Pliocene) sedimentary deposits. The difficulty in groundwater geology in most of California's groundwater basins is the ability to relate surficial exposed geologic units to those in the subsurface. The cause of this is the generally continuous accumulation of Quaternary sedimentary deposits in subsiding areas or basins. These areas have not been uplifted, deformed or eroded to expose the geologic nature of these deposits to observation and study. In the AVAA, the exposed Quaternary deposits are limited largely to areas marginal to the basin where some deformation and erosion has occurred. Because the Quaternary deposits are unconsolidated or weakly consolidated, they tend to be poorly exposed, and therefore difficult to study. In addition, because the exposed areas are along the margins of the larger depositional basin, only the coarser-grained alluvial fan deposits may be exposed. These deposits may also be thinner in stratigraphic thickness, and have erosional cross-cutting relationships which may be absent in the more continuous deposits further out in the basin.

Removed from the margins of the basin, geologic observations of basin deposits are limited to indirect means, primarily lithologic logs of water well drillers reports and comparatively fewer geophysical logs (electrical logs). In addition, these deposits become progressively finer-grained with greater distance from the basin margin. Bedding distinction may become less as grain-size decreases, and bedding thickness may increase. Subtle grain-size variations and thin bed features like soil horizons, cementation zones, volcanic ashes, or erosional surfaces are difficult to discern from borehole information. Rotary drilling methods tend to 'homogenize' drill cuttings, especially with increasing depth, and sampling collection techniques or observations may over-emphasize the coarser-grained components.

Challenges in geologic interpretation of the Quaternary deposits in AVAA include recognition of the types of source rocks and the impacts of depositional processes on the nature of sediments that are ultimately being described in the context of aquifers and related materials that affect the occurrence and movement of groundwater. For example, since at least Pliocene time, the erosional source areas in the AVAA have been dominated by the Pre-Cenzoic Crystalline Rocks, primarily the granitic rocks. The most widespread rock type, quartz monzonite, is composed of medium-grained mineral crystals, and is less coherent, tending to erode rapidly into sand sized particles. In addition, other than quartz, the minerals composing the quartz monzonite tend to weather to clay-sized particles or clay minerals. A result of this homogeneity in source rocks has resulted in a monotonous sequence of ‘granitic’ gravels and sands, and brown silt and clays. The only distinctive characteristic is the grain size of the coarser particles, such as boulder, cobble, gravel, and fine, medium and coarse sand. Further, the depositional sedimentary environment in the AVAA has been of alluvial fans emerging from surrounding uplands, blending into broad alluvial plains, and terminating in perennial (‘permanent’) pluvial lakes. The silts and clays deposited within the pluvial lakes are a distinctive deposit because of their ‘blue or gray’ coloration caused by unoxidized iron minerals. The upslope marginal alluvial fan deposits appear to be the coarsest deposits of boulders, and cobbles with a coarse sand and clay matrix deposited by sediment-laden storm runoffs and debris flows. Further from the uplands, the merging alluvial plains tend to become finer-grained with distance, changing from sand and gravel to finer sand and clay at the distal margins near the lake deposits. Deposition is believed to be by sediment-laden flood-flow sheets and possibly braided streams on alluvial plains to lake-margin sandy mudflats. Bedding may be indistinct, discontinuous, and possibly, lobate or elongated, as correlation is poor between boreholes.

3.6 Groundwater Areas

In light of the historic observations and current extent of groundwater exploration and development, and recognizing the challenges of interpreting available subsurface data, this section moves from the regional geologic description above to a description of the geologic materials which comprise the complex aquifer system in the AVAA. Primarily for purposes of presenting such a description of an overall area as large as the AVAA, the balance of this section is divided into four groundwater areas based on the occurrence of distinctive geologic characteristics. The divisions, again for discussion purposes and not to be interpreted as implied or otherwise proposed subbasins, and also not to be interpreted as hydrologically separate or otherwise independent areas, are derived from interpretation of the work cross-sections, derivative maps, and the entire subsurface data set. The four areas are East Antelope Valley Area, West Antelope Valley Area, Southeast Area, and Rogers Lake Area (Figure 3-4), each of which is described in the following sections.

The division between the East Antelope Valley Area and the West Antelope Valley Area is located along the extension of the ridge of older granitic and tertiary rocks exposed at Antelope Buttes and Little Buttes. A series of subsurface knobs of tertiary rocks or quaternary fanglomerate are overlain by about 300 to 400 feet of alluvium north of Little Buttes (Figure 3-5). These knobs are separated by erosional valleys filled with up to about 650 feet of alluvium.

The division between the East Antelope Valley area and the Rogers Lake Area is located along the extension of the Buttes fault (Figure 3-5). The northern segment under Buckhorn Lake is uncertain due to lack of well control. South of this division occurs the extensive thick lake bed deposits in the subsurface. North of this division, the “Principal Aquifer’ (above the lake bed deposits) is absent.

The division between the East Antelope Valley Area and the South East Area is located along an unnamed fault defined by groundwater level differences (Bloyd, 1967; Carlson et al, 1998). In general, northwest of this division, thicker alluvial deposits and the extensive lake bed deposits are present.

3.6.1 East Antelope Valley Area

The East Antelope Valley Area is the largest of the four areas and underlies the main municipalities of Rosamond, Quartz Hill, Lancaster, and much of Palmdale (Figure 3-4). Subsurface information is mostly adequate to the south, although locally sparse near the margins. To the north beneath Edwards Air Force Base, subsurface control is very limited, and sparse west of Rosamond Lake for several miles. Electrical logs are most numerous in clusters beneath the major municipalities of Lancaster and Palmdale. Only a few widely spaced electrical logs are known outside of these municipal areas.

The distinctive geologic features of the East Antelope Valley Area are the presence of surficial playa and pluvial lake deposits; the widespread occurrence of thick, older, ‘blue clay’ pluvial lake bed deposits; and alluvial deposits from which groundwater is produced above and below the lake bed deposits.

3.6.1.1 Lake Bed Deposits

The lake bed deposits in the East Antelope Valley Area are divided into four categories: surficial, upper, middle, and deep. The surficial lake beds have features visible at the land surface (Figure 3-3), the most obvious of which are the playa dry lake deposits of Rosamond and Buckhorn, and the complex of small playas to the east of Rosamond Lake. Included with these are the lakeshore sand bars and sand dune fields adjacent and overlying the playa surfaces. Less obvious surface features are the pluvial lake clay beds extending out to the older Pleistocene Lake Thompson lakeshore features mapped by Dibblee (1967), and the lake clay soils which extend several miles further west mapped by Ponti and others (1980, 1981). These deposits are difficult to trace in the subsurface because of lack of well log control beneath Edwards Air Force Base. West of Rosamond Lake, these surficial lake deposits appear to be thin (less than 20 to 40 feet), and lacking blue or gray coloration. Drillers tend to log the surficial deposits as 'top soil', clayey soil or dune sand.

3.6.1.2 Upper Lake Beds

The Upper Lake Beds occur as a southwest trending lobe from the south shore of Rosamond Lake to just west of 10th St. East & Ave. H (Figure 3-5). Because much of the Upper Lake Beds occurs north of the Edwards AFB boundary, well control is very limited (Figure 3-6). A few well logs indicate that lake bed clay extends from near the surface, with reported thicknesses of 300 to 560 feet. However, some of this thickness may be overlying surficial lake beds, and some may be underlying Middle Lake Beds. South of Ave. E (Figure 3-6), well control indicates the Upper Lake Beds are overlain by about 100 to 150 feet of alluvium, and lake bed thickness thins from 200 to 130 feet to the south. The top of the Upper Lake Beds occurs at an elevation of about 2,200 feet at the south edge and higher to the north. Limited data suggest that the lower portions of the Upper Lake Beds may extend a mile further southwest than shown on Figure 3-5.

West of the known Upper Lake Beds, limited well control indicates that they are not present or lack the distinctive blue-gray coloration (Figure 3-7). To the north, very limited well control indicates the Upper Lake Beds may thin and merge with the surficial lake deposits towards Rosamond Hills (Figure 3-6). To the southeast along the edge of the lobe, limited data indicates interbedding with alluvial deposits overlying the Middle Lake Beds. To the northeast, no well control exists east of Rosamond Lake, but shallow, thin gray-blue clay beds at the southern edge of the adjacent Rogers Lake Area may be equivalent to the Upper Lake Beds (Figure 3-7).

3.6.1.3 Middle Lake Beds

The Middle Lake Beds lie east of the Upper Lake Beds (Figure 3-5). Along the southern edge of the Middle Lake Beds, they are covered by slightly more than 300 feet of alluvial deposits, and the top occurs at about 2,000 feet elevation. The thickness of the Middle Lake Beds is poorly known; a few well control points indicate about 300 feet, although some of this may be the underlying Deep Lake Beds (?). The top of the Middle Lake Beds appears to rise gently northeastward to just above 2,100 feet elevation, where they are covered with about 200 to 240 feet of alluvium near the boundary with the Rogers Lake Area (Figure 3-9). Thickness variations are less known, but appear to thin to the north (Figure 3-9).

The top of the Middle Lake Beds appears to gently rise to the north, again to about 2,100 feet elevation, and are overlain by about 200 feet of alluvium. Well control on EAFB remains scant, but it appears that the Middle Lake Beds are overlain by the Upper Lake Beds further north. Limited subsurface control may indicate that the Middle Lake Beds thin and merge northward into the Upper Lake Beds beneath Rosamond Lake.

The southern edge of the Middle Lake Beds trends northwestward and occurs beneath the lobe of the Upper Lake Beds north of Lancaster (Figure 3-5). Limited well control further west appears to indicate that the Middle Lake Beds do not extend further west than the Upper Lake Beds (Figure 3-7).

3.6.1.4 Deep Lake Beds

The Deep Lake Beds occur south of the Middle Lake Beds boundary, and extend under much of the southern East Antelope Valley Area (Figure 3-5). The top of the Deep Lake Beds occurs just south of the Middle Lake Beds at an elevation of about 1,850 feet, where they are covered with slightly over 500 feet of alluvium. It is not clear if the abrupt 100 to near 200 foot elevation difference between top of the two lake beds is attributable to depositional processes, or possibly to a fault offset. Because of the lack of deep well control near the boundary, it is not apparent if the Deep Lake Beds extend below the Middle Lake Beds to the north (Figures 3-6, 3-9).

The Deep Lake Beds appear to descend gently to the southwest, to an elevation of about 1,700 feet, and are overlain by about 800 feet of alluvium in the Plant 42 area. Further south, in northern Palmdale, alluvium thickness may reach 900 feet with rising topographic elevation. The thickness of the Deep Lake Beds ranges from 200 to 300 feet over much of their extent, but appears to thin rapidly (to 100 feet or less) near the eastern limit.

Northwest of the Deep Lake Beds apex in Palmdale, the edge appears to extend northwest towards south Lancaster (Figure 3-5). The top elevation remains at about 1,700 feet, with lake bed thicknesses of about 300 feet. North across Lancaster, the Deep Lake Beds rise to slightly above 1,800 feet elevation, and are covered by about 500 feet of alluvium.

West of Lancaster, a gap of several miles occurs where deep well control is lacking (Figure 3-8). A final occurrence of Deep Lake Beds is encountered at the Mira Loma Facility, where several deep wells encountered thin blue clays at about 1,850 foot elevation, and covered by about 500 feet of alluvium. West and north of this area, limited deep well control indicates that 'blue' lake bed deposits are not present.

3.6.1.5 Aquifers Above the Lake Beds

The alluvial deposits above the various lake beds have been historically termed the "Principal Aquifer", although the USGS (Philips et al., 2003) recently subdivided these units into an upper and middle aquifer at an elevation of about 1,950 feet. A similar subdivision of the alluvial deposits is reflected in this report. Alluvium, which lies on top of the Middle and Upper Lake Beds, is believed to be younger alluvium of sequence Q4 and Q5 (Figures 3-6, 3-7). These sequences appear to extend southward to their exposures (Figure 3-3), and basically correspond to the USGS' upper aquifer.

From the southern edge of the Middle Lake bed (Figure 3-5), it appears that older alluvium of Sequence Q3 overlies the Deep Lake Beds (Figure 3-6). Further south, Sequence Q2 alluvium appears to lie on top of the Deep Lake Beds (Figure 3-6). These two sequences are considered herein to basically correspond to the USGS' middle aquifer. It is not clear if sequence Q1 alluvium lies on top of the Deep Lake Beds in the far south or has some other relationship (Figure 3-6).

Overall, there appear to be three general aquifer areas above the Lake Beds. Above the Upper Lake Beds, a thin (100 to 150 foot north thinning) wedge of Sequence Q4 (?) and Q5 alluvium (Figures 3-6 and 3-7), or the upper aquifer, occurs where high water levels exist (2,250 foot elevation; Carlson et al, 1998). The thin aquifer above the Upper Lake Beds is used mostly for individual domestic supply with reported well capacities of a few gallons per minute (gpm) to a few tens of gpm. Maximum reported well capacity is 50 gpm with a specific capacity of 1.7 gpm/ft.

Above the Middle Lake Beds (Figure 3-5), a thicker (about 300 foot) north-thinning wedge of Sequence Q4 and Q5 alluvium occurs (Figures 3-6 and 3-9), this also corresponds to the upper aquifer. Reported well capacities from the aquifer above the Middle Lake Beds range from about 200 to 800 gpm. Specific capacity values are limited in number, but are generally reported to be less than 10 gpm/foot. A few wells near the southern boundary of the Middle Lake Beds have higher reported capacities (up to 2,000 gpm) and specific capacities up to 44 gpm/ft.

Above the Deep Lake Beds to the south, the older alluvium (sequences Q3 and Q2, or the middle aquifer) thickens southward. There is some evidence that older alluvium (sequence Q2 and possibly Q3) above the Deep Lake Beds may transition to fine-grained texture, which extends to north of Ave. M (Figure 3-6). North of Ave. K, the alluvium (Q3) appears to be somewhat coarser-grained above the Deep Lake Beds. Possible explanations of this may be limited sediment input from the south, or 'capture' of coarser material along faults. The coarser-grained Q3 alluvium to the north might reflect a different, possibly southeasterly source area. A similar pattern may occur in Sequence Q3 alluvium above the Deep Lake Beds, with coarser-grained west of 30th St. W transitioning to finer-grained extending east to 30th St. E (Figure 3-8). Coarser-grained Q3 may occur further to the east from the southeasterly source (Figure 3-8). A similar explanation may be that sediment input occurred from a southern source area west of the Quartz Hill area. From the southern and southeastern edge of the Deep Lake Beds, reported well capacities range generally from about 1,000 to 2,500 gpm. Specific capacities tend to be in the 25 to 65 gpm/ft range, although some are up to 100 gpm/ft. Well yields and specific capacities seem to decline northwestward. In northern Lancaster and about two miles east, reported well capacities are 1,000 gpm or less, with specific capacities of less than 10 gpm/ft. West of Lancaster, limited information seems to show increasing well capacities and specific capacities, to 2,500 gpm and 25 to 45 gpm/ft respectively.

3.6.1.6 Aquifers Below Lake Beds

Alluvial deposits below the Lake Beds have been historically termed the "Deep Aquifer", generally considered to be confined aquifer materials as a result of the overlying Lake Beds. Because the Lake Beds rise in elevation and become younger to the north, the USGS (Philips et al, 2003) revised its terminology to avoid conflicts in elevation, age relationships, and aquifer characteristics. The resultant terminology consisted of upper, middle, and lower aquifers initially based on studies in the Rogers Lake area on Edwards Air Force Base. While clarifying in some sense, it also is confusing in others. In the Rogers Lake area, the upper aquifer encompassed the surficial lake beds and some alluvium below them. The middle aquifer extended to a depth of about 837 feet (based on interpretation from one borehole), and the lower aquifer was considered to be continental deposits of late Pliocene to early Pleistocene in age (Nishikawa and others, 2001; Sneed and Galloway, 2000).

The confusion arises from the "middle" aquifer alluvium occurring below the lake beds in the north, while occurring above the lake beds in the south. Conceptually, the premise was that alluvial sediments were fed from the south at a higher rate, which forced the lake bed environment to move northward. Concurrently, a northern-sourced, lower rate alluvial sequence was forced north as the lake beds overlapped them.

For this overall description, the alluvial deposits below the lake beds are divided into two areas. South of the Middle Lake Beds (Figure 3-5), the alluvial deposits are considered to be late Pliocene (?) to early Pleistocene continental sediments. Electrical logs of these deposits appear to be of lower resistivity in general than these above the lake beds. Bedding thickness seems to vary from thick to thin, apparently corresponding to finer-grained and coarser-grained, respectively. Driller's logs tend to be variable, reporting sand, gravel and clay. These continental sediments are believed to be weakly consolidated and compacted sandstones and mudstones formed by a southward (?) flowing fluvial system (Cox and others, 2003). The analogous exposed geologic units are believed to be the early Pleistocene Harold Formation and Pliocene Crowder Formation. These continental sediments are not well known, as relatively few wells have been drilled into them. Their aquifer characteristics are also poorly known, as most wells were constructed with intake intervals (screens or perforations) above, across, and below the Deep Lake Beds (Figures 3-6, 3-8, and 3-9). Reported well capacities from such wells range from about 1,000 to 3,000 gpm. Specific capacities range from 20 to 120 gpm/ft to the southeast. Well capacities in the Lancaster area tend to have a similar range, but specific capacities appear to decrease northward, from about 60 to less than 20 gpm/ft. Near the western margin of the Deep Lake Beds at Mira Loma, well capacities reach 2,500 gpm with specific capacities up to 45 gpm/ft. These aquifer materials are considered to be equivalent to the USGS's lower aquifer unit of recent reports (Philips, et al, 2003).

The second area in the East Antelope Valley area is to the north of the southern edge of the Middle Lake Beds (Figure 3-5), where the relationship between the deposits below the Middle

Lake Beds and those to the south is not clear. The possibility of a fault relationship along the southern edge of the Middle Lake Beds cannot be eliminated because of lack of well control. Well control below the Middle Lake Beds is limited and only a single electrical log has been found. It is believed that continental sediments occur at depth, but has not been identified with the well control available (Figure 3-9). Overlying those deposits is believed to be older alluvium of sequence Q1 to Q3 formed by processes from northern sources. Considered to be equivalent to the USGS middle aquifer on Edwards AFB (Nishikawa and others, 2001; Sneed and Galloway, 2000), these deposits appear to be slightly coarser-grained, thinner bedded, and less compact than the underlying continental deposits. Deep wells completed above, across and below the Middle Lake Beds range in capacity from 500 to 2,200 gpm, with specific capacities up to 55 gpm/ft. Wells completed only below the Middle Lake Beds have reported capacities between 800 and 2,500 gpm. The few reported specific capacities range from 9 to over 100 gpm/ft. (Figures 3-7, 3-8, and 3-9).

3.6.1.7 Aquifer Areas Beyond the Lake Beds

In the East Antelope Valley Area, the alluvial deposits beyond the extent of the Lake Beds (Figure 3-5) are difficult to differentiate because of their general homogenetity and monotonous nature. In this report, separation has been made largely on stratigraphic relationships seen in the lake beds area and on mapped surface exposure relationships. These aquifer materials have been subdivided into a number of general regions.

West of the lake beds, there appears to be eastward thickening wedge of alluvial deposits (Figure 3-7). Along the western area boundary (Figure 3-5), the alluvium overlies a series of subsurface knobs of Tertiary or older rocks, and possibly older fanglomerate (possibly sequence Q1 alluvium) to the north. In erosional valleys or canyons, older alluvium (sequence Q2? and Q3) appear to spread eastward (Figure 3-7). Unfortunately, deep well control east to the Lake Beds is very limited. Overlying the older alluvium appears to be younger alluvium of sequence Q4 and Q5 (Figure 3-7). Well yields and aquifer characteristics of irrigation wells appear similar, whether completed deep or shallow. Reported well capacities range from 500 to 2,500 gpm and specific capacities vary from 10 to 60 gpm/ft, with a few higher specific capacities, to over 100 gpm/ft. Limited data eastward to the edge of the Lake Beds suggest that well capacities and specific capacities may decrease. Numerous individual domestic wells in this overall area seem to have a common 300 to 400 foot depth terminating in ‘hard rock’.

To the southwest, a similar alluvial aquifer system appears to extend from southern-sourced areas from south of Antelope Buttes and west of Quartz Hill (Figure 3-8). It appears that older alluvium of sequences Q1?, Q2 and Q3 extends northerly to interfinger and overlie the Deep Lake Beds. An overlying sequence of Q4 and Q5 younger alluvium also extends across the area. Groundwater production appears to occur from both the younger and older alluvium sequences. Reported well capacities range from 500 to 2,000 gpm and specific capacities vary between 20 to 80 gpm/ft, with a few as high as 100. South of Antelope Buttes, information is scarce.

Along the southern area, thin alluvium occurs over pre-Cenozoic crystalline rock and Tertiary rocks in the Quartz Hill area. It appears that the older alluvium may be thin and overlain by younger alluvium (Q4 and Q5). Well capacities range from 400 to 1,200 gpm and specific capacities vary from less than 10 to 20 gpm/ft. Specific capacities are higher, in the 25 to 38 gpm/ft, to the northeast of Quartz Hill. Between Amagorsa Creek and Palmdale (Figure 3-5), older alluvium (Q1, Q2, Q3) sourced from the south may have been deformed by faulting (Figure 3-6). Relationships are unclear in this area because of lack of well control.

