4.2 Land Use, Water Requirements and Water Supplies

As part of describing overall historical and current water resource conditions, land uses and associated water requirements were analyzed, most notably for agricultural and municipal-type uses but also including rural residential and small private water uses. The sources of water supply that have been developed to meet those various uses were also identified and analyzed to develop a history of the use of those supplies, which include groundwater, local surface water, imported supplemental surface water, and recycled water. Following is a summary discussion of land uses, water requirements and water supplies in the AVAA; more thorough details, and supporting tables and figures, are presented in Appendix D.

4.2.1 Land Uses

While a focus of this overall Summary Report on Basin Conditions is to describe historical and projected water requirements and water supplies, a fair amount of water requirement analysis derives from interpretation of water use data related to respective land uses; thus, the following summary of land uses is presented as a basis for the subsequent discussion of water requirements.

There are generally four land uses with which water requirements can be associated in the AVAA: agricultural, municipal and industrial (M&I, including mutual water companies and military), rural residential, and environmental/open space (artificial lakes). While rural residential land use, and associated water requirements, might be relatively insignificant in many settings, there are numerous developed rural parcels in the AVAA which, in aggregate, logically represent a notable water requirement. Consequently, they are accounted herein; however, since rural residential water use is similar in nature to individual water use in municipal areas, it is grouped with municipal and industrial use herein.

Agricultural land use is reported to have begun with dry-farming of about 4,000 to 5,000 acres of grain in the western end of the Valley in the late 1800’s, but those efforts were abandoned during a prolonged drought from 1894 to 1905. Agricultural recovery began around 1910, when rainfall was normal and groundwater was initially developed to augment local surface water for irrigation. Beginning with about 5,000 acres of alfalfa and orchards, agriculture expanded into areas where farming continues to be practiced today. Total land in agricultural production progressively increased, except for a decline through the Great Depression, to about 55,000 acres by 1950 as illustrated in Figure 4.2-1.

For most of the next 30 years, some 55,000 to 60,000 acres remained in agricultural production, dominated by alfalfa but with stable acreages of truck, field, and deciduous (orchard) crops and a noteworthy increase in grain crops, as illustrated in Figure 4.2-2. Changes in the spatial distribution of total cropped areas are periodically illustrated in Appendix D. From the mid to late-1970’s through the 1980’s, agricultural land use significantly declined, to about 12,000 acres by 1990-91. On the declining total farmed area, cropping patterns changed as well, as also illustrated on Figure 4.2-2. Through the decade of the 1990's, agricultural land use progressively increased, by more than double, to about 28,000 acres; since 2000, agricultural land use was in a range of about 25,000 to 28,000 acres through 2005, and slightly declined into a range of about 23,000 to nearly 26,000 acres through 2009. The recent period of generally stable agricultural land use has been marked by somewhat constant alfalfa farming but significantly increased truck cropping (Figure 4.2-2).

Municipal land use in the Antelope Valley began with initial settlements that were small, generally established to promote agricultural development, and therefore scattered along the southwestern flanks of the Valley near known sources of surface water for irrigation and domestic supply. The settlements were established in the mid- to late-1800s and included towns still present today, such as Littlerock, as well as many barely or no longer in existence such as Almondale, Harold, Del Sur, Manzana, and Neenach. With the completion of railroad lines to service other portions of the Valley in the late-1800s, towns such as Palmdale and in particular Lancaster eventually grew into the primary population centers. The establishment of Muroc Army Air Field (today's Edwards AFB) in 1933 and the development of the aerospace industry at the Air Force's Plant 42 facility following World War II also contributed to growth in the Antelope Valley.

Since the 1940's, when the town of Lancaster was the largest and essentially only urban center, with a reported population of less than 4,000 people, the total population and extent of urban development in the Valley have continually grown. From 1950 to 1970, the Valley's population is reported to have grown from around 3,600 to over 70,000, as illustrated in Figure 4.2-3. In 1970, the City of Palmdale and towns like Quartz Hill, Rosamond, and Littlerock were still quite small, and it wasn't until the late 1980s that a marked increase in total population occurred, specifically from about 85,000 in 1980 to over 206,000 in 1990. Further, the population in the City of Palmdale had grown sufficiently to approach that of Lancaster and, by the year 2000, the two cities each had a population approaching 120,000. Presently, the AVAA has a total population of over 300,000 with Lancaster and Palmdale having by far the greatest populations of any urban center in the AVAA (about 145,000 to 150,000 each). In contrast, Quartz Hill, Rosamond, Littlerock, and North Edwards, the developments of Desert View Highlands and Lake Los Angeles, as well as the Edwards AFB, each has a population of about 15,000 or less.

The combined populations of the *mutual and private water companies* in the AVAA are estimated to be around 12,000. While there is no readily available record of *rural residential* population in the AVAA, available data from Los Angeles and Kern Counties indicate that slightly more than 7,000 improved parcels are located throughout the AVAA, outside the service areas of municipal water purveyors or smaller mutual or other private water companies.

Two *environmental/open space areas* in the AVAA are recognized as having water requirements separate from those associated with M&I or agricultural land use, specifically the Paiute Ponds wetlands and Apollo Lakes Park impoundments. The Paiute Ponds were originally created in 1961 with the construction of a dike across Amargosa Creek to prevent its overflow into Rosamond Dry Lake. Currently, the Paiute Ponds wetlands occupy an area of 400 acres, and consist of five main ponds and an extensive marshland area. Within the wetlands, a minimum of 200 acres is to be maintained as marsh-type habitat according to a three-party Letter of Agreement between the Los Angeles County Sanitation District 14, the California Dept. of Fish and Game, and Edwards AFB. The ponds include a series of impoundments occupying an additional 90 acres for duck hunting built by Ducks Unlimited and Edwards AFB in 1991.

The recreational impoundments at the Apollo Lakes Park occupy a collective area of about 40 acres, and they first received deliveries of recycled (currently tertiary-treated) water from the Lancaster WRP in 1972.

4.2.2 Water Requirements

Water requirements in the AVAA are primarily related to the land uses described above, combined for purposes of this overall assessment into three categories: agricultural, municipal and industrial (M&I, including municipal-type uses by mutual water companies, military facilities, and rural residential), and environmental/open space (artificial lakes). The predominant historical water requirements have been for agriculture and municipal uses.

Historical agricultural water requirements for 1920 to 2006 were determined by compiling previously reported estimates for the period 1920 to 1950 and estimating the water demand for the period thereafter as detailed in Appendix D. Historical M&I water requirements for 1946 to 2006 were established by compiling reported annual water use data (from 1946 to 1995) and water use records (through 2009) for the public water purveyors, and by estimating the municipal-type water demand of mutual and private water companies, and rural residential land use (1946 to 2009). All available environmental water use data from the Los Angeles County Sanitation Districts were compiled for the period through 2009.

Total historical water requirements in the AVAA, consisting of agricultural, M&I, and environmental water uses, are illustrated in Figure 4.2-4. The total water requirements have varied greatly throughout the historical period, primarily affected by agricultural water use. During the period of agricultural expansion through 1950, the AVAA experienced the greatest increase in water requirements from early development to nearly 360,000 afy. Agricultural water demand comprised the vast majority of the total requirements through that period, increasing to nearly 350,000 afy by 1950. At that time, M&I use was about 10,000 afy. During the period of peak agricultural activity through the early 1970s, total water requirements remained high, between about 300,000 and 370,000 afy. Through that period, agricultural water use was slightly declining, and M&I water requirements were gradually increasing, from about 10,000 to 30,000 afy.

With the subsequent significant decline in agricultural activity through the early 1990s, total water requirements substantially decreased, from approximately 300,000 to about 150,000 afy, primarily as a result of the substantial decline in agricultural water demand from about 260,000 to about 70,000 afy. During the latter half of that period of agricultural decline, M&I water requirements increased from about 30,000 afy to about the same as the agricultural water demand, about 70,000 afy, by 1990. Both agricultural and M&I water requirements increased at comparable rates throughout the 1990s; by 2000, total water requirements, by then including a small amount for environmental uses, had increased to approximately 255,000 afy. Since 2000, total water demand has remained generally stable between about 240,000 and 255,000 afy, a result of a generally offsetting increase in M&I water use and decrease in agricultural water use. Since 2000, agricultural water demand has ranged between about 110,000 and 140,000 afy; total M&I water requirements have ranged between about 98,000 and 122,000 afy (87,000 to 107,000 afy for the main purveyors, and around 13,000 afy for mutual, small private and rural residential users); and environmental water use has been about 7,000 to 10,000 afy.

4.2.3 Water Supplies

Prior to 1972, essentially all water requirements in the AVAA were met by local groundwater, augmented by a small amount of local surface water, generally less than 3,000 afy, diverted from Littlerock Creek. Beginning in 1972, supplemental water has been imported into the AVAA from the State Water Project (SWP) to augment the local water supplies. Water is imported from the SWP by three State Water Contractors in the AVAA, specifically Antelope Valley East Kern Water Agency (AVEK), Palmdale Water District (PWD), and Littlerock Creek Irrigation District (LCID); their collective SWP Table A amounts are 165,000 acre-feet per year (although that total amount is not available in all years, nor is it all dedicated to the AVAA). Imported SWP water was first made available for treatment and municipal use by Littlerock Creek Irrigation District in 1972; SWP water was initially imported by AVEK in 1976 for agricultural water supply to augment local groundwater production.

Since the 1970s, overall water demand in the AVAA has been met by a combination of local groundwater and imported SWP water, plus continued use of a small amount of local surface water diversions and recycled water from LACSD14. The relative contributions of those components of overall water supply toward total water requirements are detailed as follows.

The earliest reported development of *local surface water supplies* in the Valley involved the diversion of streamflow from local creeks such as Littlerock and Big Rock Creeks for irrigating orchards in the late 1880s (Thompson, 1929). Further development led to the construction of a dam on Littlerock Creek in 1924 to provide supplemental water for irrigation locally. Later, from the mid-1950s through early 1970s, Littlerock Creek diversions were utilized by both LCID and PWD, although PWD's use of the diversions transitioned from agricultural water supply toward primarily meeting M&I water demands. Since completion of the Littlerock Dam rehabilitation project in 1995, Littlerock Creek diversions have been primarily for M&I water supply, with diverted water delivered to PWD and some returned for both M&I and agricultural supply by LCID.

Littlerock Creek diversions have been stable since 1946, typically providing a total of 1,000 to 3,000 afy of local surface water toward agricultural and M&I water supplies. There have been only a few years(in the 1960s, in 2002, in 2007, and for all practical purposes in 2009) when water was not available for diversion. Beginning in the mid-1990s, coincident with the dam rehabilitation project (during which time the dam was also raised 12 feet, increasing the reservoir's capacity), total diversions have typically exceeded 3,000 afy and in some years have approached 7,000 afy, again excepting dry years in 2002, 2007 and 2009.

Records of *imported water* from the State Water Project begin with the first deliveries to the Valley in 1972 and continue through the present. The first SWP deliveries in 1972 were limited, when 338 af were delivered for M&I water supply by LCID. SWP deliveries greatly increased beginning in 1976, when about 27,000 af were delivered for agricultural irrigation supplies by AVEK. Imported SWP water for irrigation notably increased into the early 1980's, reaching a peak of nearly 64,000 af in 1981. Since then, deliveries of SWP water for agricultural irrigation have been notably smaller, approaching 40,000 af in only one year (1982) and less than 30,000 af in all other years. Over the last ten years, deliveries of SWP water for agricultural use have ranged between approximately 1,900 and 28,000 afy and averaged about 12,000 afy.

Except for reduced SWP availability in 2008 and 2009, SWP deliveries for municipal water supply have nearly linearly increased since the early 1980's, to nearly 72,000 afy in 2006 and 2007, and have exceeded SWP deliveries for agricultural water supply since 1986. Due to dry conditions in the SWP system over the last two years, SWP deliveries for municipal water supply were only about 52,000 afy in 2008 and 2009. Combined SWP deliveries for agricultural and municipal water supply have generally been between about 70,000 and nearly 90,000 afy over the last ten years, again except in the last two years when total deliveries were reduced to about 55,000 afy due to dry conditions. Local surface water diversions from Littlerock Creek increase the total surface water supply as described above, typically by 3,000 afy or more. The history of surface water use in the AVAA since the 1940's is illustrated in Figure 4.2-5 (and tabulated in Appendix D).

Groundwater use in the AVAA has dramatically fluctuated in response to wide variations in historical agricultural activity and, more recently, in response to development of M&I water demand. Groundwater pumping for M&I water supply is generally recorded by Valley water purveyors. In contrast however, total agricultural water requirements are necessarily estimated from historical agricultural land use; and groundwater pumping for agricultural water supply is calculated as the difference between total agricultural water requirements and all other components of agricultural water supply (supplemental surface water and recycled water). Total groundwater pumping for agricultural and M&I water supplies from 1946 through 2009 is illustrated in Figure 4.2-6 (and tabulated in Appendix D).

Groundwater pumping for agricultural irrigation has fluctuated greatly throughout the historical period, and has always exceeded pumping for M&I supply in the Valley. At the peak of agricultural irrigation in the early 1950's, groundwater pumping for agricultural water supply was as high as about 360,000 afy. During the 1950s and 1960s, agricultural pumping consistently exceeded 300,000 afy, and remained above 200,000 afy through most of the 1970s. Groundwater pumping for agricultural water supply significantly declined through the 1980s, to about 50,000 afy by 1990. Since then, agricultural pumping notably increased, to about 120,000 afy in 2002, subsequently fluctuating between about 80,000 and 115,000 afy through 2009. Groundwater pumping for major M&I water supply gradually and steadily increased for over 50 years, from about 5,000 af in 1946 to as much as about 45,000 af in 2001 and 2008. Since 2000, groundwater pumping for major M&I water supply has ranged from as low as about 31,000 afy to peaks of about 45,000 afy in 2001 and 2008. Addition of estimated pumping for municipal-type use by mutual and small private water companies, and by rural residential water users, increases the total estimated recent pumping for municipal-type uses into a range of about 42,000 to 57,000 afy since 2000. While M&I water requirements have rapidly increased since the early 1980s, to a peak of about 107,000 afy in 2007 (about 122,000 afy including mutual and small private water company, and rural residential uses), an increasingly large part of the M&I water demand has generally been met by imported SWP water supplies.

Overall, groundwater pumping to meet both agricultural and M&I water requirements in the AVAA has ranged from as much as 370,000 to 380,000 afy in the 1950's-1960's to about 85,000 afy by 1990. Since then, total groundwater pumping has increased, as high as nearly 175,000 afy in 2002, followed by a decline to about 150,000 af in 2005, and to about 130,000 af in 2006 and 2007; over the last two years, total pumping increased to more than 160,000 af in 2008, and to about 145,000 af in 2009. Over the last decade, total groundwater pumping has averaged about 153,000 afy.

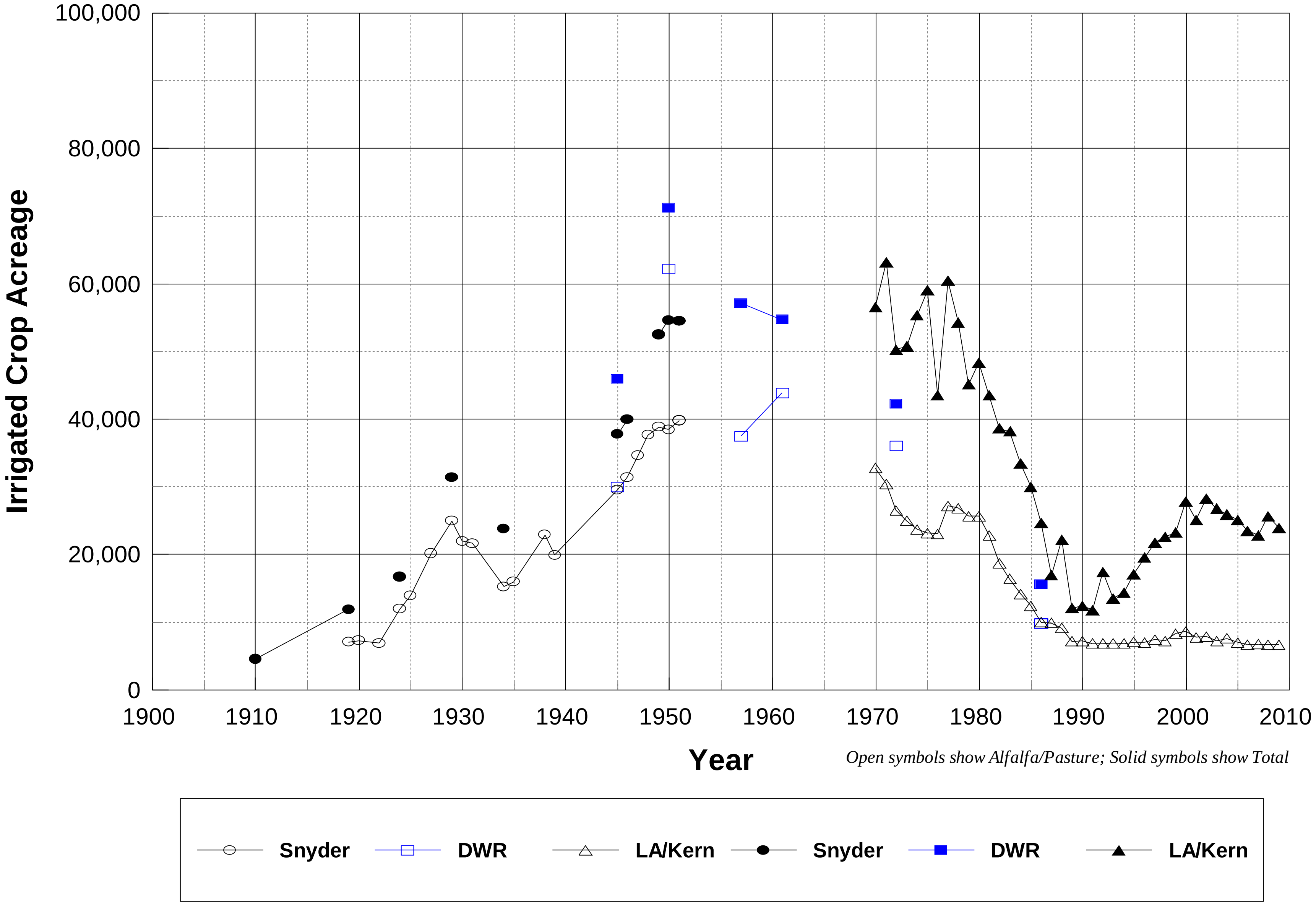
Recycled water from both LACSD14 (Lancaster) and LACSD20 (Palmdale) water reclamation plants (WRPs) has been utilized for agricultural irrigation and environmental water use in the AVAA since at least the early 1990s. Use of recycled water for irrigation and environmental water supply has steadily increased over recent time, from less than 1,000 afy for irrigation and environmental uses, respectively, in 1975, to as much as nearly 15,000 afy and 10,000 afy (in different years), respectively, in the last five years. The historical trends in use of recycled water are illustrated in Figure 4.2-7. Total recycled water use for irrigation and environmental supplies in the AVAA is now about 21,000 afy.

In summary, water requirements in the AVAA are met by a combination of four water supply components, specifically groundwater, local and imported surface waters from Littlerock Creek and the State Water Project respectively, and recycled water from LACSD14/20. Historical trends in the various components of total water supply are illustrated in Figure 4.2-8. Groundwater was the predominant water supply in the AVAA throughout the period of highest water demand, generally between about 280,000 and 380,000 afy, from the late 1940s through the mid-1970s. Groundwater pumping has subsequently decreased, into a range of about 130,000 to nearly 175,000 afy since 2000, and has averaged about 153,000 afy over the last decade. Since the mid-1970's, imported SWP water has added to a small amount of local surface water to provide a surface water component of water supply that varied through the 1980s-1990s, and has been about 70,000 and 90,000 afy since 2000, except during the last two years of reduced SWP deliveries, when total surface water supplies have been reduced to 54,000 and 59,000 afy. Recycled water supply steadily increased from the 1970's, to about 21,000 afy since 2005.

Figure 4.2-1

Historical Irrigated Crop Acreage

Antelope Valley Area of Adjudication

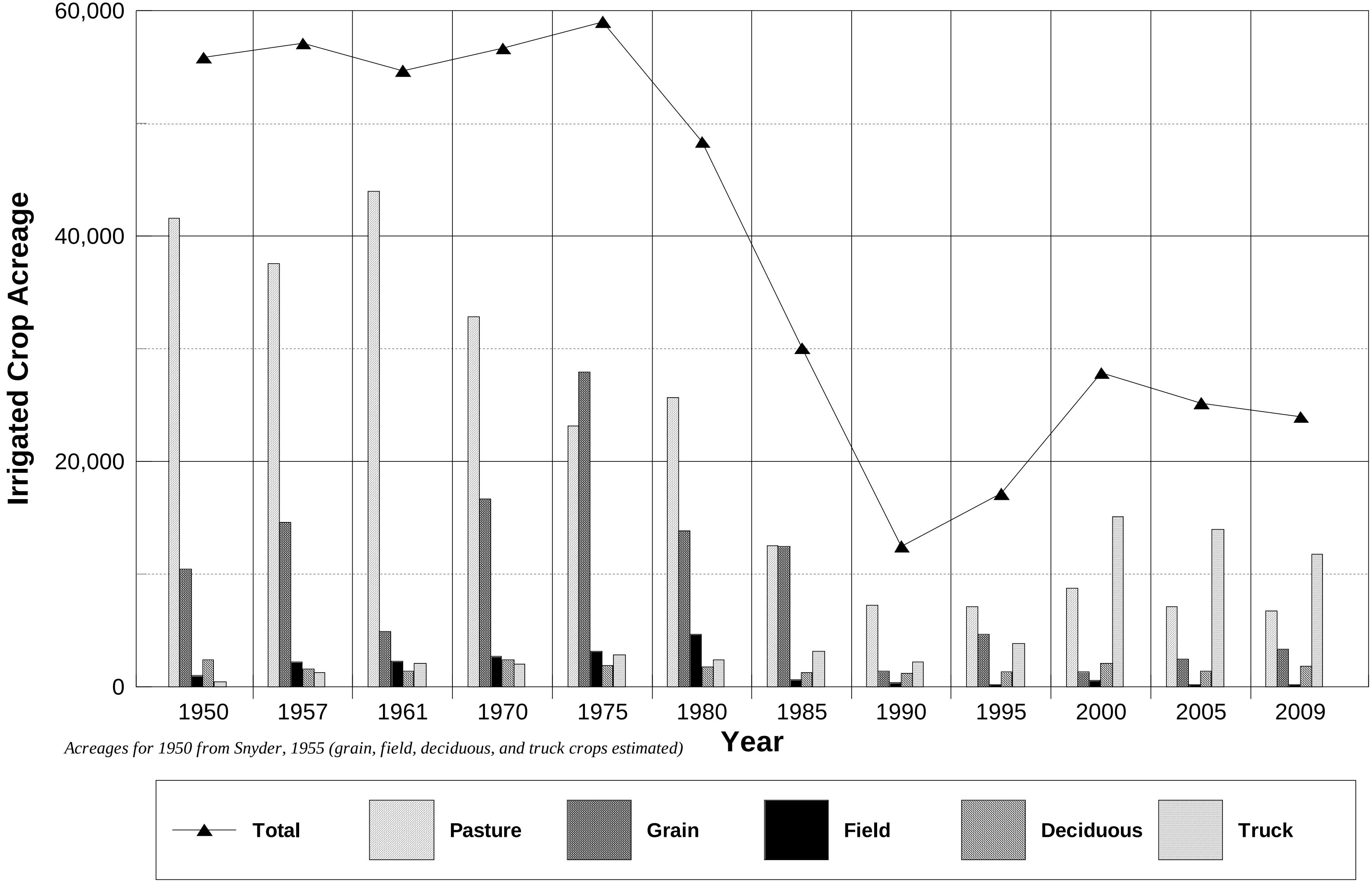


Open symbols show Alfalfa/Pasture; Solid symbols show Total

Figure 4.2-2

Historical Cropping Pattern

Antelope Valley Area of Adjudication



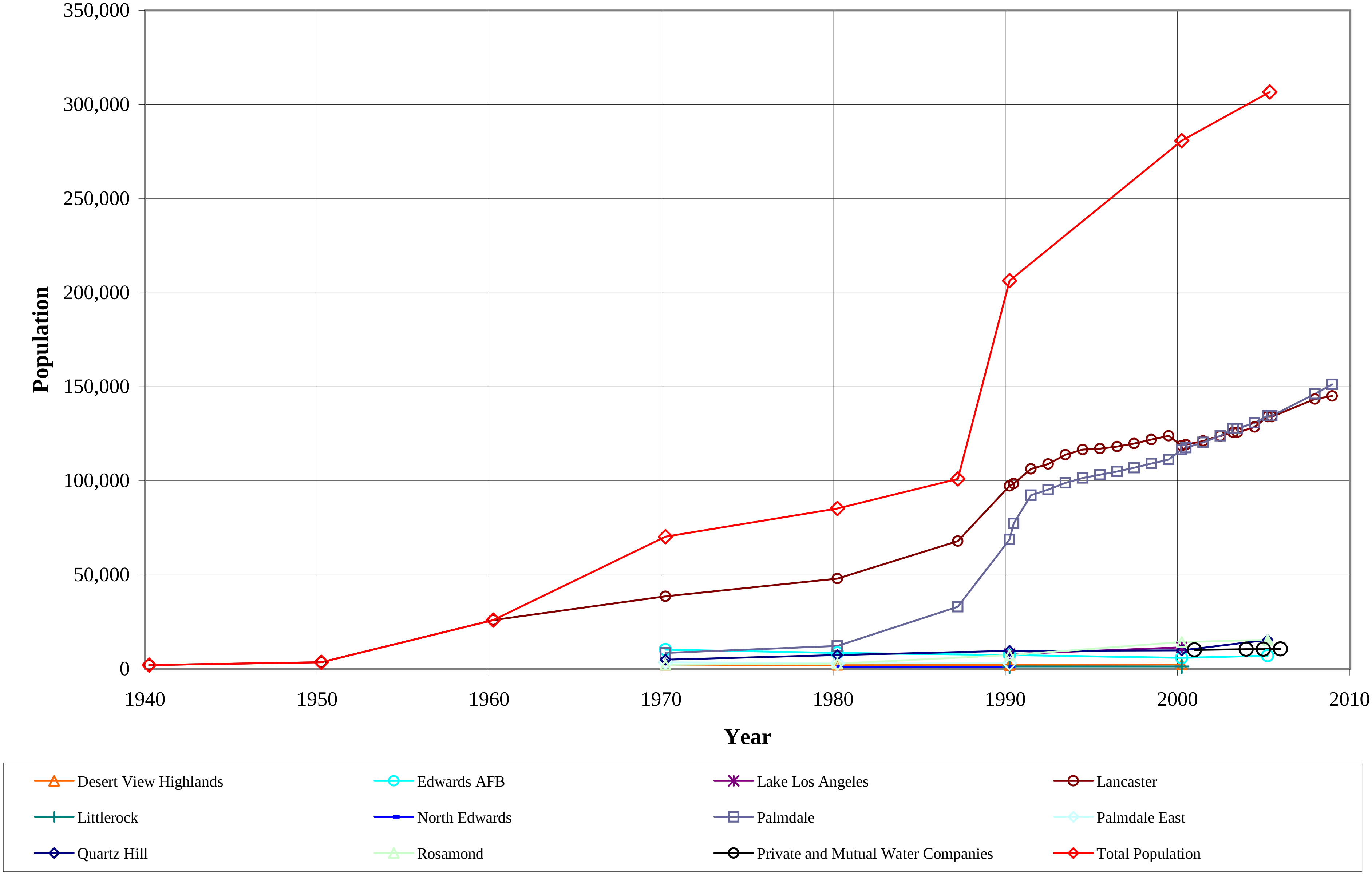


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Figure 4.2-3
Historical Population
Antelope Valley Area of Adjudication

