**EXHIBIT "B"**
**TO DESIGNATION OF EXPERT WITNESS**

**PART 1 OF 4**
**TO EXHIBIT "B"**

# Antelope Valley Groundwater Basin Subbasin Analysis

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# 1.0 Introduction

The groundwaters of the Antelope Valley basin are being adjudicated. Within that context, the question has arisen as to whether subareas of the valley can be treated as separate and independent areas for the purpose of the adjudication. This report describes my opinion regarding that question and the basis of that opinion.

The Antelope Valley groundwater basin (Figures 1.1 and 1.2) functions hydrologically as a single basin, even though the basin often is characterized as being comprised of various subareas or subbasins. The subarea boundaries were defined initially by Thayer (1946) in a report published by the Los Angeles Flood Control District. The boundaries were refined by Bloyd (1967) in a report published by the U. S. Geological Survey. The refined subarea boundaries were adopted in subsequent reports by the U. S. Geological Survey, including the report authored by Durbin (1978). The subareas used by Bloyd (1967), Durbin (1978), and subsequent others are shown on Figure 1.3.

The subarea boundaries defined by Bloyd (1967) are locally coincident with faults that cut through the Antelope Valley groundwater basin. Some faults within the basin are characterized by a groundwater-level differential across the fault, which locally can be several hundred feet or more. The groundwater-level differential results because the fault plane is composed of lower-permeability materials than the aquifer materials cut by the fault. Such a fault is often referred to as a "barrier" to groundwater flow. However, to the extent that the term implies the absence of groundwater flow across a fault, the term is misleading. For a groundwater-flow path across a fault, the volumetric flow of groundwater is undiminished by the fault. A sufficiently large groundwater-level differential occurs across the fault such that volumetric flow is identical on each side of the fault. Where the fault plane is less permeable, the differential required to pass the upgradient flow can be large.

For the Antelope Valley groundwater basin, natural groundwater recharge occurs almost entirely along the fronts of the San Gabriel and Tehachapi mountains. Groundwater flows radially inward from the mountain fronts towards Rosamond Lake, which is located within the Lancaster subarea (Figure 1.3). Groundwater flow into the Lancaster subarea follows paths from the recharge areas through other subareas. For groundwater recharge along the Tehachapi Mountains front, groundwater flows through the northwestern subareas into the Lancaster subarea. For the groundwater recharge along the southeastern part of the San Gabriel Mountain front, groundwater flows through the southeastern subareas into the Lancaster subarea. For predevelopment conditions, part of the groundwater inflow to the Lancaster subarea subsequently flowed into the North Muroc subarea, and that condition might continue. Except for the Oak Creek, Finger Buttes, and Pearland subareas, the groundwater conditions within the subareas are dependent on the groundwater flows from other subareas. Much as for streamflow, groundwater conditions progressively downstream are dependent on the upstream recharge and cumulative upstream water use. The faults that cut through the Antelope Valley groundwater system do not change that dependency.

Groundwater flow across a fault is shown diagrammatically on Figure 1.4. The diagram represents groundwater flow of 100 acre-ft/yr (as an example) from left to right across the diagram. This is the component of groundwater flow perpendicular to the fault, even though a component parallel to the fault usually also exists. The lower permeability of the fault zone results in groundwater-level differential across the fault. However, the flow of 100 acre-ft/yr occurs through the fault and on the downstream side of the fault, which follows directly from the physical law of mass conservation. If the continuity of groundwater flow were not to be maintained across the fault, and the flow immediately downstream was less than the flow immediately upstream, groundwater would perpetually accumulate within the region on the upstream site of the fault. However, that does not occur, because the upstream and downstream flows in actuality are always equal. This is a general concept that applies to faults generally and the Antelope Valley faults particularly.

This report relies in part on the U. S. Geological Survey reports by Bloyd (1967), Durbin (1978), and Leighton and Phillips (200w), which are attached respectively as Appendices A, B, and C. Furthermore, this report includes figures that were modified from the report by Leighton and Phillips (2003). To illustrate particular points in this report, the figures taken from the U. S. Geological Survey have been modified by adding or modifying line work and notations.

# 2.0 Description of the Study Area

## 2.1 Location and General Features

Antelope Valley lies in a westward-pointing wedge formed by the intersection of the San Andreas and Garlock fault zones (Figure 2.1). The valley is bordered on the northwest and north by the Tehachapi Mountains, the Rosamond Hills, and the Bissell Hills; on the southwest and south by the San Gabriel Mountains; and on the east by low hills and divides that separate the valley from upper Mojave, Harper, and Fremont valleys further east. Mountain and foothill land within Antelope Valley covers about 1,200 $mi^2$. Relatively flat valley land covers about 1,000 $mi^2$. The floor of the valley ranges from 2,300 to 3,500 ft above sea level, thus lying at an altitude higher than most of the nearby desert valleys and considerably higher than the coastal plain to the south and the San Joaquin Valley to the north.

Antelope Valley is characterized by interior drainage that terminates at either Rosamond Lake or Rogers Lake playas. Broad alluvial fans extend as much as 15 mi from the base of the mountains and hills that surround Antelope Valley. During extreme runoff events, streamflow debouches from the mountain canyons, flows across the sloping alluvial fans, flows across the flatter valley floor, and accumulates on the Rosamond Lake and Rogers Lake playas.

The Antelope Valley ground-water basin covers about 900 $mi^2$. The basin is divided into ground-water subareas by faults and other structural features. Subdivisions of the Antelope Valley ground-water basin are the Lancaster, Buttes, Pearland, Neenach, West Antelope, Finger Buttes, Willow Springs, Oak Creek (southwestern part) and North Muroc subareas. The names and boundaries of the subareas that were proposed by Bloyd (1967) are used in this report.

## 2.2 Groundwater Geology

The Antelope Valley ground-water basin occupies part of a structural depression that has been downfaulted between the Garlock and San Andreas faults. Consolidated, virtually non-water-bearing rocks crop out in the mountains and hills that surround the ground-water basin (Figure 2.1). These rocks also underlie and form the bottom of the ground-water basin. The consolidated rocks consist of igneous and metamorphic rocks, which form the basement complex of the study area, and of indurated continental rocks that are interbedded with volcanic flows. Water-bearing, mostly unconsolidated deposits that contain sufficient water for economic use overlie the consolidated rocks. The unconsolidated deposits consist of alluvium of Pliocene to Holocene age and of lacustrine deposits of Pleistocene to Holocene age (Dutcher and Worts, 1963), which are interbedded with the alluvium.