To the southeast of the Lake Beds (Figure 3-5), it appears that a southeasterly-sourced, westward thickening, older alluvium (Q2 and Q3) overlies pre-Cenozoic granitic rocks. This bedrock surface appears to be highly irregular, possibly because of subsurface faulting. Some irrigation wells in this area appear have very high well capacities, but aquifer characteristics are variable. Well capacities range from 500 to 1,400 gpm and specific capacities vary from 5 to 40 gpm/ft. Stratigraphy in this area is considered to consist of older alluvium (Q2 and Q3) overlain by younger alluvium of sequence Q4 and Q5.

To the north and east of the Lake Beds (Figure 3-5), well control is sparce. It appears that locally derived older alluvium (Q1, Q2 and Q3) may possibly interfinger with the Deep (?) and Middle Lake Beds (Figure 3-8). Overlying younger alluvium appears to consist of sequence Q4 and Q5, fine (?) texture and a thin sequence of sequence Q6 alluvium (Figure 3-8). Reported well capacities range from 400 to 2,200 gpm and specific capacities tend to be in the range of 20 to 60 gpm/ft drawdown, with some specific capacities reported over 100 gpm/ft.

3.6.2 West Antelope Valley Area

The west Antelope Valley Area is the second largest subarea in AVAA (Figure 3-4). The area is characterized by a lack of surficial lake bed deposits, little evidence of widespread subsurface lake beds, and thick alluvial deposits. Well control is sparse over much of the area, and non-existent in some regions. Only a few electrical logs are known to exist. For purposes of this description, the area is subdivided into three regions: the western margin, the valley floor, and north of Willow Springs Fault (Figure 3-4).

The western margin is characterized by steep slopes underlain by older alluvium (sequences Q1 to Q3) of coarse-grained alluvial fan deposits. Deformation and uplift has caused the deposits to be partially dissected by erosional canyons and washes. Well control is limited to a handful of wells and well yields are unknown.

The valley floor of West Antelope Valley is a broad, gentle, generally eastward sloping plain. Well control is adequate along the central valley floor, but is sparse towards the edges. Many of the irrigation wells are in the 1,000 foot depth range, with maximum depth to about 1,300 feet (Figure 3-10). Driller's reports tend to show monotonous sequences of gravelly, sandy, clayey alluvial deposits. Correlation between even closely spaced wells is unclear. Scattered across the valley floor, some well logs indicate thin blue to gray clays, but the occurrences are generally several miles apart, and at variable elevations. The depositional origin of these deposits is not clear, but may represent small, localized ponds, lakes or marshlands formed by either structural movements (faults) or topographic configuration.

Because correlation is unclear, interpretation is largely based on stratigraphic relationships and the surficial geologic features (Figure 3-10). A large part of the overall aquifer system, to a depth of about 300 feet, is unsaturated. Across the southern West Antelope Valley Area, roughly corresponding to Q4 on Figure 3-3, reported well capacities range from 200 to 800 gpm and specific capacities are generally less than 10 gpm/ft.

In the western tip of the Valley out to the narrow neck of Q6 (Figure 3-3), reported well capacities range from 500 to 2,400 gpm and specific capacities vary from 12 to 40 gpm/ft, with two reported specific capacity values up to 80 gpm/ft.

East of the Q6 neck (Figure 3-3), the remainder of the Valley floor region has reported well capacities in the 1,000 to 2,500 gpm range. Specific capacities are variable but tend to be between 20 and 50 gpm/ft, with few reported specific capacities up to and over 100 gpm/ft.

Along the eastern edge of the West Antelope Valley Area, well capacities and specific capacities appear to decline near the exposed or subsurface older rock knobs. However, higher capacities and specific capacities similar to those to the west, appear to occur in the possible valleys (Figure 3-5).

The region north of Willow Springs Fault is similar to the West Antelope Valley Area (Figure 3-3). The Willow Springs Fault is one of the few faults in the AVAA that shows surface evidence of recent movement. Well control north of the fault is scarce and only a few electrical logs are available. Most deep well logs indicate about 800 feet of alluvium overlying an older, more consolidated formation, which may be either Pliocene alluvial deposits or Tertiary deposits (Figure 3-11). The small southeast trending valley north of Willow Springs Mountain and Tropico Hill (Figure 3-1) appears to contain thin (100 to 200 foot) alluvium overlying Tertiary rocks of Gem Hill Formation and Fiss Fanglomerate.

Reported well capacities in the area north of the Willow Springs Fault range from 300 to 2,200 gpm, and specific capacities are between 8 and 16 gpm/ft. Groundwater levels north of the Willow Springs Fault have remained at least 200 feet, and as much as 300 feet, higher than those to the south, indicating that the fault is a significant impedance or barrier to groundwater flow. The higher groundwater levels north of the fault also suggest that the unsaturated zone is notably smaller than in the West Antelope Valley area to the south.

3.6.3 South East Area

The South East Area is characterized by granitic buttes to the north, shallow granitic rocks in the southwest, and a lack of lake bed deposits (Figures 3-4 and 3-12). Well control tends to be sparse over much of the area, and only a few electrical logs are known to exist. In the northern region, the numerous granitic knobs and buttes are surrounded by alluvium up to 300 feet or more thick. Local surficial and shallow playa lake deposits of grey clay occur, possibly the result of local topographic damming.

Reported well capacities north of Lovejoy and Piute Buttes range from 350 to 800 gpm, and specific capacities are from about 4 to as high as 48 gpm/ft. South of Lovejoy Buttes, higher well capacities of 600 to 3,000 gpm are reported, with specific capacities from 4 to as high as 77 gpm/ft. Along the AVAA boundary to the east, well capacities range from 500 to 1,350 gpm, but specific capacities are mostly less than 10 gpm/ft.

Southwest of the buttes, an irregular granitic bedrock surface occurs with alluvium thickness of 300 to 600 feet (Figure 3-13). There appears to be a series of subsurface, faulted (?) granitic ridges separated by deeper alluvium filled valleys in this region. West of Little Rock Creek, well capacities tend to be in the 200 to 800 gpm range, and a few reported specific capacities are less than 10 gpm/ft. East of this, higher well capacities are reported in the range of 500 to 2,700 gpm, with specific capacities in the range of 10 to 25 gpm/ft.

To the southeast, thick older alluvium (sequence Q1 to Q3) consists of coarse-grained alluvial fan deposits overlain by younger alluvium (sequence Q4, Q5 and Q6; Figure 3-3; 3-12; 3-14). Some deep wells may indicate that the Harold Formation could have been reached (Figure 3-14). Correlation in the South East Area is generally poor due to lack of distinctive beds and limited well control. Groundwater levels are not well known. Further to the southeast, reported well capacities are limited in number, with a range from several hundred to 1,200 gpm, and specific capacities lower than 12 gpm/ft.

Along the southern boundary of the South East Area, a small region along the San Andreas Fault is characterized by thin Pleistocene deposits, which have been deformed and partially dissected. The underlying Pliocene deposits are strongly deformed and folded by fault movement. Nearly all wells are for individual domestic supply, with generally low well yields from a few gallons per minute to a rare 100 gallons per minute.

3.6.4 Rogers Lake Area

The Rogers Lake Area is characterized by surficial pluvial Lake Thompson and playa deposits, and a narrow, fault-bound, central trough filled with alluvial deposits (Figures 3-3 and 3-4). The area is divided into north and south subareas on opposite sides of a buried ridge of granitic rock in the north lake (Figure 3-4). Well control is extremely limited in the Rogers Lake Area, largely restricted to south and north of the lake itself. A few electrical logs are available mostly to the south.

The south lake region is defined by a series of northeast trending faults on both sides of the valley defined as the Antelope Valley fault zone by surficial geophysical surveys conducted by the USGS (Nishikawa and others, 2001). The faults are concealed at the surface by recent deposits. A small structural fault-bound trough appears to occur west of Hospital Ridge, filled with at least 1,000 feet of alluvial deposits and Tertiary (?) sediments (Figure 3-1). Reported well capacities range from 500 to 1,100 gpm; a single specific capacity is reported to be 66.7 gpm/ft. The main trough is filled with about 1,000 feet of alluvial deposits south of Rogers Lake. In that area, a 'blue to gray' lake bed deposit occurs at shallow depth (<100 feet) with a thickness of about 100 feet. This is believed to be part of, or equivalent to, the Upper Lake Beds of the East Antelope Valley area. These beds appear to pinch out by the south end of Rogers Lake, but may merge with the surficial pluvial Lake Thompson and playa deposits (Figure 3-15).

The alluvial deposits are typical interstratified sand and clay mixtures lacking distinctive bedding. The upper portion appears to be slightly coarser grained, possibly reflecting a local source and a more confined depositional setting within the central trough. The USGS has subdivided the deposits south of the Rogers Lake as upper, middle and lower aquifers. The upper aquifer includes the surficial lake beds, upper lake beds, and uppermost alluvium (sequence Q4 & Q5) (Figure 3-11). The middle aquifer is believed to be equivalent to Sequence Q1 to Q3 alluvium, probably sourced from the north. The lower aquifer was termed continental sediments by the USGS, and may represent early Pleistocene or late Pleiocene fluvial (?) deposits. Well capacities south of the lake range from 1,500 to 3,500 gpm and specific capacities range from 10 to 90 gpm/ft. Two miles north and just west of the lake, well capacities are reported between 500 and 1,000 gpm, with only one reported specific capacity value of 4 gpm/ft. East of the lake, well capacity information is sparse; two wells have reported capacities of 1,000 gpm, but no specific capacity values are reported. The south Rogers Lake Area may be partially isolated from the Antelope Valley Area by possible faults (Figure 3-9; 'Buttes' Fault and Rosamond Fault). The USGS (Nishikawa and others, 2001) has interpreted a northwest trending fault (Figure 3-15; El Mirage Fault) to extend across the valley, although surface evidence is lacking. Well control northward is limited and the nature of the alluvial deposits is poorly known.

The north lake region lies north of the buried granite ridge, and partially overlies the Kramer sedimentary basin (Figures 3-1 and 3-4). The connection with the south lake region occurs through many tens of feet of saturated alluvium. Well control remains sparse north of the lake. A southward thickening alluvial sequence (Q1 to Q4?) overlies Tertiary Tropico Group volcanic and sedimentary rocks from the northern AVAA boundary (Figure 3-15). Dibblee (1967) indicates alluvium thickness of 1,000 feet or more near the Muroc Fault at the north shore of Rogers Lake. Reported well capacities range from 300 to 1,500 gpm, and specific capacities vary from less than 10 to over 100 gpm/ft.

Tributary valleys marginal to Rogers Lake appear to contain limited alluvium of perhaps 100 to 200 foot thickness. Well control in these marginal areas is limited or non-existent. The large eolian sand field covered area east of Rogers Lake may contain some thicker alluvial fan deposits, particularly to the south. Well control, except near to the lake, is nonexistent. Topographic and geologic relationships would indicate that most of these marginal areas have little groundwater potential.

3.6.5 Fractured Bedrock

Since the unconsolidated aquifer system beneath the AVAA is largely bounded by bedrock, the well logs made available by DWR were reviewed to extract well yield information and, based on well yields, to indirectly estimate the hydraulic properties of the fractured bedrock, notably its transmissivity and hydraulic conductivity. Most likely because the bedrock has low permeability and, as a result, only yields low capacities to wells, there are limited wells with well completion records and tested well yield results. A total of 48 wells were found to have well yield data in the San Gabriel and Tehachapi mountains along the southerly and westerly boundary of the AVAA. The lithologic descriptions on the well logs were interpreted to identify wells completed in bedrock, and specific capacity values were computed in the same manner as used to describe the relative water yielding capabilities of the unconsolidated aquifer materials described above. All the fractured bedrock well completion, aquifer description, well yield, and aquifer properties are summarized into Table 3.6-1.

All the bedrock well yields are exceptionally low, on average about 5 gpm (geometric mean of 5.2 gpm; median pumping rate of 5 gpm); and all but one have fractional specific capacities (less than 1 gpm/foot of drawdown). All those values are in stark contrast to the kinds of capacities and individual yields of wells completed in the overall unconsolidated AVAA aquifer system, where yields are two or more orders of magnitude higher, with some pumping capacities exceeding 2,500 gpm and specific capacities up to, and exceeding in some cases, 100 gpm/ft.

Well yields, as expressed by specific capacity values, can be used to indirectly estimate fractured aquifer transmissivity where the respective wells are constructed. Those estimated values of transmissivity can then be used with lithologic or well completion details (from the well logs) to estimate the hydraulic conductivity of the fractured aquifer materials where the wells are located. Transmissivity estimates were made using methodology described in Driscoll (1986), after methods originally developed by Thomasson (1960) and Phillips (1966). The resultant transmissivity estimates are listed for each fractured bedrock well in Table 3.6-1. Like the well yields, all the transmissivity values are exceptionally low (geometric mean of 55 gpd/ft.; median of 40.5 gpd/ft.) and in stark contrast to the significantly higher values that are typical of the more highly conductive unconsolidated aquifer materials within the AVAA. Hydraulic conductivity values were estimated from transmissivity values by conventional division of transmissivity by saturated well completion interval. Again, all the estimated hydraulic conductivity values, listed in Table 3.6-1, are extremely low, essentially all less than 1 ft/day (geometric mean of 0.055 ft/day; median of 0.0445 ft/day).

In summary, it is well recognized that subsurface materials in nature are almost never truly impermeable. However, all available well yield and related hydraulic characteristic data for the bedrock around the AVAA show it to be of very low hydraulic conductivity, and thus of very limited capability to transmit groundwater flow to wells or from the surrounding mountains to the unconsolidated aquifer materials beneath the AVAA.

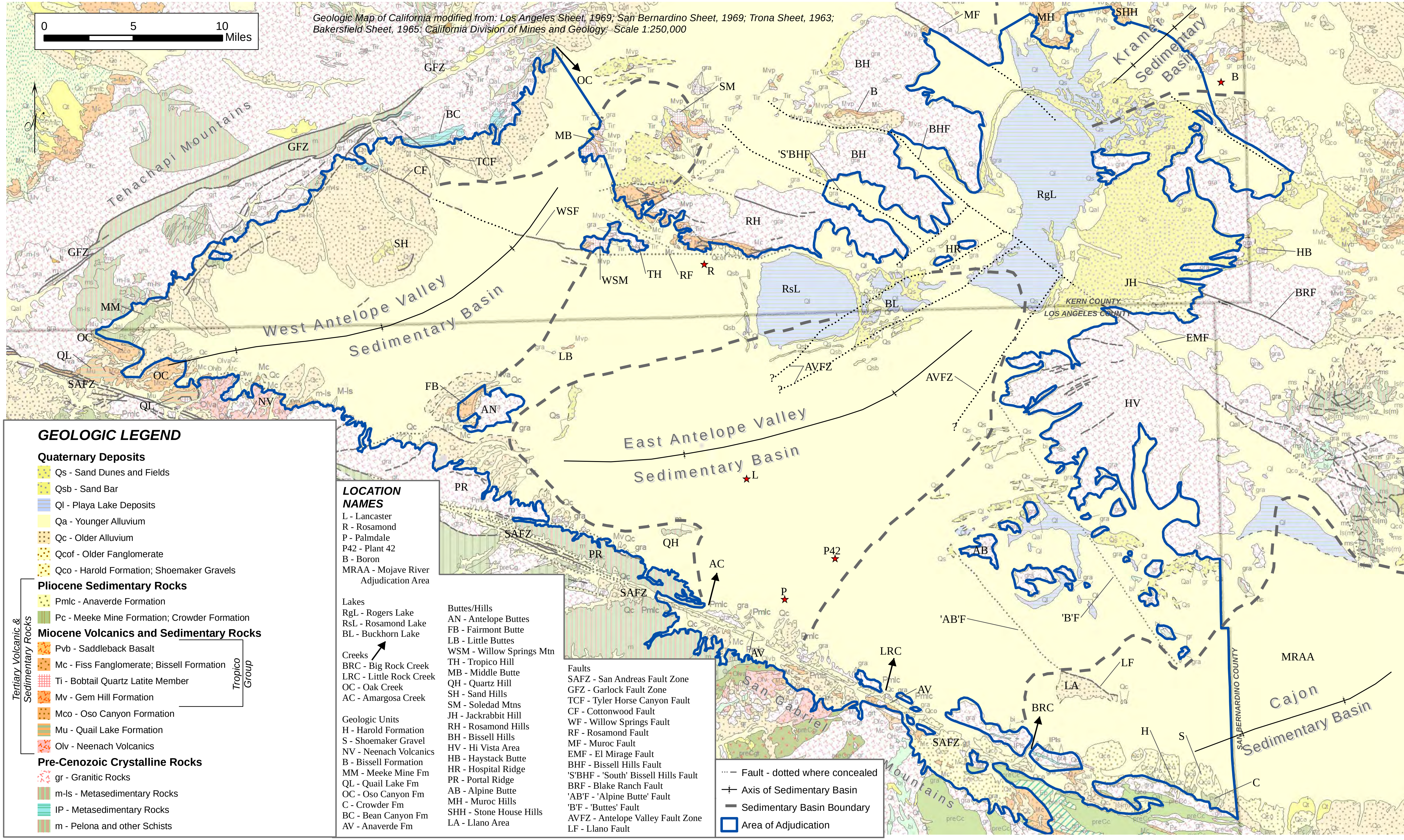

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Figure 3-1
Regional Geologic Map
Antelope Valley Area of Adjudication

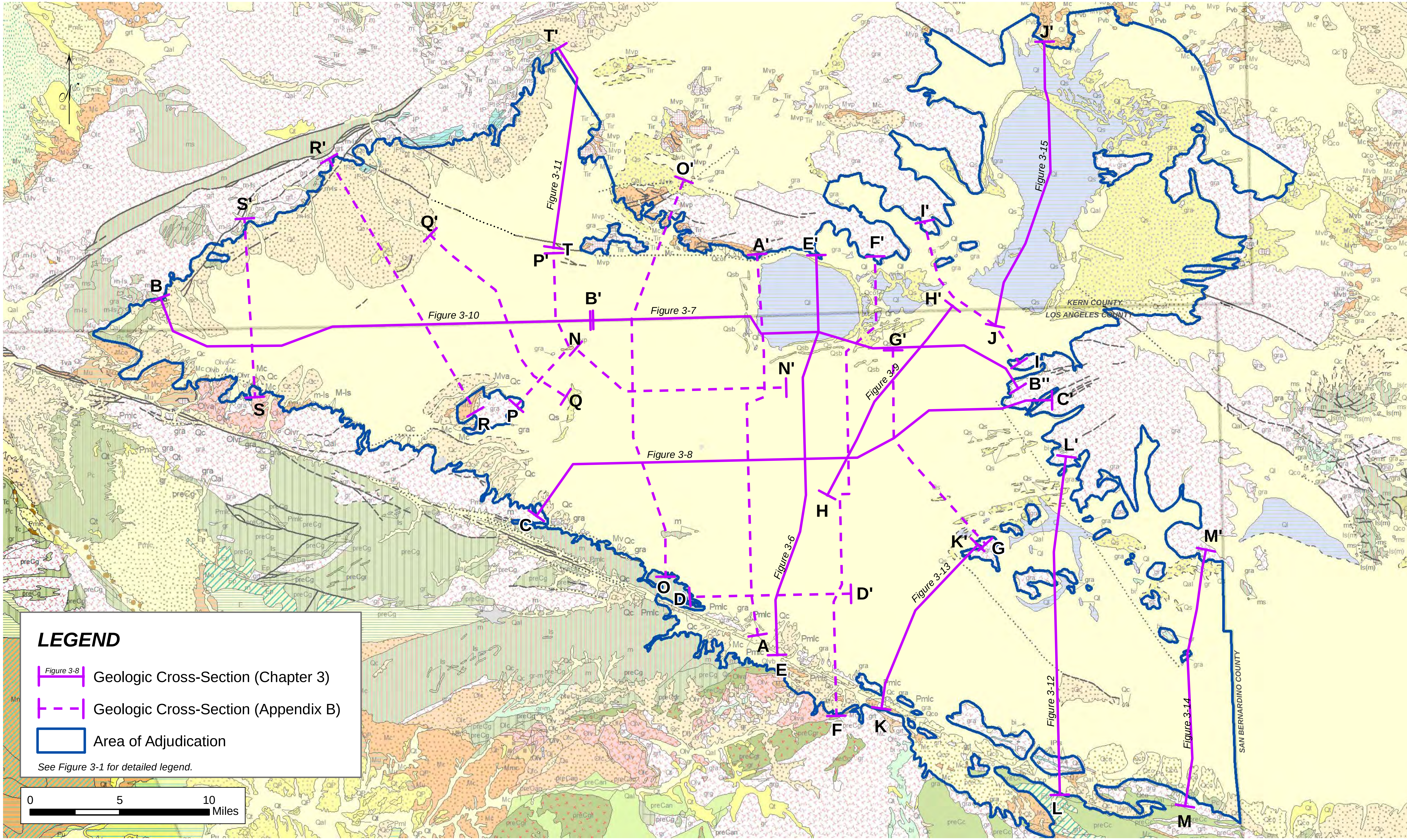

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Figure 3-2
Location Map - Geologic Cross-Sections
Antelope Valley Area of Adjudication