Figure 4.2-4
Estimated Historical Total Water Requirements

Antelope Valley Area of Adjudication

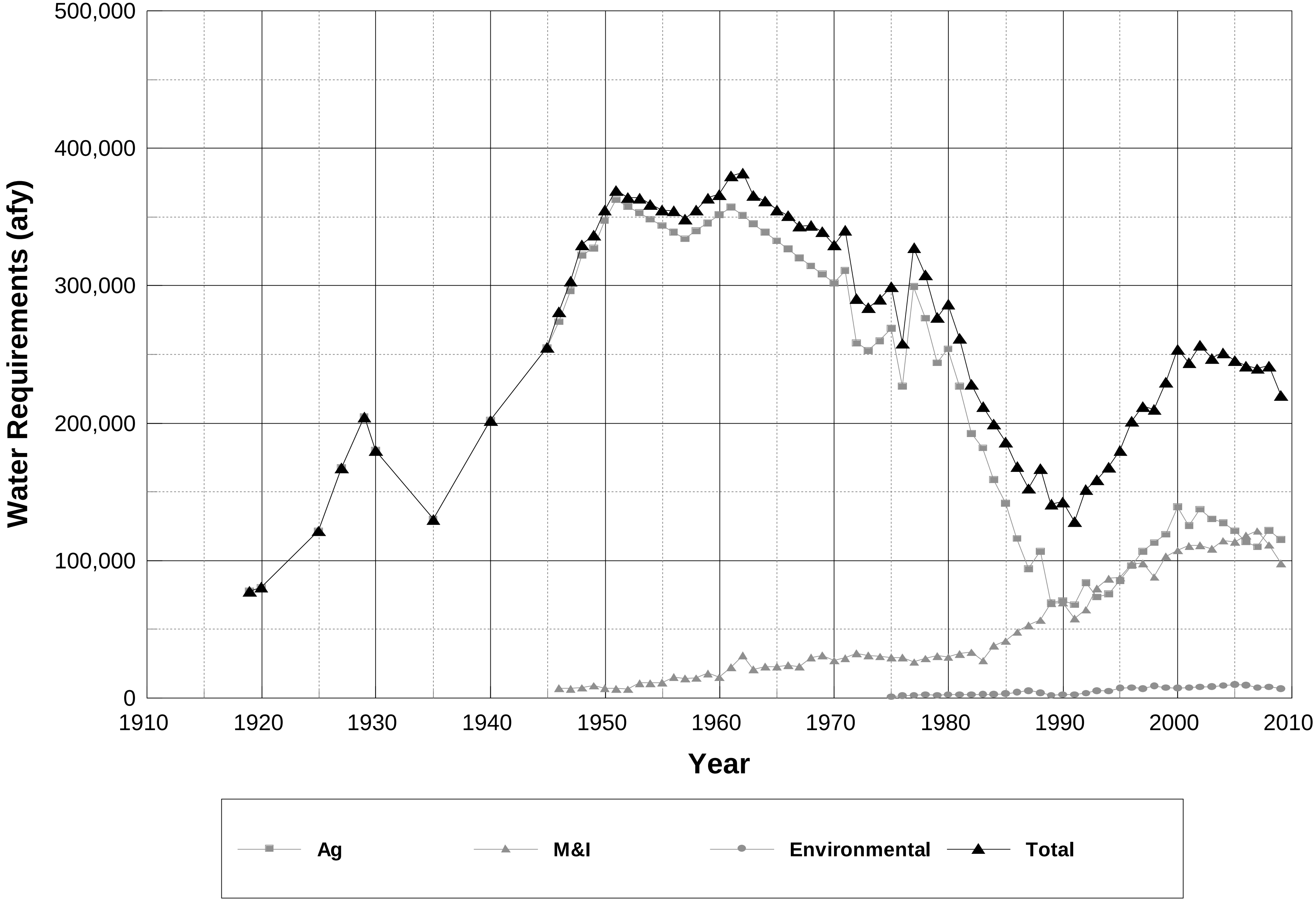


Figure 4.2-5
Historical Supplemental Surface Water by Source

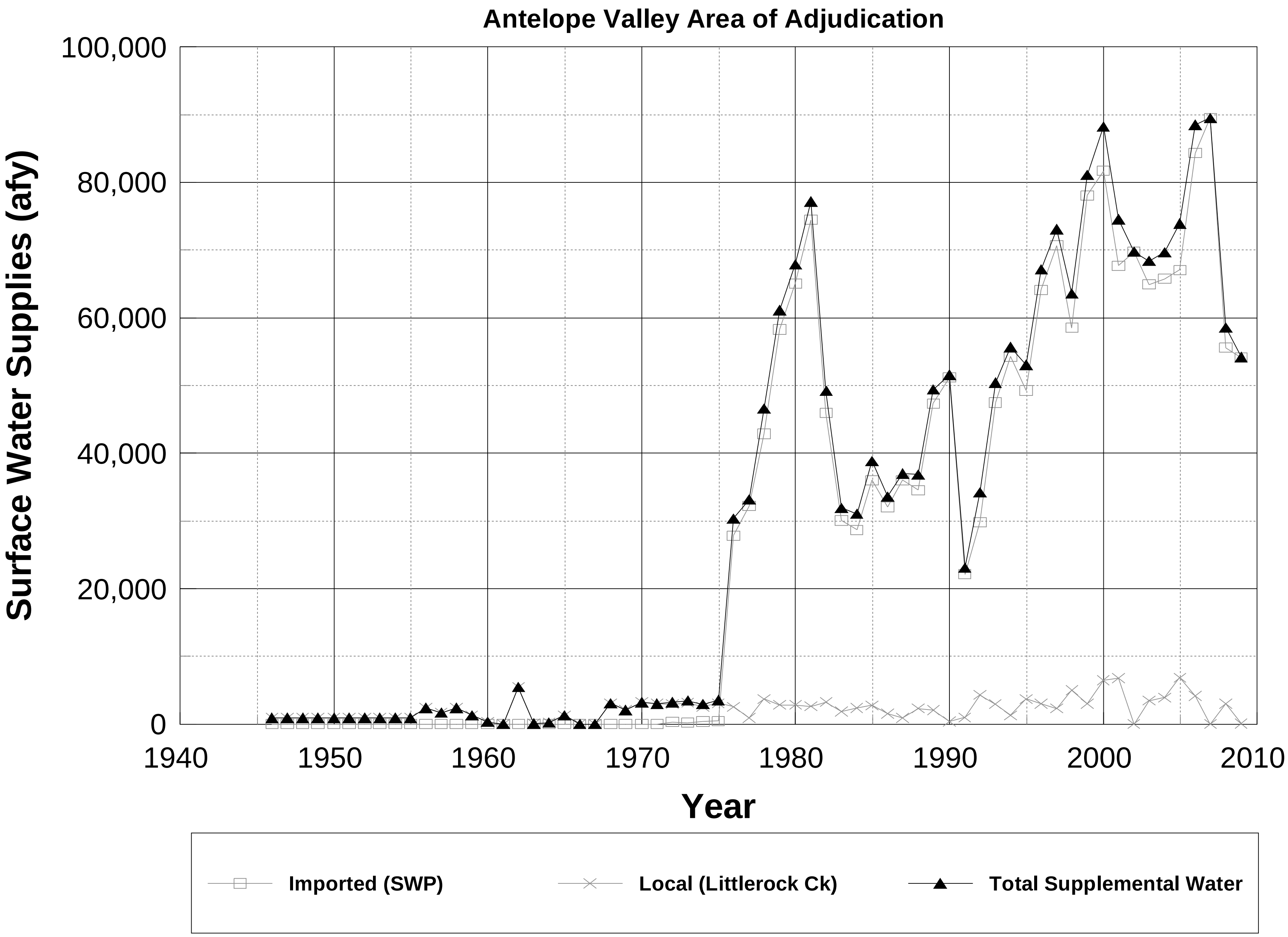


Figure 4.2-6
Estimated Historical Groundwater Pumping
Antelope Valley Area of Adjudication

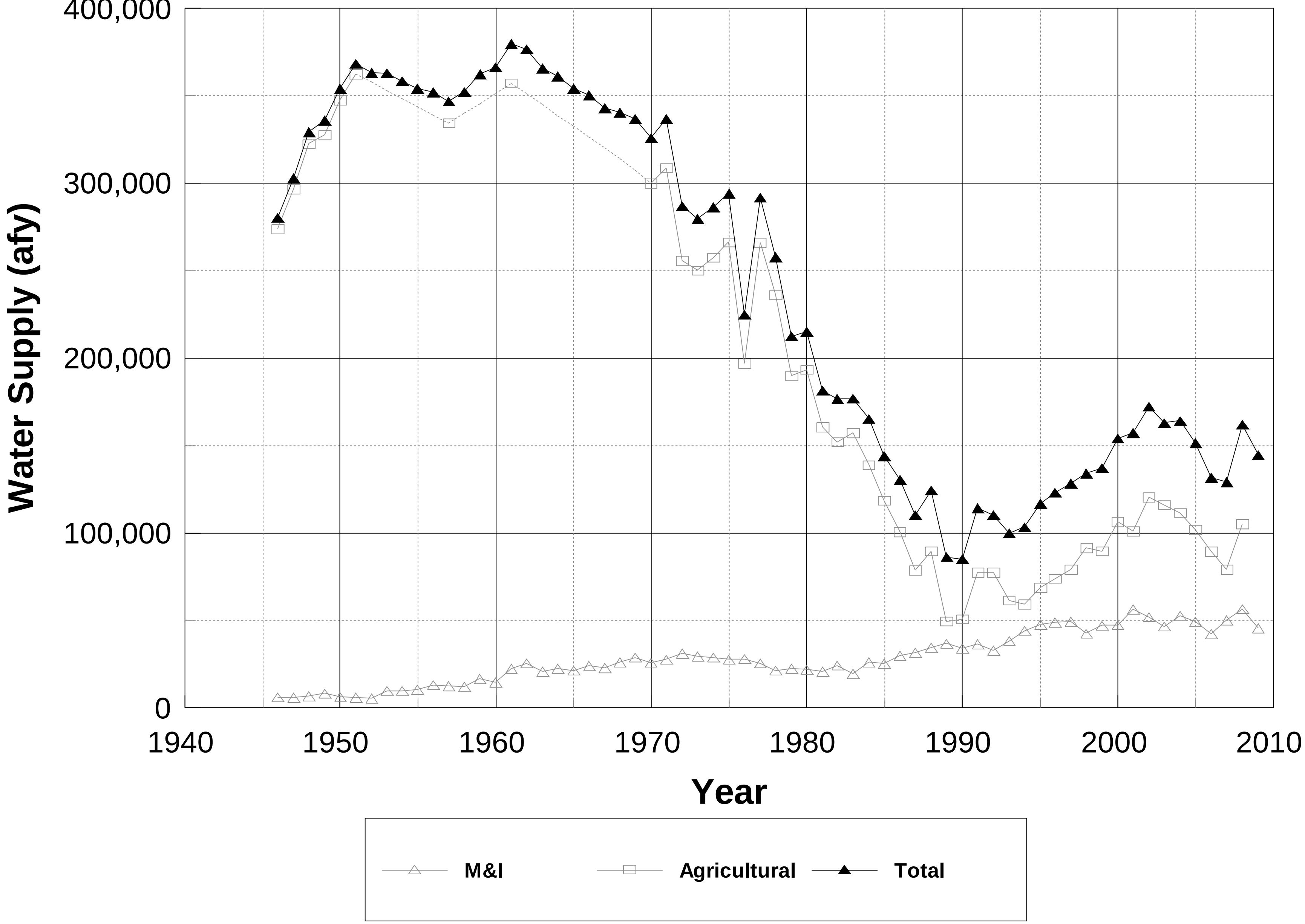
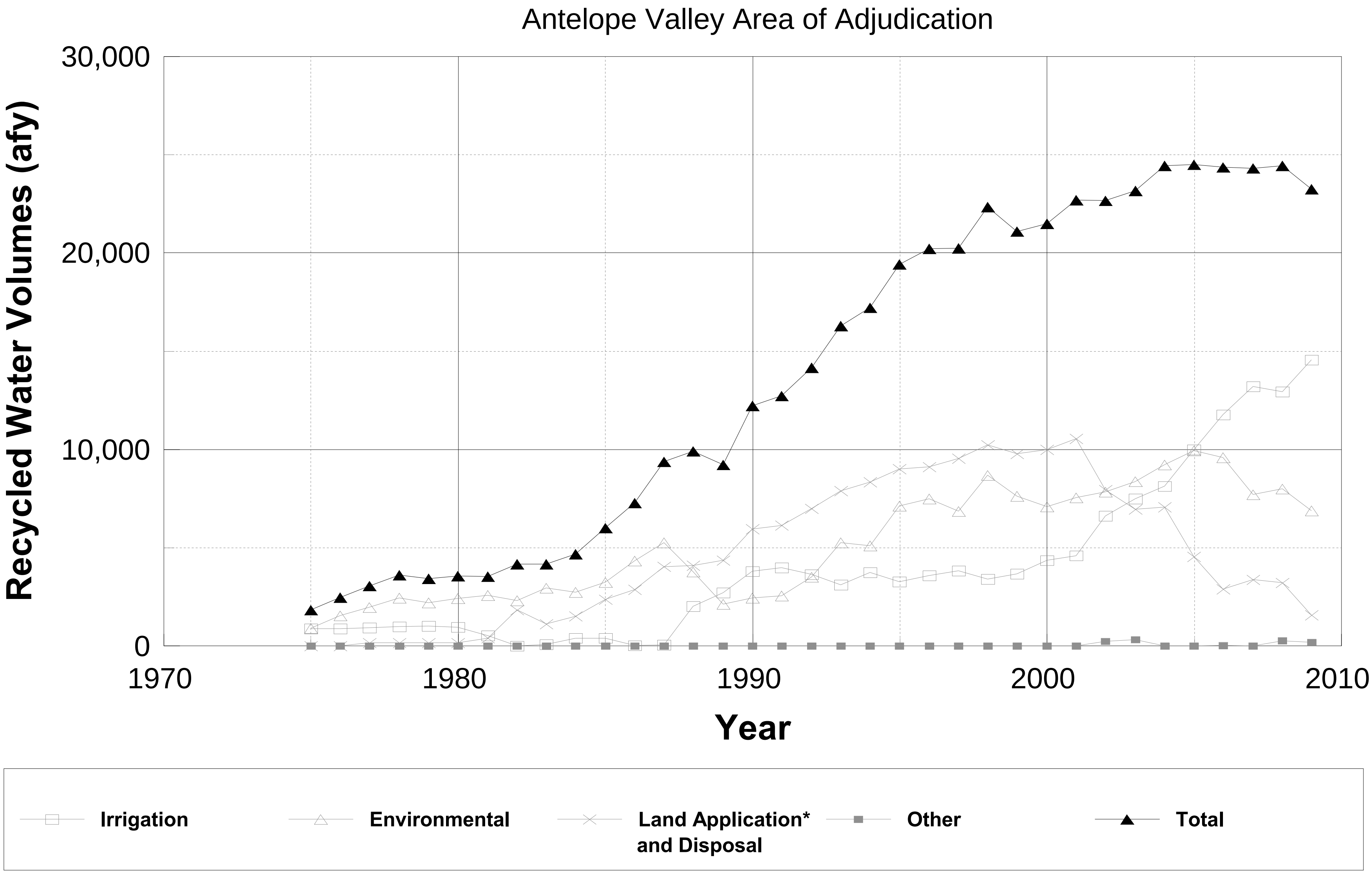


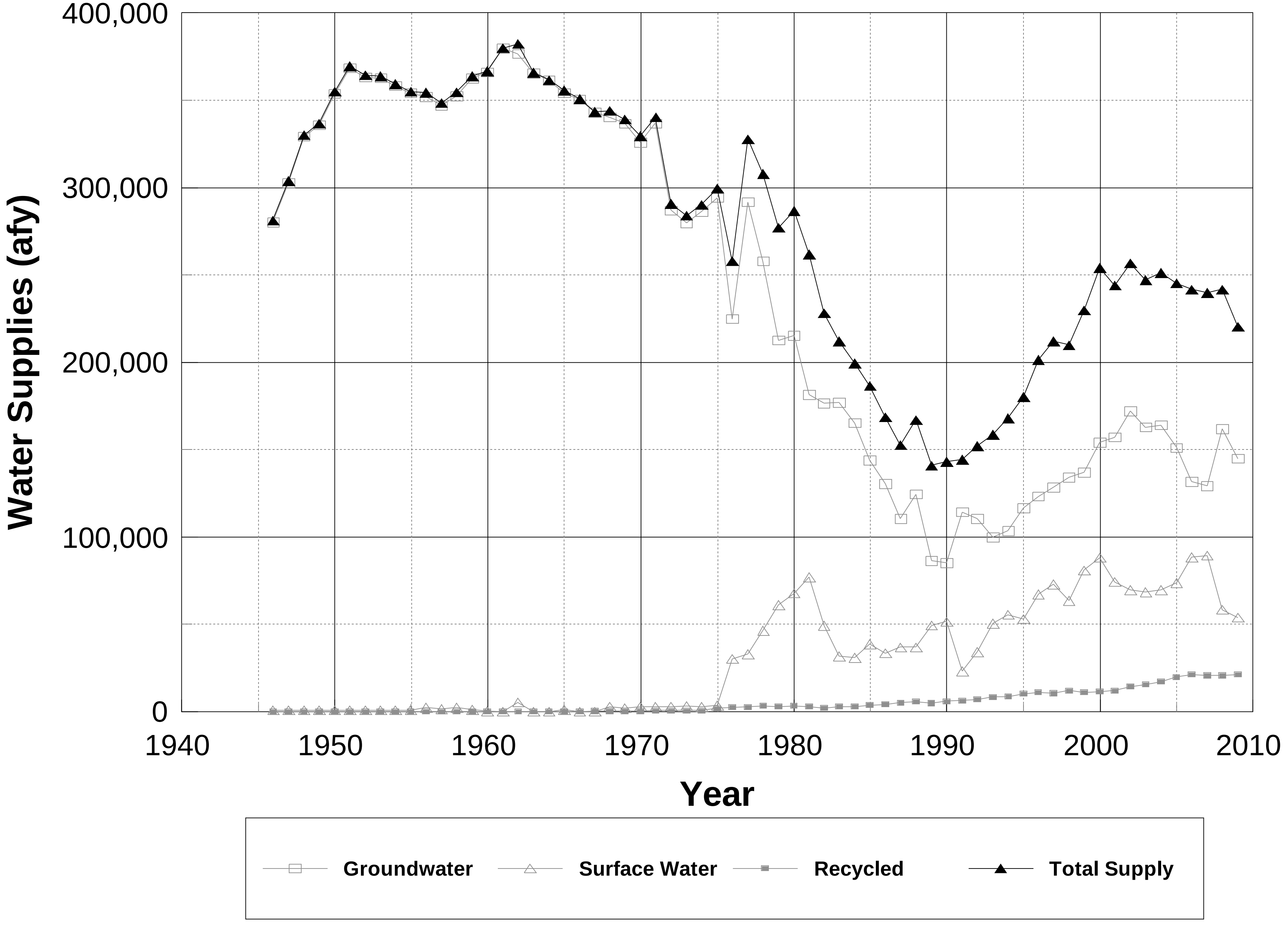
Figure 4.2-7
Recycled Water Supply



*(with and w/out crops)

Figure 4.2-8
Estimated Historical Water Supplies

Antelope Valley Area of Adjudication



4.3 Groundwater Levels, Storage and Natural Recharge

4.3.1 Groundwater Levels and Trends

A series of groundwater elevation contour maps was created to determine groundwater flow patterns and elevation trends within the basin and to estimate the change in storage over the base period through 2005, and subsequently to the present (2009). Groundwater elevation contour maps were prepared for 1951, 1963, 1971, 1979, 1985, 1992, 1998, 2005 and 2009, and are presented as Figures 4.3-1 through 4.3-9, respectively. Because of the paucity of data in the Finger Buttes and Oak Creek subbasins, (historical subbasin names and boundaries are shown in Appendix E, Figure E2-2) and along the fringes of the basin, these areas are excluded from groundwater elevation contouring and subsequent storage change calculations.

The investigation area was divided into four areas to characterize common trends in groundwater levels and storage. These areas are shown in Figure 4.3-10 and include the North Antelope Valley, South Antelope Valley (Lancaster and Palmdale), West Antelope Valley, and East Antelope Valley areas. The groundwater level trends in these areas are described below.

4.3.1.1 North Antelope Valley

This area generally comprises Willow Springs, Rosamond, Edwards Air Force Base, and North Edwards. Over the period 1951 through 2009, groundwater levels in this area continuously declined up to approximately 100 feet (09N/13W-Q3). Unlike areas along the southern part of the basin, groundwater levels show no correlation to seasonal or drought-wet periods. Several factors most likely contribute to the declining groundwater level trends, including distance from the primary recharge areas along the southern part of the basin, continuous groundwater pumping for urban and agricultural uses, and negligible deep percolation of precipitation. The groundwater levels shown in Figures 4.3-1 through 4.3-9 suggest that this area is draining towards a pumping depression concentrated in the central part of the overall investigation area. This means that groundwater levels in this area are decreasing due to pumping from outside the local area.

4.3.1.2 South Antelope Valley

Groundwater levels underlying the urban centers of Lancaster and Palmdale show continuous declines from the early 1950s through 2009. Declines in excess of 250 feet have occurred (06N/11W-19E6) and are primarily the result of heavy groundwater pumping to support the historical agricultural irrigation and subsequent municipal growth in these areas. Groundwater elevation contours from 1951 and 1963 (Figures 4.3-1 and 4.3-2, respectively) indicate that agricultural pumping to the northeast was the dominant influence on groundwater levels in this portion of the basin. By 1971 (Figure 4.3-3), pumping depressions develop just northeast of Palmdale and in the vicinity of Lancaster. The depression has continued to develop in this area through the present and has become the dominant influence on groundwater movement within this portion of the basin.