### 2.2.1 Alluvium

The alluvium is composed of unconsolidated to moderately indurated, poorly sorted gravel, sand, silt, and clay. Older units of the alluvium are more compacted and indurated, somewhat coarser grained, more weathered, and more poorly sorted than the younger units. The hydraulic conductivity of the alluvium decreases with increasing age (Dutcher and Worts, 1963) and, consequently, with increasing depth.

Dutcher and Worts (1963) identified seven lithographic units within the alluvium. These units are older fan deposits, older alluvium, younger fan deposits, younger alluvium, lakeshore deposits, old wind-blown sand, and dune sand. The older fan deposits comprise old moderately to highly indurated fanglomerate and stream-channel deposits that yield little water to wells. The older alluvium comprises the coarse-grained, weathered, and moderately well-sorted alluvium that underlies the valley areas beneath the younger alluvium. The older alluvium is locally as much as 5,000 ft thick, and these deposits constitute the bulk of the water-bearing deposits in the Antelope Valley ground-water basin. The younger fan deposits commonly are composed of very poorly sorted boulders, gravel, sand, silt, and clay. The younger alluvium is composed predominantly of sand and gravel.

### 2.2.2 Lakebed Deposits

During the depositional history of the Antelope Valley groundwater basin, a large lake occupied parts of the Lancaster and North Muroc subareas. Fine-grained lacustrine deposits formed in this lake.

The depositional environment of the lacustrine deposits has varied (Dutcher and Worts, 1963). During pluvial periods, or times of relatively heavy precipitation, massive beds of blue clay formed in deep, perennial lakes. At least two pluvial periods have been followed by interpluvial periods, during which playa and similar deposits formed in shallow, intermittent lakes. Individual clay beds are locally as much as 100 ft thick. These are interbedded with lenses of coarser material as much as 20 ft thick. The clay yields virtually no water to wells, but interbedded materials supply some water to wells.

During deposition of the lacustrine deposits, alluvial debris that was supplied from the San Gabriel Mountains encroached upon the lake, forcing the south shore of the lake northward, and causing the northward transgression of alluvium over lacustrine deposits. Near the southern limit of the Lancaster subarea, the lacustrine deposits are buried beneath as much as 800 ft of alluvium, but near the northern limit the lacustrine deposits are exposed at the land surface. These deposits underlie the central part of the Lancaster subarea and the southwestern part of the North Muroc subarea. They extend from near Little Buttes on the west to the east edge of Rogers Lake and from near the southern limit of the Lancaster subarea on the south to the north edge of Rogers Lake.

The buried body of lacustrine deposits has a somewhat lenticular shape (Figures 2.1 and 2.2). The thickest section occurs near the center of the Lancaster subarea and the unit thins toward its edges. Near Little Buttes and near the east and north edges of Rogers Lake, the unit thins to extinction. Along the northern and southern boundaries of the Lancaster subarea, the lacustrine deposits terminate against buried escarpments that have formed on the consolidated rocks; the thicknesses along these boundaries are 100 ft and 250 ft, respectively.

### 2.2.3 Principal and Deep Aquifers

Two major aquifers occur within the Antelope Valley ground-water basin: the principal and the deep aquifers (Dutcher and Worts, 1963). The lacustrine deposits separate these aquifers both vertically and horizontally. The principal aquifer, which supplies nearly all water pumped from wells in the Antelope Valley ground-water basin, overlies the lacustrine deposits (pl. 1) and is unconfined. This aquifer extends over the area to the south and west of Rogers Lake and includes the Neenach, West Antelope, Finger Buttes, Buttes, and Pearland subareas and part of the Lancaster subarea. The deep aquifer, in part, underlies the lacustrine deposits. The extent of this aquifer includes the area of the lacustrine deposits and the area east and north of Rogers Lake. This area includes the North Muroc subarea and part of the Lancaster subarea (pl. 1). In the area where the deep aquifer is overlain by the lacustrine deposits, the aquifer is confined; in other areas it is unconfined.

# 3.0 Groundwater Movement

## 3.1 General Features of Groundwater Flow

Ground water in the Antelope Valley ground-water basin moves radially from the base of the San Gabriel and Tehachapi Mountains toward the Rosamond Lake, which is located within the north-central part of the Lancaster subarea (Figure 1.3). As a result of the mountain-front recharge along the base of the Tehachapi Mountains, ground water in the Neenach, West Antelope, Willow Springs, Oak Creek, and Finger Buttes subareas moves into the Lancaster subarea. At the western limit of the lacustrine deposits, part of this water moves over the lacustrine deposits and within the principal aquifer, and part moves under the lacustrine deposits and within the deep aquifer. As a result of the mountain-front recharge along the base of the San Gabriel Mountains, ground water in the Buttes and Pearland subareas also moves into the Lancaster subarea. The upper surface of the lacustrine deposits is below the path of the inflowing water, however, and this water moves into the Lancaster subarea wholly over the top of the lacustrine deposits and within the principal aquifer.

In the Lancaster subarea, subsurface discharge of ground water in the principal aquifer is impeded by consolidated rocks on the east and north and by the lacustrine deposits on the northeast. Before about 1940, ground water in the deep aquifer moved northward out of the Lancaster subarea, under the lacustrine deposits, and into the North Muroc subarea. By 1961, the direction of ground-water movement in the deep aquifer had been reversed in the area underlying and immediately south of Rogers Lake, and the direction of ground-water movement there is now southward toward the center of the Lancaster subarea. Reversal of the direction of ground-water movement in the area south of Rogers Lake was caused for the most part by pumping ground water from the principal aquifer. This pumping also produced significant changes from 1915 to 1961 in water levels in the principal aquifer, especially in the Lancaster subarea. The main change was the development of areas of low water levels near the west and east sides of the Lancaster subarea.