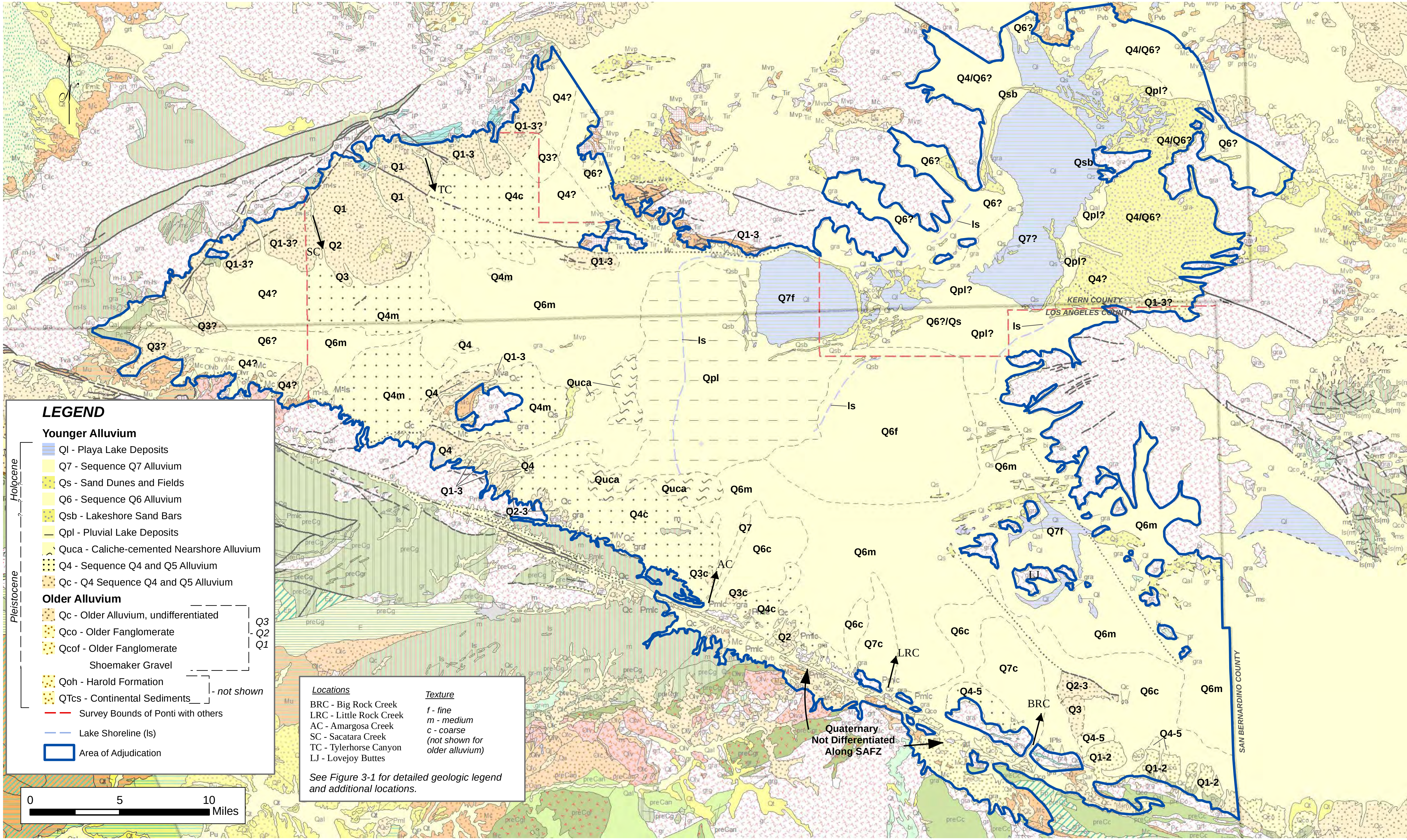

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Figure 3-3
Generalized Quaternary Geologic Map
Antelope Valley Area of Adjudication

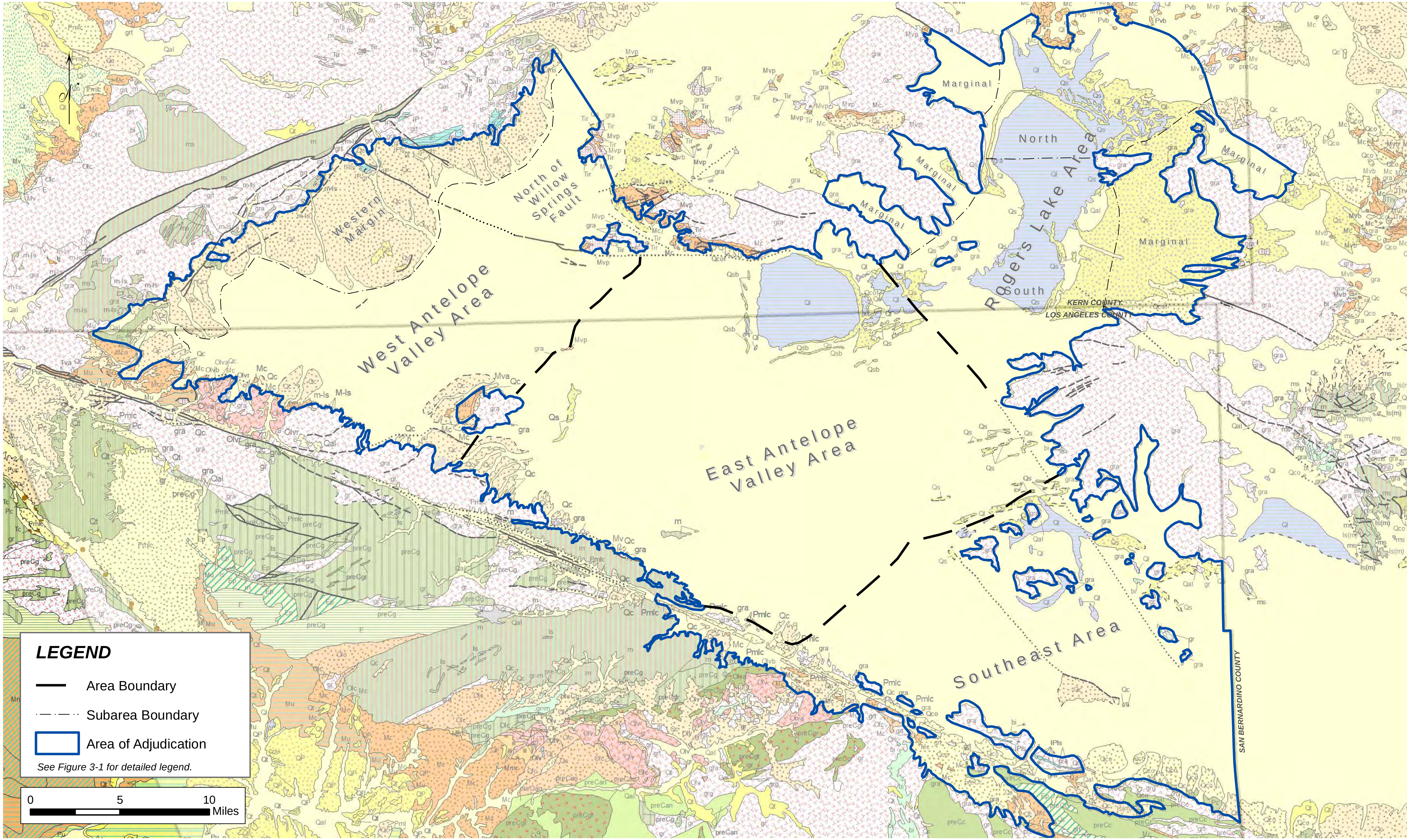

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Figure 3-4
Groundwater Geology Areas
Antelope Valley Area of Adjudication

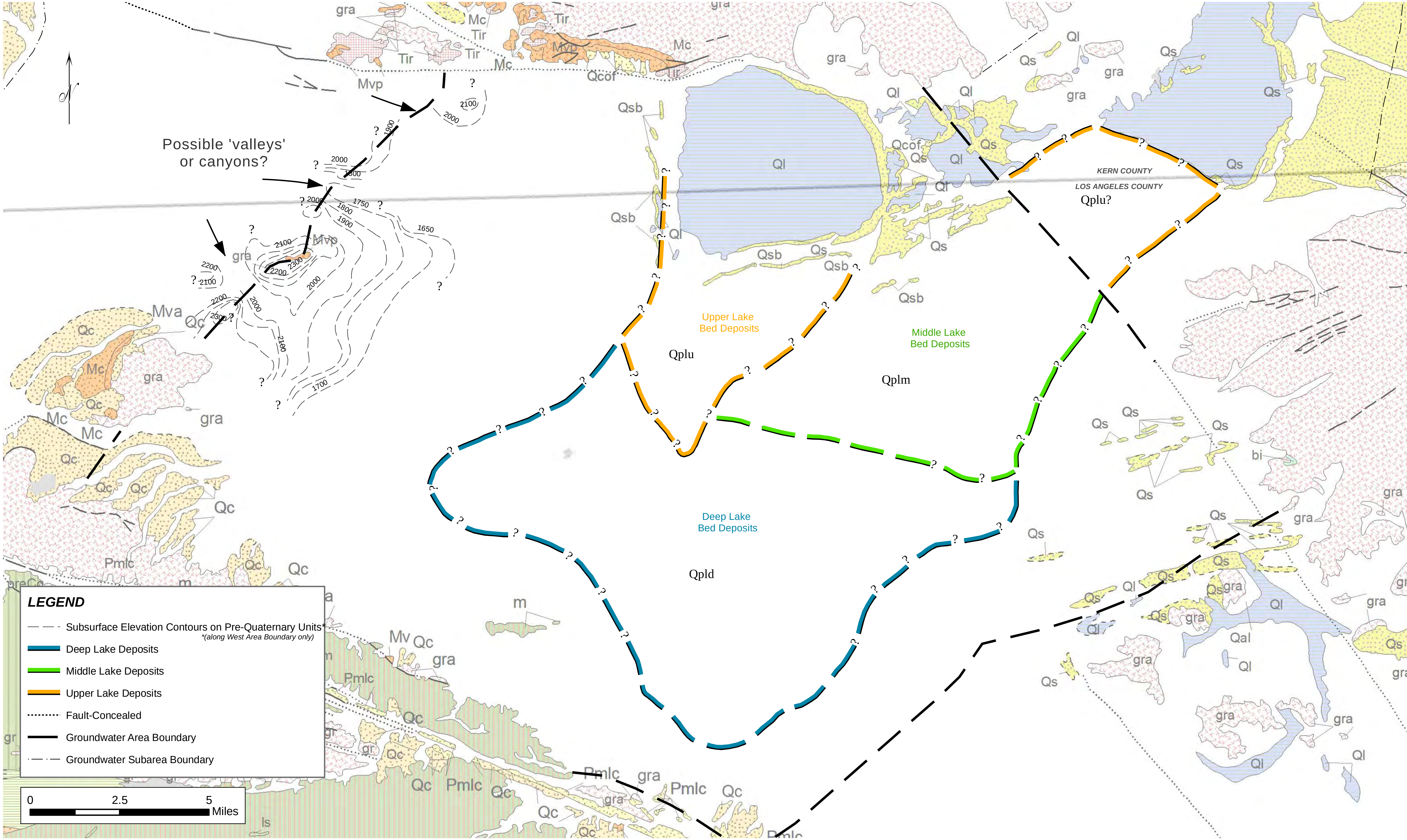

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Figure 3-5
Subsurface Extent of Lake Bed Deposits
Antelope Valley Area of Adjudication

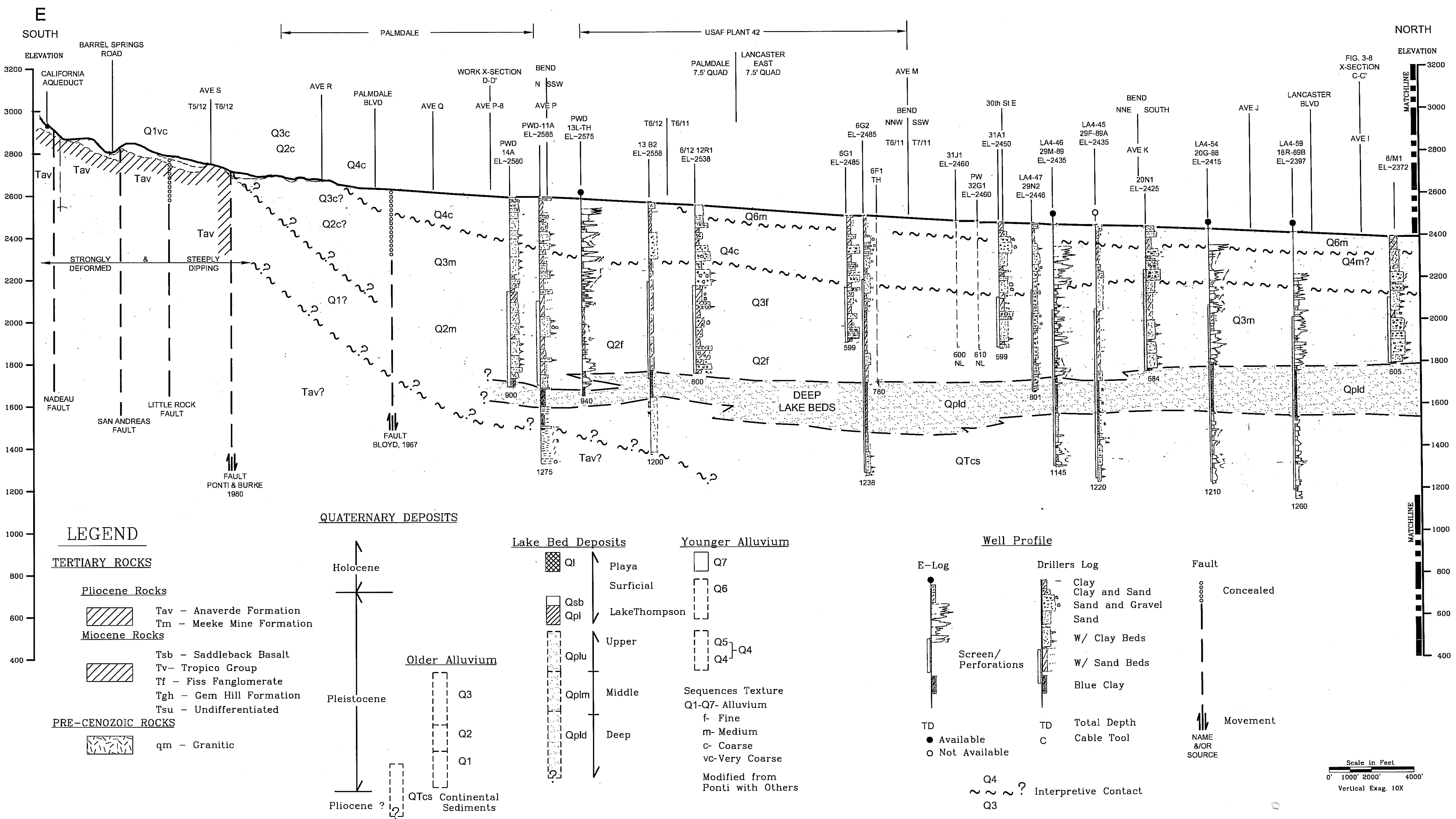

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Figure 3-6
Sheet 1 of 2
Geologic Cross Section E-E'
Antelope Valley Area of Adjudication

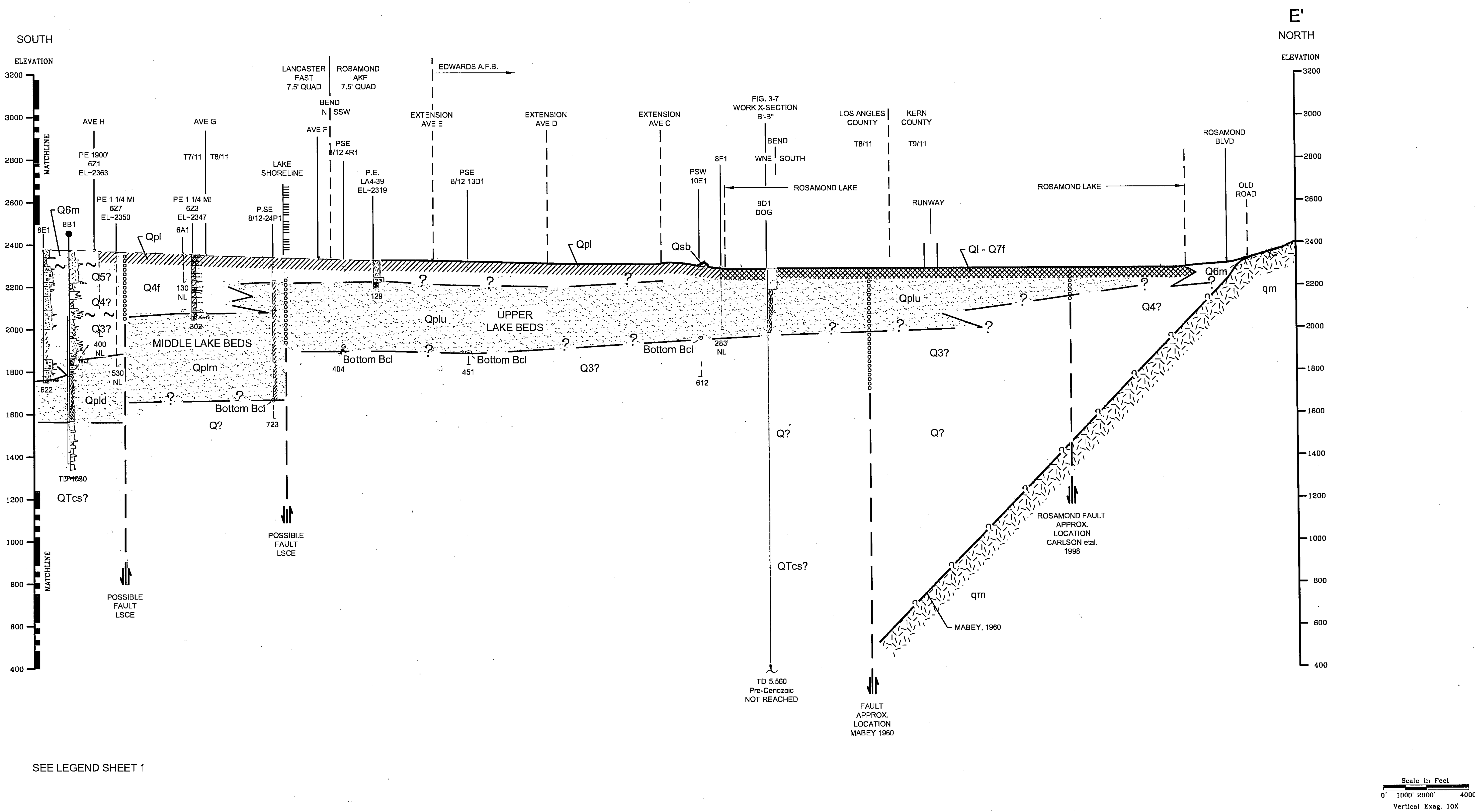

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Figure 3-6
Sheet 2 of 2
Geologic Cross Section E-E'
Antelope Valley Area of Adjudication