4.3.1.3 West Antelope Valley

This area includes the western portion of the Lancaster subbasin and the Neenach and West Antelope subbasins. Groundwater elevations in this area show similar trends of groundwater level decline from the early 1950s through the mid-1970s, followed by stabilizing and/or increasing groundwater elevations through approximately 2000. Since 2000, groundwater elevations have been generally declining. In general, groundwater levels have declined between 50 and 100 feet since 1951 with the greatest declines occurring in the agricultural areas of the eastern portion of the Neenach subbasin and the western portion of the Lancaster subbasin. Groundwater flow direction in this area is generally to the east and has not changed significantly since 1951.

4.3.1.4 East Antelope Valley

This area includes the eastern portion of the Lancaster subbasin and the Buttes and Pearland subbasins. Groundwater elevations in this area show similar trends of groundwater level decline from the early 1950s through the mid-1970s, followed by stabilizing and/or increasing groundwater elevations through approximately the mid to late 1990’s. Since the mid to late 1990’s, groundwater elevations have been relatively stable, with only minor declines in the west Pearland basin (well 05N10W-06N1). Groundwater elevations within the Buttes and Pearland subbasins are very sensitive to precipitation and runoff, as the majority of the natural recharge to the groundwater basin occurs in this area at Littlerock Creek and Big Rock Creek. This is observed in the hydrographs (not presented in figures) from a number of shallow wells near the Littlerock and Big Rock creeks. In general, groundwater levels in the Buttes and Pearland subbasins have not changed significantly since 1951 and, in some cases, have risen (06N/10W-22D1). Groundwater flow direction in this area is generally to the west and has not changed significantly since 1951.

4.3.2 Change in Groundwater Storage

The volume of groundwater in storage within an aquifer is a function of the volume of the aquifer materials and the volume of pore space within the aquifer material that will readily yield water under the force of gravity. Two mechanisms of storage change are present within the Antelope Valley; 1) draining or filling of aquifer materials, and the associated changing water levels as described in this section, and 2) irreversible compaction of aquifer materials and resulting subsidence from lowering water levels below a “pre-consolidation” head as described in Section 4.5. For mechanism 1, the change in storage over a particular time period is determined by multiplying the water level change by the specific yield of the aquifer materials over which the water level change occurred for a unit area of aquifer. For mechanism 2, the change in storage is simply the volume of subsidence that occurred (Section 4.5). The sum of the change in storage resulting from these two mechanisms is the total storage change, and is summarized in Section 4.3.2.6.

4.3.2.1 Investigation Period

The investigation or base period for this effort is 1951 through 2005. This period was selected based on several factors, including the availability of data and evaluation of cumulative departure from mean plots of annual precipitation, as discussed in Section 4.8 below. Groundwater levels and change storage are analyzed through 2009.

4.3.2.2 Data Sources

All available data was used to calculate groundwater elevation changes as well as aquifer geometry and storage properties for the periods of interest. The primary groundwater level database used in this analysis was obtained from the National Water Information System: a web-based database that contains water and groundwater related data and is maintained by the US Geological Survey (USGS). The database used in this analysis contained over 38,000 records. These data were supplemented with information provided by the Antelope Valley-East Kern Water Agency, Los Angeles County Water Works and Palmdale Water District.

Aquifer storage and geometry data were derived from published reports and Department of Water Resources (DWR) well completion reports. The specific yield of the sediments was determined by analyzing a comprehensive library of over 2,500 well completion reports that were obtained from the DWR. Each lithologic description was assigned a specific yield value derived from Johnson (1967). Specific yield values within the basin typically range from 0.25 (coarse sand) to 0.03 (clay).

Data sources for subsidence are from Ikehara and Phillips (1994) and Leighton (2003).

4.3.2.3 Method of Storage Change Calculation

A storage change model (Model) was developed to estimate the groundwater storage changes that occurred within the AVAA during the initial investigation period (1951 through 2005) and were subsequently updated through 2009.

The accuracy of the Model relates directly to the accuracy of the groundwater elevation contour maps created for each period and to the accuracy of the assignment of specific yield values to the unconfined aquifer materials where groundwater elevation changes occurred.

The storage change for each period (ΔS, in acre-feet) is calculated as follows:

$$\text{Change in Storage } (\Delta S) = \Delta WL \text{ x } SY_{avg} \text{ x } A \qquad (4.3.1)$$

Where ΔWL is the change in groundwater elevation for a specific period (feet), SY_{avg} is the thickness-weighted average specific yield of the sediments where the groundwater elevation change occurred during a specific period, and A is the area (acres) where storage change and groundwater elevation have changed. Specific details of the Model development and storage change calculation are presented in Appendix E.

4.3.2.4 Storage Change from Gravity Drainage

The methods and data described above were used to estimate groundwater storage changes that occurred within the investigation area for the period of 1951 through 2009. The total change in storage as a result of gravity drainage over this 59-year period is approximately -5,200,000 acre-ft. That is, the volume of groundwater in storage decreased by 5,200,000 acre-ft. The average specific yield of the cells included in the storage change calculation is approximately 14 percent. Figure 4.3-11 presents a graph of the cumulative and total change in storage and the components of the storage change (gravity drainage and compaction). Table 4.3-1 summarizes the calculated change in storage for each period. Figures 4.3-12a and b show the regional distribution of storage change by gravity drainage for each period and for the entire period between 1951 and 2009, respectively.

Just as agricultural pumping peaked in the early 1960s, so did the change in groundwater storage. The storage change from gravity drainage between 1951 and 1962 was approximately -3,300,000 acre-ft or 60% of the total storage change from gravity drainage over the entire investigation period. Groundwater storage decreased by about 1,200,000 acre-ft between 1963 and 1970, and from 1971 to 2009, the total decrease in storage from gravity drainage was about 700,000 acre-ft. The only period to show a significant increase in groundwater storage was during the 1992 to 1997 period, where storage increased by about 200,000 acre-ft.

4.3.2.5 Storage Change from Aquifer Compaction (Subsidence)

The volume of water derived from aquifer compaction between 1951 and 2005 was approximately 400,000 acre-ft. Figure 4.3-13 shows the cumulative volume of water derived from subsidence and clearly shows that the majority of the subsidence occurred between 1957 and 1985. The volume of water derived from aquifer compaction between 2005 and 2009 was not estimated due to lack of measured subsidence data.

4.3.2.6 Total Change in Storage

The total change in storage from gravity drainage and compaction is shown in Table 4.3-1 and graphically in Figure 4.3-14. The total decrease in storage over the 1951 through 2009 investigation period (excluding water derived from compaction from 2006 through 2009) was about 5,600,000 acre-ft with about 5,200,000 acre-ft from gravity drainage and about 400,000 acre-ft from compaction.

4.3.3 Natural Recharge

An estimate of the average annual natural recharge of the AVAA groundwater basin is presented herein using the continuity equation, the change in storage developed in Section 4.3.2, and the hydrologic components reported elsewhere in this Summary Report. The following equation was used to estimate natural recharge.

$$\text{Change in Storage } (\Delta S) = \text{Inflow (I)} - \text{Outflow (O)} \qquad (4.3.2)$$

where

I = Natural Recharge (I_{nr}) + Artificial Recharge (I_{ar}) + Return Flows ($I_{rf.}$)

O = Groundwater Pumping (O_p) + Subsurface Outflow (O_{ss})

This equation is algebraically rearranged to estimate natural recharge:

$$I_{nr} = \Delta S + O_p + O_{ss} - I_{ar} - I_{rf.} \qquad (4.3.3)$$

Various co-preparers of this report have estimated the hydrologic components on the right side of equation 4.3.2. These estimates can be substituted into this equation to yield estimates of natural recharge.

The results of the natural recharge calculation are summarized in Tables 4.3-2a and 4.3-2b for average irrigation return flow lag times of 15 and 20 years, respectively. These tables show the estimated natural recharge for the following periods:

- 1951 to 1962
- 1963 to 1970
- 1971 to 1978
- 1979 to 1984
- 1985 to 1991
- 1992 to 1997
- 1998 to 2005
- 1951 to 2005

The natural recharge for the 1951 through 2005 period is about 57,000 acre-ft/yr and 55,000 acre-ft/yr for 15 and 20-year lag times, respectively. These estimates of natural recharge are very close to the independently developed natural recharge estimate of about 56,000 acre-ft/yr for the 1949-2005 period (Section 4.1, Appendix C) and about 58,000 acre-ft/yr for the 1951 to 2005 period. Recall that the other natural recharge estimates are based on precipitation and the subsequent recharge of runoff from precipitation: they do not depend on any of the information used to develop the natural recharge estimates provided in Tables 4.3-2a and 4.3-2b.

Table 4.3-1: Change in Storage for 1951 - 2009

Period	Storage Change				
	Gravity Drainage (acre-ft)	Compaction (acre-ft)	Total (acre-ft)	Gravity Drainage	Compaction
1951-1962	-3,229,489	-117,000	-3,346,489	62%	27%
1963-1970	-1,220,748	-141,000	-1,361,748	24%	33%
1971-1978	-361,432	-80,000	-441,432	7%	19%
1979-1984	31,751	-60,000	-28,249	-1%	14%
1985-1991	24,971	-10,000	14,971	0%	2%
1992-1997	209,801	-9,000	200,801	-4%	2%
1998-2005	-485,163	-12,000	-497,163	9%	3%
2006-2009	-153,400	N/A	-153,400	3%	
1951-2009	-5,183,709	-429,000	-5,612,709		

Notes:

N/A - Not analyzed owing to lack of subsidence data for the 2006 to 2009 time period.

Table 4.3-2a
Natural Recharge 1951 to 2005 With 15-Year Lag

Period	Period Length	Total Outflow[1]	Storage Change[2] ΔS			Return Flows[3]	Artificial Recharge[4]	Natural Recharge[5]
	(yr)	$O_p + O_{ss}$ (acre-ft)	Gravity Drainage (acre-ft)	Compaction (acre-ft)	Total ΔS (acre-ft)	I_{rf} (acre-ft)	I_{ar} (acre-ft)	I_{nr} (acre-ft)
1951-1962	12	4,348,524	-3,229,489	-117,000	-3,346,489	822,342	0	179,693
1963-1970	8	2,780,733	-1,220,748	-141,000	-1,361,748	872,333	0	546,652
1971-1978	8	2,261,964	-361,432	-80,000	-441,432	881,447	0	939,086
1979-1984	6	1,130,679	31,751	-60,000	-28,249	561,154	0	541,276
1985-1991	7	798,198	24,971	-10,000	14,971	559,196	0	253,973
1992-1997	6	684,542	209,801	-9,000	200,801	493,096	894	391,353
1998-2005	8	1,236,702	-485,163	-12,000	-497,163	458,713	5,570	275,256
1951-2005	55	13,241,343	-5,030,309	-429,000	-5,459,309	4,648,280	6,464	3,127,290
1951-2005	Annual Mean	240,752	-91,460	-7,800	-99,260	84,514	118	56,860

Notes:

1) Sum of all groundwater pumping [O_p (ag, M&I, and rural residential)] and subsurface flow out of the basin (O_{ss}).

2) Sum of gravity drainage and water from compaction of sediments (subsidence).

3) Sum of return flows from agriculture, urban/M&I, and recycled water.

4) Sum of artificial recharge of imported water via spreading and injection.

5) = $\Delta S + O_p + O_{ss} - I_{ar} - I_{rf}$

Table 4.3-2b
Natural Recharge 1951 to 2005 With 20-Year Lag

Period	Period Length	Total Outflow[1]	Storage Change[2] ΔS			Return Flows	Artificial Recharge	Natural Recharge
	(yr)	$O_p + O_{ss}$ (acre-ft)	Gravity Drainage (acre-ft)	Compaction (acre-ft)	Total ΔS (acre-ft)	I_{rf} (acre-ft)	I_{ar} (acre-ft)	I_{nr} (acre-ft)
1951-1962	12	4,348,524	-3,229,489	-117,000	-3,346,489	654,584	0	347,451
1963-1970	8	2,780,733	-1,220,748	-141,000	-1,361,748	732,735	0	686,250
1971-1978	8	2,261,964	-361,432	-80,000	-441,432	886,399	0	934,134
1979-1984	6	1,130,679	31,751	-60,000	-28,249	668,601	0	433,829
1985-1991	7	798,198	24,971	-10,000	14,971	669,227	0	143,942
1992-1997	6	684,542	209,801	-9,000	200,801	513,692	894	370,757
1998-2005	8	1,236,702	-485,163	-12,000	-497,163	613,090	5,570	120,879
1951-2005	55	13,241,343	-5,030,309	-429,000	-5,459,309	4,738,328	6,464	3,037,242
1951-2005	Annual Mean	240,752	-91,460	-7,800	-99,260	86,151	118	55,223

Notes:

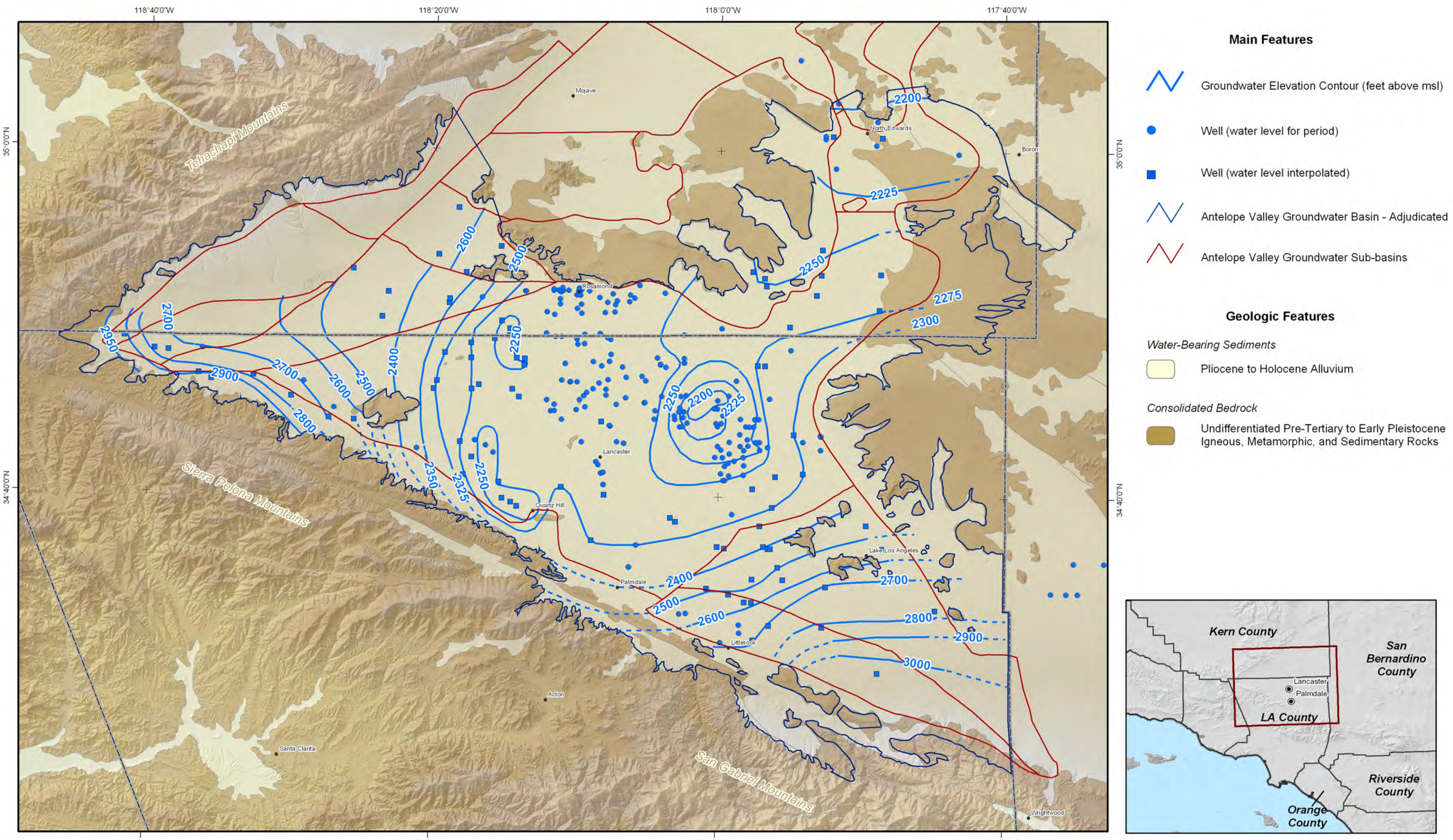
1) Sum of all groundwater pumping [O_p (ag, M&I, and rural residential)] and subsurface flow out of the basin (O_{ss}).

2) Sum of gravity drainage and water from compaction of sediments (subsidence).

3) Sum of return flows from agriculture, urban/M&I, and recycled water.

4) Sum of artificial recharge of imported water via spreading and injection.

5) $= \Delta S + O_p + O_{ss} - I_{ar} - I_{rf}$



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File: 1951_wl.mxd

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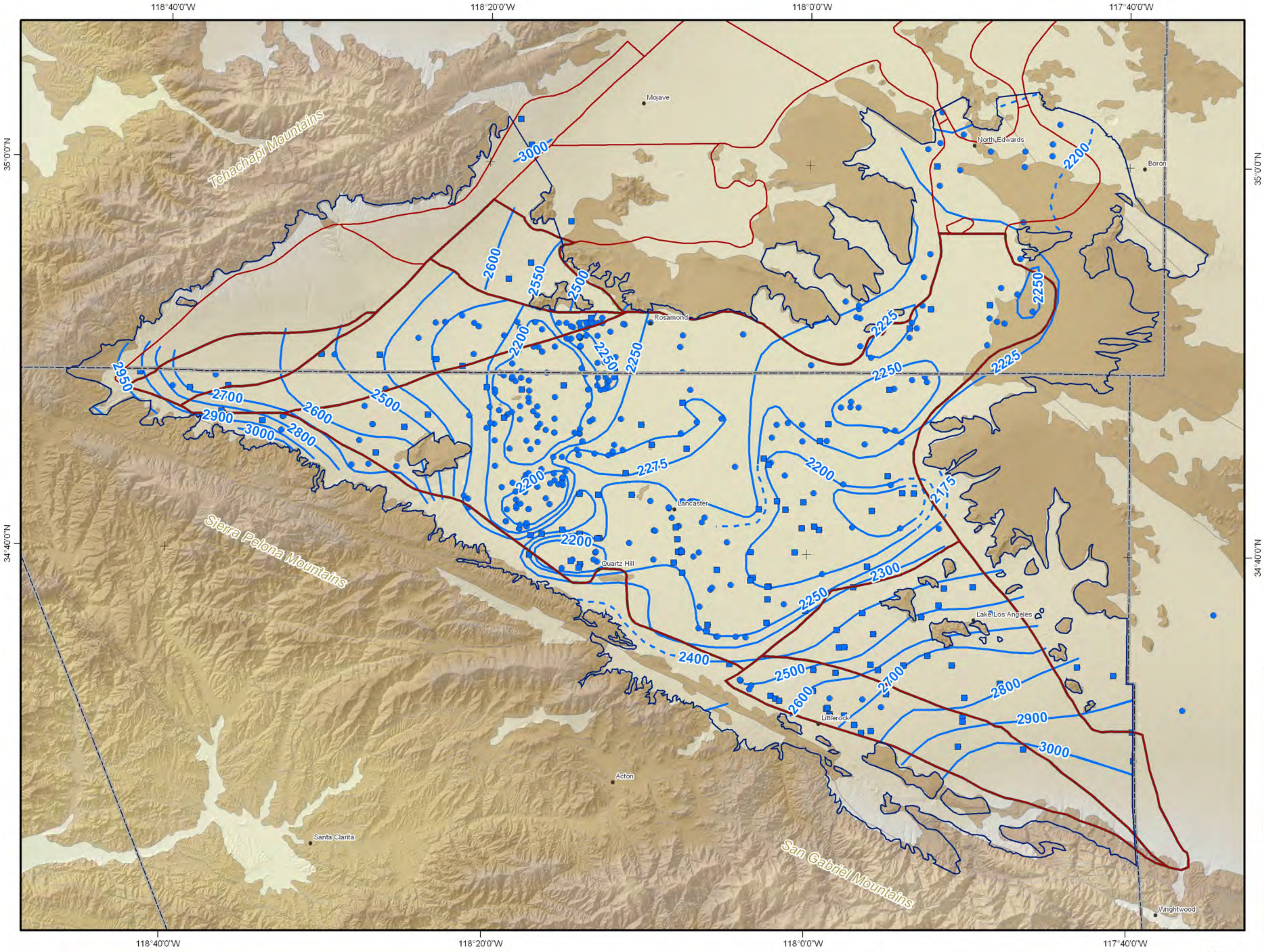
Groundwater Elevation Contours - 1951

Antelope Valley Groundwater Basin

Figure 4.3-1



Main Features

- Groundwater Elevation Contour (feet above msl)
- ● Well (water level for period)
- ■ Well (water level interpolated)
- Antelope Valley Groundwater Basin - Adjudicated
- Antelope Valley Groundwater Sub-basins

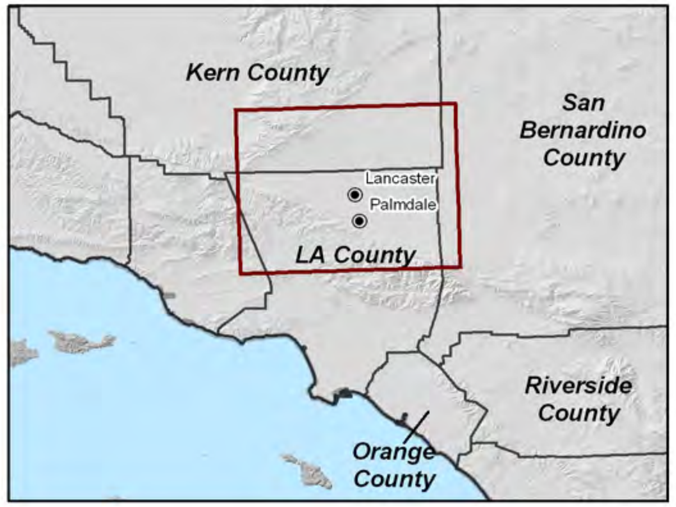
Geologic Features

Water-Bearing Sediments

- ▭ Pliocene to Holocene Alluvium

Consolidated Bedrock

- ▬ Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks



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0 6 12 Miles
0 10 20 Kilometers

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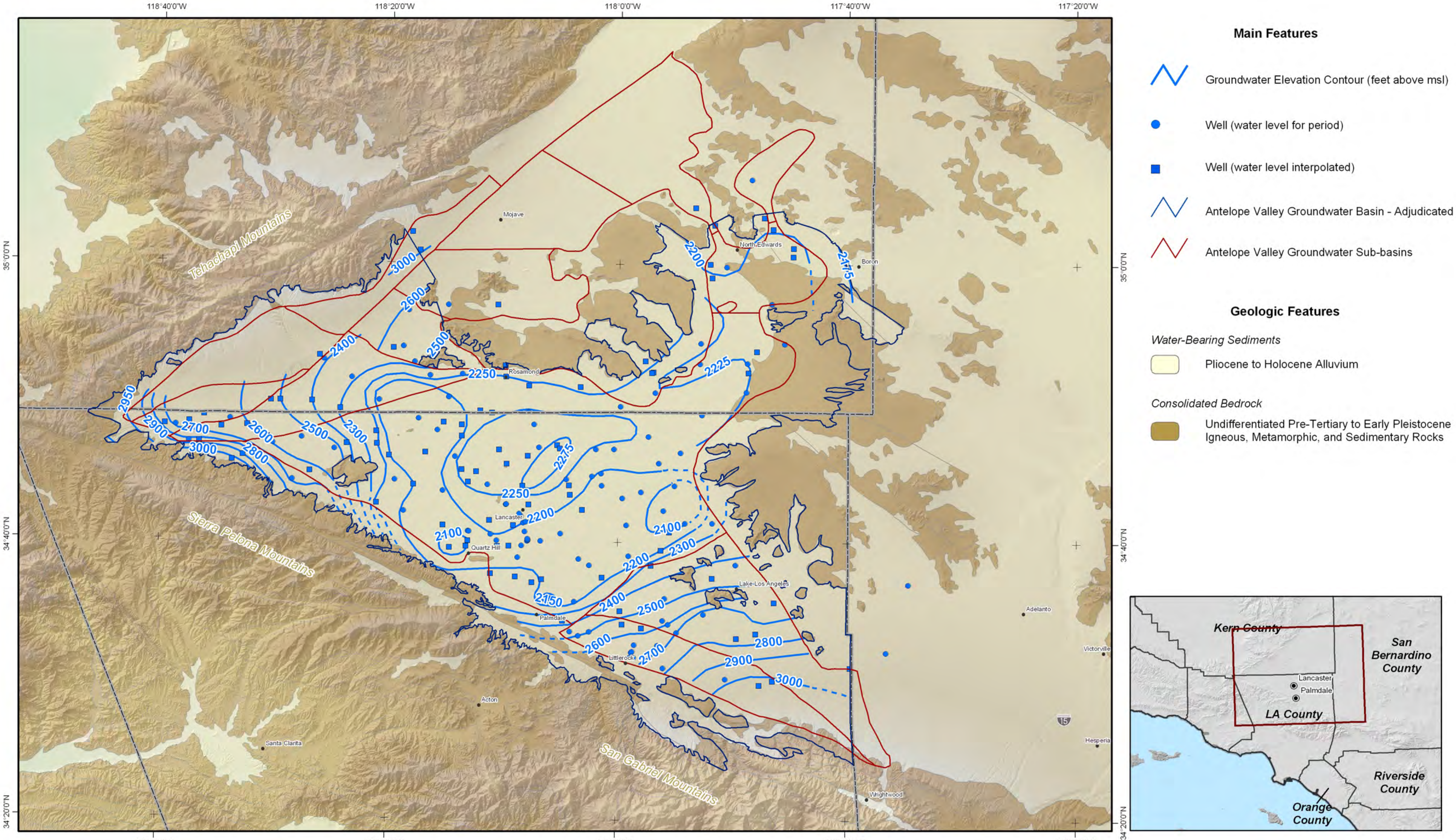
Groundwater Elevation Contours - 1963