Leakage of ground water between the principal and deep aquifers occurs through the lacustrine deposits. Based on hydraulic heads for the principal and deep aquifers, the direction of leakage is downward from the principal aquifer into the deep aquifer along the western and southern periphery of the lacustrine deposits. In the north-central part of the area underlain by lacustrine deposits, the direction of leakage historically was upward from the deep aquifer into the principal aquifer. Because of pumping of ground water from the principal aquifer, the area in which upward leakage occurs is now more toward the south in the areas of concentrated pumping.

Faults in the Antelope Valley, especially the Randsburg-Mojave and Willow Springs faults, create groundwater-level differentials, which often was the field evidence for identifying the existence of a fault. Water-level differentials of as much as 300 ft occur across the Randsburg-Mojave and Willow Springs faults. Along several other faults that cross the Antelope Valley ground-water basin the water table is several tens of feet higher on the upgradient side of the fault than on the downgradient side. The studies of faults near Long Beach, Calif., by Poland, Piper, and others (1956) and near San Bernardino, Calif., by Dutcher and Garrett (1963) indicate that some possible causes of the barrier effect along faults cutting alluvial deposits are (1) local and incomplete offsetting of sand beds against clay beds; (2) sharp local folding of beds near the faults, causing relatively impermeable clay beds to be turned across the direction of ground-water movement; (3) cementation of gravel and sand beds immediately adjacent to the fault by deposition of carbonate minerals from water moving along the fault plane; and (4) development of secondary clayey gouge zones along the faults.

## 3.2 Groundwater Flow within the Northwestern Antelope Valley

Groundwater flow within the northwestern part of Antelope Valley is southeastward. The principal source of the flow is the groundwater recharge along the Tehachapi mountain front, and that mountain-front recharge occurs mostly within the Finger Buttes and Oak Creek subareas. Groundwater flows southeastward from the Oak Creek subarea into the Willow Springs and Finger Buttes subareas. Likewise, groundwater flow flows from the Finger Buttes into the West Antelope and Neenach subareas. Next, groundwater flows from the West Antelope, Finger Buttes, and Willow Springs subareas into the Neenach subarea. Finally, groundwater flows from the Neenach subarea into the Lancaster subarea. These interconnections are shown diagrammatically on Figure 3.1.

The groundwater flow into the Neenach subarea equals the groundwater flow across the Randsburg-Mojave and Willow Springs faults, and the groundwater flow into the Lancaster subarea equals the groundwater flow across the Neenach fault. Furthermore, for natural conditions, the volumetric groundwater flow across the Randsburg-Mojave and Willow Springs represents the entire recharge along the Tehachapi Mountain front. Likewise, the volumetric groundwater flow across the Neenach fault represents the entire recharge along the Tehachapi Mountain front. This follows from the physical law of mass conservation: what goes in must come out, for steady-state conditions. The recharge within the Finger Buttes and Oak Creek subareas all crosses the Randsburg-Mojave and Willow Springs faults, and then it all crosses the Neenach fault. Because the Randsburg-Mojave and Willow Springs faults each cut entirely across the Antelope Valley groundwater basin, all the recharge occurring west of these faults necessarily must flow eastward in entirety across the faults. These flow paths are shown on Figure 3.2 for 1915 (pre-development conditions) and on Figure 3.3 for 1996 conditions.

Significant groundwater-level differentials occur across the Randsburg-Mojave and Willow Springs faults, and smaller differentials occur across the other faults within the northwestern part of Antelope Valley. However, for natural conditions, those faults allow the transmittal of all the recharge from the Tehachapi Mountains into Lancaster subarea. The faults are not barriers to groundwater flow.

## 3.3 Groundwater Flow within the Southeastern Antelope Valley

Groundwater flow within the southeastern part of Antelope Valley is northwestward. The principal source of the flow is the groundwater recharge along the San Gabriel Mountain front, and that mountain-front recharge occurs mostly within the Pearland subarea. Groundwater flows northwestward from the Pearland subarea into the Buttes and Lancaster subareas. Likewise, groundwater flows from the Butte subarea into the Lancaster subarea. These interconnections are shown on Figure 3.2.

Within the southeastern part of Antelope Valley, the groundwater flow into the Lancaster subarea equals the groundwater flow across the northeast trending unnamed fault that forms the southeast boundary of the Lancaster subarea. For natural conditions, the volumetric groundwater flow across the unnamed fault equals the recharge from the San Gabriel Mountain front adjacent to the Pearland subarea. This again follows from the physical law of mass conservation: what goes in must come out, for steady-state conditions. These flow paths are shown on Figure 3.2 for 1915 (pre-development conditions) and on Figure 3.3 for 1996 conditions.

Groundwater-level differentials occur across the faults within the southeastern part of Antelope Valley. However, for natural conditions, those faults allow the transmittal of all the recharge from the Tehachapi Mountains into the Lancaster subarea. The faults are not barriers to groundwater flow.

## 3.4 Groundwater Flow within the Northeastern Antelope Valley

For natural conditions the direction of groundwater flow within the northeastern part of Antelope Valley was northeastward. Groundwater flowed from the Lancaster subarea into the North Muroc subarea. However, groundwater pumping within the Lancaster subarea has reversed the groundwater-flow direction. These flow paths are shown on Figure 3.2 for 1915 (pre-development conditions) and on Figure 3.3 for 1996 conditions.

# 4.0 Conclusions

The Antelope Valley groundwater basin represents a single hydrologic system. While the basin has been described in terms of subareas based on groundwater-level differentials across faults, significant groundwater flow occurs across the subarea-bounding faults. For natural conditions, all of the recharge from the Tehachapi Mountains crossed the faults within the northwestern part of Antelope Valley to eventually enter the Lancaster subarea. Likewise, all of the recharge from the southeastern part of the San Gabriel Mountains crossed the faults within that region to eventually enter the Lancaster subarea. Throughout Antelope Valley, the inflow to an upstream subarea represents the inflows to the downstream subareas. Even though groundwater-level differentials occur across faults, the volumetric groundwater flow on the upstream side of faults equals the downstream groundwater flow. For current groundwater conditions, these principles apply, with the exception that the inflows to the Lancaster subbaisn are depleted by the groundwater usage and storage effects within the upstream subareas.