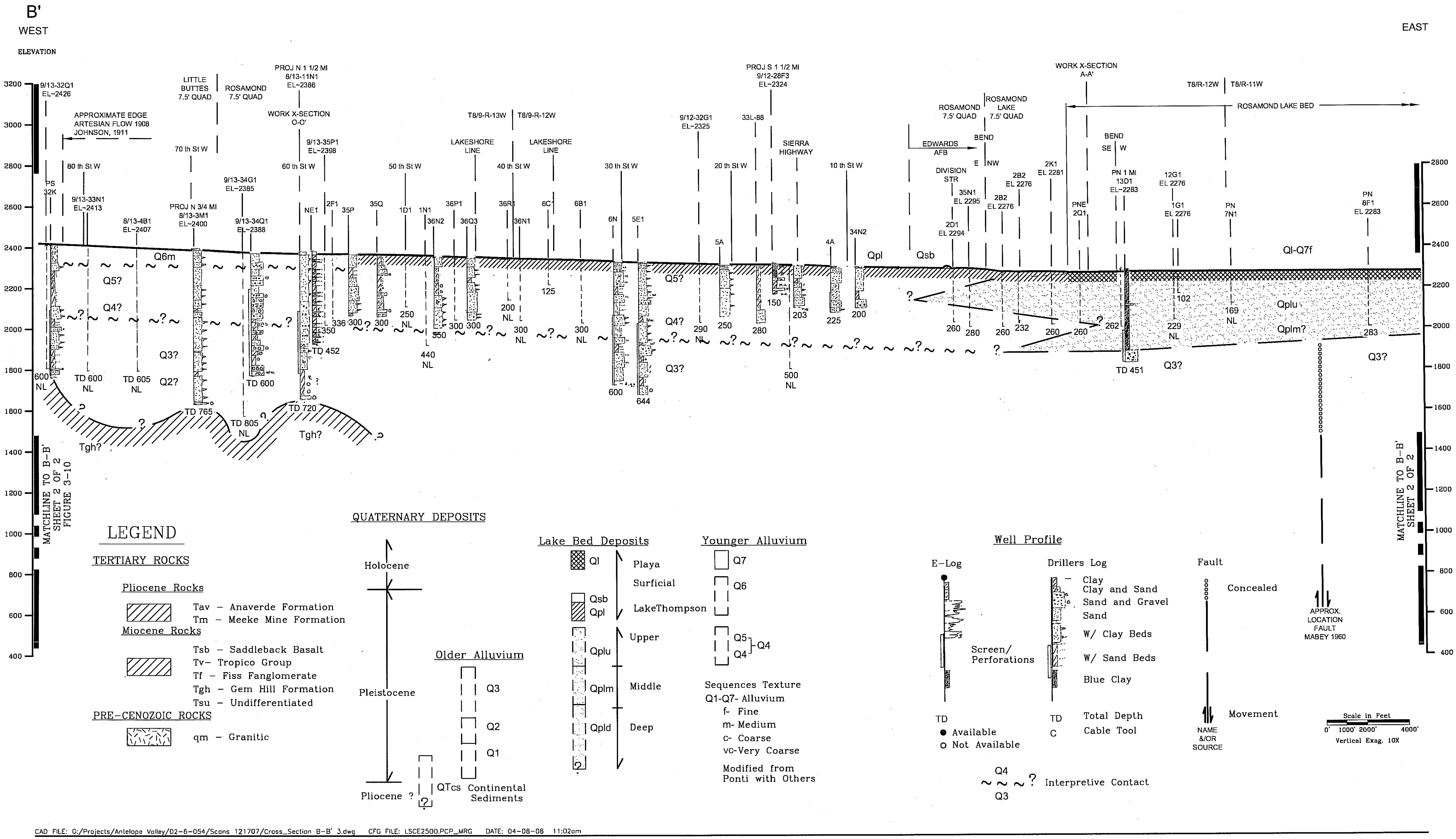

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Figure 3-7
Sheet 1 of 2
Geologic Cross Section B'-B"
Antelope Valley Area of Adjudication

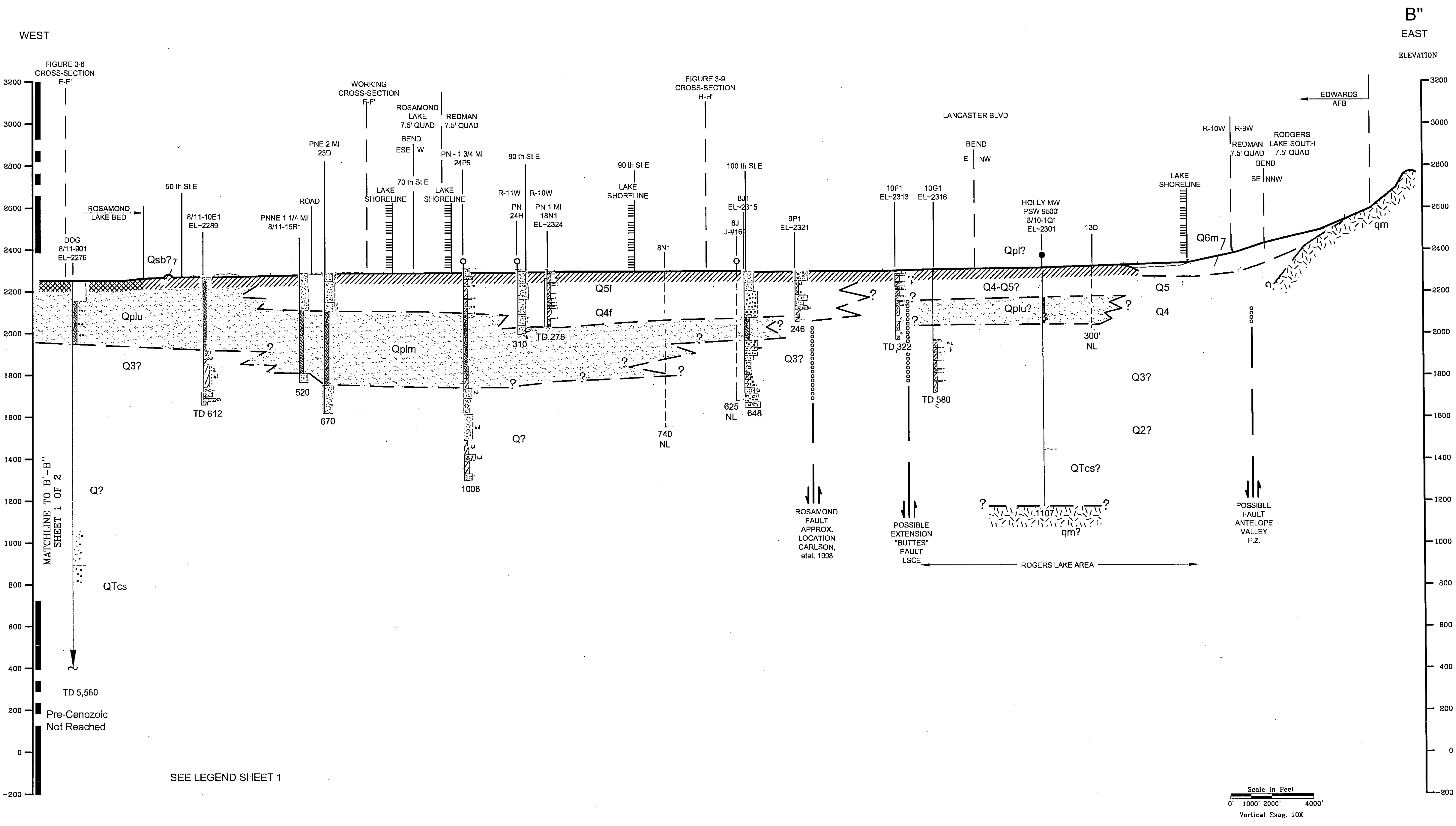

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Figure 3-7
Sheet 2 of 2
Geologic Cross Section B'-B''
Antelope Valley Area of Adjudication

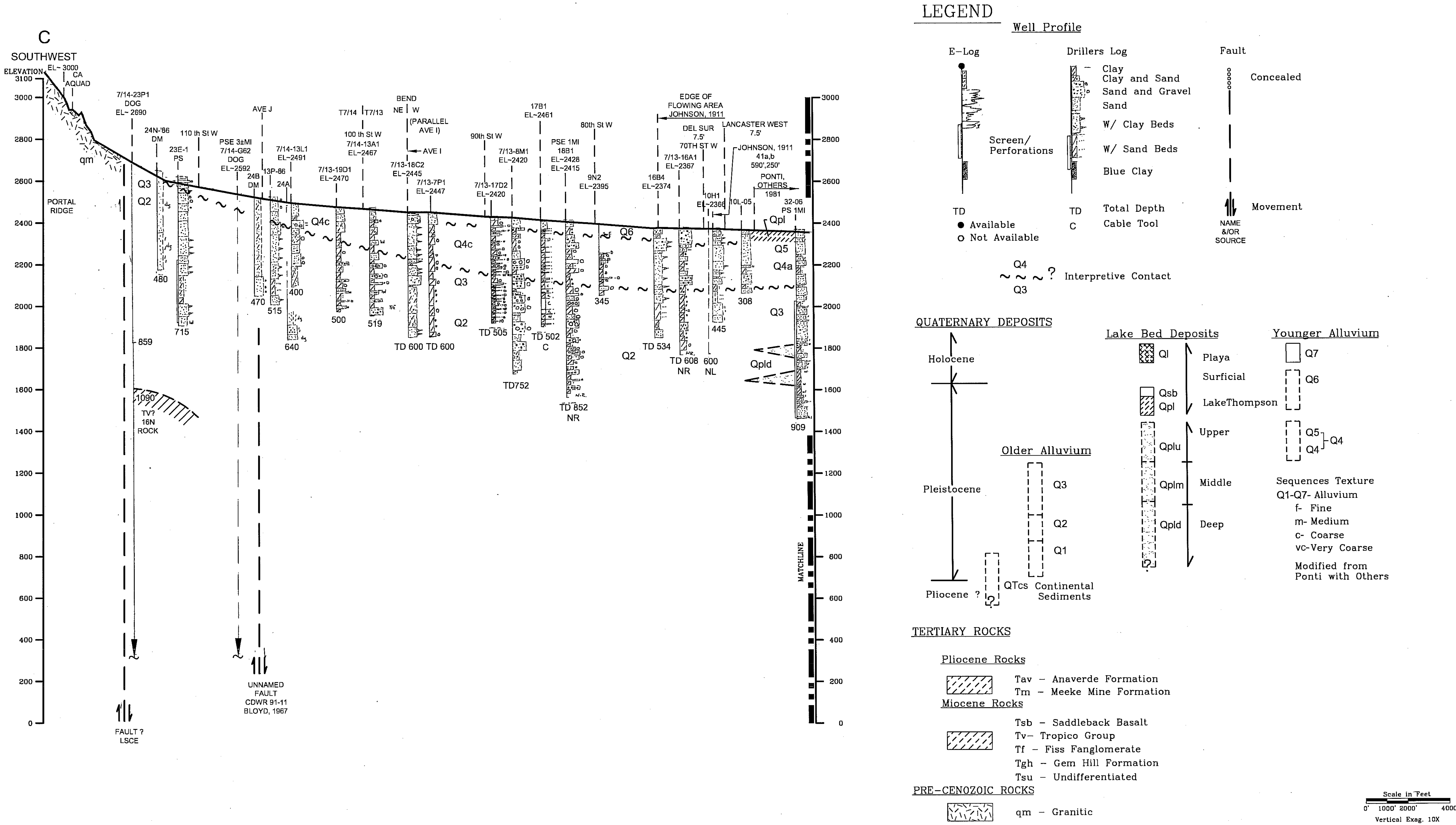

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Figure 3-8
Sheet 1 of 3
Geologic Cross Section C-C'
Antelope Valley Area of Adjudication

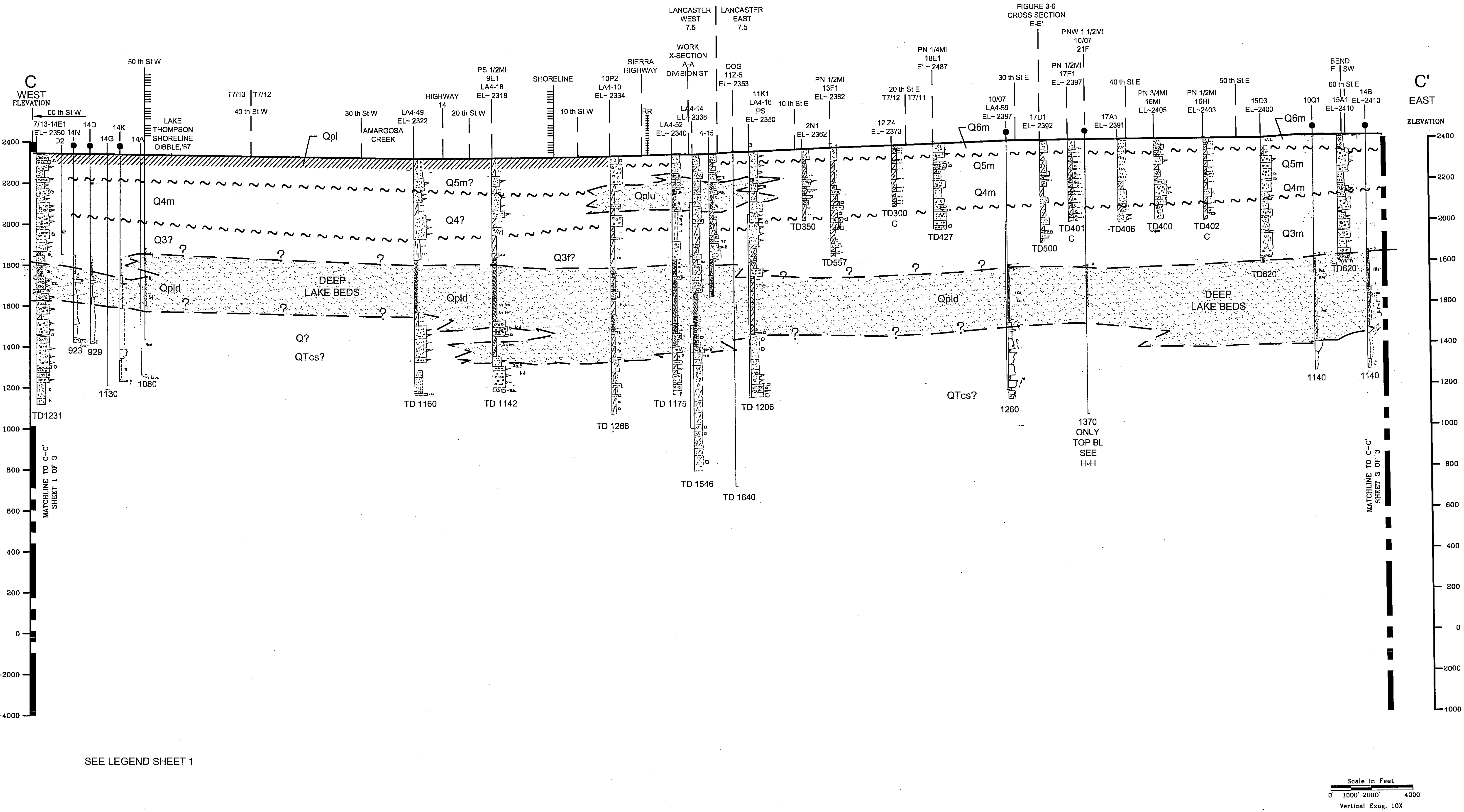

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Figure 3-8
Sheet 2 of 3
Geologic Cross Section C-C'
Antelope Valley Area of Adjudication

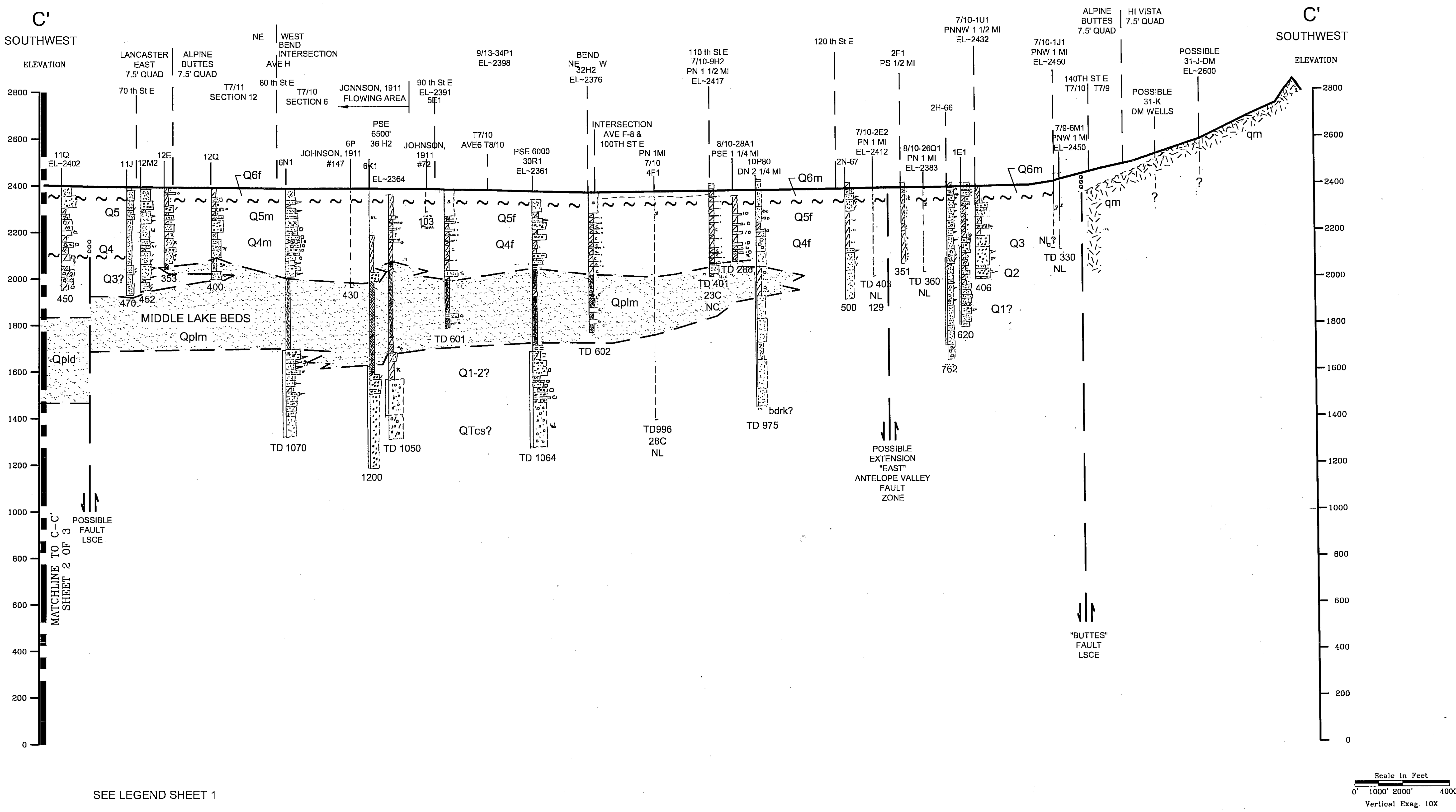

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Figure 3-8
Sheet 3 of 3
Geologic Cross Section C-C'
Antelope Valley Area of Adjudication

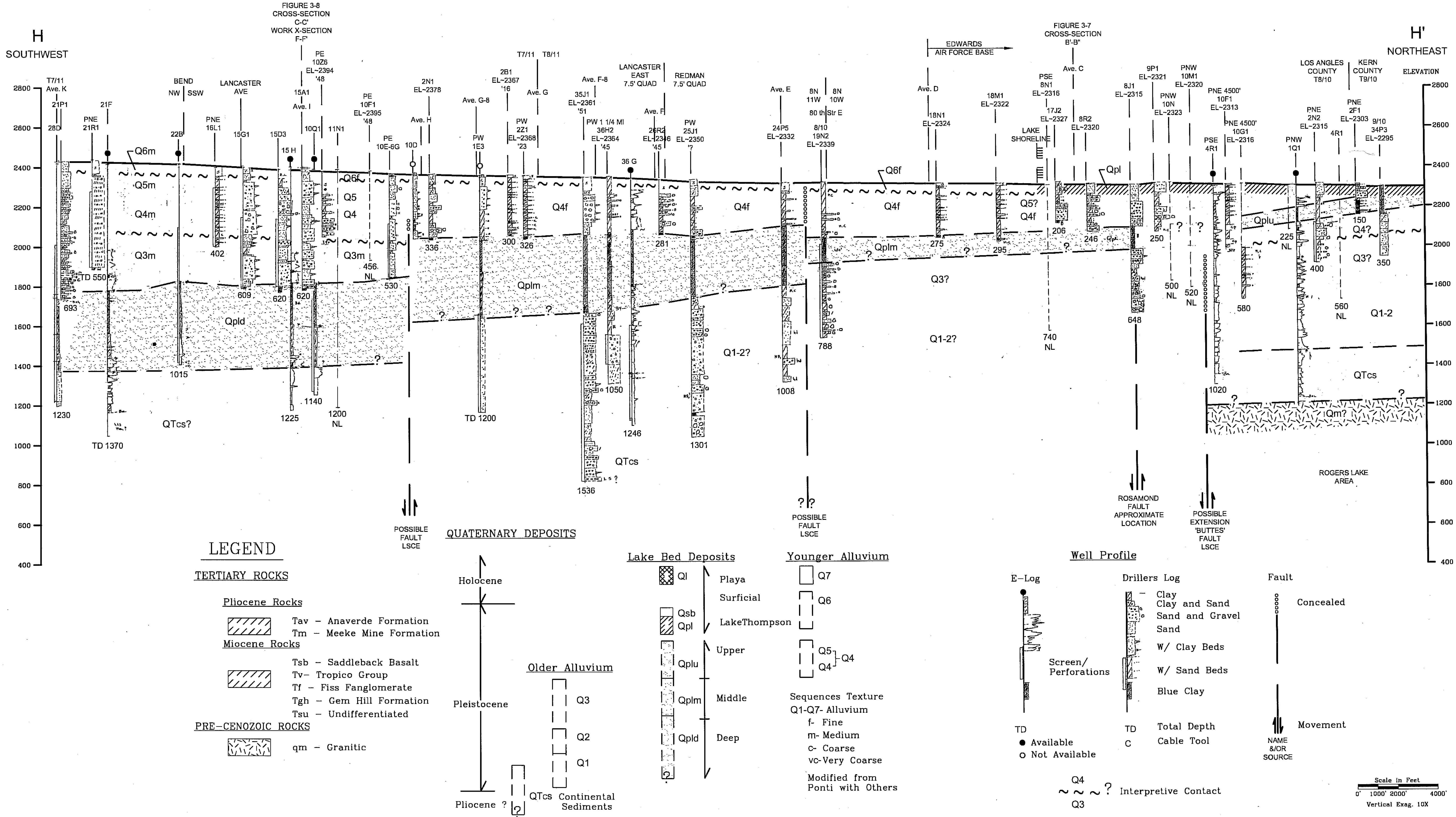

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Figure 3-9
Sheet 1 of 1
Geologic Cross Section H-H'
Antelope Valley Area of Adjudication