Antelope Valley Groundwater Basin

Figure 4.3-2



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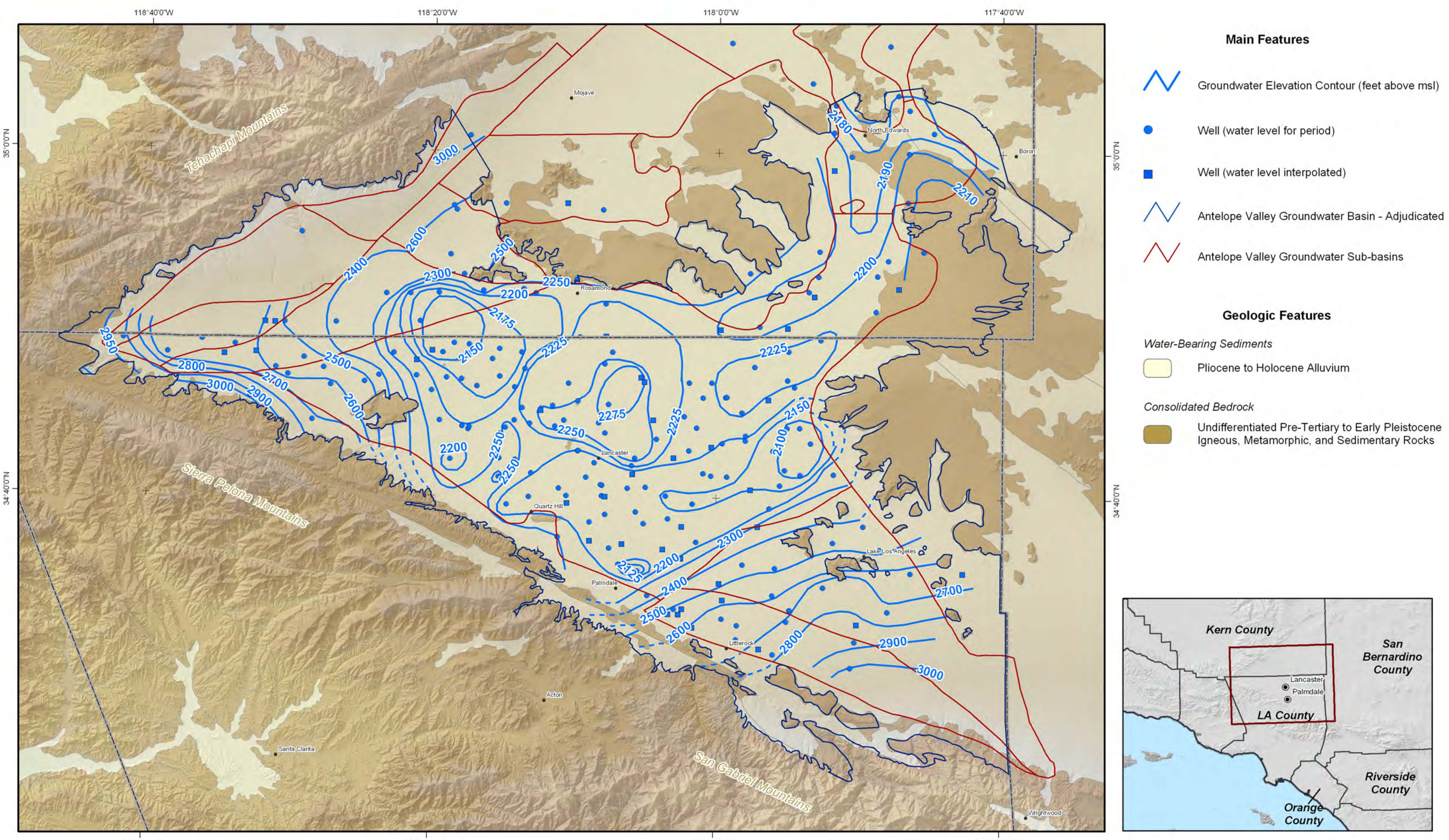
Groundwater Elevation Contours - 1971

Antelope Valley Groundwater Basin

Figure 4.3-3



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0 6 12 Miles
0 10 20 Kilometers

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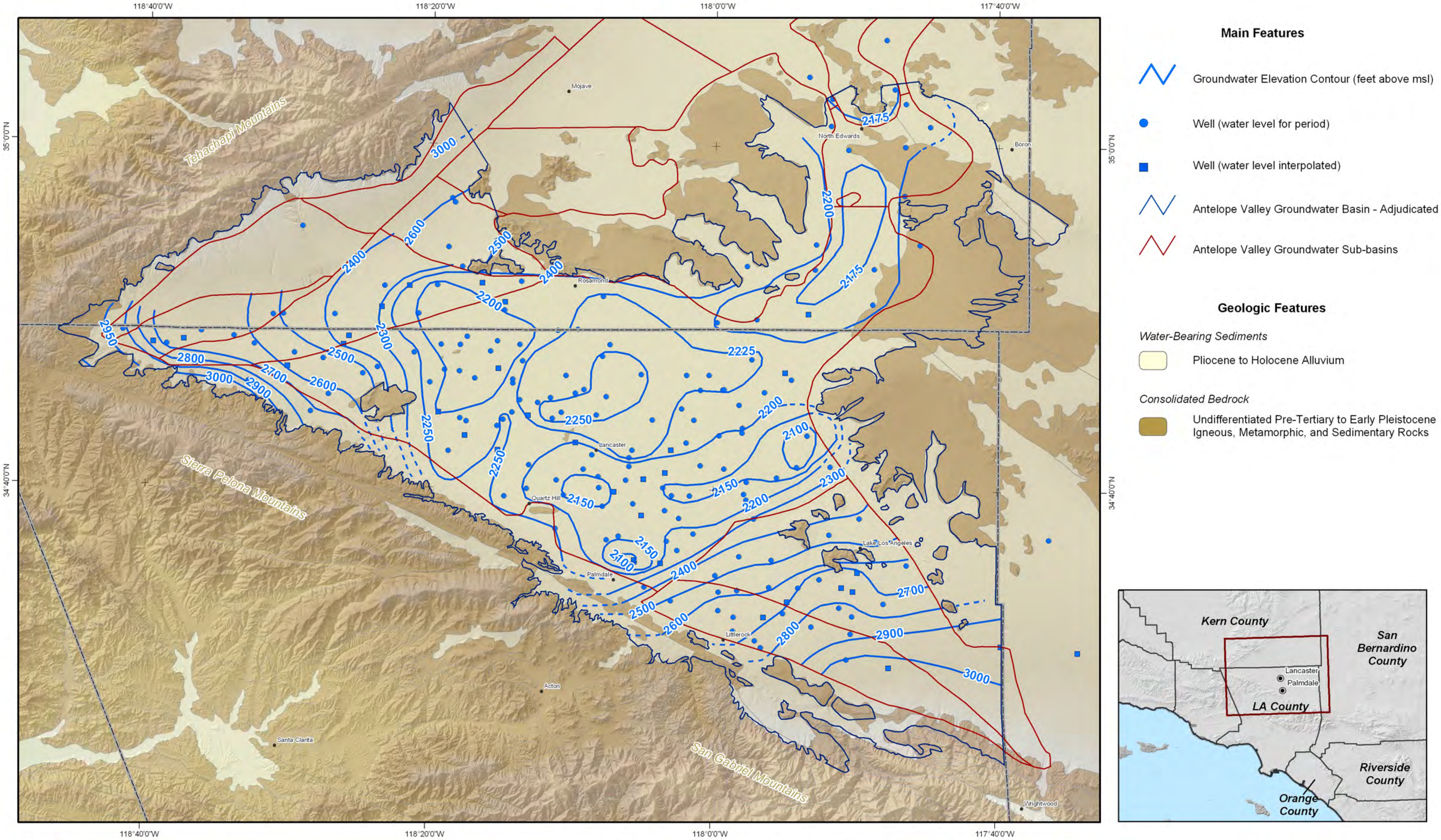
Groundwater Elevation Contours - 1979

Antelope Valley Groundwater Basin

Figure 4.3-4



Main Features

Groundwater Elevation Contour (feet above msl)

● Well (water level for period)

■ Well (water level interpolated)

Antelope Valley Groundwater Basin - Adjudicated

Antelope Valley Groundwater Sub-basins

Geologic Features

Water-Bearing Sediments

Pliocene to Holocene Alluvium

Consolidated Bedrock

Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks

0 6 12 *Miles*

0 10 20 *Kilometers*

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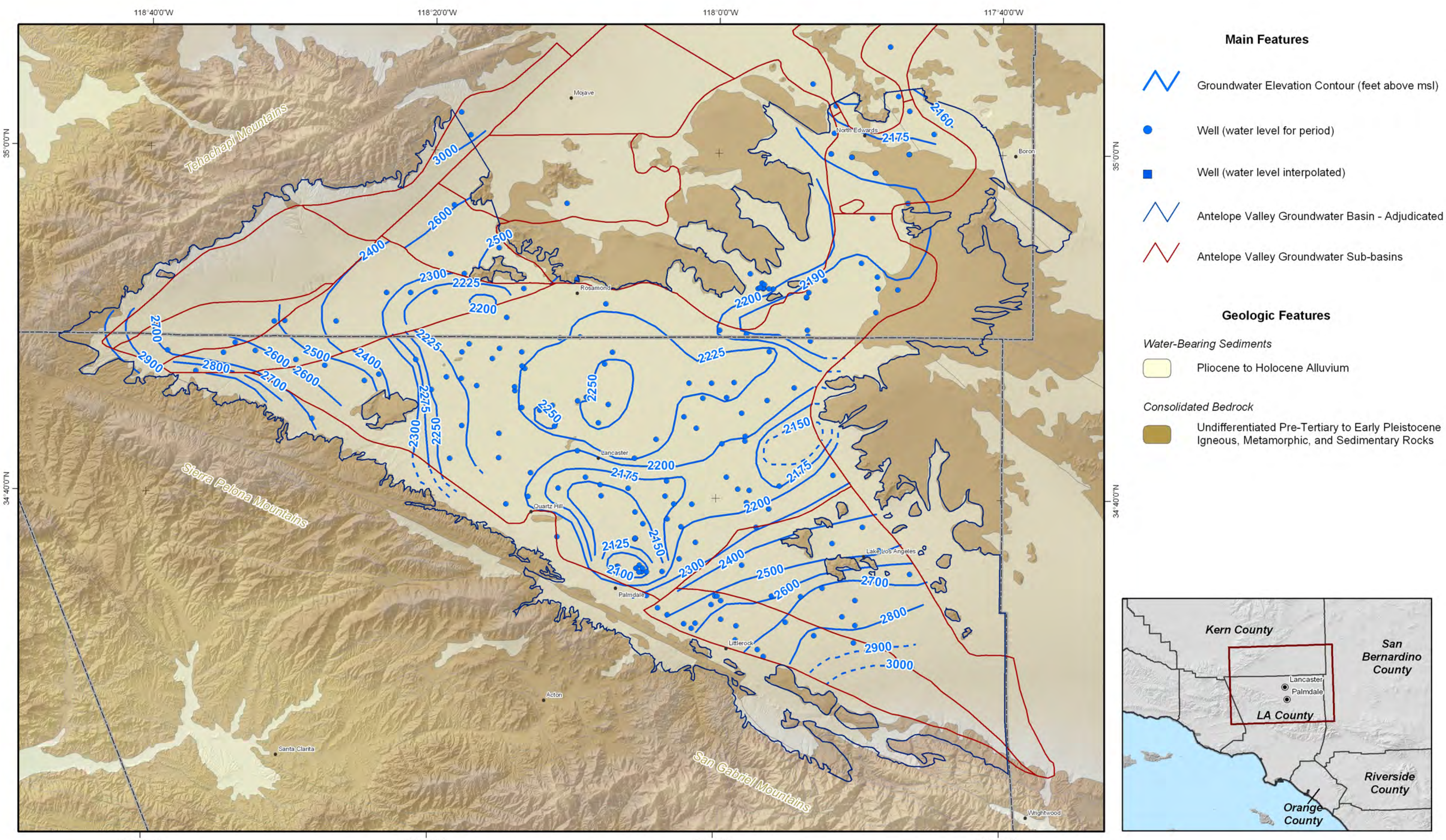
Groundwater Elevation Contours - 1985

Antelope Valley Groundwater Basin

Figure 4.3-5



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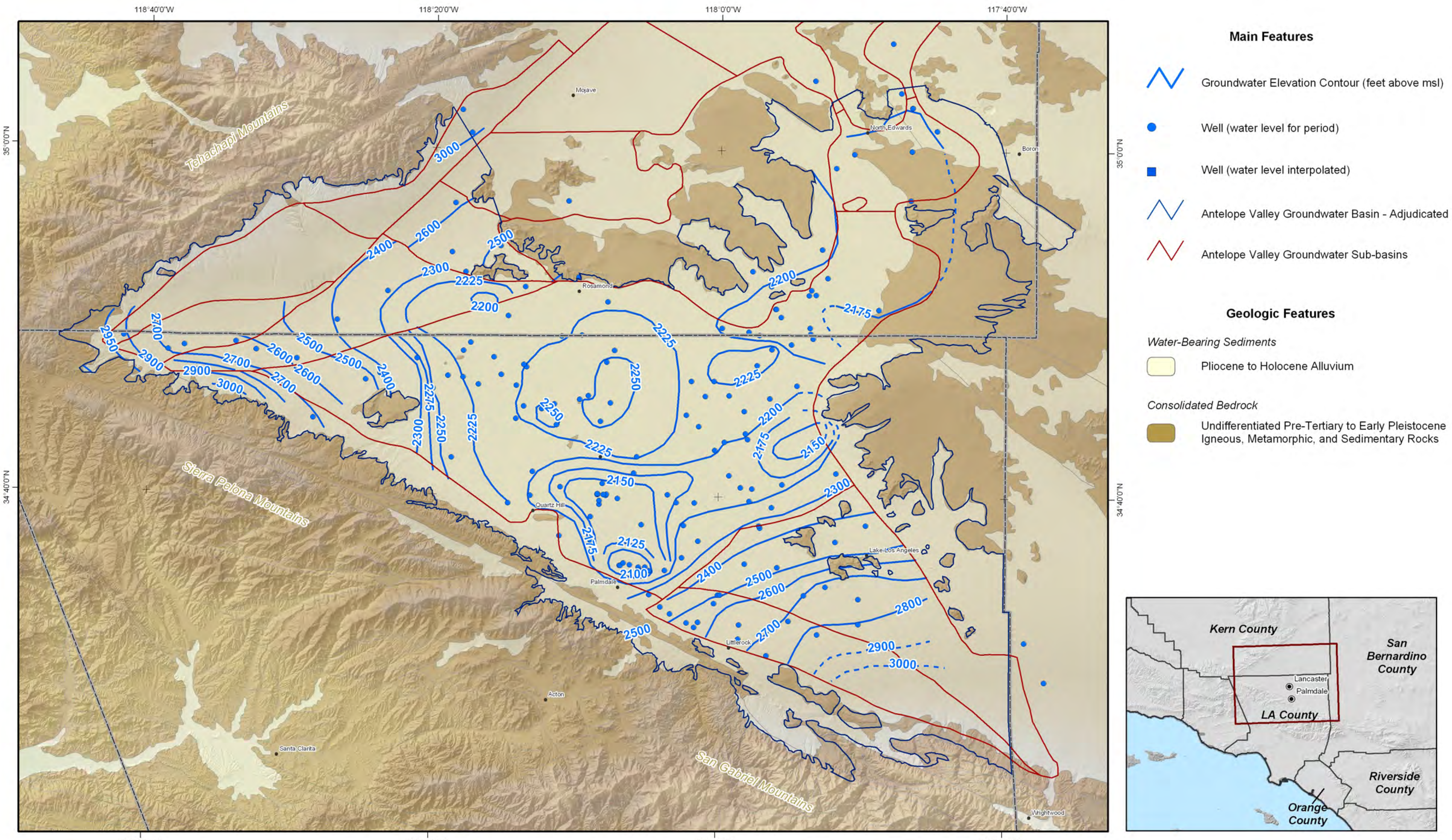
Groundwater Elevation Contours - 1992

Antelope Valley Groundwater Basin

Figure 4.3-6



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0 6 12 Miles
0 10 20 Kilometers

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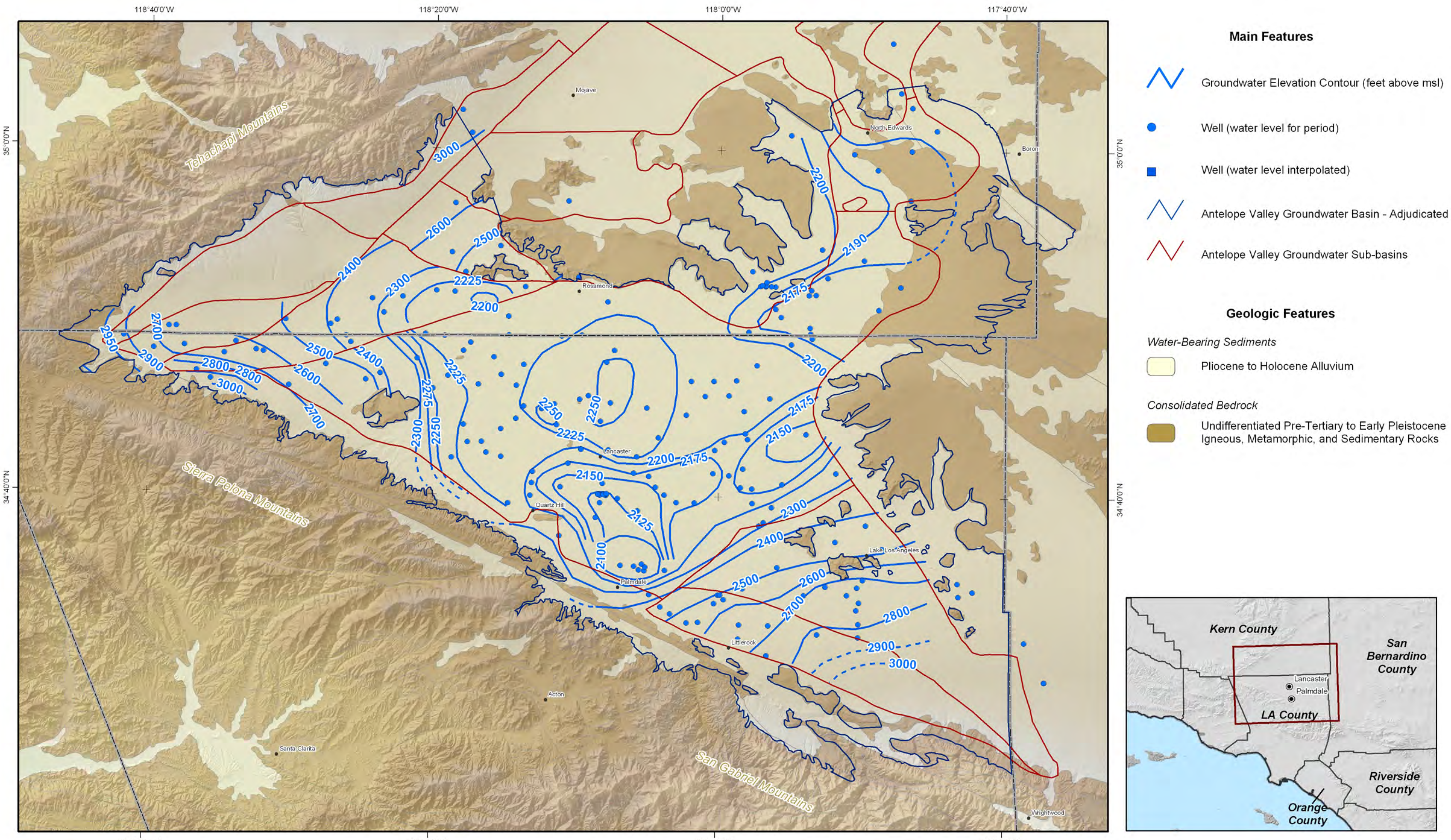
Groundwater Elevation Contours - 1998

Antelope Valley Groundwater Basin

Figure 4.3-7



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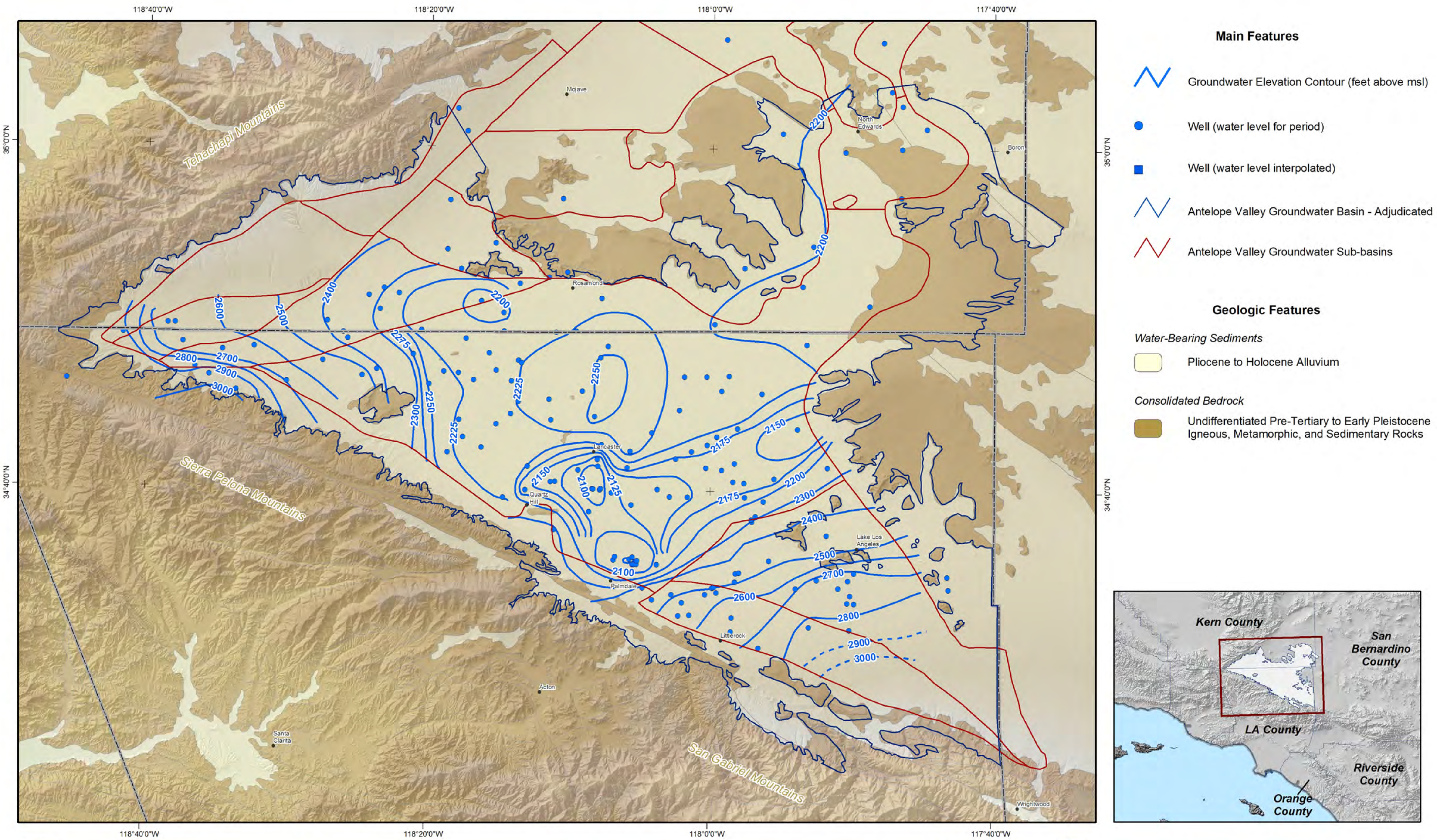
Groundwater Elevation Contours - 2005