If the Antelope Valley groundwater basin were to be considered in the adjudication as consisting of separate subbasins, significant difficulties arise in assessing whether a particular subbasin is in overdraft. Overdraft typically would be based on examining the water budget for the subbasin; by comparing the inflows to the outflows. The water budget for a subbasin has as its inflows the local recharge and groundwater flows from upstream subareas. The budget has outflows on net pumping (pumping less returns) and groundwater flows to downstream subareas. If the long-term outflows exceed the long-term inflows, an overdraft exists. However, whether a particular basin is in overdraft depends on the ultimate adjudicated obligations to pass groundwater flows to downstream basins. Furthermore, it depends on the adjudicated obligations of upstream subbasins to pass groundwater flows to the subject subbasin. Correspondingly, the question of whether overdraft exists within individual subbasins cannot be answered without first adjudicating the inter-subbasin obligations, which suggests that the overall groundwater basin should not be treated as individual subbasins.

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**Figure 1.1 Location of Antelope Valley**

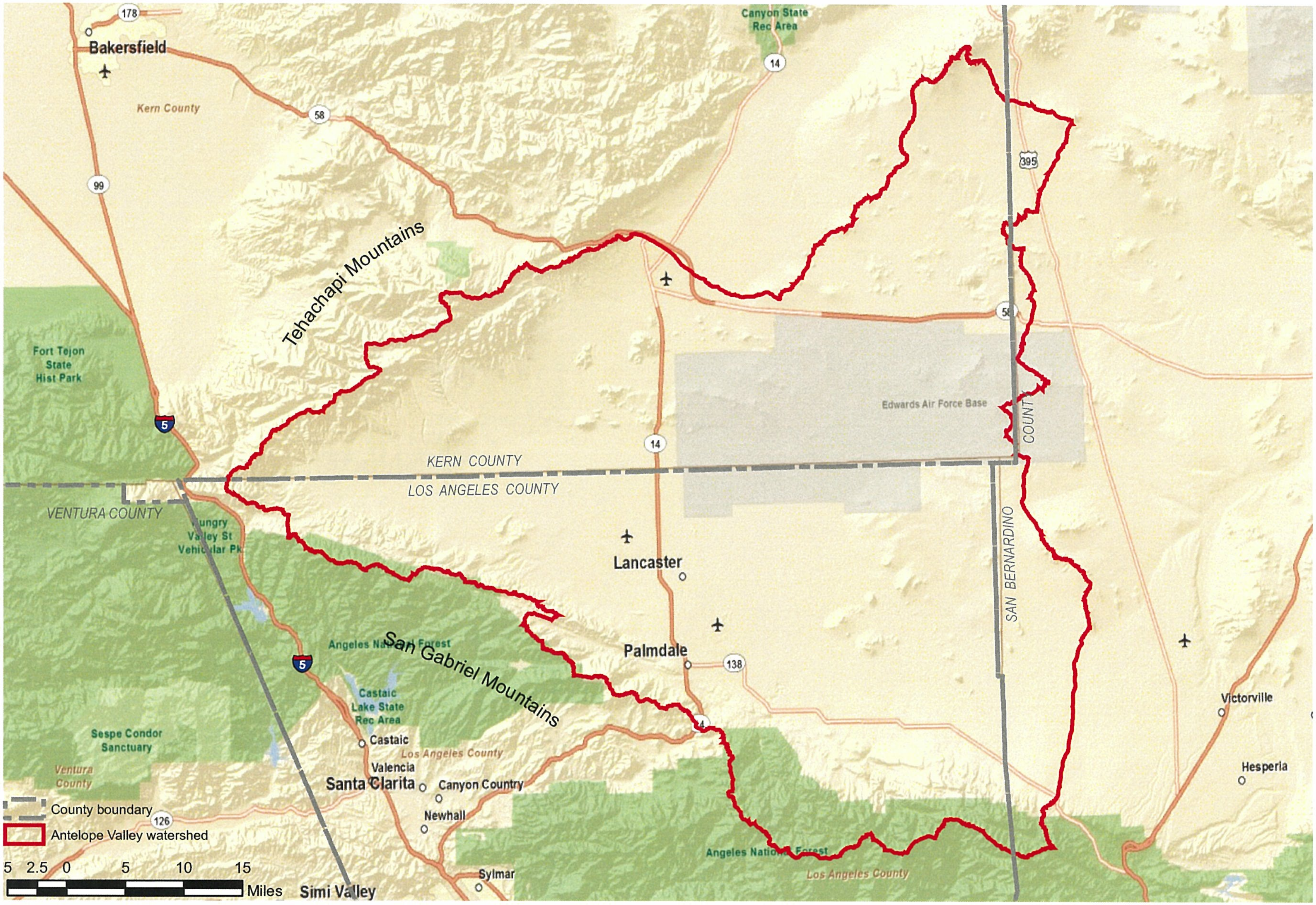