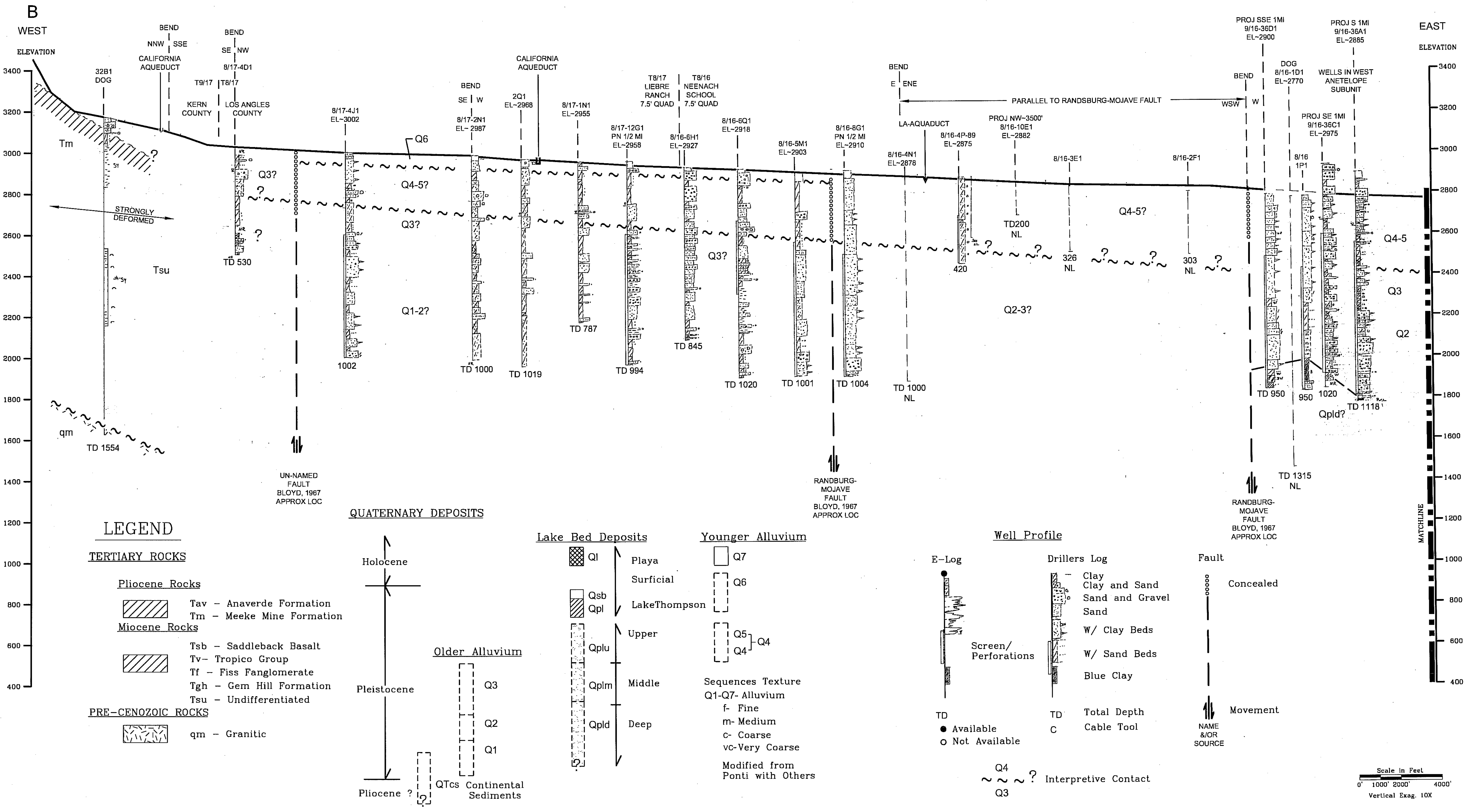

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Figure 3-10
Sheet 1 of 2
Geologic Cross Section B-B'
Antelope Valley Area of Adjudication

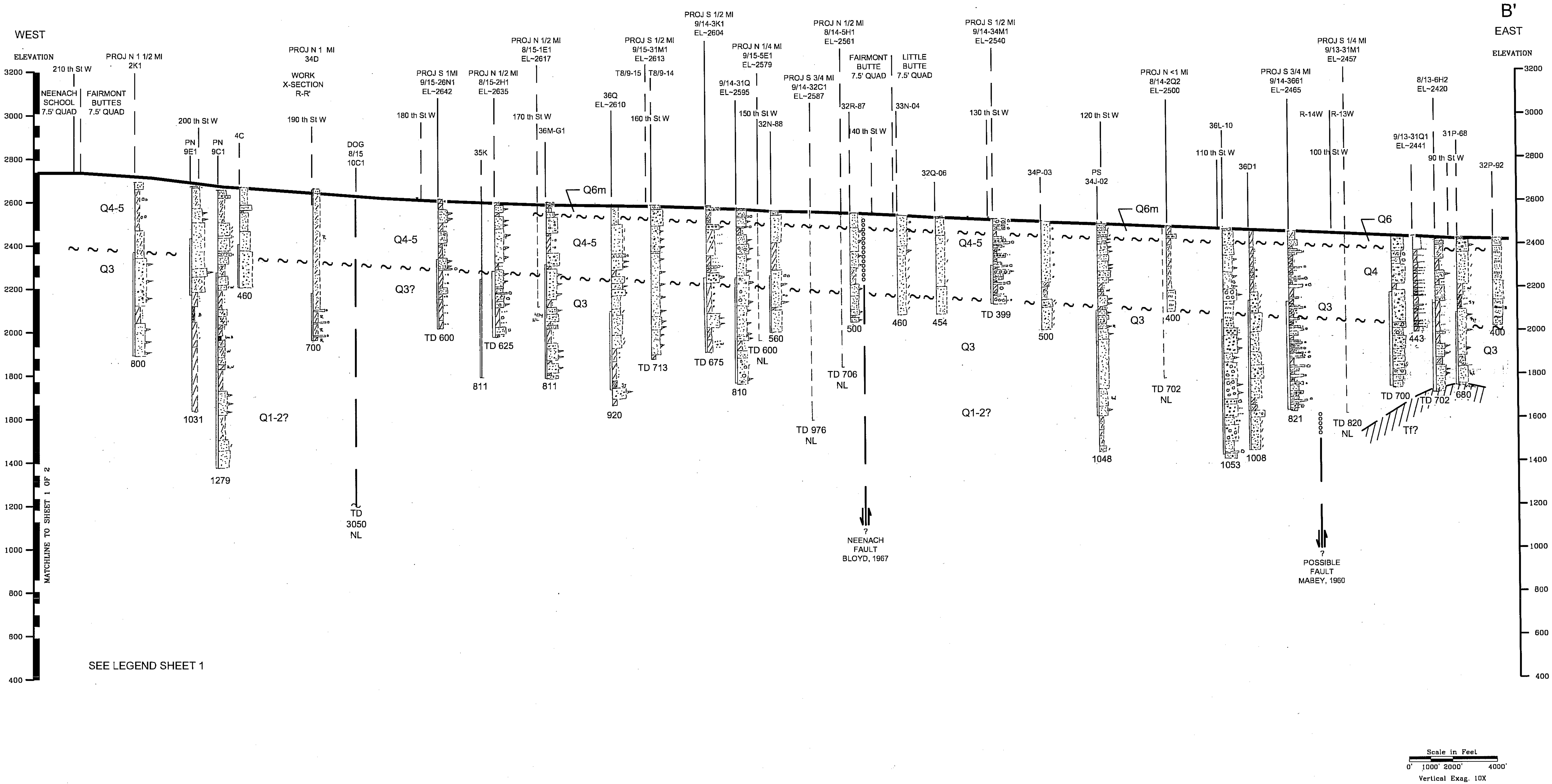

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Figure 3-10
Sheet 2 of 2
Geologic Cross Section B-B'
Antelope Valley Area of Adjudication

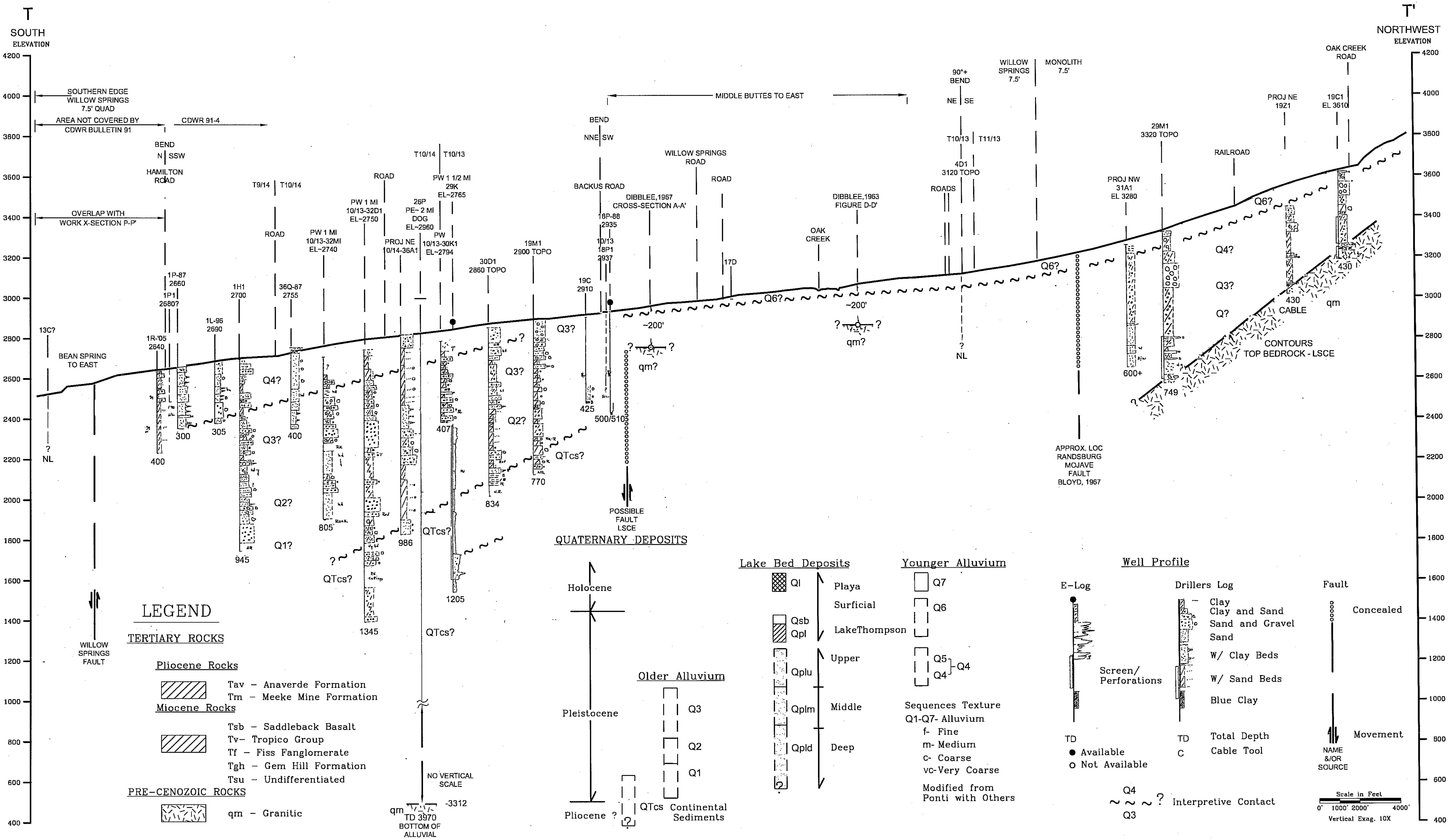

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Figure 3-11
Geologic Cross Section T-T'
Antelope Valley Area of Adjudication

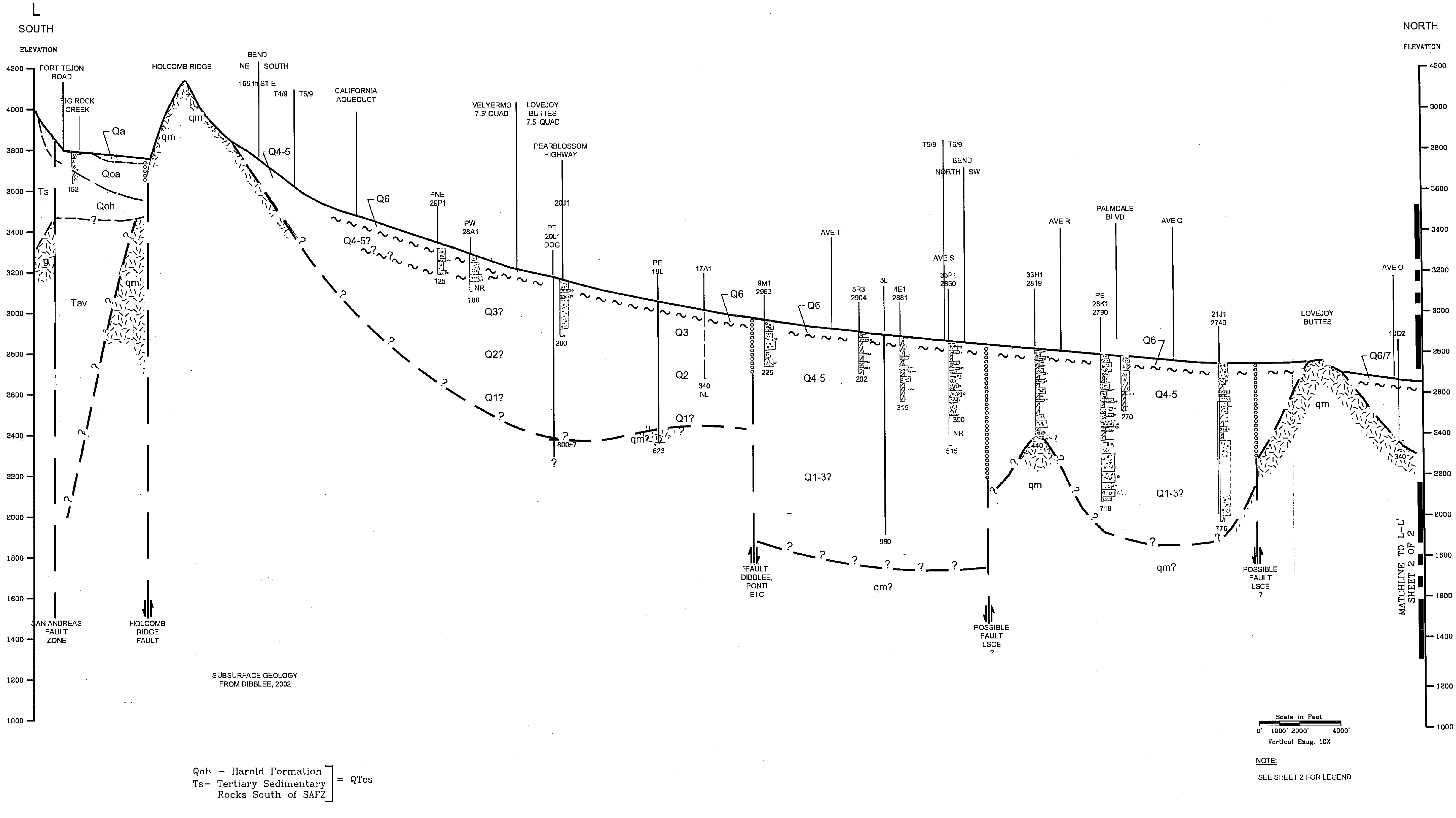

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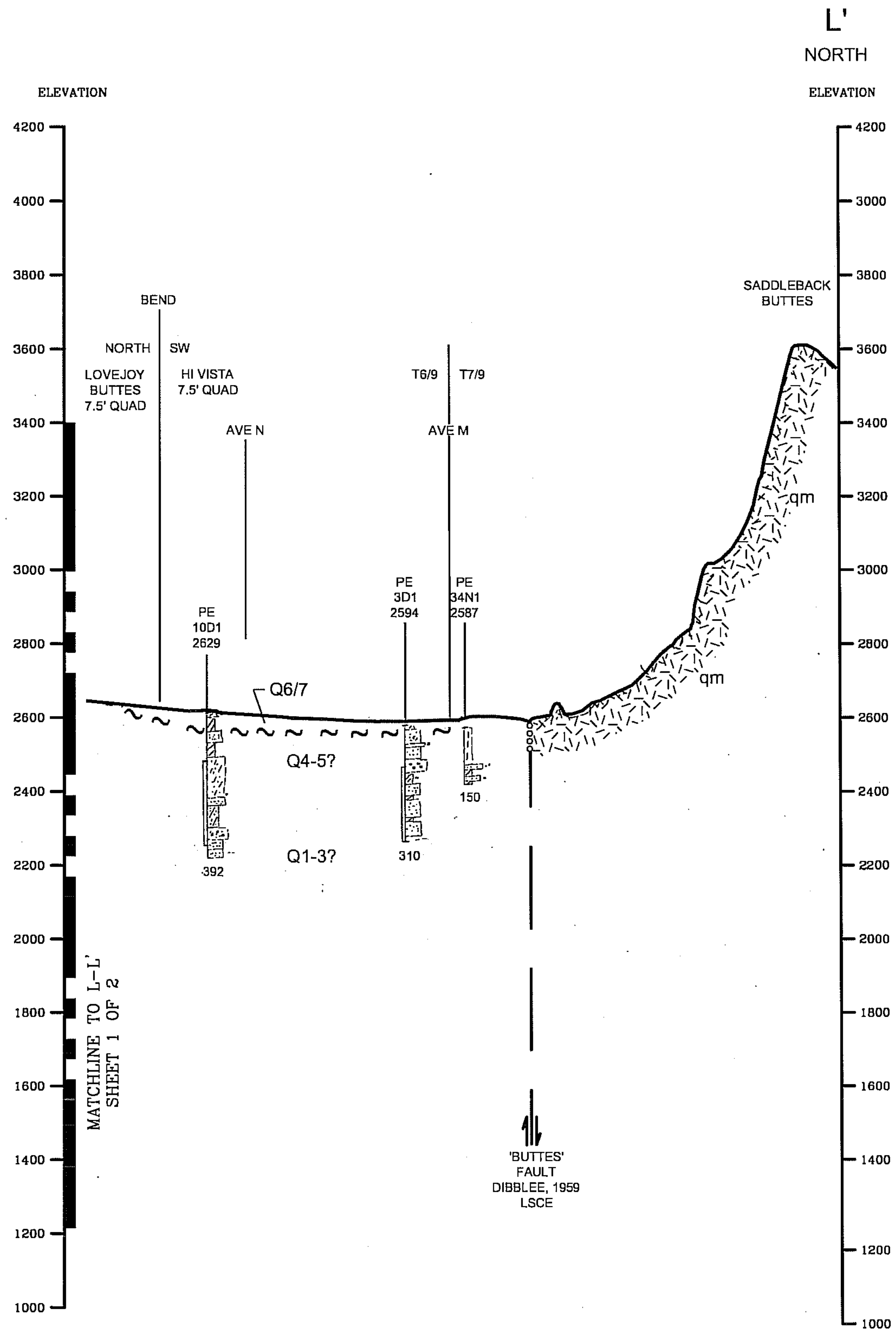
Figure 3-12
Sheet 1 of 2
Geologic Cross Section L-L'
Antelope Valley Area of Adjudication



LEGEND

Well Profile

E-Log

Screen/ Perforations

TD
- ● Available
- ○ Not Available

Drillers Log

- Clay
- Clay and Sand
- Sand and Gravel
- Sand
- W/ Clay Beds
- W/ Sand Beds
- Blue Clay

TD – Total Depth
C – Cable Tool

Fault

- Concealed
- Movement

NAME &/OR SOURCE

Q4 ～～～? Q3 Interpretive Contact

QUATERNARY DEPOSITS

Holocene

Pleistocene

Pliocene ?