Antelope Valley Groundwater Basin

Figure 4.3-8



Main Features

〰 Groundwater Elevation Contour (feet above msl)

● Well (water level for period)

■ Well (water level interpolated)

〰 Antelope Valley Groundwater Basin - Adjudicated

〰 Antelope Valley Groundwater Sub-basins

Geologic Features

Water-Bearing Sediments

🟨 Pliocene to Holocene Alluvium

Consolidated Bedrock

🟫 Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks

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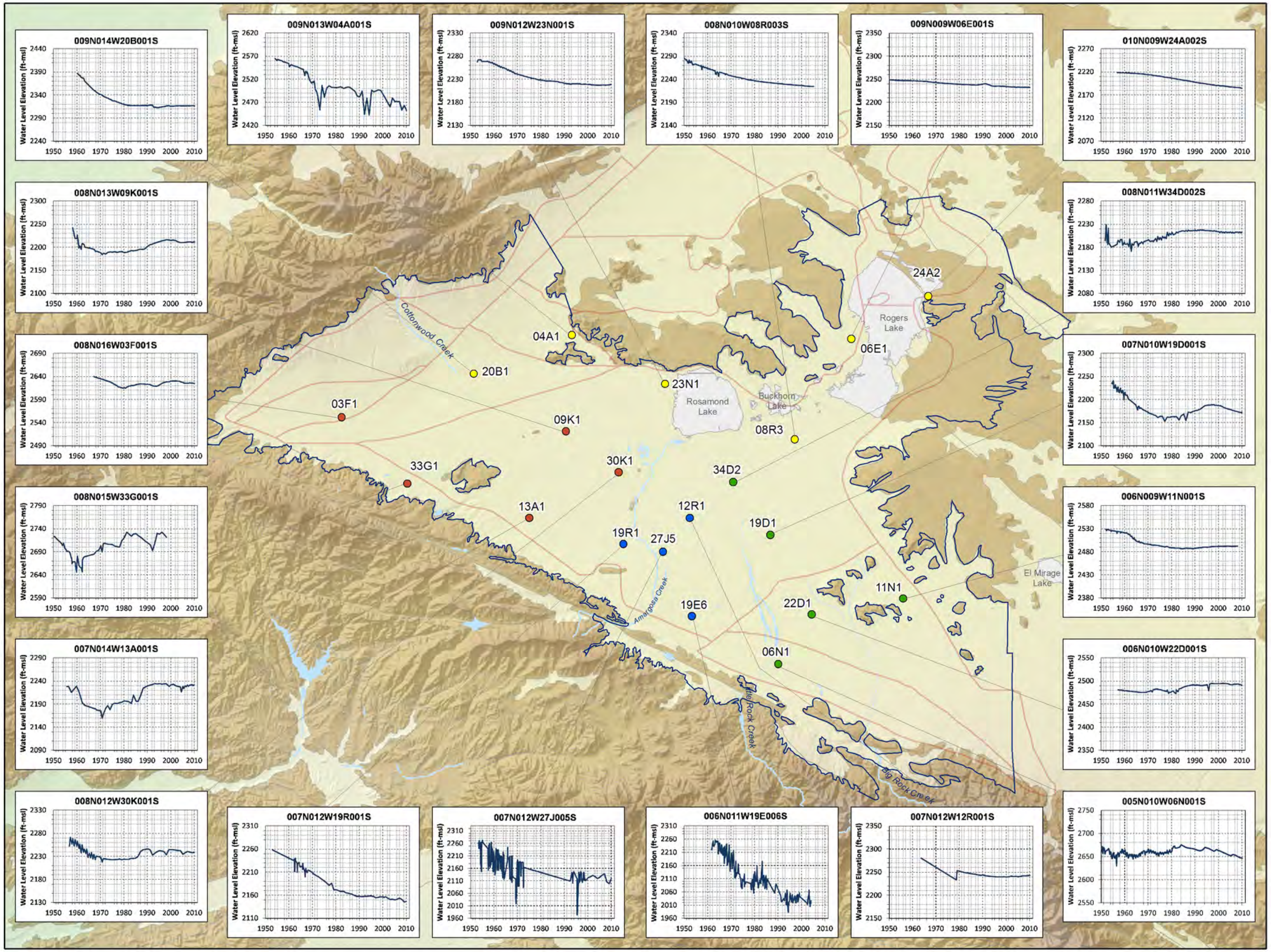
Groundwater Elevation Contours - 2009

Antelope Valley Groundwater Basin

Figure 4.3-9



Main Features

- 🔴 West Antelope Valley
- 🟢 East Antelope Valley
- 🟡 North Antelope Valley
- 🔵 South Antelope Valley
- Antelope Valley Groundwater Basin - Adjudicated
- Antelope Valley Groundwater Sub-basins

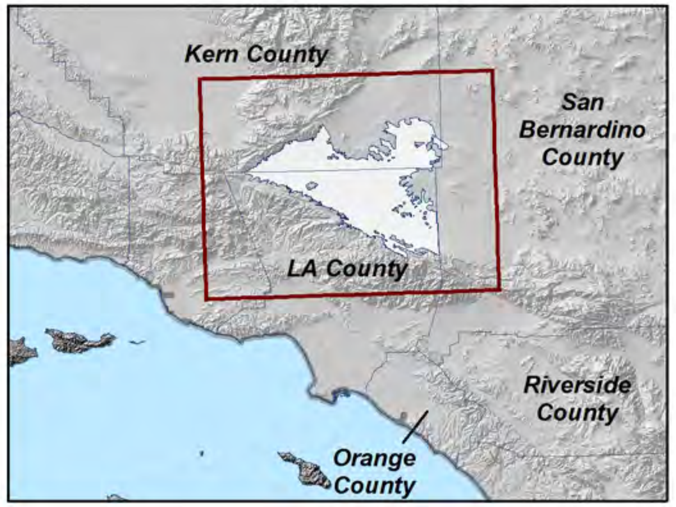
Geologic Features

Water-Bearing Sediments

- ▭ Pliocene to Holocene Alluvium

Consolidated Bedrock

- ▨ Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks



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File: hydrograph_analysis_report.mxd

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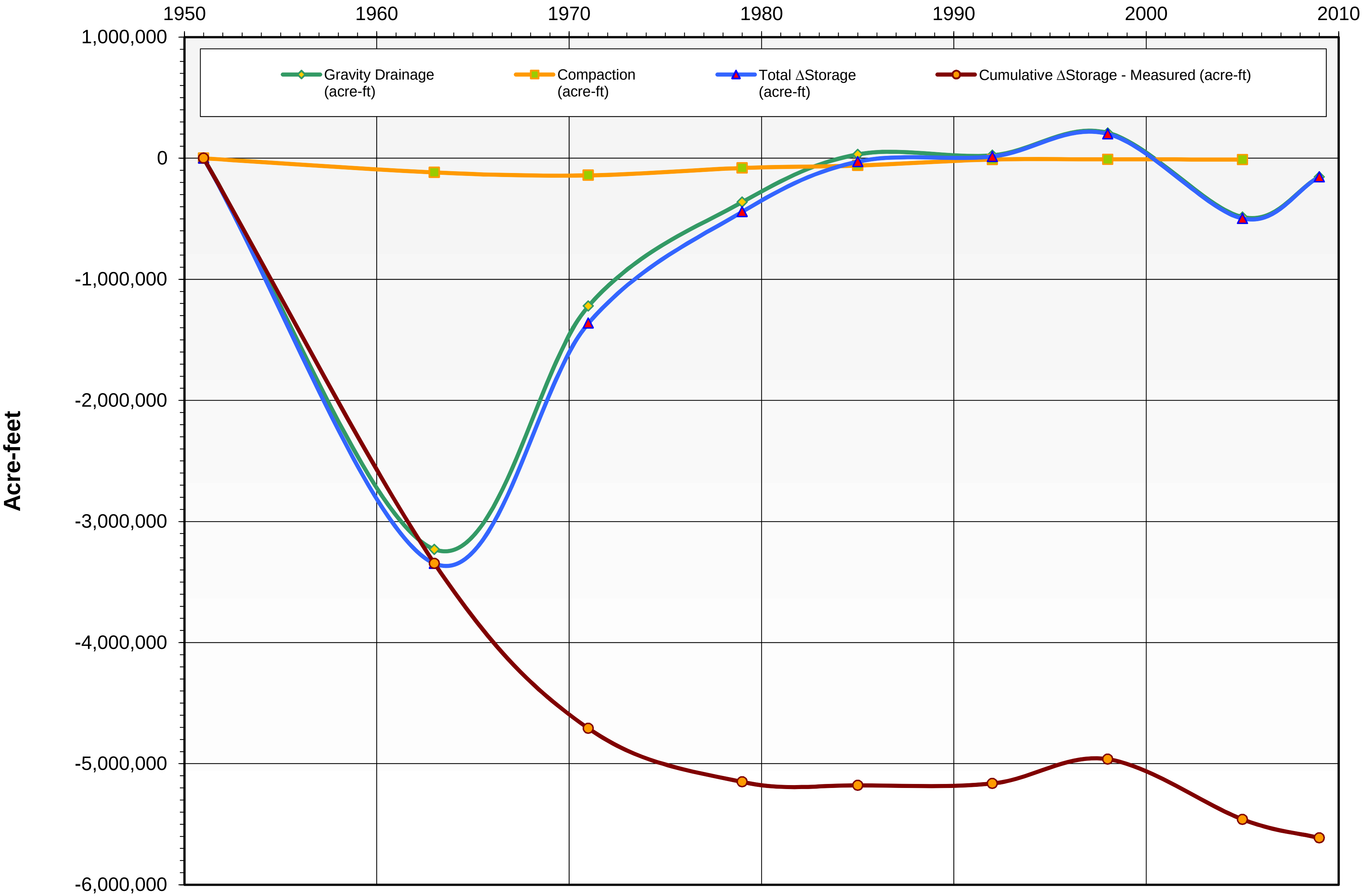
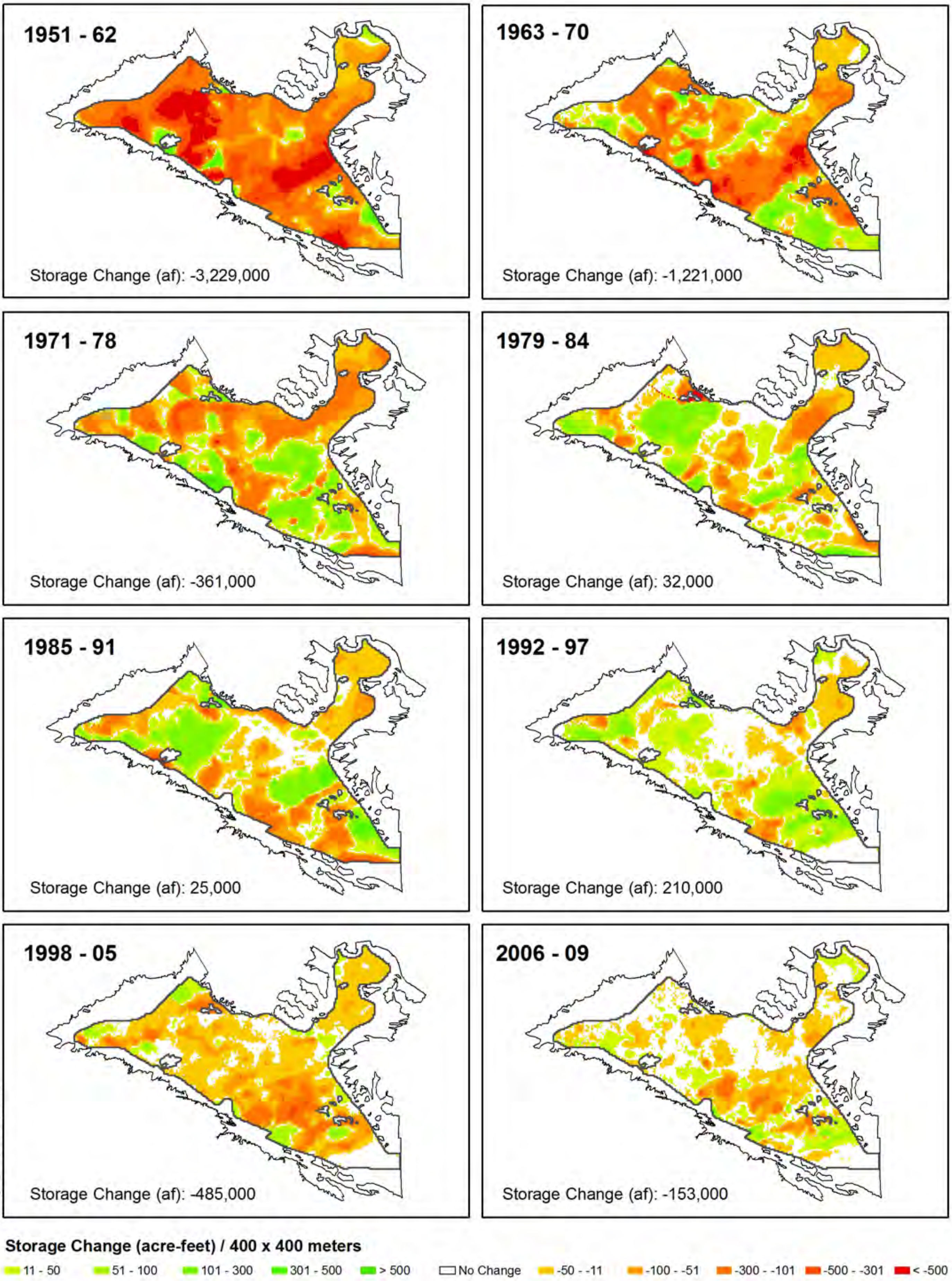
Groundwater Elevation Trends

Antelope Valley Groundwater Basin

Figure 4.3-10

Figure 4.3-11: Storage Change and Storage Change Components 1951 - 2009





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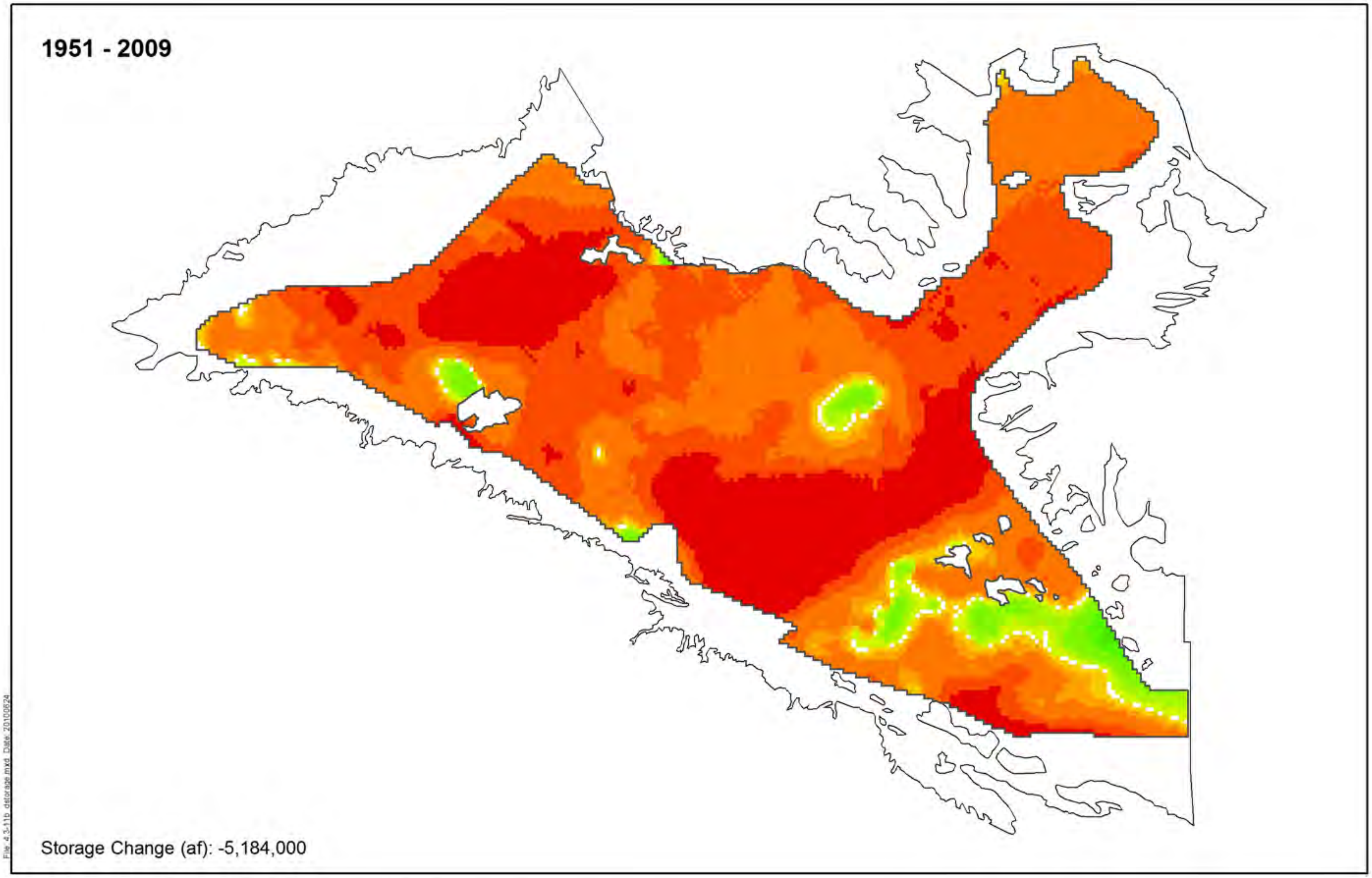
Groundwater Storage Change - Gravity Drainage

Antelope Valley, CA

Figure 4.3-12a



File: 4.3-11b_dstorage.mxd Date: 20100624

Storage Change (acre-feet) / 400 x 400 meters

🟩 11 - 50 🟩 51 - 100 🟩 101 - 300 🟩 301 - 500 🟩 > 500 ☐ No Change 🟨 -50 - -11 🟧 -100 - -51 🟧 -300 - -101 🟥 -500 - -301 🟥 < -500

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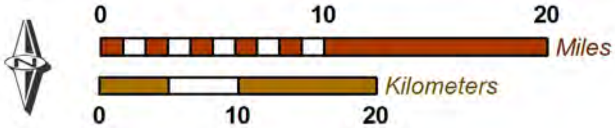


Groundwater Storage Change - Gravity Drainage

Antelope Valley, CA

Figure 4.3-12b

Figure 4.3-13: Water Derived from Compaction (Subsidence)

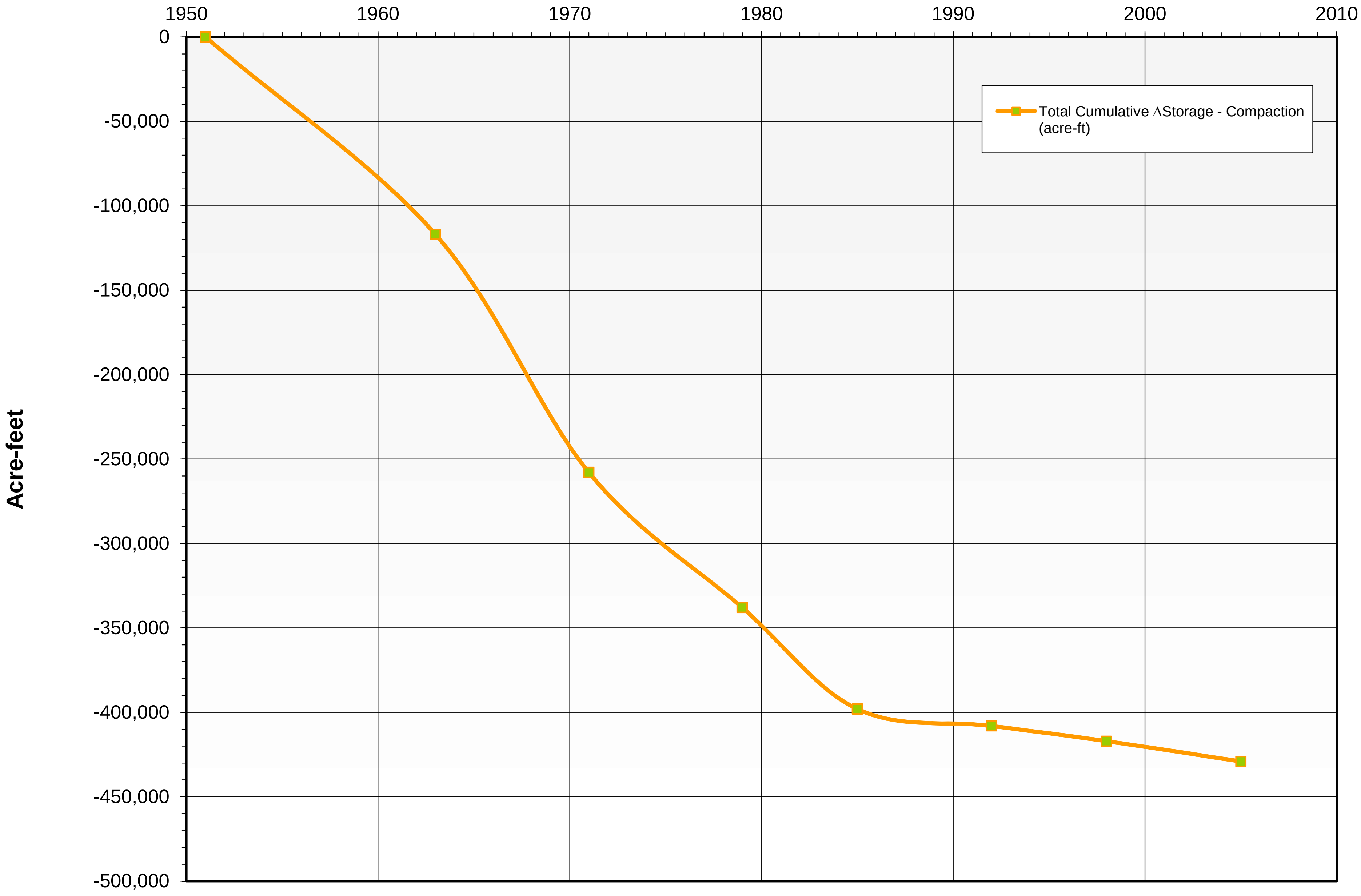
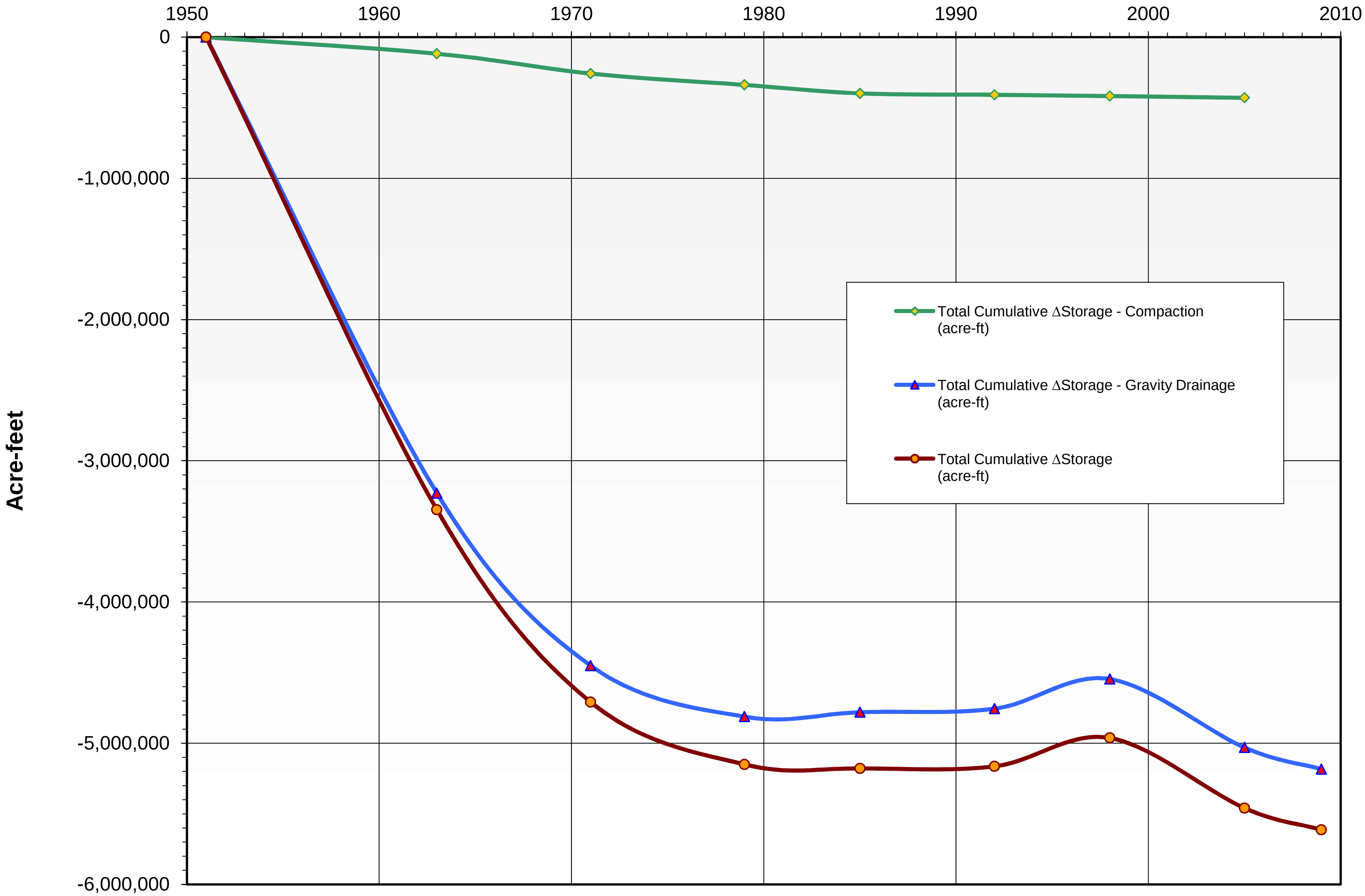


Figure 4.3-14: Change in Storage from Gravity Drainage and Compaction



4.4 Sustainable Groundwater Yield

The sustainable yield of a groundwater basin is considered to be the amount of pumping that, for given land use conditions, produces return flows which, in combination with other recharge, result in no long-term depletion of groundwater storage. Fundamentally, for all cases where groundwater is used on lands overlying a basin and where such uses produce return flows that ultimately reach the underlying aquifer system, those return flows result in the aquifer's ability to sustainably support pumping at a rate that is higher than the rates of natural or other recharge to the aquifer. In a simple form, sustainable yield is conceptually illustrated as shown in Figure 4.4-1.