**Figure 1.2 Features within and Nearby Antelope Valley**

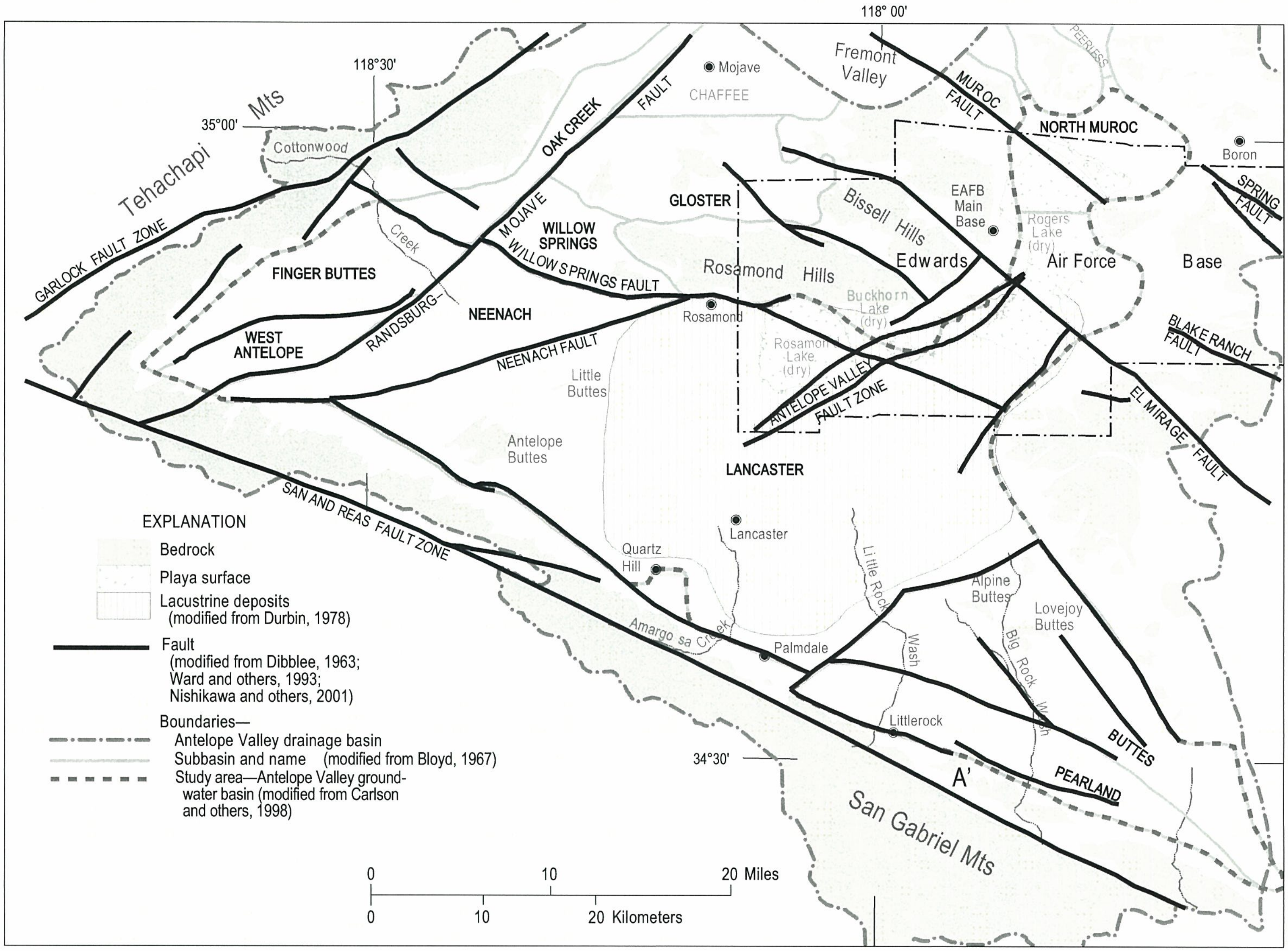


**Figure 1.3 Groundwater Subareas within Antelope Valley**

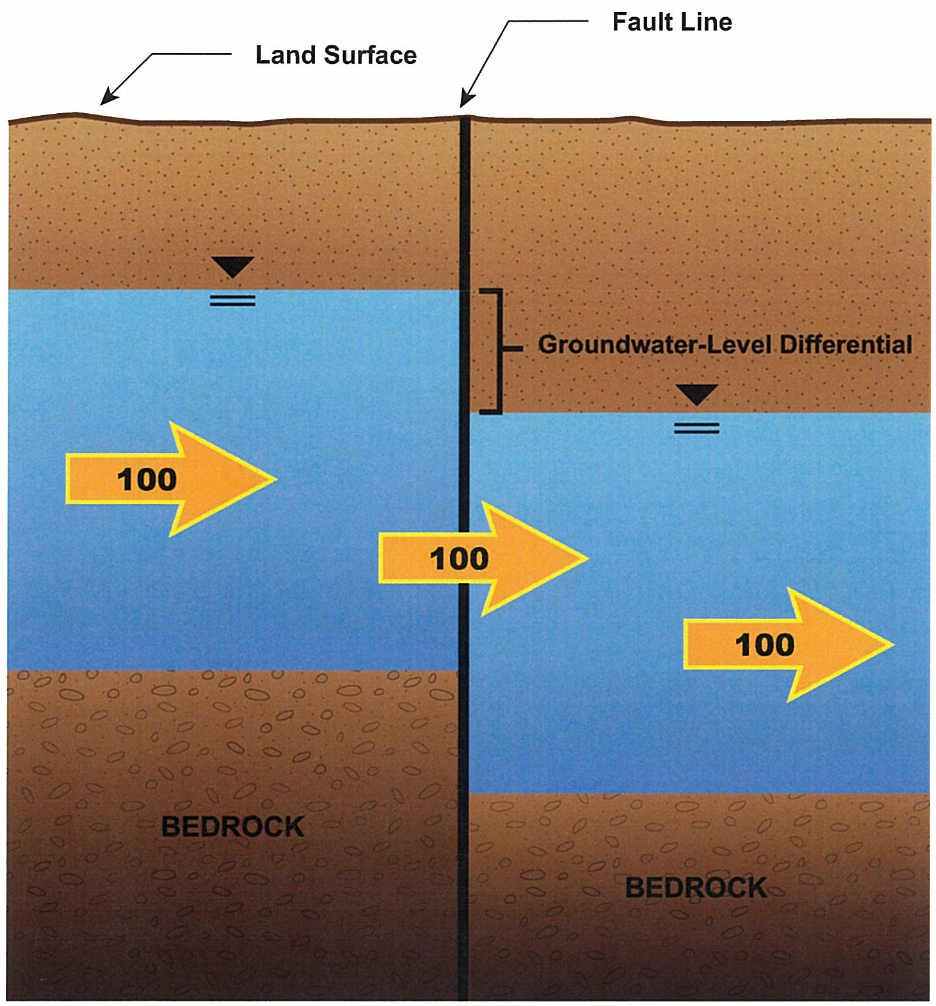


**Figure 1.4 Groundwater Flow Across Fault**

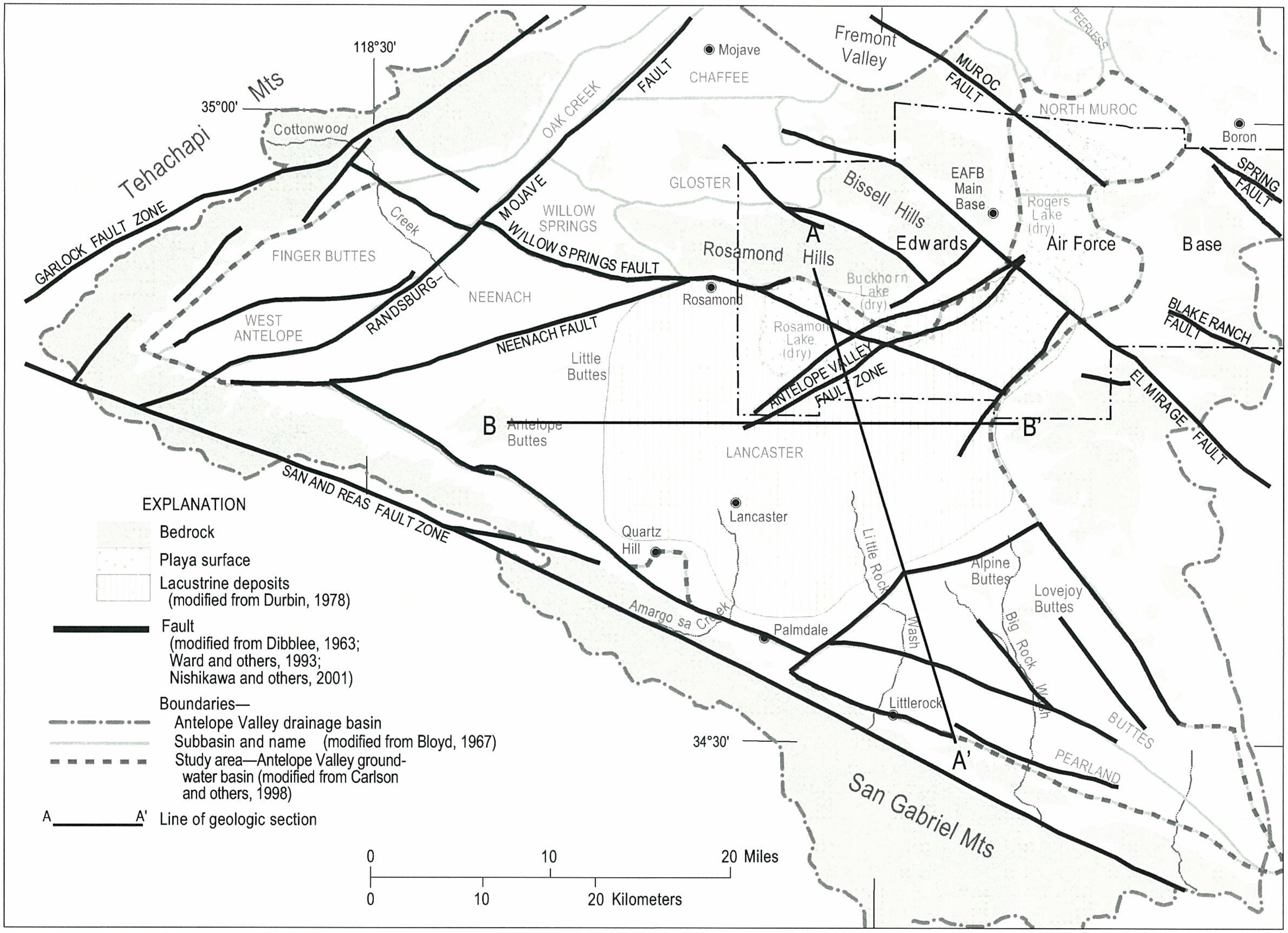


**Figure 2.1** Hydrogeology

**Figure 2.1 Hydrogeology of Antelope Valley study area**

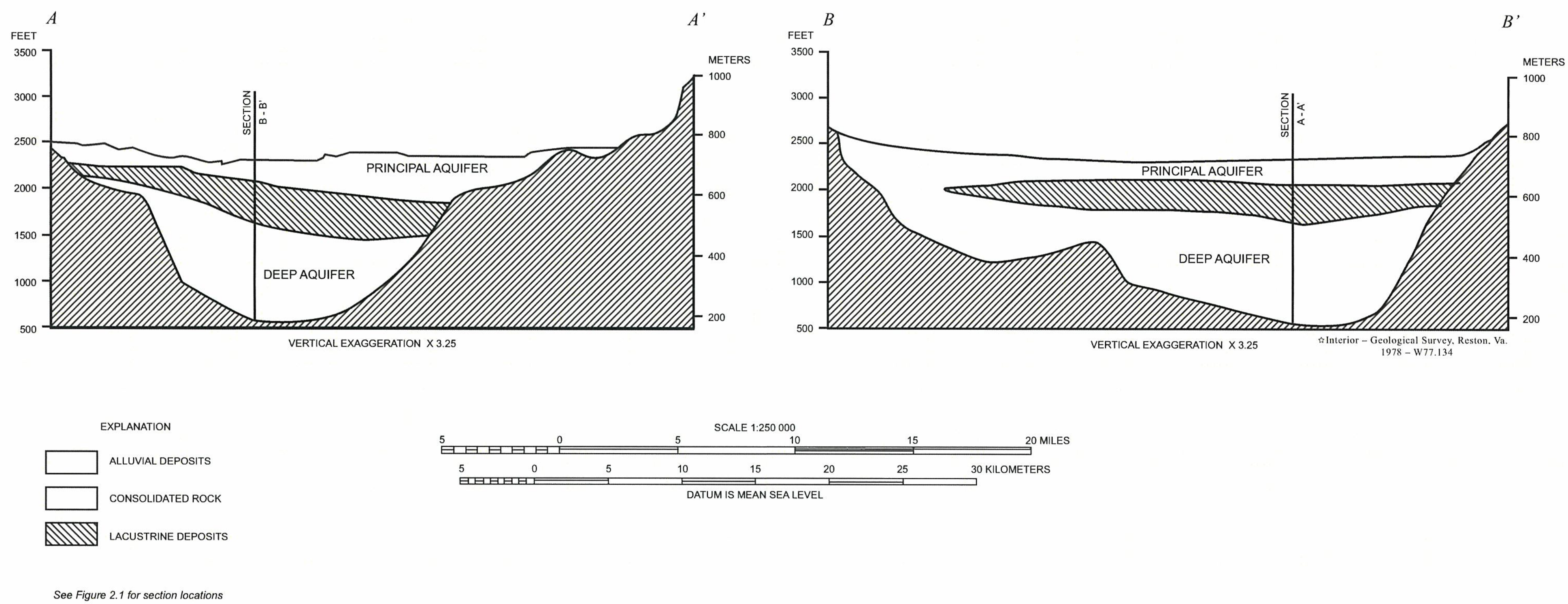