Older Alluvium

- Q3
- Q2
- Q1
- QTcs Continental Sediments

Lake Bed Deposits

- Ql – Playa
- Surficial
- Qsb, Qpl – LakeThompson
- Qplu – Upper
- Qplm – Middle
- Qpld – Deep

Younger Alluvium

- Q7
- Q6
- Q5, Q4 – Q4

Sequences Texture
Q1-Q7- Alluvium
- f- Fine
- m- Medium
- c- Coarse
- vc-Very Coarse

Modified from Ponti with Others

TERTIARY ROCKS

Pliocene Rocks

- Tav – Anaverde Formation
- Tm – Meeke Mine Formation

Miocene Rocks

- Tsb – Saddleback Basalt
- Tv– Tropico Group
- Tf – Fiss Fanglomerate
- Tgh – Gem Hill Formation
- Tsu – Undifferentiated

PRE-CENOZOIC ROCKS

- qm – Granitic

Scale in Feet
0' 1000' 2000' 4000'
Vertical Exag. 10X

CAD FILE: G:/Projects/Antelope Valley/02-6-054/Scons2/Cross_Section L-L' 2 OF 2.dwg CFG FILE: LSCE2500.PCP_MRG DATE: 04-10-08 2:21pm

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Figure 3-12
Sheet 2 of 2
Geologic Cross Section L-L'
Antelope Valley Area of Adjudication

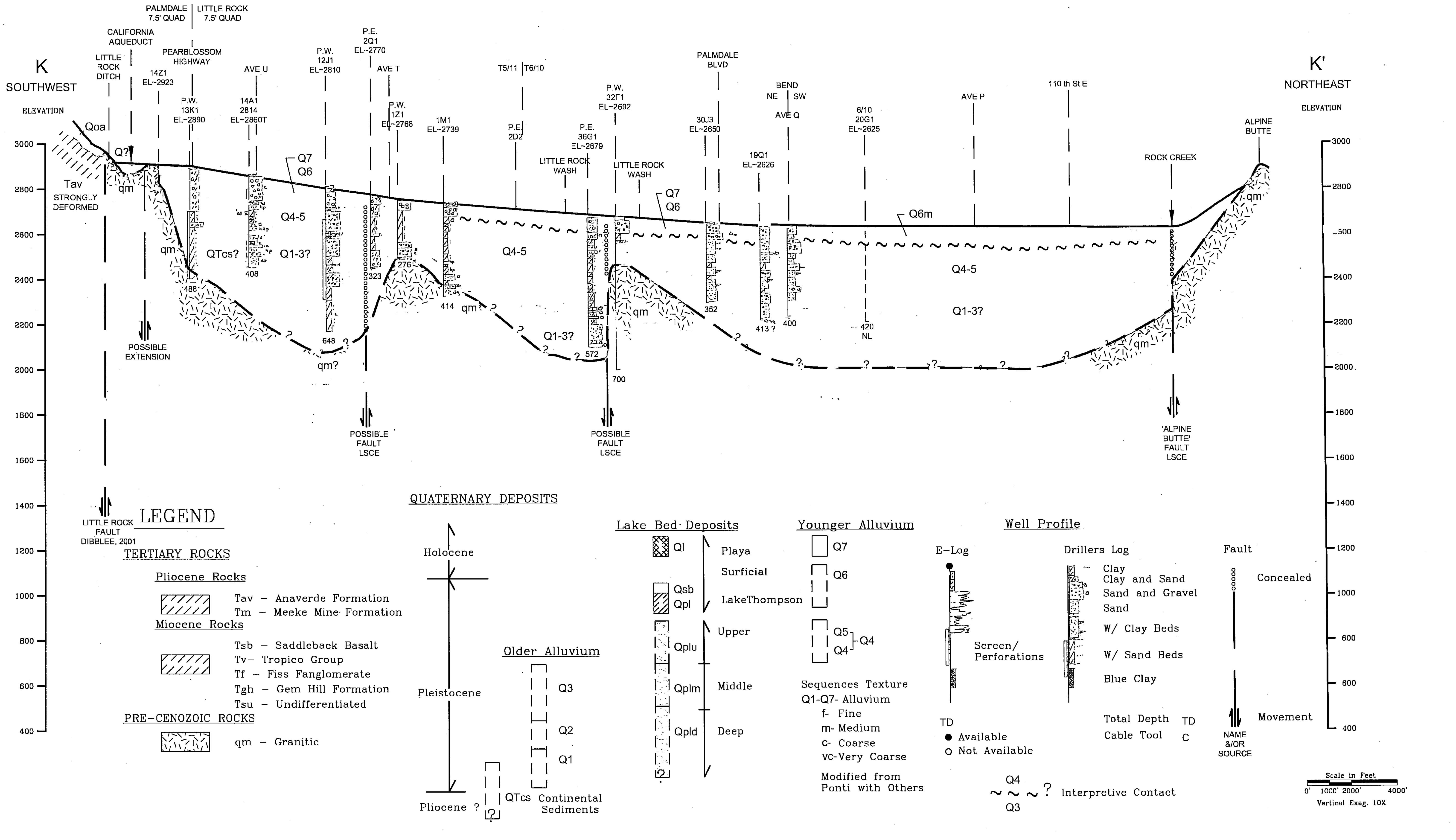

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Figure 3-13
Sheet 1 of 1
Geologic Cross Section K-K'
Antelope Valley Area of Adjudication

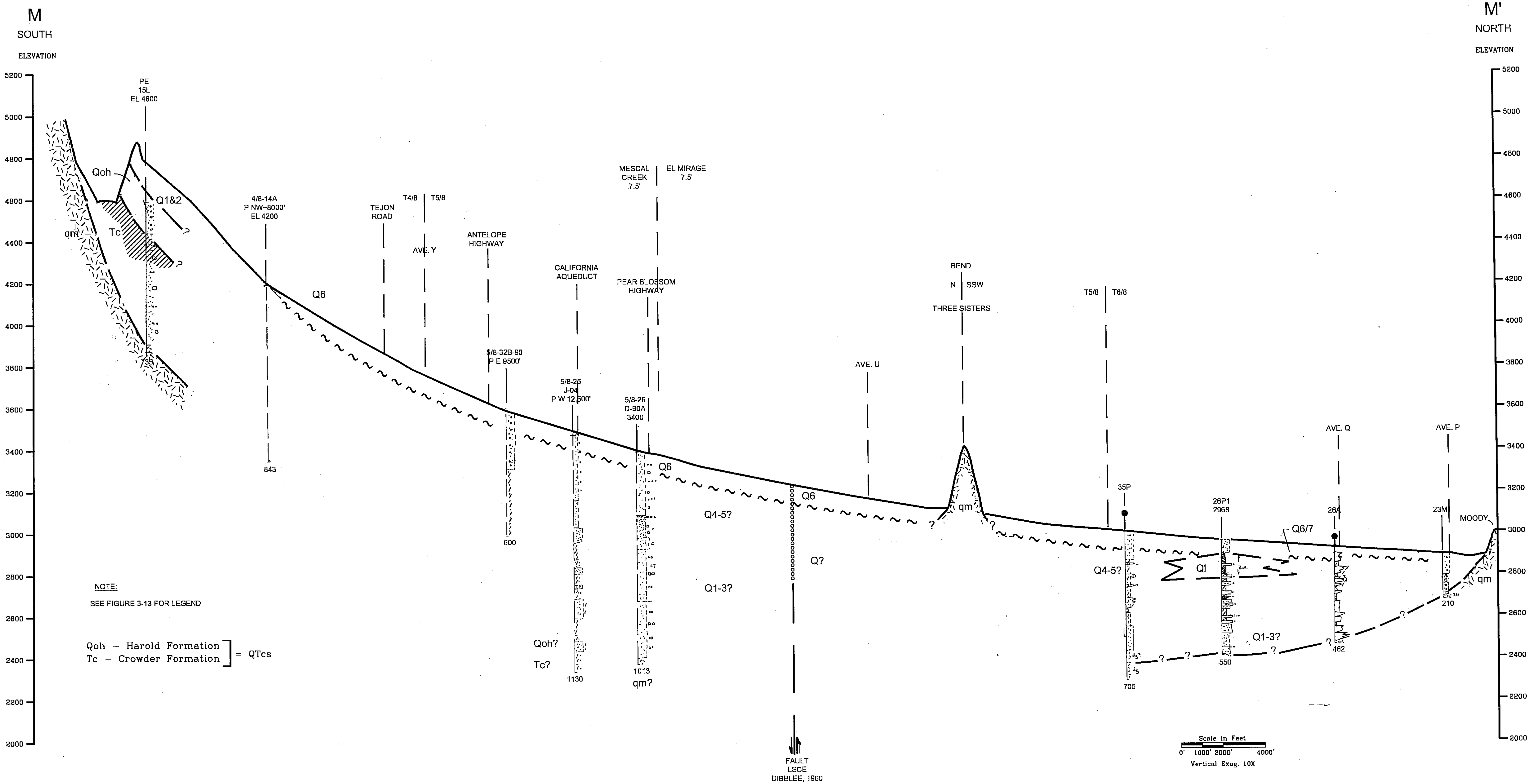

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Figure 3-14
Geologic Cross Section M-M
Antelope Valley Area of Adjudication

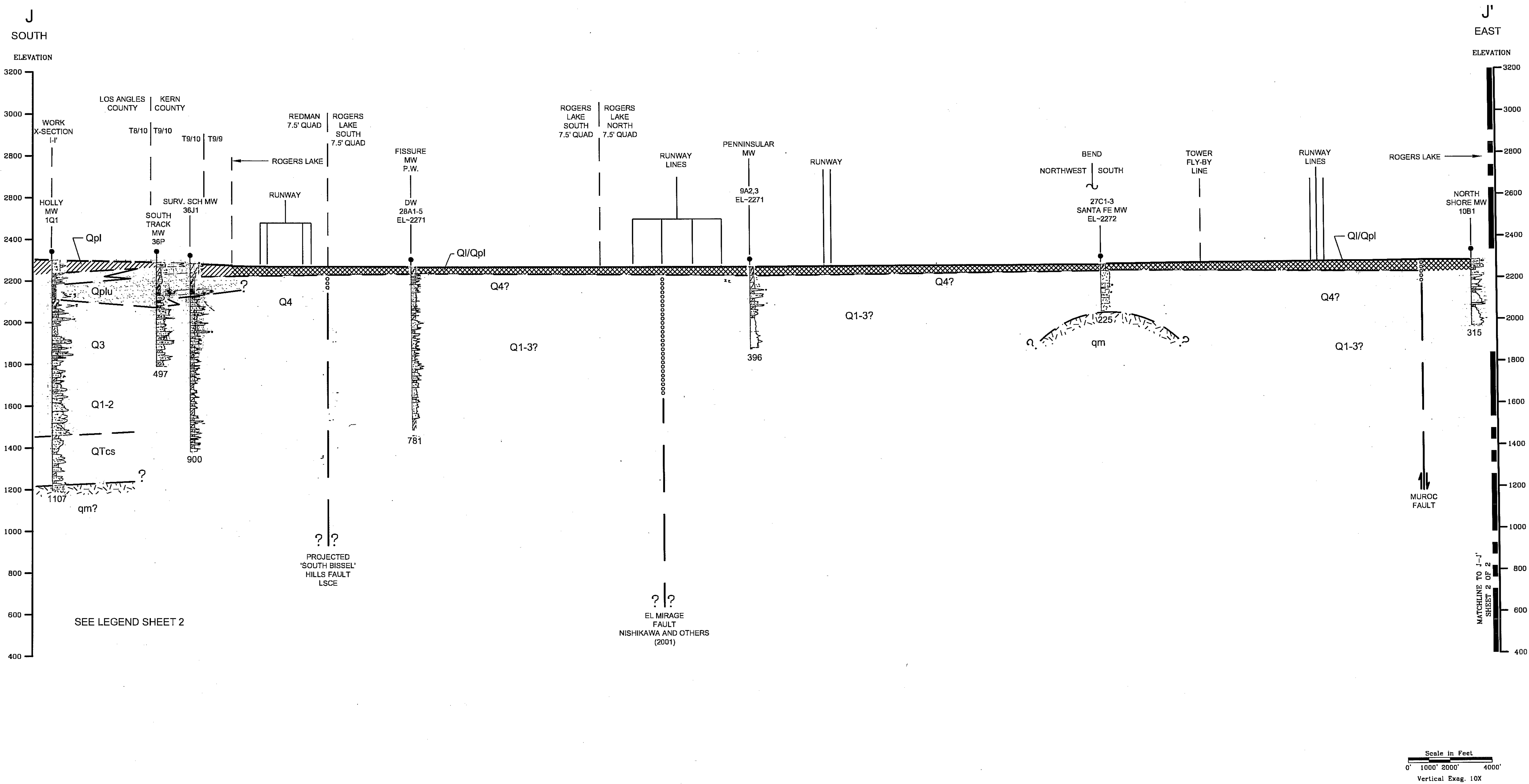

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Figure 3-15
Sheet 1 of 2
Geologic Cross Section J-J'
Antelope Valley Area of Adjudication

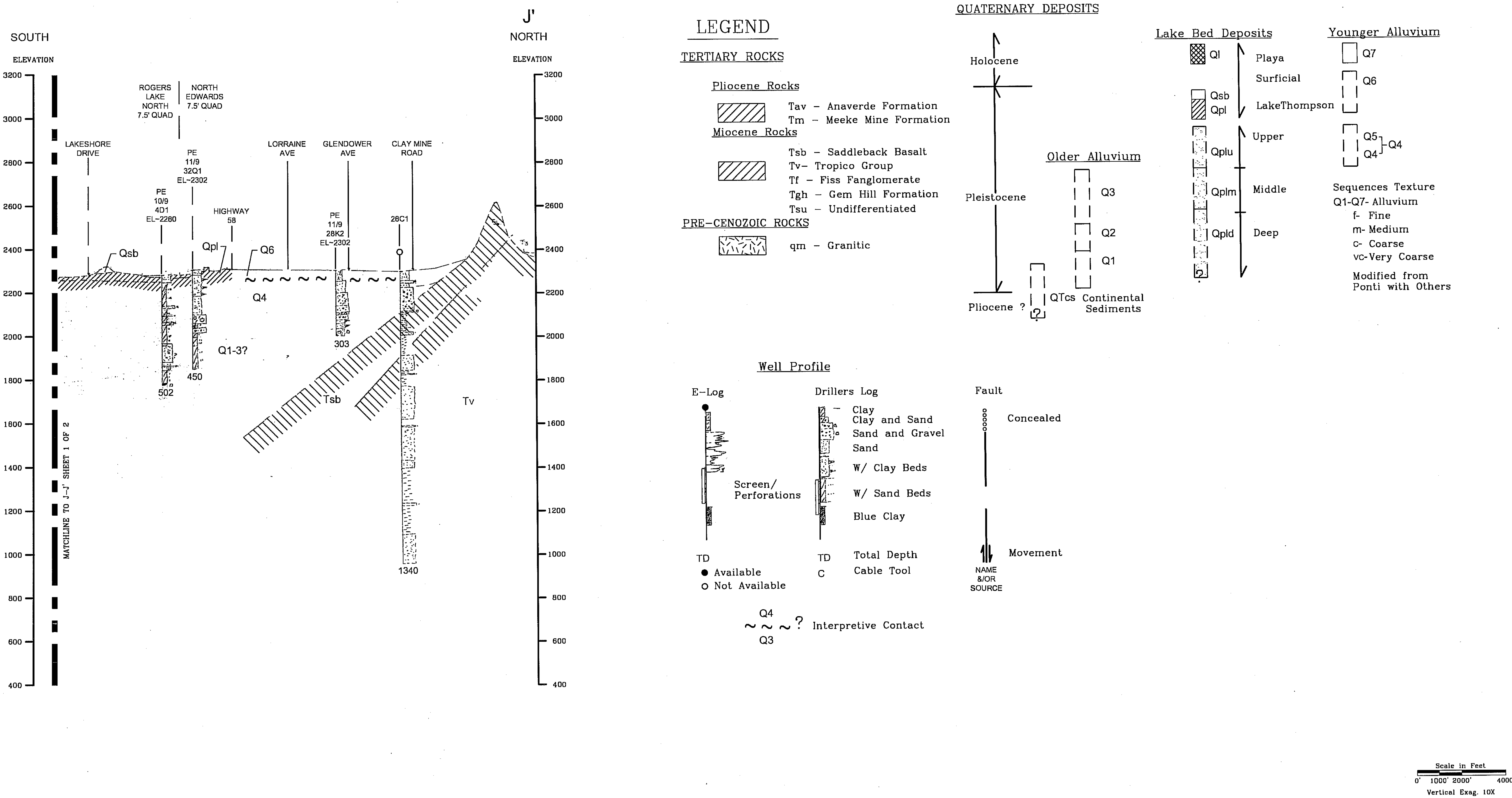

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Figure 3-15
Sheet 2 of 2
Geologic Cross Section J-J'
Antelope Valley Area of Adjudication

Table 3.6-1
Well Yield and Bedrock Hydraulic Characteristics
San Gabriel and Tehachapi Mountain Ranges around Antelope Valley Area of Adjudication

Well ID	Log No.	Screen Interval (feet bgs)	Static Water Level (feet bgs)	Saturated Screen Length (ft)	Pumping Rate (gpm)	Method	Duration (hours)	Drawdown	Q/s (gpm/ft)	T (gpd/ft)	K (ft/d)	Fractured Bedrock Type	Location
4N/9W-19	67835	344-500	375	125	1.5	Bailer	3	105	0.014	21	0.023	Granite	San Gabriel Mtn.
4N/10W-1	438937	200-380	145	180	15	Air Lift	3	100	0.150	225	0.167	Granite	San Gabriel Mtn.
4N/10W-4	398854	60-140	55	80	10	Air Lift	2	30	0.333	500	0.836	Gray Rock	San Gabriel Mtn.
4N/10W-4	574895	100-600	500	100	1	Air Lift	5	100	0.010	15	0.020	Granite	San Gabriel Mtn.
4N/10W-4	453128	110-700	115	585	5	Air Lift	3	400	0.013	19	0.004	Granite	San Gabriel Mtn.
4N/10W-8	775920	100-420	100	320	7	Air Lift	4	250	0.028	42	0.018	Decomposed Granite/Crushed Rock	San Gabriel Mtn.
4N/10W-8	273789	325-345; 425-445	300	40	0.25	Bailer	24	165	0.002	2	0.008	Decomposed Granite/Granite	San Gabriel Mtn.
4N/10W-13	67852	289-457	155	168	2	Bailer	6	275	0.007	11	0.009	Decomposed Granite	San Gabriel Mtn.
4N/10W-15	354067	240-440	200	200	2	Air Lift	3	200	0.010	15	0.010	Shale	San Gabriel Mtn.
4N/10W-15	453129	80-500	80	420	7	Air Lift	2	400	0.018	26	0.008	Broken Rock/Shale	San Gabriel Mtn.
4N/10W-16	453131	110-620	80	510	7	Air Lift	4	450	0.016	23	0.006	Broken Rock/Shale	San Gabriel Mtn.
5N/10W-19	273788	120-150; 190-210; 330-390	90	110	0.5	Bailer	12	200	0.003	4	0.005	Granite	San Gabriel Mtn.
5N/10W-21	505824	67-247	88	159	2.5	Bailer	12	159	0.016	24	0.020	Quartz Rock	San Gabriel Mtn.
5N/10W-29	194475	150-190	90	40	35	Air Lift	2	70	0.500	750	2.507	Granite	San Gabriel Mtn.
5N/10W-29	336636	170-190; 310-350	160	60	3	Bailer	4	200	0.015	23	0.050	Decomposed Granite	San Gabriel Mtn.
5N/10W-29	456678	204-302	60	98	12	Bailer	4	120	0.100	150	0.205	Decomposed Granite	San Gabriel Mtn.
5N/10W-30	47123	485-665	150	180	5	Air Lift	2	250	0.020	30	0.022	Granite	San Gabriel Mtn.
5N/10W-31	151788	150-170; 535-575	125	60	5	Air Lift	1	375	0.013	20	0.045	Decomposed Granite	San Gabriel Mtn.
5N/11W-8	15225	95-115; 400-420	90	40	2	Bailer	2	330	0.006	9	0.030	Sandstone/Decomposed Granite	San Gabriel Mtn.
5N/11W-15	172213	430-450; 470-490; 530-550	150	60	5	Air Lift	1.5	350	0.014	21	0.048	Decomposed Granite/Granite	San Gabriel Mtn.
5N/11W-21	151797	110-130; 190-310; 330-350	75	160	5	Air Lift	1	225	0.022	33	0.028	Shale/Decomposed Granite/Black Rock	San Gabriel Mtn.
5N/11W-21	505830	70-400	42	330	15	Bailer	8	150	0.100	150	0.061	Sandstone	San Gabriel Mtn.
5N/12W	194459	310-390	290	80	2	Air Lift	1	90	0.022	33	0.056	Granite	San Gabriel Mtn.
5N/12W	172228	175-195; 400-420; 480-500	150	60	5		2	225	0.022	33	0.074	Granite/Red Stoney Clay	San Gabriel Mtn.
5N/12W-3	354073	60-400	55	340	18	Air Lift	1	325	0.055	83	0.033	Blue Rock/Gray Rock	San Gabriel Mtn.
5N/12W-5	e017187	200-490	80	290	3	Pump	5	100	0.030	45	0.021	Granite	San Gabriel Mtn.
5N/12W-5	e023454	190-490	150	300	3	Pump	6.5	320	0.009	14	0.006	Granite	San Gabriel Mtn.
5N/12W-11	113333	200-400	200	200	5	Pump	4	150	0.033	50	0.033	Volcanic Rock	San Gabriel Mtn.
5N/12W-13	817237	300-640	250	340	40	Air Lift	2	280	0.143	214	0.084	Sandstone/DG/Green Serpentine	San Gabriel Mtn.
5N/12W-14	47124	435-615	400	180	2	Air Lift	2	200	0.010	15	0.011	Granite	San Gabriel Mtn.
5N/13W	15783	60-190	62	128	10	Bailer	1	25	0.400	600	0.627	Sandstone/Decomposed Granite	San Gabriel Mtn.
6N/12W	171321	225-325	150	100	25		2	5	5.000	7500	10.027	Granite	San Gabriel Mtn.
6N/13W-15	58375	20-90	6	70	7	Bailer	4	64	0.109	164	0.313	Shale/Granite	San Gabriel Mtn.
6N/13W-15	67866	20-100	8	80	1.5	Bailer	4	86	0.017	26	0.044	Shale	San Gabriel Mtn.
6N/13W-23F	138487	30-125	13.5	95	30	Air Lift	2	111.5	0.269	404	0.568	Decomposed Granite	San Gabriel Mtn.
6N/13W-23F	138488	20-92	16.5	72	2	Bailer	4	68.5	0.029	44	0.081	Decomposed Granite	San Gabriel Mtn.
6N/13W-23F	1085140	60-250	23	190	18	Air Lift	4	227	0.079	119	0.084	Decomposed Rock	San Gabriel Mtn.
7N/14W-24	160777	200-480	250	230	4	Air Lift	4	175	0.023	34	0.020	Decomposed Granite	San Gabriel Mtn.
7N/14W-27	251727	244-324	45	80	12	Pump	8	255	0.047	71	0.118	Decomposed Granite	San Gabriel Mtn.
7N/14W-33	58391	136-176	50	40	1	Bailer	4	125	0.008	12	0.040	Granite	San Gabriel Mtn.
7N/14W-34	51280	120-403	90	283	3		2	40	0.075	113	0.053	Decomposed Granite/Granite	San Gabriel Mtn.
7N/15W-6E1	33849	4.5-82.5	4	78	25			46	0.543	815	1.397	Decomposed Granite/Granite	San Gabriel Mtn.
8N/16W-22	1085155	100-403	48	303	15	Air Lift	6	350	0.043	64	0.028	Sandstone/Rock	San Gabriel Mtn.
8N/16W-23	58393	68-128	60	60	5	Pump		68	0.074	110	0.246	Decomposed Granite	San Gabriel Mtn.
8N/16W-26	161185	82-142	20	60	3	Air Lift	1	110	0.027	41	0.091	Granite	San Gabriel Mtn.
8N/16W-26	438938	60-400	30	340	8	Air Lift	3	300	0.027	40	0.016	Broken Rock/Decomposed Granite	San Gabriel Mtn.
8N/16W-26	337567	200-400	180	200	10		8	170	0.059	88	0.059	Granite	San Gabriel Mtn.
11N/14W-24B	506091	180-440	293	147	23	Pump	6	97	0.237	356	0.323	Limestone/Shale	Tehachapi Mtn.
					5.2				0.037	55	0.055	Geometric Mean	
					5				0.027	40.5	0.0445	Median	