Estimates of sustainable (production) yield are derived herein for both "native" and "supplemental" conditions. Those estimates are based on a combination of estimated natural recharge to the groundwater basin, utilization of supplemental water and its contribution to groundwater recharge, and land use practices in the AVAA that utilize water in different ways and thus contribute different amounts of return flows as contributions to groundwater recharge. Under native conditions, return flows derive from the use of local groundwater only; that return flow is the only source of recharge other than natural recharge that derives from local precipitation and runoff within the watershed surrounding the AVAA. Under supplemental conditions, return flows derive from the use of both local groundwater and supplemental water; those return flows add to other sources of recharge that include natural recharge plus any purposeful recharge of supplemental water.

Under both "native" and "supplemental" conditions, natural recharge is considered to be a constant average annual value that is representative of long-term average hydrologic conditions in the basin. Based on interpretation of historical hydrologic conditions, it can be expected that natural recharge will not actually be a constant average value every year; rather, there will be fluctuations in yearly hydrologic conditions, and fluctuations in resultant yearly amounts of natural recharge (see Section 4.1.3 and Appendix C). Ultimately, however, the basin can be expected to receive average natural recharge over a long-term period; and that recharge, in combination with return flows deriving from sustainable pumping (plus recharge from use of supplemental water), will result in fluctuating but long-term stable groundwater storage. Thus, under sustainable pumping conditions, groundwater levels and storage can logically be expected to fluctuate through wet and dry hydrologic cycles, but to be generally stable and not tend toward depletion of the resource on a long-term basis.

The long-term average annual natural recharge used for estimation of sustainable groundwater basin yield was derived from the results of the two independent analyses of natural groundwater recharge as described in Sections 4.1 and 4.3 above, and as detailed in Appendices C and E. Those analyses reached independent estimates of long-term natural recharge of about 55,000 to 58,000 afy. In light of the nature of the respective methods, those results were interpreted to reflect average long-term natural recharge of about 60,000 afy. Sustainable groundwater basin yield was then estimated by adding components of return flow that derive from the various uses of water in the AVAA, and thus contribute to additional groundwater recharge.

Recognizing that agricultural and municipal-type land uses contribute different return flow fractions that, in turn, contribute to the sustainable yield of the groundwater basin, it is evident that sustainable yield is not necessarily a constant and can be, on the other hand, a variable that is dependent on prevailing land use in the basin. Recognizing also that groundwater recharge primarily derives from both natural supplies (i.e. local precipitation and runoff) and supplemental supplies (e.g. local surface water and imported water), it is further evident that sustainable yield is not necessarily a constant and is, on the other hand, a variable that is also dependent on prevailing water supplies and utilization of water supplies to meet water requirements and/or to otherwise manage water resources.

To capture the variations in the preceding factors, which are commonly described as part of cultural conditions in a given basin, two sets of sustainable yields were prepared for the AVAA: one set for different mixes of land use under “native” conditions, where only natural recharge is the primary source of sustainable groundwater supply in the basin; and a second set, also for different mixes of land use but under “supplemental” conditions, where natural recharge is augmented by recharge from the use of supplemental water supplies such as has occurred with the importation of SWP water since the 1970’s. In both sets of estimated sustainable yield, land use mixes were based on actual conditions as have occurred in both earlier and recent times, as described below. Details of the native and supplemental sustainable yield estimates are included in Appendix F; following are summaries of sustainable groundwater yields for the AVAA under native and supplemental recharge conditions.

4.4.1 Native Sustainable Yield

Native sustainable yield is the amount of pumping which, under a given set of land use and other prevailing cultural conditions, generates return flows that, when combined with long-term average natural recharge, result in no long-term depletion of groundwater storage. As discussed above, native sustainable yield is not a constant in that it can vary as a function of differing mixes of land use. Recognizing the evolution of land use practices in the basin over the last several decades, estimates of native sustainable yield were derived as follows for four sets of land use conditions: 1) early historical conditions when essentially all land use was devoted to agriculture; 2) mixed agricultural and municipal-type land use as existed, on average, over the five-year period immediately prior to the filing of the present adjudication, 1995-1999; 3) mixed agricultural and municipal-type land use as existed, on average, over the ten-year period 1996-2005 at the end of the overall base period used in this report; and 4) mixed agricultural and municipal-type land use as was present in 2005, at the end of the overall base period used in this report.

In all the estimates based on those historical mixes of land uses, it should be noted that the sustainable yield values are estimated to reflect the amount of pumping that the AVAA could sustainably support if land uses had developed in the proportions as actually existed in the respective scenario periods. For purposes of estimating sustainable groundwater pumping, total land and water uses are idealistically limited to result in sustainable groundwater pumping. Other than serving as bases for the proportions of respective land use types, the magnitudes of actual land and water uses have no bearing on estimated sustainable groundwater basin yield.

When the AVAA was predominately dedicated to irrigated agriculture, throughout its period of significant increase in groundwater pumping through the 1960's, the sustainable yield that derived from about 60,000 afy of average natural recharge would be about 80,000 afy. As municipal-type land use increased in the 1990's and beyond 2000, the slightly higher return flows associated with that type of land use contributed to a small increase in native sustainable yield, to about 82,300 afy. The evolution of land uses from the mid 1990's to present has had no impact on native sustainable yield. Under all three sets of land use conditions that were considered (prevailing land uses prior to the initial filing of the current adjudication, average 1996-2005 land use conditions, and most recent (2005) land use conditions) native sustainable yield was consistently 82,300 afy. The respective estimates of native sustainable yield are summarized in Table 4.4-1.

In summary, for the range of land uses as have occurred over most of the last 15 years, native sustainable groundwater yield (relying only on natural recharge as the primary source of groundwater recharge) is about 82,300 afy.

4.4.2 Sustainable Yield with Native and Supplemental Waters

Since the mid-1970's, groundwater supplies in the AVAA have been augmented by importation of supplemental water from the State Water Project (SWP). Groundwater supplies have also been, and continue to be, augmented by local surface water diversions from Littlerock Creek; however, in comparison to SWP deliveries, the local surface water diversions are relatively small. Since the mid-1990's, for the various periods used to estimate sustainable yield, SWP imports have been between about 50,000 and 80,000 afy. During that same time, local surface water diversions have ranged up to nearly 7,000 afy. The use of all supplemental water supplies contributes to an increase in the sustainable yield of the groundwater basin since, depending on how the supplemental waters are used, the uses produce an additional amount of groundwater recharge (supplemental recharge) that adds to natural recharge. The contribution of supplemental water use to sustainable groundwater yield is conceptually illustrated in Figure 4.4-2.

As with the estimates of native sustainable yield above, estimates of sustainable yield for a combination of native and supplemental conditions need to recognize that they are similarly dependent on land and water use practices, including prevailing practices related to how supplemental waters are used in the AVAA and how they thus add groundwater recharge to that which occurs naturally. In this case, of course, they are also dependent on the amounts of supplemental water that are used to produce additional groundwater recharge that, in turn, supports additional sustainable yield. Recognizing those factors, estimates of total sustainable yield, and the incremental increases attributable to utilization of supplemental waters, were derived for three sets of land use conditions that coincide with those used for the native yield estimates above, but when supplemental water was also being used: 1) mixed agricultural and municipal-type land uses as existed, on average, over the five-year period immediately prior to the filing of the present adjudication, 1995-1999; 2) mixed agricultural and municipal-type land uses as existed, on average, over the ten-year period 1996-2005 at the end of the overall base period used in this report; and 3) mixed agricultural and municipal-type land uses as were present in 2005, at the end of the overall base period used in this report.

Throughout the periods considered for estimating total sustainable yield, the respective proportions of agricultural and municipal-type land uses have been comparable, with both increasing in the late 1990's, followed by some agricultural decline in the 2000's and general stability in municipal-type land use over that same time. For the five year period prior to the filing of the current adjudication, average use of supplemental water was nearly 68,000 afy. Its use augmented natural recharge sufficiently to support total sustainable groundwater yield of nearly 108,000 afy. Since then, use of supplemental water has increased, to an average of about 73,000 afy over the 1996-2005 period, and to 73,500 af in 2005; these uses augmented natural recharge to support increases in sustainable yield to about 110,000 afy. The respective estimates of total sustainable yield, including the incremental increases attributable to the use of supplemental water, are summarized in Table 4.4-1.

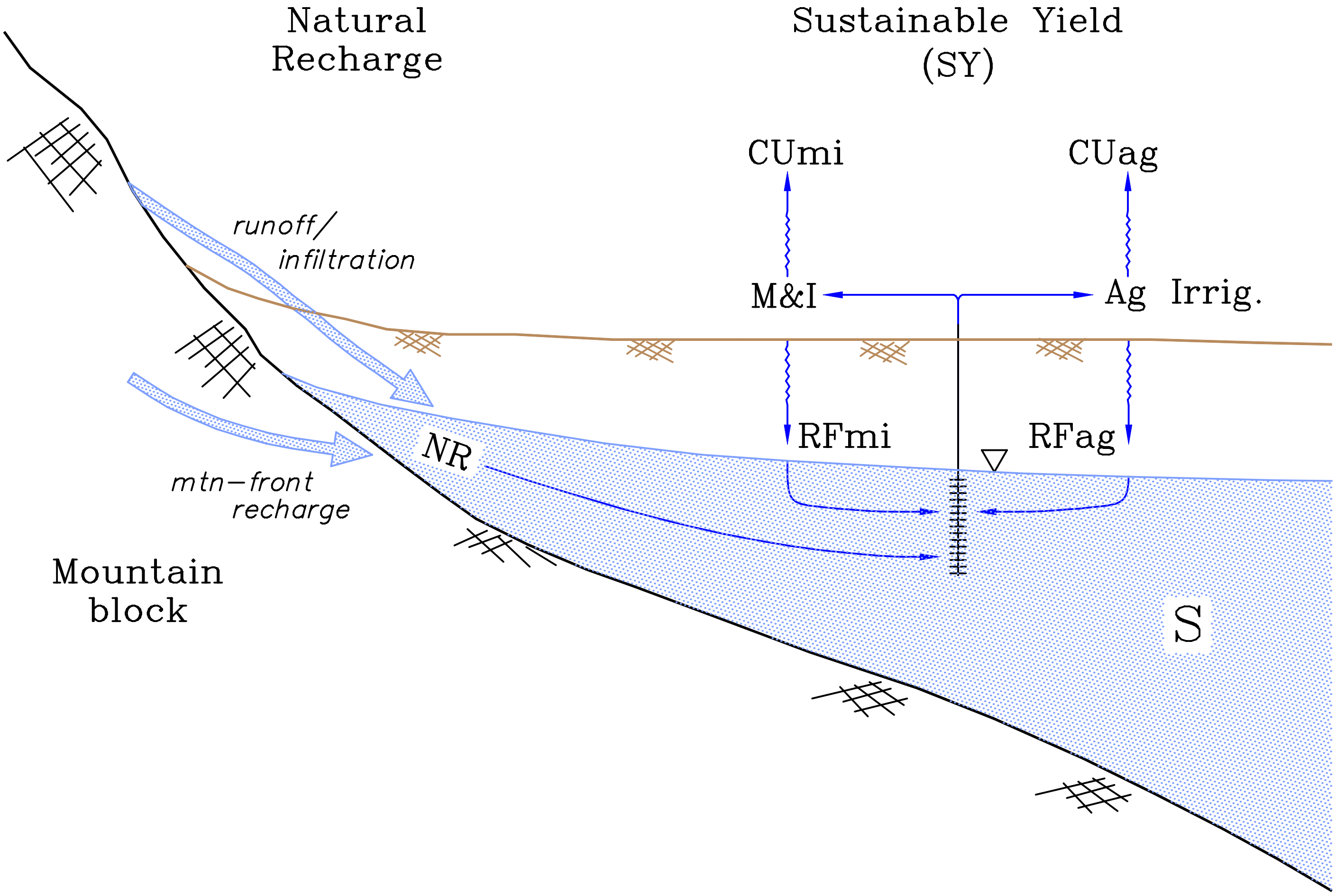
A final consideration with regard to the increment of total sustainable yield that derives from utilization of supplemental water supplies is allocation, or attribution, of the incremental yield increase to the types of land use that utilize the water in such ways that it adds new recharge which, in turn, contributes to additional yield. In earlier years, e.g. through the 1995-99 period prior to the initial filing of the current adjudication, a larger fraction of supplemental water was being used by agriculture; as a result, about 25 percent of the increase in total sustainable yield can be considered to have been attributable to agricultural land uses at that time, with the balance (about 75%) attributable to municipal-type uses of supplemental water. With time, supplemental water use and the fraction of it used by municipal-type land uses both increased; by 2005, municipal-type land uses were responsible for about 89 percent of the increase in sustainable groundwater yield due to supplemental water use in the AVAA. The respective contributions to increases sustainable yield for the time periods considered herein are included in summary Table 4.4-1.

4.4.3 Summary

As would logically be expected, with the additional recharge that has derived from the use of supplemental water in the AVAA, the sustainable groundwater yield has been increased above native conditions. For the mixes of land use that have occurred since the mid-1990's, native sustainable yield has been about 82,300 afy. Depending on what time period is selected to be representative of prevailing or otherwise applicable conditions (recognizing the variations in imported water supply and its utilization in the three scenarios described above), total sustainable yield has increased to as much as about 110,000 afy as a result of supplemental water use. Of that increase, again depending on what time period is considered representative, the respective contributions to the increase vary as a result of the respective agricultural and municipal-type uses of supplemental water. For the time periods represented by the scenarios herein, the native and supplemental sustainable yield values are summarized in the following table; included in the table are the contributions to increased sustainable yield by agriculture and by municipal-type uses as a result of their respective uses of imported water.

Table 4.4-1
Sustainable AVAA Groundwater Yield Summary

Scenario	Land Use Period and Type	Native Sustainable Yield (afy)	Supplemental Sustainable Yield (afy)	Total Sustainable Yield (afy)	Contribution to Yield Increase (afy)	
					Ag.	M&I
1	Pre-1970's (all ag.)	80,000	---	---	---	---
2a/3a	1995-1999 (mixed ag-M&I)	82,300	25,300	107,600	6,500	18,800
2b/3b	1996-2005 (mixed ag-M&I)	82,300	27,500	109,800	5,500	22,000
2c/3c	2005 (mixed ag-M&I)	82,300	28,200	110,500	3,200	25,000



Sustainable Yield (SY) = Natural Recharge (NR) + Ag Return Flows (RFag) + M&I Return Flows (RFmi)
(when S = constant over time)

Ag = agricultural irrigation

M&I = municipal and industrial use

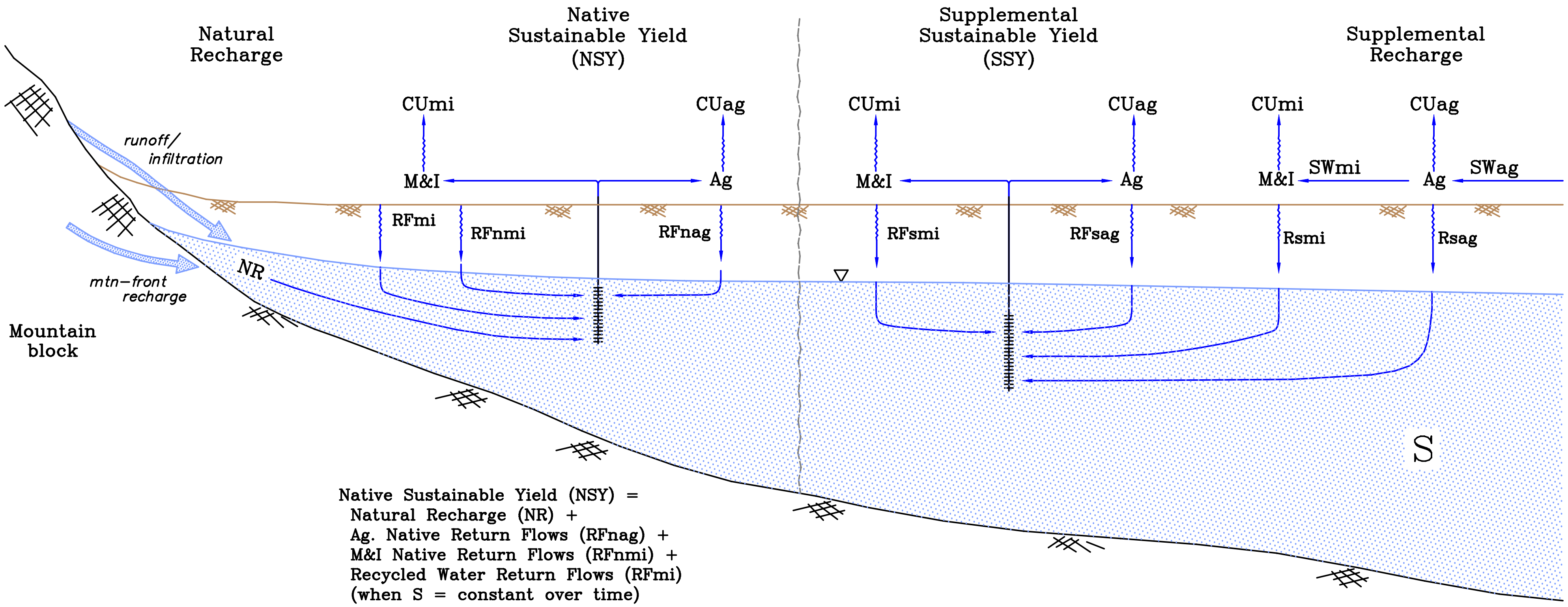
CU = consumptive use

S = groundwater storage

CAD FILE: G:/Projects/Antelope Valley/06-6-075/AV Sustainable Yield Diagram.dwg

LUHDORFF & SCALMANINI
CONSULTING ENGINEERS

Figure 4.4-1
Schematic Illustration of Sustainable Yield
Antelope Valley Area of Adjudication



Native Sustainable Yield (NSY) =
Natural Recharge (NR) +
Ag. Native Return Flows (RFnag) +
M&I Native Return Flows (RFnmi) +
Recycled Water Return Flows (RFmi)
(when S = constant over time)

Supplemental Sustainable Yield (SSY) =
Recharge from Ag. Use of Supp. Water (Rsag) +
Recharge from M&I Use of Supp. Water (Rsmi) +
Ag. Supp. Return Flows (RFsag) +
M&I Supp. Return Flows (RFsmi)
(when S = constant over time)

Ag = agricultural irrigation
M&I = municipal and industrial use
CU = consumptive use
SW = supplemental water
S = groundwater storage

CAD FILE: G:/Projects/Antelope Valley/06-6-075/AV NST Sustainable Yield Diagram.dwg

Figure 4.4-2
Schematic Illustration of Native, Supplemental, and Total Sustainable Yield
Antelope Valley Area of Adjudication

4.5 Land Subsidence and Storage Change from Compaction

4.5.1 Groundwater Withdrawals and Land Subsidence

Land subsidence is the sinking of the Earth's surface due to the rearrangement of subsurface materials. In the United States alone, over 17,000 square miles in 45 states have experienced land subsidence (Galloway, 1999). In many instances, land subsidence is accompanied by adverse impacts at the land surface, such as sinkholes, earth fissures, encroachment of adjacent water bodies, modified drainage patterns, and others. In populated regions, these subsidence-related impacts can result in severe damage to man-made infrastructure and the need for costly remediation measures.

Over 80 percent of all documented cases of land subsidence in the United States have been caused by groundwater extractions from underlying aquifer systems (Galloway, 1999). Groundwater extraction is an especially well-documented cause of subsidence in the arid southwestern United States where aquifer systems are typically composed of unconsolidated sediments that are susceptible to permanent compaction when groundwater is extracted. Some infamous examples include the San Joaquin and Santa Clara Valleys in California, the Las Vegas Valley in Nevada, the Houston-Galveston area in Texas, and several basins in Arizona. In many of these regions, fissuring occurred in areas of differential subsidence (i.e. where rates of subsidence vary over short horizontal distances).

Although the drawdown of groundwater levels is the driving force that causes land subsidence, the geology of a groundwater basin also plays an important role. Clay layers within the aquifer system are relatively compressible materials. Therefore, aquifer systems that contain thick and/or numerous clay layers are more susceptible to permanent compaction and land subsidence when groundwater is extracted. In addition, faults that act as groundwater barriers can focus and augment drawdown in the aquifer system when pumping wells are located nearby. When pumping and drawdown are concentrated on one side of a fault barrier, differential land subsidence and ground fissuring are a possible result.

The scientific model that describes the phenomenon of pumping-induced land subsidence is termed the aquitard-drainage model. This model has been successfully applied to numerous cases of land subsidence world-wide. It has been incorporated into the industry-standard computer models of groundwater flow and is increasingly recognized as critical to the understanding of aquifer-system hydraulics (flow and storage) and mechanics (deformation). The following is a brief summary of the aquitard-drainage model.

An aquifer system consists of permeable sand and gravel layers (the aquifers) interbedded with less-permeable silt and clay layers (the aquitards). Pumping wells cause water level drawdowns in the aquifers that, in turn, cause aquitards to slowly drain into the aquifers. The draining allows aquitard pore pressures to decay toward equilibrium with the reduced heads in the adjacent aquifers. Since the pressure of the pore water provides some internal support for the sedimentary structure of the aquitards, this loss of internal support causes the aquitards to compress, resulting in a small amount of subsidence at the land surface. When the pumping wells turn off and water levels recover in the aquifers, groundwater migrates back into the aquitards and they expand, resulting in a small amount of rebound at the land surface. Over a limited range of seasonal water level fluctuations this process can occur in a purely elastic fashion. That is, a recovery of water levels to their original values causes the land surface to rebound to its original elevation. However, when drawdown falls below a certain “threshold” level, elastic compression transitions to a non-recoverable inelastic compaction of the aquitards. The “threshold” water level, referred to as the preconsolidation stress, is taken to be the maximum past stress to which the sedimentary structure had previously equilibrated under the gradually increasing load of accumulating sediments.

Drawdowns exceeding a previous threshold water level result in an increase in the value of maximum past stress and, thus, the establishment of a deeper threshold, accompanied by an increment of inelastic aquitard compaction. Concomitantly, the compaction results in a one-time irreversible mining of groundwater from the aquitards and the deformation and subsidence of the land surface.

4.5.2 Land Subsidence in the Antelope Valley

Historical land subsidence in the Antelope Valley is attributed to the lowering of groundwater levels beyond the preconsolidation stress of the underlying materials (Leighton, 2003). Figure 4.5-1 shows subsidence measured from 1930-1992 and the approximate extent of lacustrine (clay) deposits (Leighton, 2003), which are attributed to be the primary compressible material in the Antelope Valley (Ikehara & Phillips, 1994). Between 1930 and 1992, the ground surface subsided by a maximum of about 6.6 feet. The water derived from the compaction of aquitards is a non-renewable source of recharge to the aquifer-system.

The water derived from compaction of sediments must be accounted for in the water budget; otherwise, estimates of natural recharge would be artificially high. In this Summary Report, the estimates of the water derived from compaction are conservative in that the water from the compaction of sediments where subsidence was less than one foot is not accounted for in the water budget.