**Figure 2.2 Cross Sections through Antelope Valley Groundwater Basin**

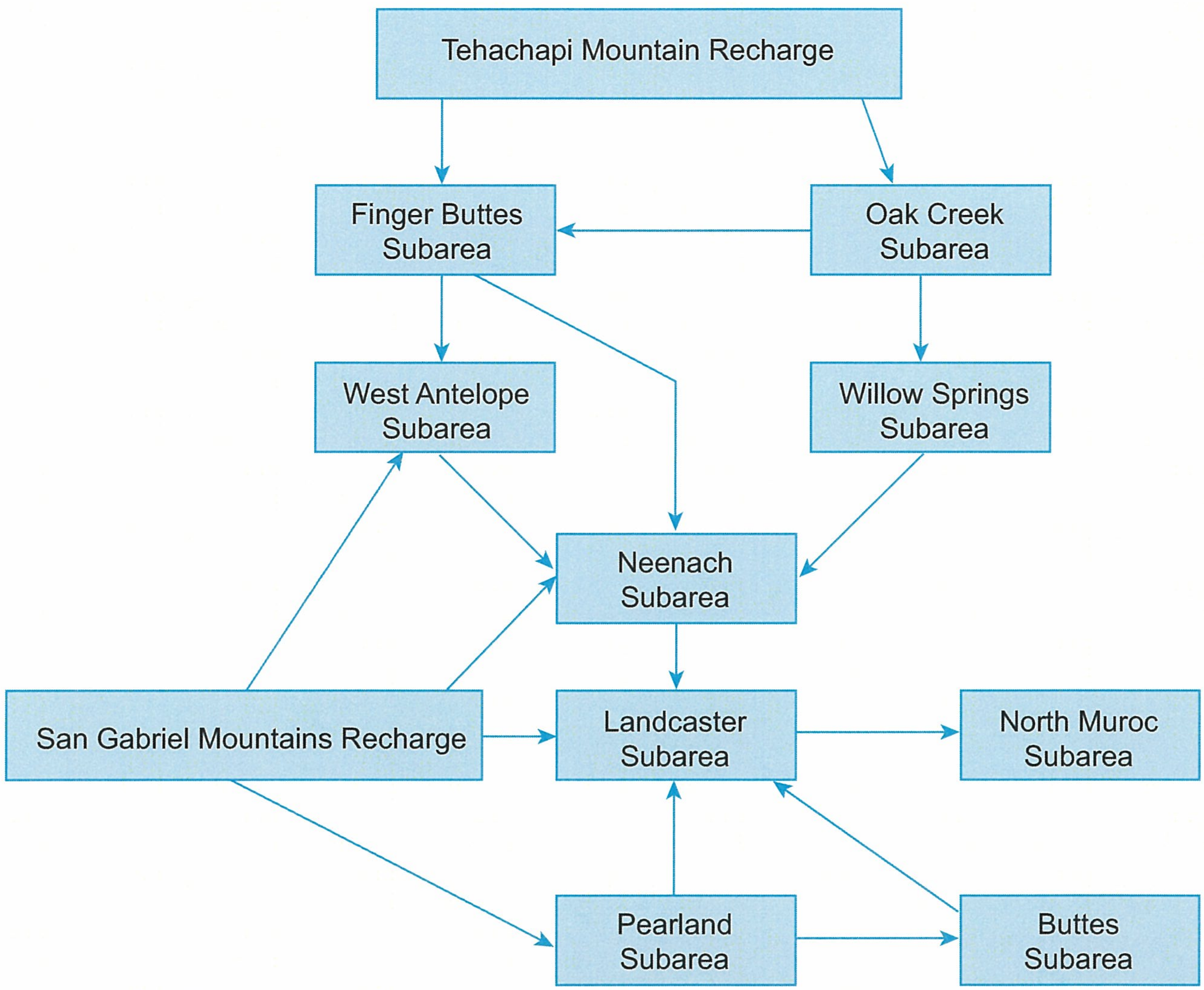


**Figure 3.1 Groundwater flow between subareas within Antelope Valley**

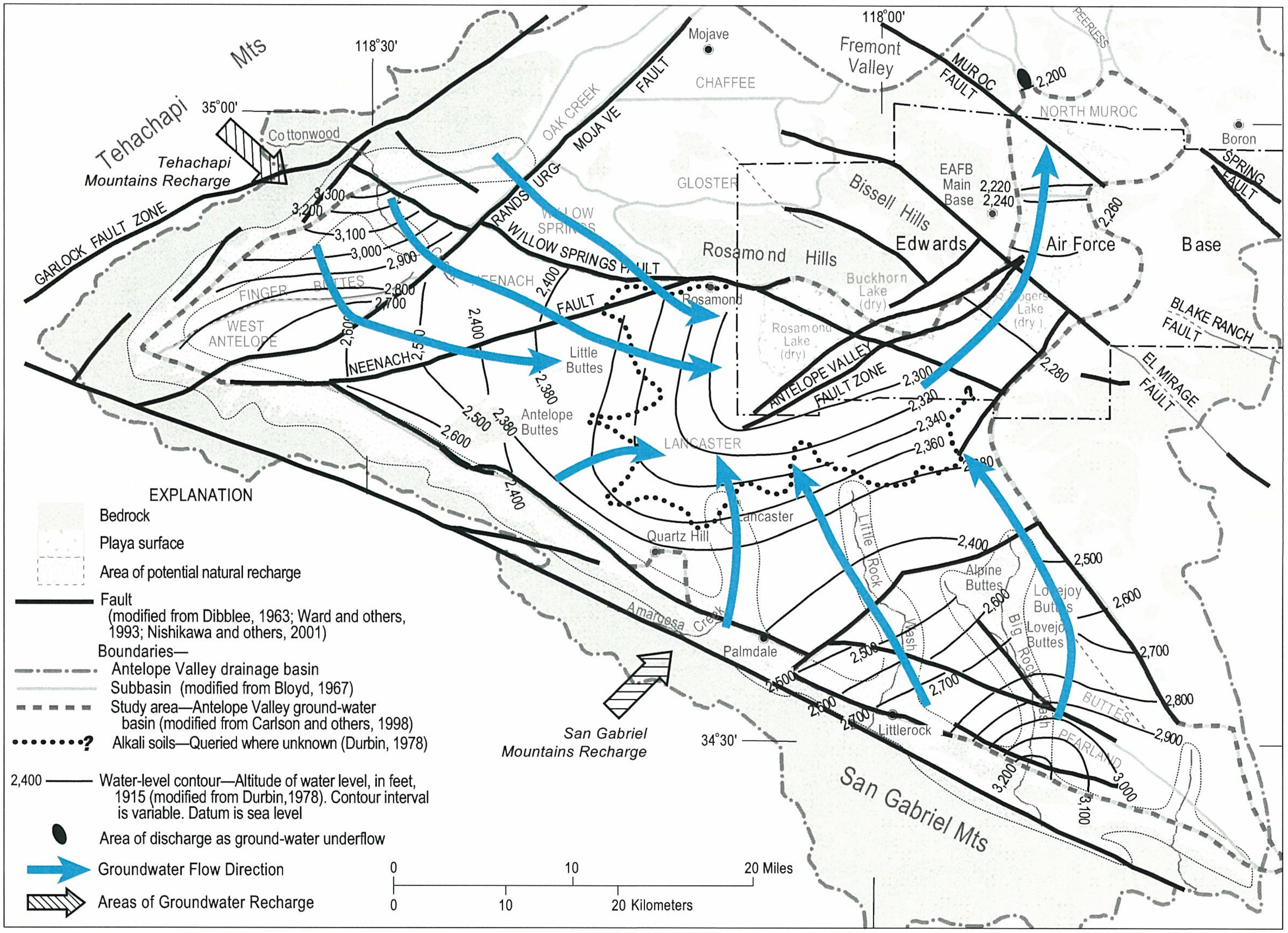


**Figure 3.2 Groundwater levels in groundwater-flow directions in 1915**

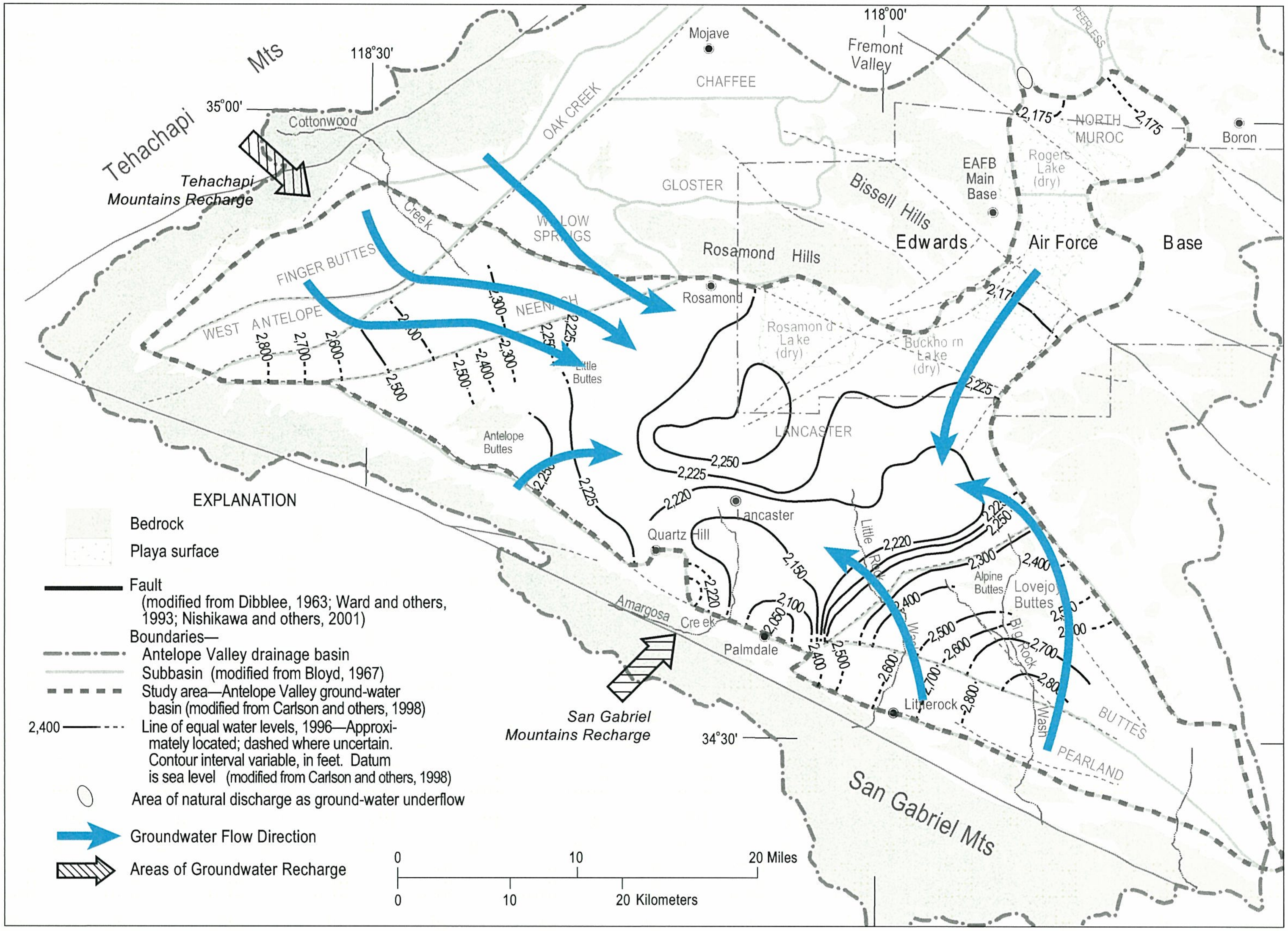


**Figure 3.3 Groundwater Levels and Groundwater-Flow Directions in 1996**