IV. Water Resources Analyses

In order to analyze the overall water supply and groundwater resource conditions in the Antelope Valley Area of Adjudication (AVAA), detailed analyses of the individual components of water supplies and the groundwater basin were undertaken. The individual analyses were ultimately used in various combinations to estimate or otherwise describe the nature and condition of water resources, with particular focus on groundwater, and to place historic and current groundwater pumping in the context of groundwater conditions. Each of those analyses is summarized in the following sections of this chapter; for some sections, further detail is included in the Appendices. Since analysis of some aspects of water resource conditions is necessarily dependent on proper selection of a period of study, or "base period", Section 4.7 discusses the selection of base period for the analyses reported herein. Finally, since the nature of data availability and analytical methodology in any water resource or groundwater investigation results in some degree of imprecision, and does not necessarily allow determination of a single, unique "right" result, this chapter concludes with a discussion of precision and certain sensitivity analyses that were undertaken to examine the degree to which data constraints and/or analytical methods affected the results reported herein.

4.1 Precipitation, Runoff and Natural Groundwater Recharge

4.1.1 Antelope Valley Hydrologic System

The precipitation within the Antelope Valley watershed is the source of natural recharge to the underlying groundwater basin. As schematically illustrated on Figure 4.1-1, the precipitation not consumed by evapotranspiration or evaporation becomes groundwater recharge in this closed basin. During rainfall or snowmelt events, streamflow runoff or soil infiltration is produced. The streamflow in turn produces streambed infiltration and sometimes produces streamflow discharges onto playa surfaces, such as those represented by Rosamond, Rogers, and other dry lakes. The streambed infiltration is removed in part by evaporation from the streambed surface, but the remaining infiltration produces groundwater recharge by the deep percolation of the infiltrated water to the groundwater table. The streamflow discharges onto playa surfaces evaporate and do not produce recharge. Soil infiltration is removed in part by evapotranspiration, but the remaining infiltration can produce groundwater recharge again by the deep percolation of the infiltrated water to the groundwater table.

Based on this conceptual model, groundwater recharge within the Antelope Valley occurs by either streambed infiltration or soil infiltration. While these processes occur throughout the watershed, soil infiltration probably is more important within the mountain-block areas, and streambed infiltration probably is more important within the valley-floor areas. Within the valley-floor areas, recharge most likely does not occur from soil infiltration where the average annual precipitation is less than about 8 inches (Maxey and Eakin, 1949; Dettinger, 1989; Avon and Durbin, 1992; Tyler and others, 1992; Tyler and others, 1996; Russell and Minor, 2002), which represents the entire valley-floor area except for the higher parts of the alluvial fans.

Within the mountain-block areas, such as represented by the San Gabriel and Tehachapi mountains, significant runoff is generated from rainfall and snowmelt. However, much of the runoff is discharged from the mountain canyons onto the alluvial fans comprising the valley-floor areas. Therefore, to the extent that groundwater recharge occurs within the mountain-block areas, it probably is produced mostly by the deep percolation of soil infiltration. The mountain-block recharge in turn produces either groundwater flows directly from the mountain-block into the valley-floor areas or perennial streamflows from mountain canyons into valley-floor areas.

On the valley-floor areas, little runoff is generated by either rainfall or snowmelt. Correspondingly, the precipitation is disposed almost entirely to soil infiltration. However, essentially all of the soil infiltration is consumed by the evapotranspiration processes, and little groundwater recharge occurs through soil infiltration on valley-floor areas. Nevertheless, runoff and stream baseflow generated within the mountain-block areas do produce significant groundwater recharge within the valley-floor areas. Streamflows on the alluvial fans also produce streambed infiltration and subsequently groundwater recharge.

4.1.2 Quantification of the Hydrologic System

Figure 4.1-1 shows not only the components of the hydrologic system but also the estimated water flows between components. Furthermore, Figure 4.1-1 assigns each flow letter identifier to help the reader to match the various part of the recharge analysis to the hydrologic system as represented by Figure 4.1-1. The water flows were estimated based on the hydrologic data available for the Antelope Valley and the analysis of the data using empirical relations between the water inflow and outflows for the various components of the hydrologic system. The hydrologic data and the methods used to analyze the data are described in detail in Appendix C; an abbreviated description of that data and the methodology used to derive an estimate of natural groundwater recharge to the groundwater basin in the Antelope Valley Area of Adjudication (AVAA) is as follows.

4.1.2.1 Hydrologic Data

The principal hydrologic data available for the Antelope Valley watershed include precipitation, streamflow, and evapotranspiration data, and those data were compiled for analysis. Long-term precipitation gaging has occurred at 23 sites within or nearby the Antelope Valley watershed as shown on Figure 4.1-2. These stations represent data compiled by the Western Regional Climatic Center (2009) for 1949-2009. Long-term and intermediate-term streamflow gaging has occurred at 18 sites within the watershed as shown on Figure 4.1-3. These stations represent data collected by the U. S. Geological Survey (2009) for 1949-2009. Intermediate-term micro-climatic measurements, which are used to compute potential evapotranspiration, have been made at four sites as shown on Figure 4.1-4. These stations represent data collected through the California Department of Water Resources (2007) California Irrigation Management Information System (CIMIS) program. In addition to the compilation of precipitation, streamflow, and evapotranspiration data, channel-geometry data were collected in the field, and those data were used to estimate streamflow at sites not gaged by the U. S. Geological Survey. The channel-geometry sites are shown on Figure 4.1-5.

4.1.2.2 Analysis of Hydrologic Data

The compiled data were used in several analyses. The precipitation data were used to construct a map showing average annual precipitation over the Antelope Valley watershed. The map was constructed using a two-step process. First, the gaging data were used to identify a relation between the average annual precipitation at a site and the altitude of the site. The resulting relation is shown diagrammatically on Figure 4.1-6, where the relationship range shown on Figure 4.1-6 corresponds to a geographically variable intercept but constant slope, as described in Appendix C. Second, the precipitation-altitude relation was used to transform a map representing topographic contours into a map representing precipitation contours. The resulting map is shown on Figure 4.1-7, which corresponds to flows A_1 and A_2 on Figure 4.1-1. Flow A_1 is the precipitation on areas where the average annual precipitation is greater than 8 inches; flow A_2 is the precipitation on areas where the average annual precipitation is less than or equal to 8 inches. The partitioning is introduced because almost all the precipitation in the dryer partition is consumed by evapotranspiration, and little water yield is produced.

The precipitation map was used in turn to identify runoff-precipitation and total yield-precipitation relations, where the total yield corresponds to flows B, C, and D on Figure 4.1-1. The relations were identified by a calibration to watershed with estimates of average annual streamflow, where the estimates were derived from either stream gaging data or channel-geometry measurements. The runoff relation was identified by a calibration to watersheds for which the streamflow represents only runoff, and the groundwater component of the watershed yield correspondingly is manifested only as subsurface flow (flow C on Figure 4.1-1 equals zero). The yield relation was identified by a calibration to watersheds for which the streamflow represents components of both runoff and groundwater baseflow (flow C is not equal to zero), but the groundwater baseflow represents only part of the overall groundwater component of the total water yield (flow D also is not equal to zero). The resulting relations are shown on Figure 4.1-8. Those relations subsequently were used to estimate the water yield for the entire Antelope Valley watershed. As shown on Figure 4.1-1, the resulting average annual runoff for the watershed is 38,400 acre-ft/yr (flow B), the groundwater discharge to streams is 9,800 acre-ft/yr (flow C), and the groundwater flow from the mountain block to the groundwater basin is 19,800 acre-ft/yr (flow D).

The streamflow data for Big Rock Creek were used to develop a recharge-streamflow relation. The relation was identified by a calibration to the change in streamflow between upstream and downstream streamgaging sites. The sites are located along the creek immediately downstream from the mountain front, and they correspondingly represent the streamflow depletions due to streamflow infiltration. The calibrated relation was used then to estimate the recharge along Big Rock Creek from the most downstream stream gaging site to Rogers Lake. The relation was used also to estimate the streamflow discharge onto the Rogers Lake playa. The results of the estimations were then extrapolated to the entire Antelope Valley watershed. As shown on Figure 4.1-1, the average annual streamflow recharge is 36,600 acre-ft/yr (flow E on Figure 4.1-1), and the average annual streamflow discharge to the Rogers Lake playa is 9,200 acre-ft/yr (flow G on Figure 4.1-1). Both these flows account for the diversions from Little Rock Reservoir, which have averaged about 2,400 acre-ft/yr (flow H), but currently is about 4,000 acre-ft/yr.

4.1.3 Natural Recharge to the Groundwater Basin

The natural recharge to the groundwater basin includes infiltration and deep percolation from stream channels (flow E on Figure 4.1-1) and groundwater flow from the mountain-block to the groundwater basin (flow D on Figure 4.1-1). Together these components represent a total average annual recharge of 56,400 acre-ft/yr, which widely ranges from 6,000 to 230,000 acre-ft in individual years.

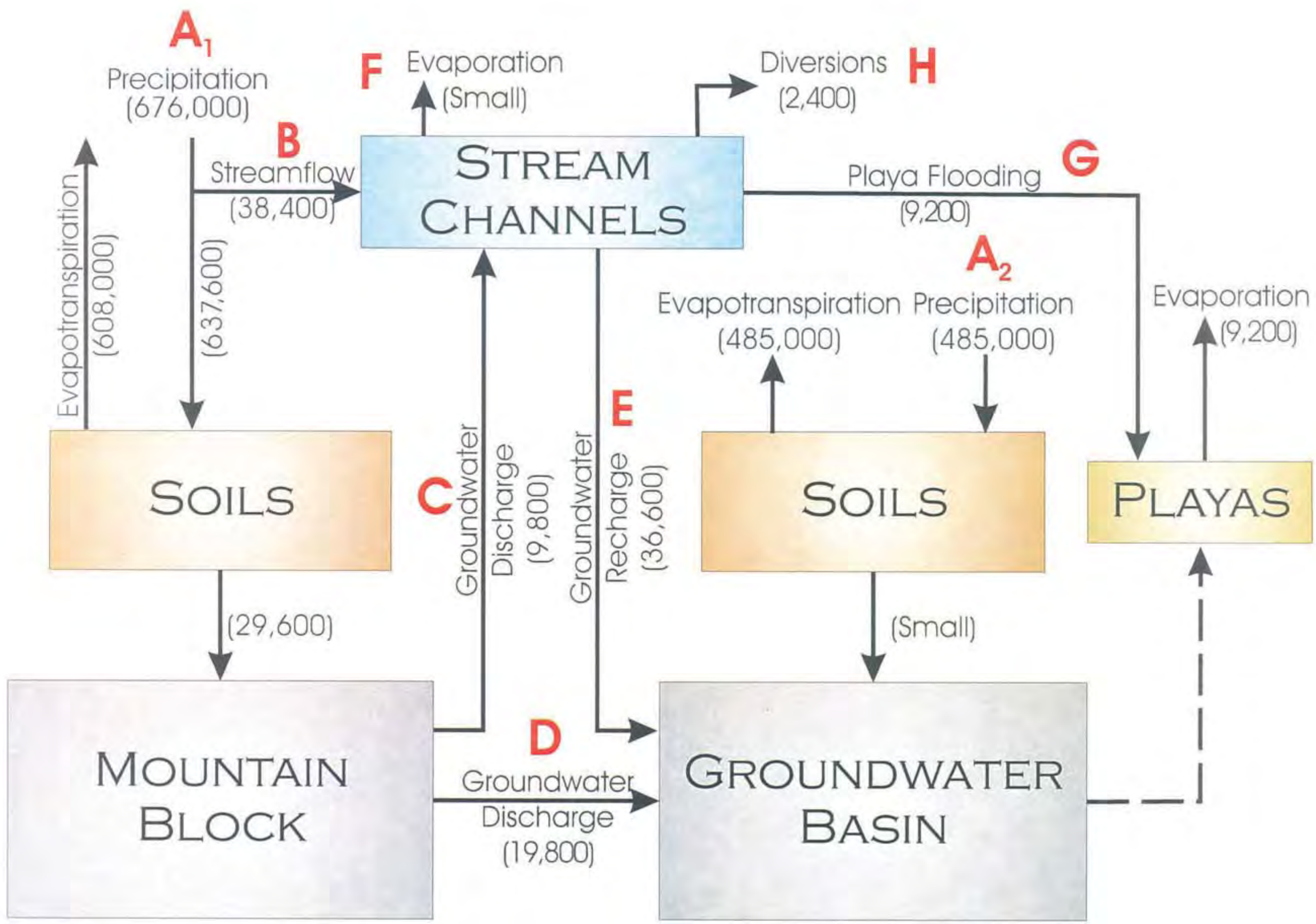

Figure 4.1-1 Average Annual Flows thoughout the Hydrologic System (acre-feet/year)