4.5.3 Calculation of Water Derived from Compaction

A GIS model was developed to estimate the volume of water that was derived from the compaction of sediments in the AVAA. The model is based on the premise that the volume of water derived from compaction of aquitards is virtually equal to the volume of land subsidence. In 1994, Ikehara and Phillips published a paper: “Determination of Land Subsidence Related to Groundwater-Level Declines using Global Positioning System and Leveling Surveys in Antelope Valley, Los Angeles and Kern Counties, California 1992.” This paper was the source of the data that were used in this volumetric calculation of subsidence. A series of contour maps (Ikehara, 1994) that show the average annual rate of subsidence in the Antelope Valley were produced for the following periods: 1957-62, 1962-65, 1965-72, 1972-75, 1975-81, and 1981-92. The following steps were executed to calculate the volume of subsidence (i.e. water derived from the compaction of aquitards):

- Digitize the Ikehara average annual rate of subsidence contour maps and import files into ArcGIS as shapefiles.
- Create a polygon shapefile that surrounds the smallest contour (0.03 feet per year) for each time interval (hereafter, time interval extent polygon). This polygon becomes a conservative estimate of the extent of land affected by subsidence.
- Convert the “annual rate of subsidence contours” into “total amount of subsidence contours” for the native yield time periods. To accommodate the difference between the subsidence time interval and the native yield time intervals, 11 shapefiles were created.
- Create three-dimensional raster surfaces (ESRI grids) of the total amount of subsidence for each set of subsidence contours using an Ordinary Kriging method of interpolation. The rasters are clipped to the appropriate time interval extent polygon.
- Calculate the volume of subsidence for each time period using the Surface Analysis function within the 3D Analyst extension of ArcGIS.
- Sum the volume of subsidence over each natural recharge or change in storage time period. These estimates of the volume of subsidence approximately equate to the volume of water derived from the compaction of the aquitards and are shown in Table 4.5-1 and Figure 4.5-2.

The volume of water derived from compaction between 1951 and 2005 was approximately 400,000 acre-ft. Figure 4.5-2 shows the cumulative volume of water derived from subsidence and clearly shows that the majority of the subsidence occurred between 1957 and 1981.

Table 4.5-1: Summary of Water Derived from Compaction 1930 - 2005

Subsidence Rate Time Period	Period Length (years)	Volumetric Rate of Subsidence (acre feet/year)	Water Derived from Compaction (acre feet)	Natural Recharge Time Period	Water Derived from Compaction (acre feet)
1951-57[1]	6	2978	17,868	1951-63[3]	116,976
1957-62	5	17737	88,683		
1962-63	1	10425	10,425		
1963-65	2	41994	83,988	1963-71	141,222
1965-71	6	9539	57,234		
1971-72	1	19078	19,078	1971-85	140,349
1972-75	3	18870	56,611		
1975-81	6	9778	58,667		
1981-85	4	1498	5,993		
1985-92	7	1498	10,488	1985-92	10,488
1992	1	1498	1,498	1992-98[2]	8,990
1993-98[2]	5	1498	7,492		
1998-05[2]	8	1498	11,987	1998-05[2]	11,987

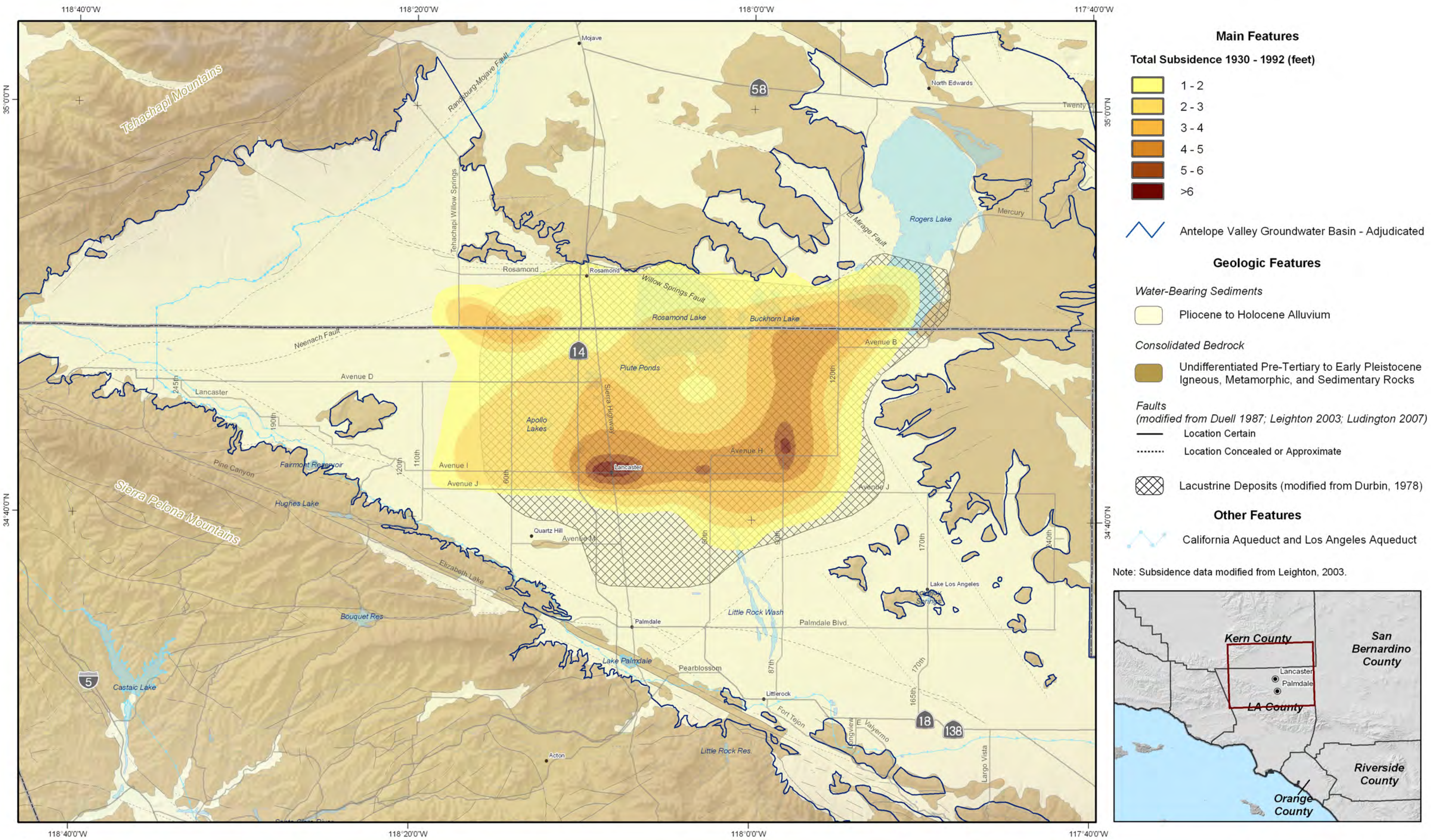
Notes:

1) Values derived from the average rate of subsidence from 1930-1957 (2,978 af/yr).

2) Estimates based upon the assumption that water from compaction remains stable at 1992 rates (1,498 af/yr) over the time periods 1992-1998 and 1998-2005.

3) The sum of the measured subsidence from 1957-1963 (99,108 af) and the average rate of subsidence from 1930-1957 (2,978 af/yr) over the period 1951-1957 (2,978 af/yr x 6 yrs).

N/A = Rate of subsidence data for the specific time period not available.



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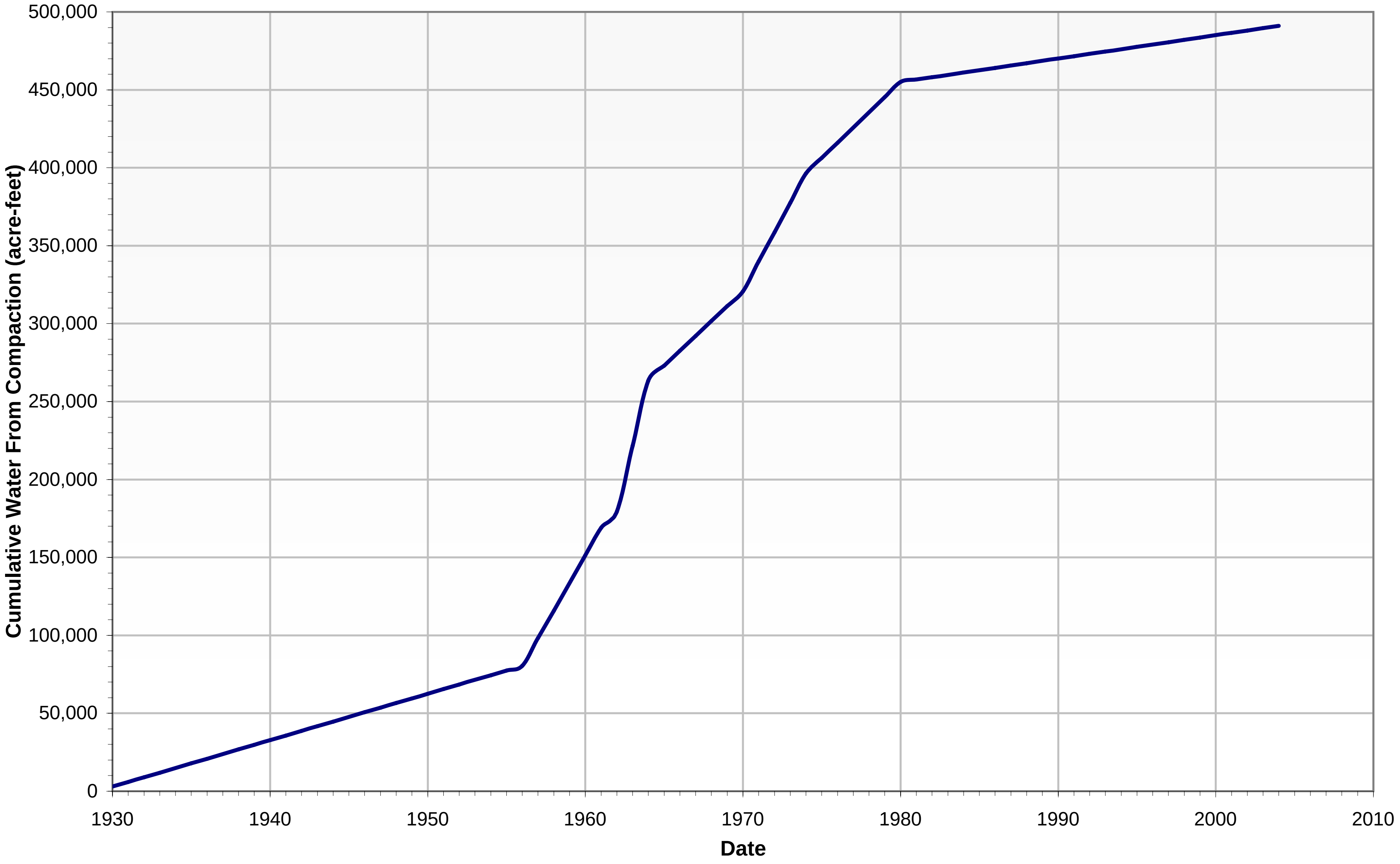
Author: WEL
Date: 20071017
File: 20071017_subsidence.mxd

Total Subsidence - 1930 to 1992

Antelope Valley Groundwater Basin

Figure 4.5-1

Figure 4.5-2: Water Derived from Compaction (Subsidence)



4.6 Recycled Water

The primary recycled water plants within the designated boundary of the AVAA groundwater basin are the Lancaster Water Reclamation Plant (LWRP) and the Palmdale Water Reclamation Plant (PWRP). Other recycled water facilities in the basin include Rosamond Community Services District and at the Edwards Air Force Base (EAFB). The locations of these recycled water facilities are shown in Figure 4.6-1. This section of the report provides a discussion of historic and proposed facilities for each plant, historic and projected future amounts of recycled water produced by each plant, and historic and proposed methods of recycled water discharge. A more detailed discussion of recycled water supplies is provided in Appendix G.

4.6.1 Lancaster Water Reclamation Plant

The LWRP facilities were built in 1959 and are operated by County Sanitation District No. 14 of Los Angeles County (District No. 14). Historically, the vast majority of recycled water produced at LWRP has received secondary treatment, with a small amount of tertiary treated water (up to 0.5 mgd) being generated since 1969 (ESA, 2004a). The locations of the treatment facilities are shown in Figure 4.6-2. The LWRP currently has a permitted capacity of 16 million gallons per day (mgd).

Available data for the annual amounts of influent received and effluent produced by LWRP date back to 1975. The amount of recycled water generated by the facility has increased from 1.4 million gallons per day (mgd) or 1,600 acre-feet per year (afy) in 1976 to 13,000 – 14,000 afy since 2004 (Figure 4.6-3). Recycled water from LWRP has been discharged to Paiute Ponds, Nebeker Ranch, Apollo Lakes and Park, and via evaporation from treatment ponds and storage reservoirs (Figure 4.6-2). Historic estimates of the annual amounts of recycled water discharged by these methods are presented in Table 4.6-1. Over the last decade, Paiute Ponds has received 50 to 70 percent (6,700 to 9,700 afy) of the total recycled water produced at LWRP, Nebeker Ranch received 30 to 37 percent of the total (3,900 to 5,000 afy), and Apollo Lakes received about 1.5 percent of the total (about 200 afy).

During the winter months in recent years, recycled water overflows from the storage reservoirs and Paiute Ponds to Rosamond Dry Lake. Since overflows of recycled water to Rosamond Dry Lake may be considered a nuisance condition by EAFB, District No. 14 has been ordered by the Regional Water Quality Control Board (RWQCB) to maintain Paiute Ponds but minimize the overflows to Rosamond Dry Lake. As part of this mandate, District No. 14 is planning to upgrade its facilities to tertiary treatment with additional storage reservoirs and additional discharge/reuse capacity to meet RWQCB requirements (ESA, 2004a).

4.6.2 Palmdale Water Reclamation Plant

The Palmdale Water Reclamation Plant (PWRP) began operations in 1953, and is operated by County Sanitation District No. 20 of Los Angeles County (District No. 20). Historically, the recycled water produced at PWRP has received secondary treatment. The amount of influent to the facility has increased from 0.22 mgd (or 250 afy) in 1954 to 8,900 – 9,500 afy since 2000 mgd(Figure 4.6-4). Prior to 1980, recycled water was discharged via pond evaporation, pond percolation, and agricultural reuse operations. In accordance with a contract agreement between District No. 20 and Los Angeles World Airports (LAWA), discharge operations were directed by LAWA between 1981 and 2002. Recycled water from PWRP was discharged by LAWA primarily via land application with a small amount being used for agricultural reuse operations. Since 2002 recycled water from PWRP has been increasingly discharged via agricultural reuse operations under the direction of District No. 20. Estimates of the historic annual amounts of recycled water discharged by these methods are presented in Table 4.6-2. The historic effluent management area is shown in Figure 4.6-5.

Historic recycled water discharge practices involving land application and agricultural reuse above agronomic rates contributed to elevated nitrate concentrations in the upper 150 feet of the water table below the effluent management area. In 2000, District No. 20 and LAWA were ordered to take action to mitigate suspected elevated nitrate concentrations in groundwater by the RWQCB. Among other actions, District No. 20 renegotiated its agreement with LAWA in 2002 to regain control of recycled water discharge practices. Recycled water discharge practices involving land application and agricultural irrigation above agronomic rates have gradually been phased out since 2002 by District No. 20. Land application practices had largely ceased by the end of 2005.

4.6.3 Rosamond CSD Plant

Rosamond Community Services District (RCSD) operates a single wastewater treatment facility that is designed for a treatment capacity of 2.0 mgd. The average daily recycled water flow rate as of 2000 was estimated at 1.05 mgd. Recycled water is discharged to a series of 17 clay-lined oxidation/evaporation ponds which are considered to contain infiltration, resulting in no deep percolation and associated groundwater recharge from those ponds. The pond capacity is designed to handle the winter season flows without need for other discharge facilities (RWQCB, May 2000).

4.6.4 Edwards AFB Plant

The EAFB Main Base Wastewater Treatment Plant consists of tertiary treatment facilities that discharge recycled water to evaporation ponds and reclamation sites. As of 2001, the facility was permitted for treating a design average daily flow of 2.5 mgd and for a design peak daily flow of 4.0 mgd (RWQCB, 2001). Based on data obtained from EAFB for the years from 2000 to 2006, the amount of recycled water produced by the facility ranged from 0.79 mgd in 2001 and 2003 (880 afy) to 1.46 mgd in 2005 (1,630 afy). In 2005, 720 AF was applied for irrigation and the remaining 910 AF was discharged to the evaporation ponds.

4.6.5 Deep Percolation of Recycled Water

Water balances for the LWRP and PWRP were constructed based upon available data and reports. The estimated annual amounts of deep percolation for LWRP and PWRP were determined from the water balances for each facility. For the purposes of this discussion, deep percolation is defined as recycled water that percolates below the root zone, in the case of agricultural operations, or that percolates through the bottom of an impoundment (e.g., storage reservoirs or Paiute Ponds). Deep percolation is different than groundwater recharge or return flows since a portion of the percolate may not reach the main aquifer due to shallow lateral flow. A more detailed discussion of estimated recycled water deep percolation is provided in Appendix G.

4.6.5.1 Lancaster Water Reclamation Plant

The overall annual water balance for LWRP and estimates of deep percolation are shown in Table 4.6-1. Total deep percolation was calculated as the sum of Paiute Pond and LWRP pond/storage reservoir deep percolation. Annual amounts of deep percolation were calculated to be less than 500 afy for most years. Deep percolation related to recycled water applied for agricultural irrigation is accounted for in the agricultural irrigation return flow section of this report.

4.6.5.2 Palmdale Water Reclamation Plant

The overall annual water balance for PWRP and estimates of deep percolation are shown in Table 4.6-2. PWRP operations between 1953 and 1980 resulted in minor deep percolation (less than 1,000 afy). Effluent management operations were modified in the early 1980’s when District No. 20 and Los Angeles World Airports (LAWA) reached an agreement whereby LAWA was to receive and distribute the treated effluent for agricultural reuse. However, agricultural reuse operations did not develop as expected and most of the recycled water was discharged via land application between the early 1980’s and 2002. Thus, estimated deep percolation ranged up to a maximum of about 7,600 afy by 2001. District No. 20 reached a new agreement with LAWA in 2002 that returned recycled water management back to District No. 20. The estimated amount of deep percolation decreased from about 7,600 afy in 2001 to less than 3,000 afy in 2005.

SOURCE: Google Earth Image.

NORTH

0 3 6

MILES

WATER RECLAMATION PLANT LOCATION MAP

Antelope Valley, California

FIGURE 4.6-1

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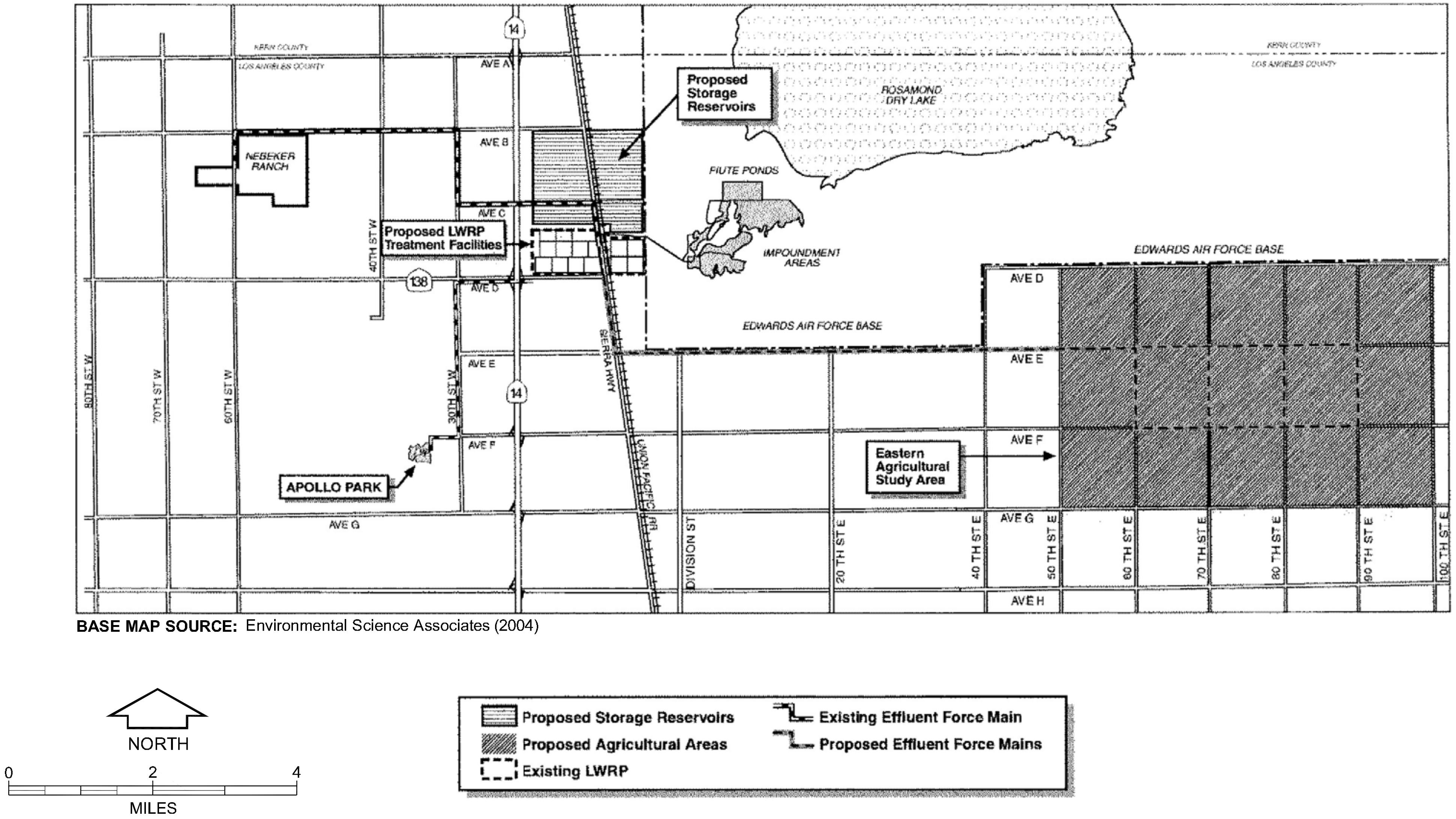

BASE MAP SOURCE: Environmental Science Associates (2004)

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LANCASTER WATER RECLAMATION
PLANT FACILITIES
Antelope Valley, California