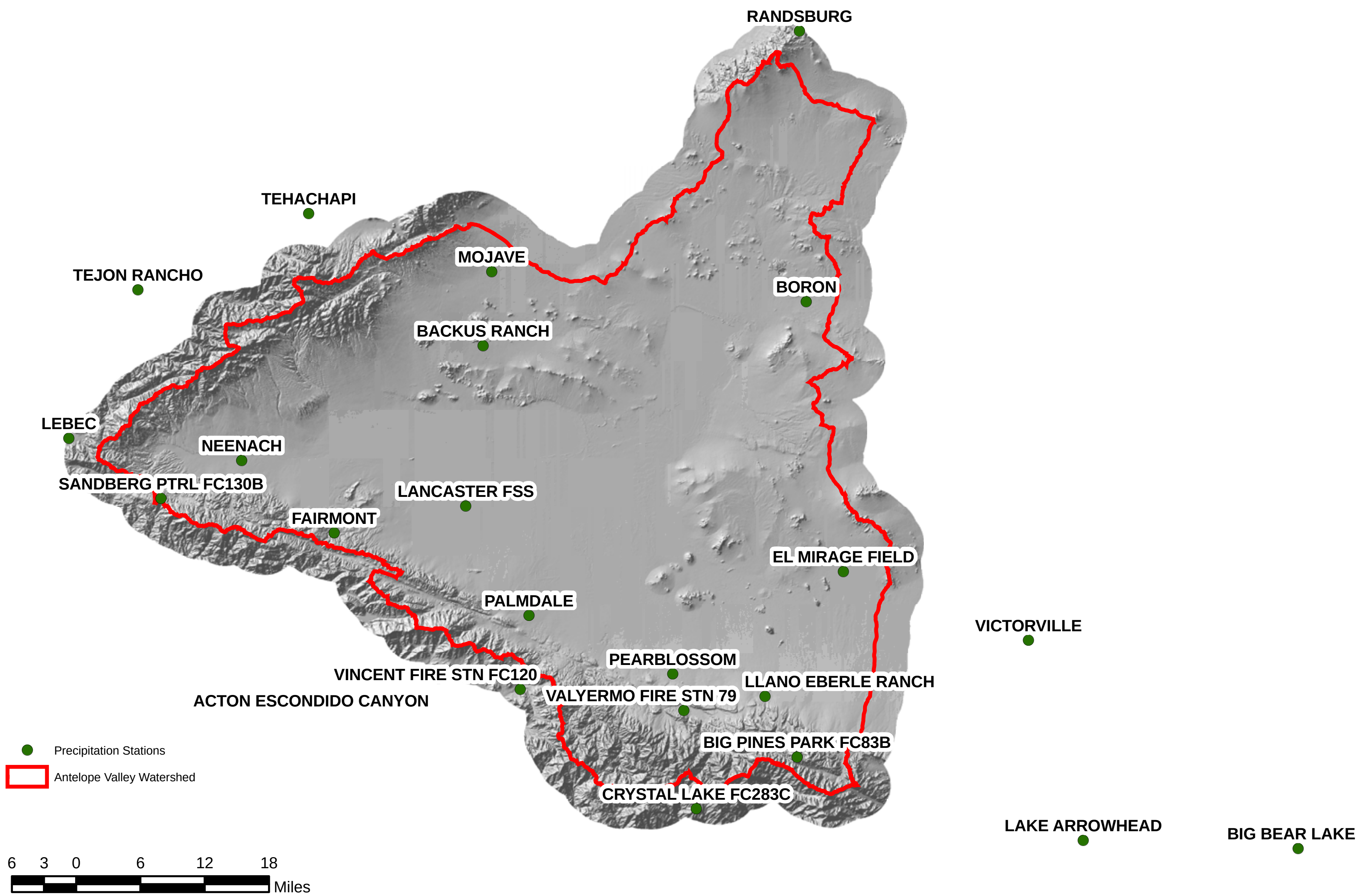

Figure 4.1-2 Precipitation Stations Within and Nearby Antelope Valley

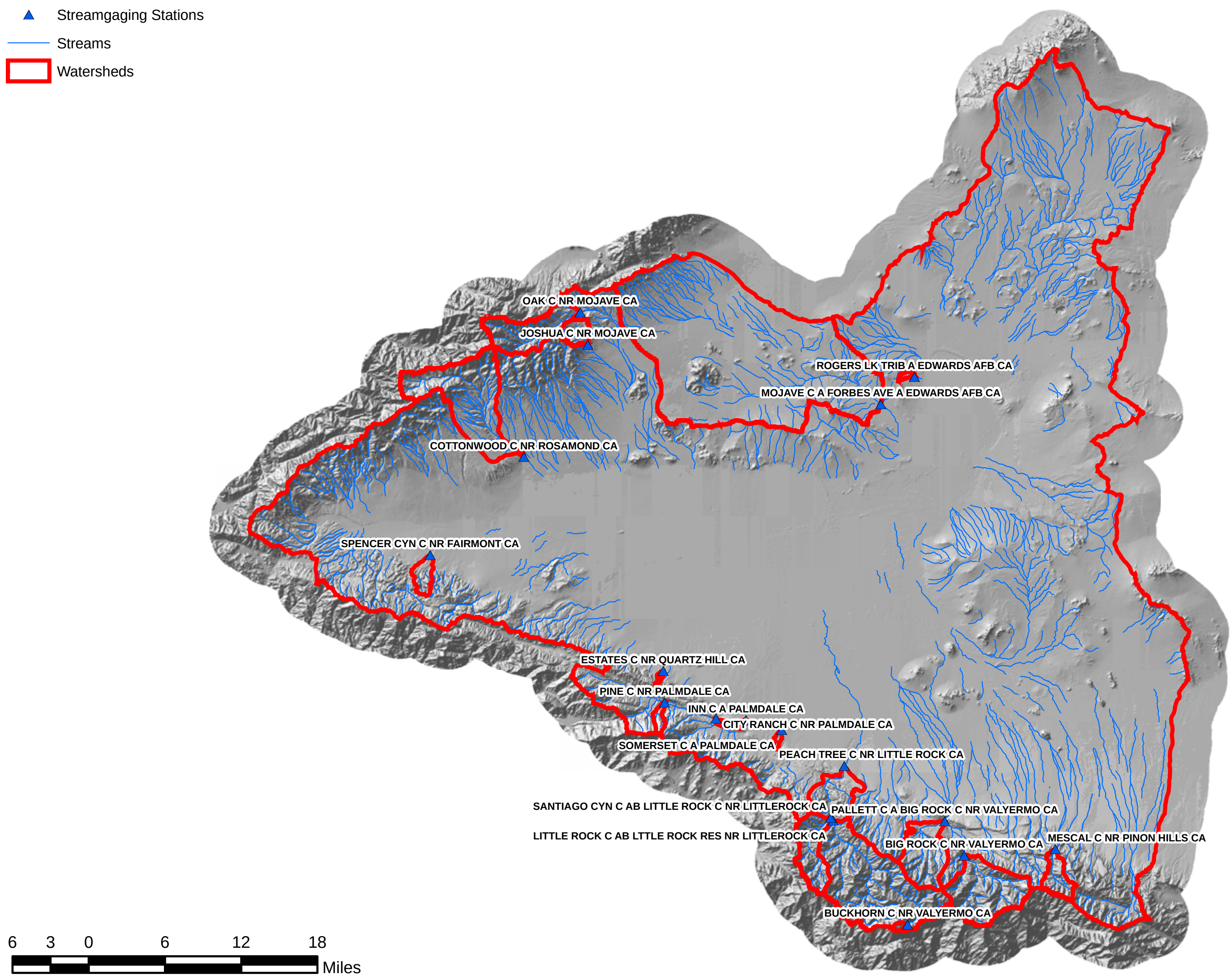

Figure 4.1-3 Locations of Streamgaging Sites

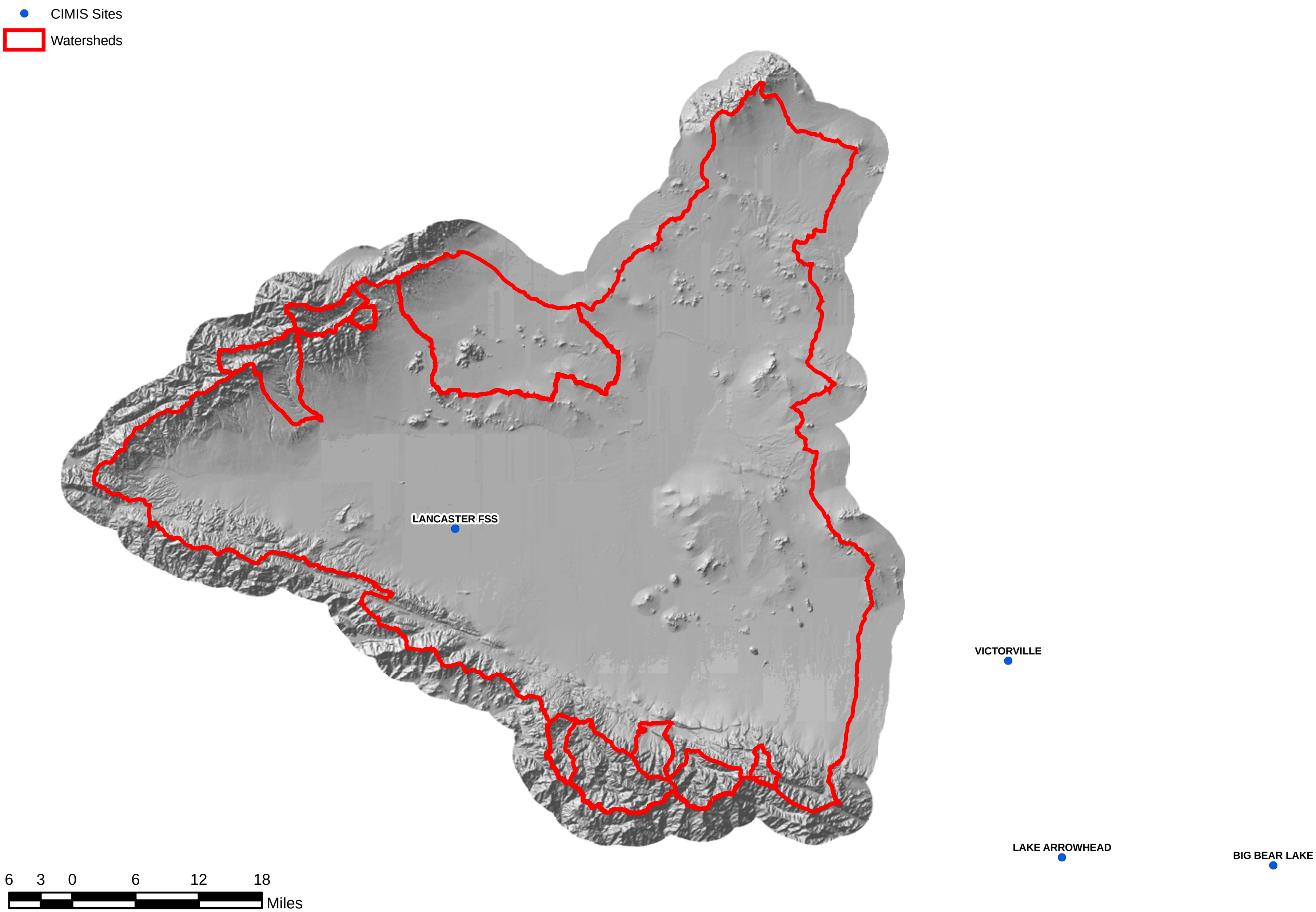

Figure 4.1-4 Locations of CIMIS Sites

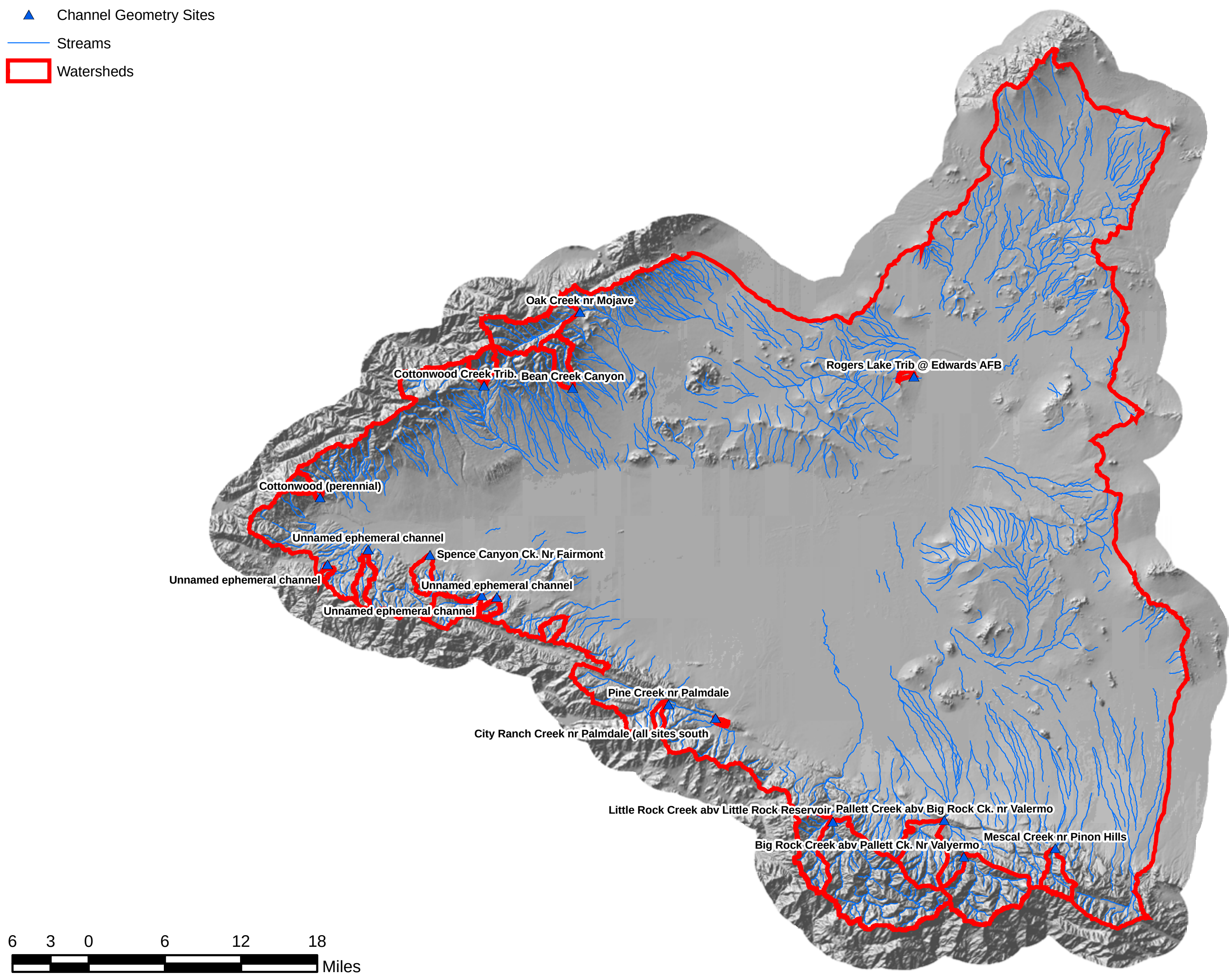

Figure 4.1-5 Locations of Channel-Geometry Sites

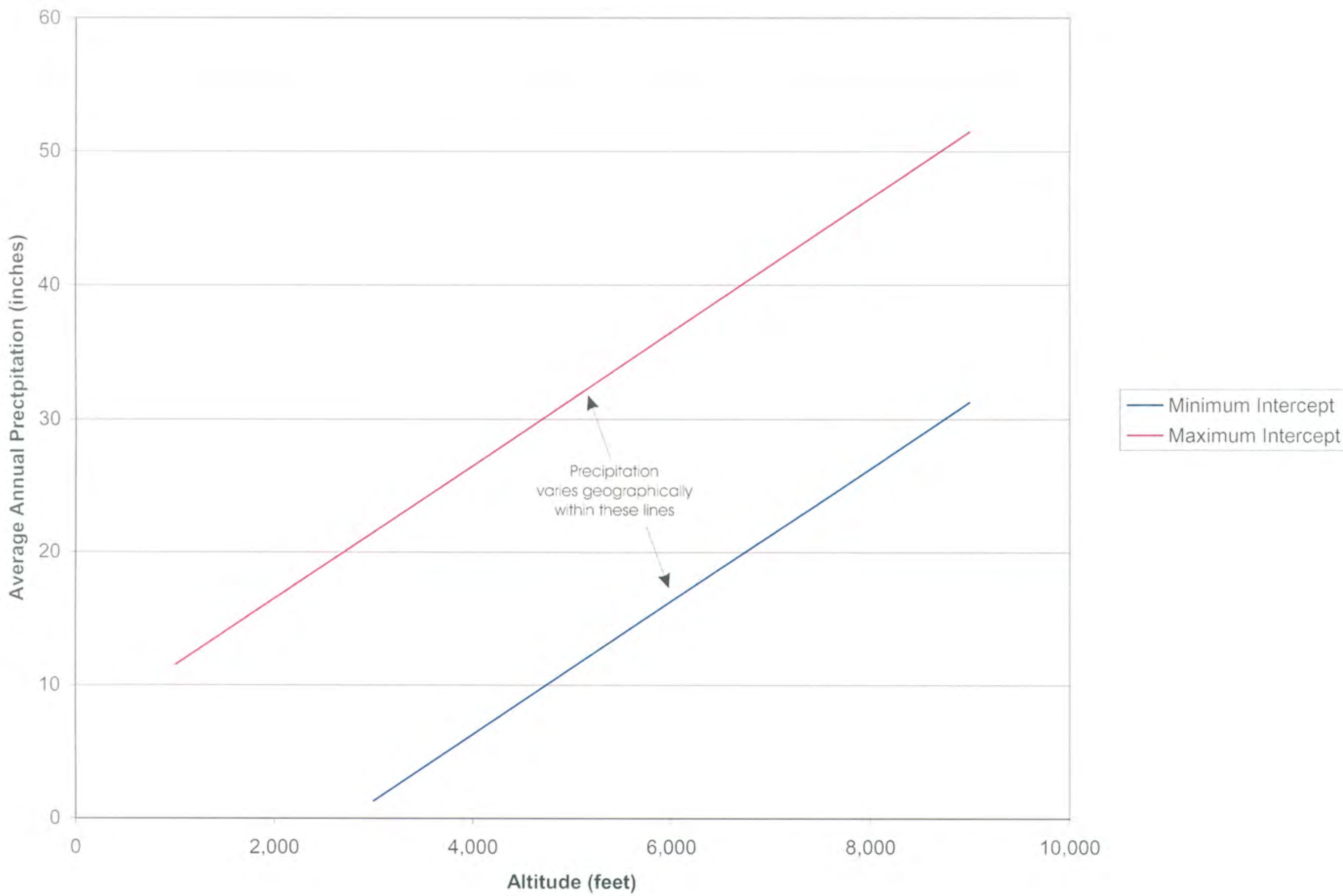

Figure 4.1-6 Precipitation-Altitude Relation

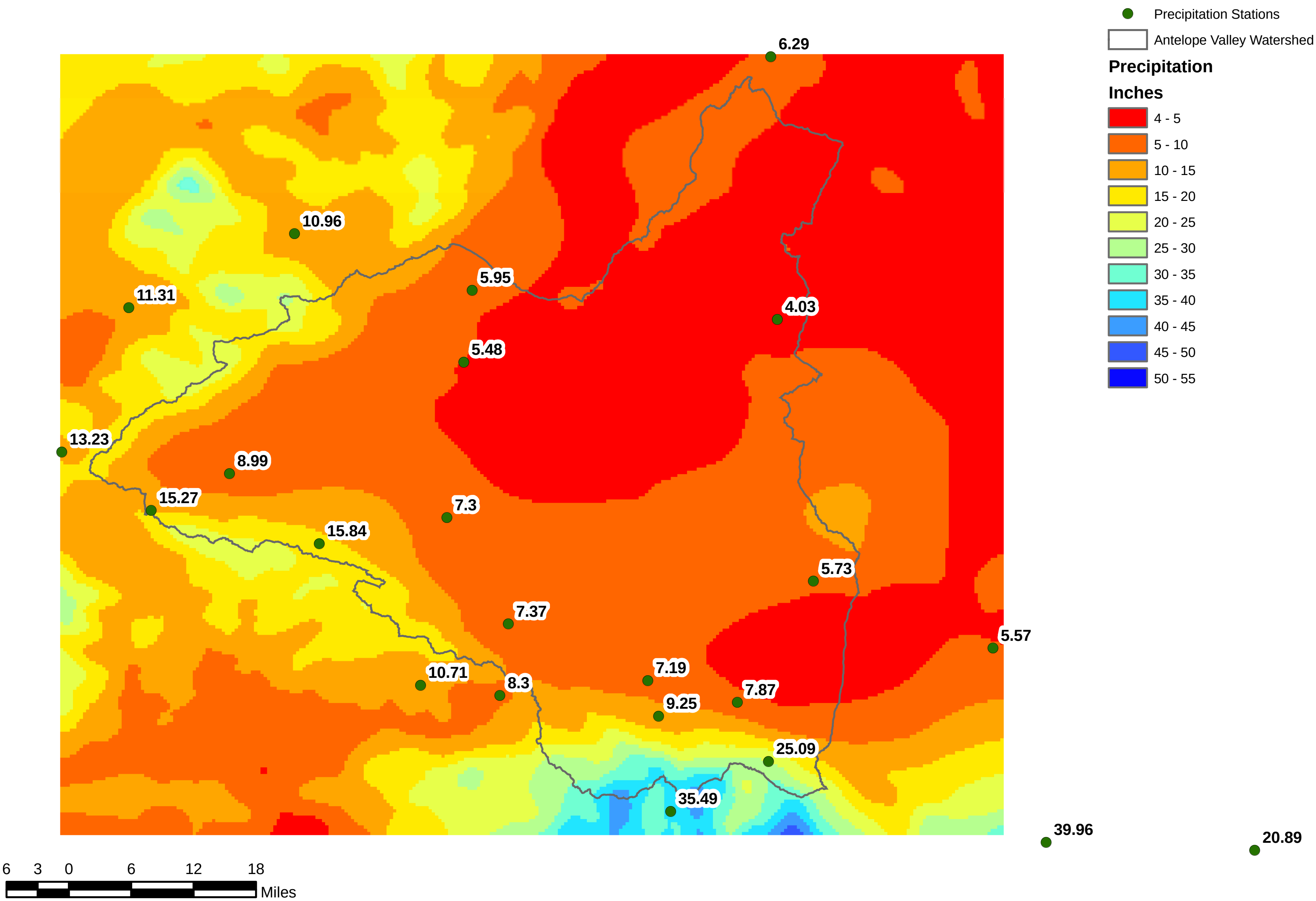

Figure 4.1-7 Geographic Distribution of Average Annual Precipitation Based on Contoured Intercept

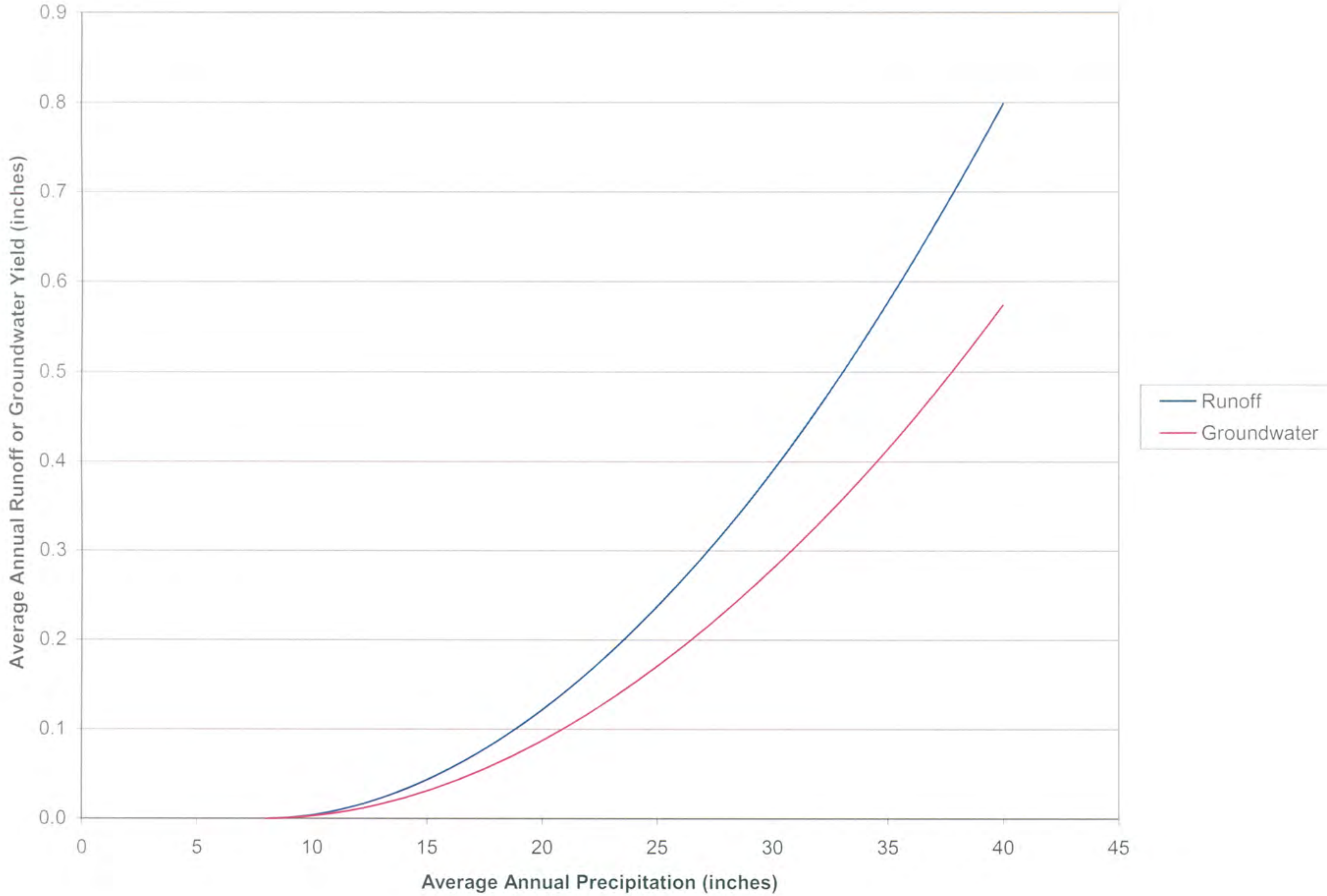

Figure 4.1-8 Runoff-Precipitation and Yield-Precipitation Relations