FIGURE 4.6-2

Figure 4.6-3
Recycled Water Volumes, 1975 - 2009

Lancaster Water Reclamation Plant

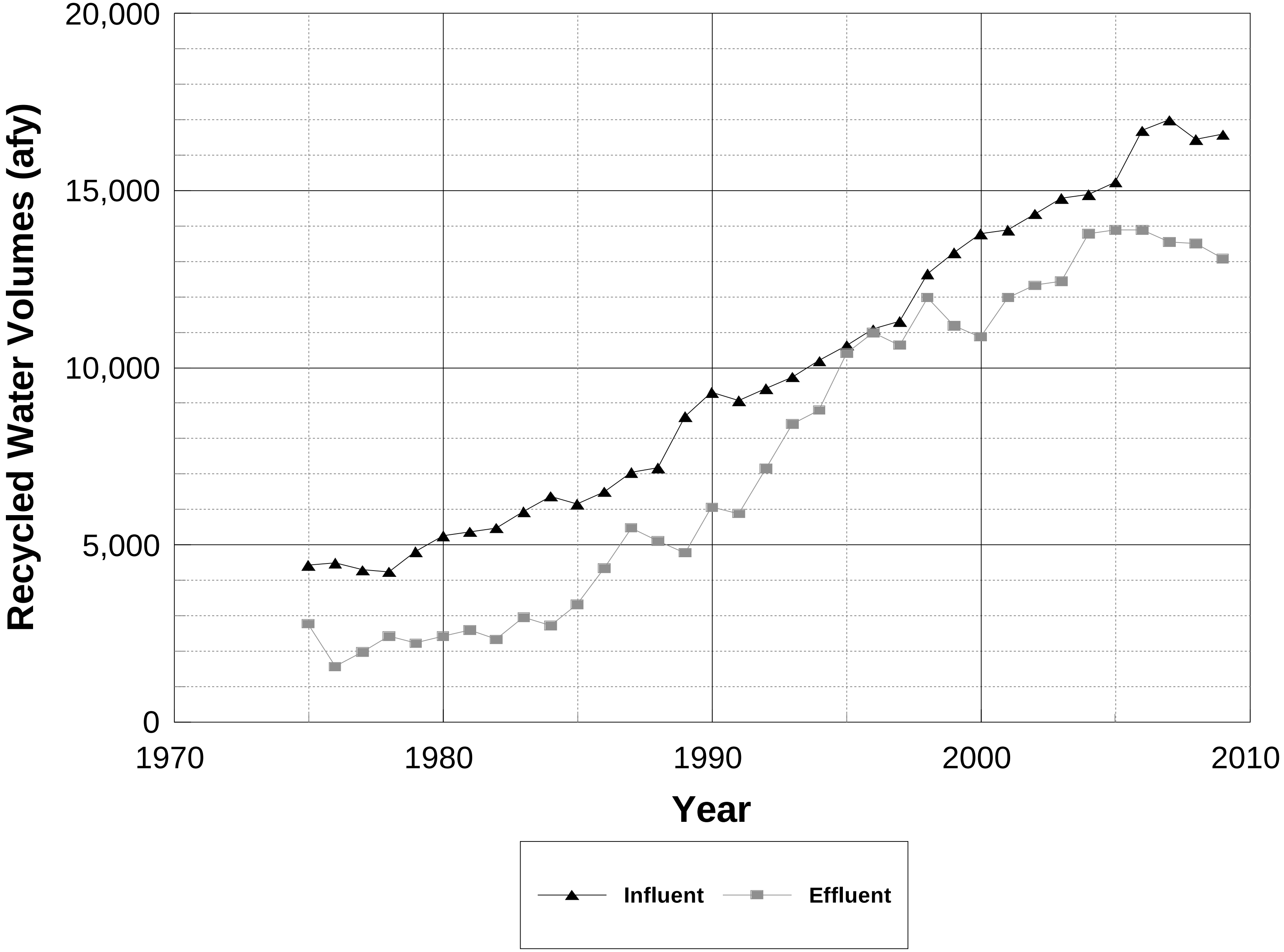
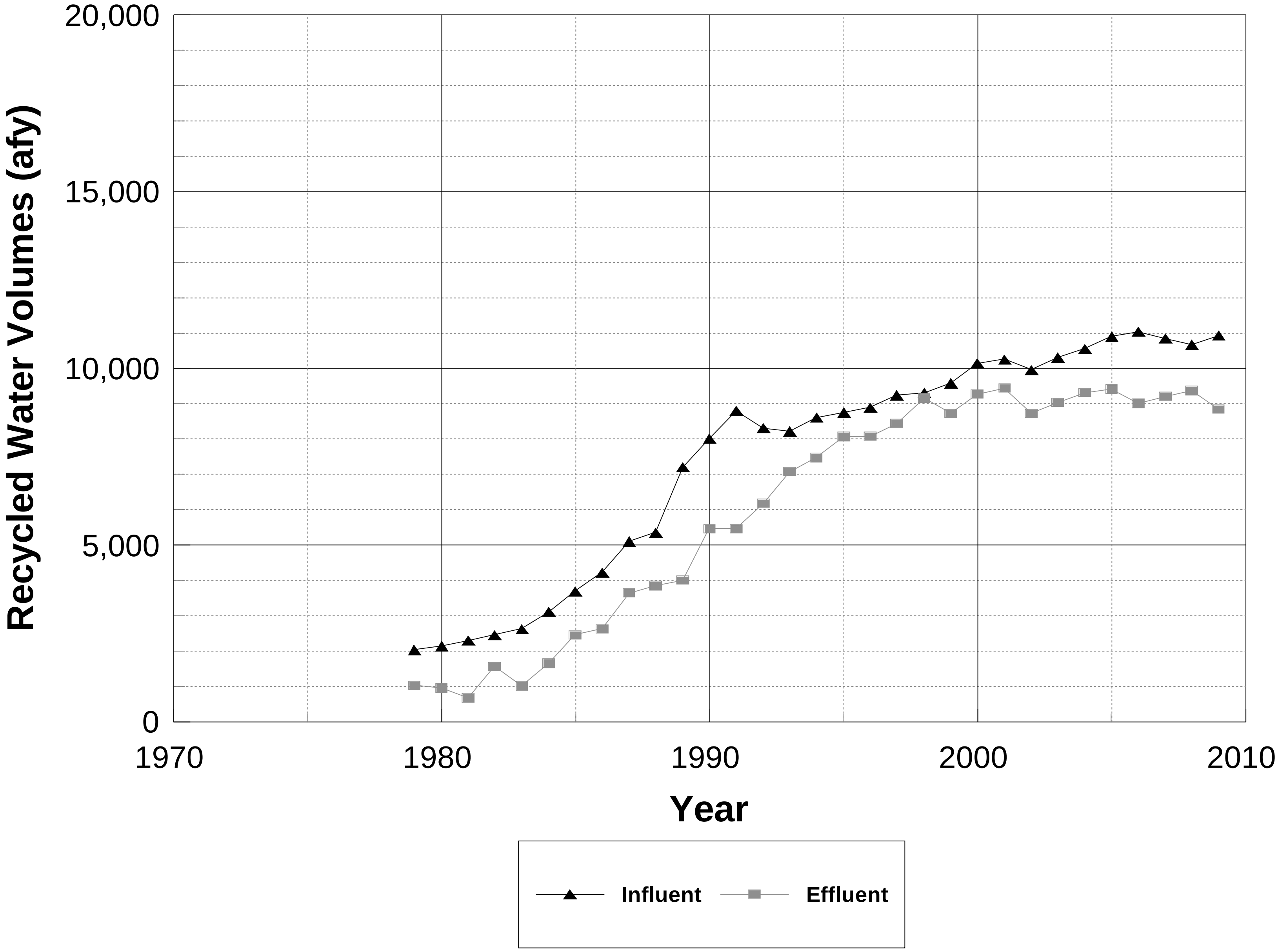
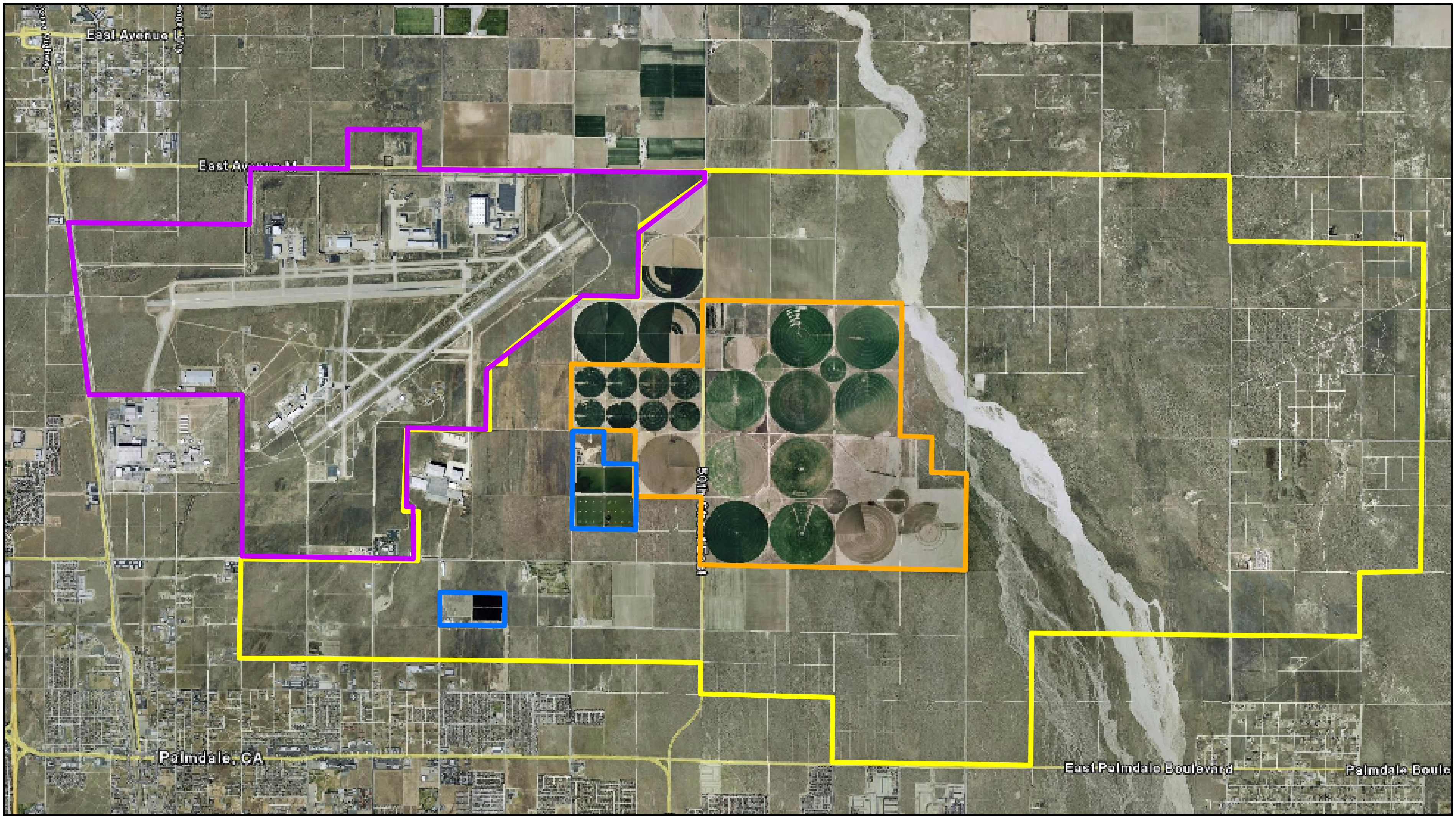


Figure 4.6-4
Recycled Water Volumes, 1979 - 2009

Palmdale Water Reclamation Plant





SOURCE: Environmental Science Associates (2005) and Google Earth Image.

Legend

□ District-Owned Property
□ USAF Plant 42
□ LAWA Boundary
□ Effluent Management Site

0 375 750 1,500 2,250 3,000 Meters

PALMALE WATER RECLAMATION PLANT FACILITIES

Antelope Valley, California

FIGURE 4.6-5

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Table 4.6-1. Estimated Historic Annual Water Balance for Lancaster Water Reclamation Plant (Values in Acre-Feet per Year)

Year	Metered Influent	Net Pond and Reservoir Evaporation	Pond and Reservoir Percolation	Influent less Evaporation and Percolation	Metered Effluent	Difference between (Influent less Evap and Perc) and Metered Effluent	Discharge to Paiute Ponds	Estimated Paiute Pond Deep Percolation	Discharge to Nebeker Ranch	Discharge to Apollo Lakes	District Uses	Sum of Paiute, Nebeker, and Apollo Discharges	Effluent minus Sum of Discharges	Total Deep Percolation
1975	4,439	1,800	125	2,514	2,780	-266	840	20	0	87	0	927	1,853	145
1976	4,506	1,800	125	2,581	1,581	1,000	1,277	20	0	282	0	1,559	22	145
1977	4,305	1,800	125	2,380	1,984	396	1,699	20	0	279	0	1,978	6	145
1978	4,260	1,800	125	2,335	2,433	-98	2,159	20	0	297	0	2,456	-23	145
1979	4,820	1,800	125	2,895	2,231	664	1,982	20	0	244	0	2,226	5	145
1980	5,269	1,800	125	3,344	2,433	911	2,172	20	0	270	0	2,442	-9	145
1981	5,381	1,800	125	3,456	2,601	855	2,323	20	0	278	0	2,601	0	145
1982	5,493	1,800	125	3,568	2,343	1,225	2,125	20	0	211	0	2,336	7	145
1983	5,941	1,800	125	4,016	2,971	1,045	2,767	20	0	191	0	2,958	13	145
1984	6,390	1,800	125	4,465	2,735	1,730	2,588	20	0	167	0	2,755	-20	145
1985	6,165	1,800	125	4,240	3,329	911	3,086	20	0	172	0	3,258	71	145
1986	6,502	1,800	125	4,577	4,349	228	4,210	20	0	146	0	4,356	-7	145
1987	7,062	2,800	125	4,137	5,493	-1,356	5,139	20	0	132	0	5,271	222	145
1988	7,174	2,800	125	4,249	5,112	-863	3,664	20	1,904	113	0	5,681	-569	145
1989	8,632	2,800	1,045	4,787	4,787	0	2,009	20	2,688	125	0	4,822	-35	1065
1990	9,304	2,800	428	6,076	6,076	0	2,266	20	3,809	185	0	6,260	-184	448
1991	9,080	2,800	384	5,896	5,896	0	2,413	20	3,921	154	0	6,488	-592	404
1992	9,416	2,800	200	6,416	7,163	-747	3,399	20	3,640	121	0	7,160	3	220
1993	9,753	2,800	200	6,753	8,419	-1,666	5,151	20	2,997	128	0	8,276	143	220
1994	10,201	2,800	200	7,201	8,811	-1,610	4,979	20	3,711	130	0	8,820	-9	220
1995	10,649	2,800	200	7,649	10,425	-2,776	7,003	20	3,226	138	0	10,367	58	220
1996	11,098	2,800	200	8,098	11,008	-2,910	7,402	20	3,528	99	0	11,029	-21	220
1997	11,322	2,800	200	8,322	10,638	-2,316	6,743	20	3,754	134	0	10,631	7	220
1998	12,667	2,800	200	9,667	11,995	-2,328	8,587	20	3,324	119	0	12,030	-35	220
1999	13,250	2,800	200	10,250	11,188	-938	7,448	20	3,549	190	0	11,187	1	220
2000	13,788	2,800	200	10,788	10,874	-86	6,960	20	3,793	160	0	10,913	-39	220
2001	13,900	2,800	200	10,900	11,995	-1,095	7,344	20	4,346	206	0	11,896	99	220
2002	14,349	2,800	200	11,349	12,331	-982	7,655	20	4,493	184	0	12,332	-1	220
2003	14,797	2,800	200	11,797	12,443	-646	8,224	20	4,188	158	0	12,570	-127	220
2004	14,909	2,800	200	11,909	13,788	-1,879	9,033	20	4,511	206	0	13,750	38	220
2005	15,245	2,800	200	12,245	13,900	-1,655	9,738	20	3,863	219	16	13,820	80	220
2006	16,703	2,800	200	13,703	13,900	-198	9,440	20	4,189	170	0	13,799	101	220
2007	17,008	2,800	200	14,008	13,554	454	7,550	20	4,932	180	0	12,661	893	220
2008	16,449	2,800	200	13,449	13,508	-59	7,815	20	4,079	210	0	12,103	1,404	220
2009	16,589	2,800	200	13,589	13,084	505	6,683	20	4,860	219	0	11,761	1,323	220

Table 4.6-2. Estimated Historic Annual Water Balance for Palmdale Water Reclamation Plant (Values in Acre-Feet per Year, except as noted)

Year	Estimated or Metered Influent	Precipitation (Inches)	Pond Area (acres)	Net Pond Evaporation	Pond Percolation	Influent less Evaporation and Percolation	Estimated or Metered Effluent	Difference between (Influent - evap perc) and Effluent	Flows to Ag Reuse	Flows to Land Application	Flows to Land Application with Crop	Land Applied (with and w/out Crop) Percolation	Total Deep Percolation
1953	247	1.96	21	124	116	7	7	0	0	0	0	0	116
1954	246	10.35	21	123	109	14	14	0	0	0	0	0	109
1955	276	5.11	21	123	142	11	11	0	0	0	0	0	142
1956	362	4.99	21	124	185	53	53	0	0	0	0	0	185
1957	414	9.87	21/49	166	171	77	77	0	0	0	0	0	171
1958	500	11.04	49/58	252	70	178	178	0	0	0	0	0	70
1959	620	4.54	58	256	42	322	322	0	83	0	0	0	42
1960	672	4.89	58	351	26	295	295	0	83	0	0	0	26
1961	706	3.69	58	352	23	331	331	0	83	0	0	0	23
1962	762	7.54	58	352	41	369	369	0	97	0	0	0	41
1963	706	7.34	58	352	37	317	317	0	97	0	0	0	37
1964	807	4.48	58	352	56	399	399	0	135	0	0	0	56
1965	919	10.35	58	353	92	474	474	0	224	0	0	0	92
1966	952	5.15	58	352	103	497	497	0	224	0	0	0	103
1967	1,143	8.26	58	353	124	666	665	1	424	0	0	0	124
1968	1,177	4.16	58	354	145	678	678	0	424	0	0	0	145
1969	1,233	10.08	58	354	154	725	725	0	512	0	0	0	154
1970	1,289	6.63	58	354	152	783	783	0	509	0	0	0	152
1971	1,457	5.23	58	354	150	953	952	1	700	0	0	0	150
1972	1,513	2.29	58/68	368	148	997	996	1	704	0	0	0	148
1973	1,793	6.89	68	412	145	1,236	1,235	1	891	0	0	0	145
1974	1,681	7.70	68	412	143	1,126	1,125	1	806	0	0	0	143
1975	1,737	3.12	68	411	142	1,184	1,183	1	891	0	0	0	142
1976	1,793	5.11	68	411	140	1,242	1,241	1	891	0	0	0	140
1977	1,793	9.75	68	411	138	1,244	1,243	1	941	0	0	0	138
1978	1,883	13.23	68	411	136	1,336	1,334	2	996	0	0	0	136
1979	2,039	9.04	68	411	134	1,494	1,036	458	1,036	0	0	0	134
1980	2,151	13.60	68/95	448	745	958	958	0	958	0	0	0	745
1981	2,305	6.18	95	572	1,049	684	684	0	548	136	0	109	1,158
1982	2,465	11.29	95	572	1,019	874	1,567	-693	0	1,567	0	1,254	2,273
1983	2,633	15.54	95	572	1,034	1,027	1,027	0	88	937	0	750	1,784
1984	3,123	6.91	95	572	879	1,672	1,672	0	404	1,277	0	1,022	1,901
1985	3,698		95	572	439	2,687	2,471	216	399	2,069	0	1,655	2,094
1986	4,238	5.17	95	572	261	3,405	2,644	761	52	2,585	0	2,068	2,329
1987	5,116	7.27	95	572	225	4,319	3,656	663	64	3,589	0	2,871	3,096
1988	5,370	5.81	105/86	562	210	4,598	3,866	732	129	3,743	0	2,994	3,204
1989	7,217	2.63	86/148	763	2,186	4,268	4,025	243	37	3,982	0	3,186	5,372
1990	8,031	2.45	148	887	2,072	5,072	5,468	-396	15	5,448	0	4,358	6,430
1991	8,808	9.12	148	887	1,956	5,965	5,475	490	90	5,371	0	4,297	6,253
1992	8,328	13.89	148	887	1,149	6,292	6,200	92	21	6,174	0	4,939	6,088
1993	8,234	14.44	148	887	647	6,700	7,088	-388	130	6,957	0	5,566	6,213
1994	8,628	3.84	148	887	267	7,474	7,486	-12	51	7,427	0	5,942	6,209
1995	8,765	9.05	148	887	255	7,623	8,068	-445	68	8,003	0	6,402	6,657
1996	8,910	5.73	148	887	253	7,770	8,085	-315	74	8,007	0	6,406	6,659
1997	9,245	5.77	148	887	251	8,107	8,447	-340	84	8,365	0	6,692	6,943
1998	9,325	12.28	148	887	249	8,189	9,169	-980	90	9,075	0	7,260	7,509
1999	9,599	2.26	148	887	247	8,465	8,739	-274	129	8,612	0	6,890	7,137
2000	10,155	4.07	148	887	245	9,023	9,280	-257	588	8,690	0	6,952	7,197
2001	10,273	7.14	148	887	243	9,143	9,459	-316	251	9,201	0	7,361	7,604
2002	9,974	2.67	148	887	241	8,846	8,729	117	2,135	6,578	0	5,262	5,503
2003	10,310	8.61	148	887	239	9,184	9,043	141	3,313	5,718	0	4,574	4,813
2004	10,562	11.83	148	887	237	9,438	9,326	112	3,631	5,693	0	4,554	4,791
2005	10,916	14.54	148	887	235	9,794	9,413	381	6,135	3,269	0	2,615	2,850
2006	11,057	- - -	148	887	235	9,935	9,008	927	7,573	0	1,436	1,149	1,384
2007	10,866	- - -	148	887	235	9,744	9,211	533	7,404	0	1,807	1,445	1,680
2008	10,670	- - -	148	887	235	9,548	9,379	169	7,731	0	1,648	1,319	1,554
2009	10,934	- - -	148	887	235	9,812	8,850	962	8,586	0	265	212	447

4.7 Base Period

In a number of developed groundwater basins in California, it is possible to observe historical conditions, depending on the selection of a period for study, that might be interpreted as indicative of overdraft (notable and progressive groundwater level decline, at least for some period of time) or, conversely, indicative of surplus (notable groundwater level increases, again for some period of time). For a number of reasons, the Antelope Valley Area of Adjudication is a good illustration of various groundwater basin conditions when looking at one or more historical periods within the overall period of record. For example, with the significant expansion of irrigated agriculture for several decades through the 1960's, there were progressive increases in irrigated acreage and groundwater pumping, and notable groundwater level declines in the AVAA. Through much of the latter part of that period, precipitation was generally below average over much of the 30 year period from the mid-1940's through the mid-1970's. On the other hand, significant decreases in agricultural land use through the 1980's to the mid-1990's, offset in part by increasing municipal development, corresponded with notable stabilization or even recovery of groundwater levels in some places. Since then however, recurrent agricultural growth and ongoing suburban growth have seen a return of declining groundwater conditions in some places despite fluctuating but somewhat average hydrologic conditions, and despite significant increases in supplemental imported water use over the same time.

The net result of the preceding is that it is possible to be misled regarding the condition of a groundwater basin by simply selecting a period of non-representative conditions. The challenge is to analyze basin conditions in order to be able to interpret whether the observed response in the basin, i.e. groundwater level changes, is a result of true surplus or deficit (overdraft) conditions, or a result of short-term anomalous hydrologic conditions. To minimize that possibility, it has long been recognized that representative periods for study of groundwater basin conditions should be selected in such a way that minimizes bias that might result from a particular set of hydrologic or other conditions.

In order to eliminate the bias that could result from inappropriate selection of a study period, and to report on representative basin conditions, the study periods discussed herein (generally from about 1950 through 2005) were selected on the basis of the following several criteria: long-term mean water supply; inclusion of both wet and dry stress periods; antecedent dry conditions; adequate data availability; reflection of cultural conditions in the basin; reflection of water management conditions in the basin; and proximity to present time (near-present end of base period).

The long-term mean water supply criterion is a measure of whether the basin has experienced average natural groundwater recharge over a selected time period. Since precipitation and runoff from the surrounding watershed are measured hydrologic components that contribute to natural groundwater recharge, and since precipitation and stream flow data are available for a long period of time, interpretation of precipitation and stream flow data was used as a basis for selection of a study period. Long term records of precipitation are available at three stations in the watershed surrounding the Antelope Valley, and a long-term record of stream flow into the Valley is available for Big Rock Creek. Mean annual discharge and cumulative departure from mean discharge for Big Rock Creek are illustrated in Figure 4.7-1; similarly, mean annual precipitation and cumulative departure from mean precipitation for the three long-term records are illustrated in Figures 4.7-2 through 4.7-4. Notable on all the plots are the long-term relatively dry periods from the mid-1940's into the 1970's (negative, or downward, slope of the cumulative departure curve), followed by a series of alternating wet and dry periods through the early 2000's. Since a base period would preferably include essentially mean, or average, precipitation over its duration, it would then have about the same cumulative departure from the mean at the beginning and end of the study period. Pending consideration of other criteria, as follow, periods from about 1950 through 2005 fulfill the long-term water supply criteria based on precipitation. Notable in the long-term record of mean annual discharge and cumulative departure from mean annual discharge (Figure 4.7-1) are the upward slopes of the study period lines, both indicating an overall slightly wet, or above-average streamflow, condition over the duration of the study period. In some cases, the existence of such conditions can result in a bias toward over-estimating average water supply conditions (due to the presence of more water in the study period than is the long-term average). In this case, however, the above-average runoff over the approximate 1950-2005 base period is small and results in minimal difference (about 200 afy) in calculated natural recharge when compared to a slightly-longer (1950-2008) period with close to long-term average stream discharge. Consequently, the selected base period from about 1950 to 2005 produces no bias toward higher estimated groundwater recharge or basin yield.

Base periods from about 1950 through 2005 include both **wet and dry years** and/or periods of years. The inclusion of both types of years is important in estimating natural recharge and assessing basin response to fluctuations in natural recharge.

Antecedent Dry Conditions is a base period, or study period, criterion intended to minimize differences in groundwater in the unsaturated zone at the beginning and at the end of the study period. It has long been recognized that measurement of the quantity of water in the unsaturated zone is practically impossible, particularly at the scale of a large groundwater basin (like the AVAA). With that recognition, selection of a base period with relatively dry conditions antecedent to the beginning and the end of the period is preferable in that such conditions tend to support a resultant assumption that water in the unsaturated zone is comparatively small and thus not contributing to a bias influenced by more water being unaccounted in the unsaturated zone at one end of the period or the other. In this case, the selected period begins with antecedent dry conditions but ends after a single wet year following six consecutive dry years. However, relative to all other selection criteria, and in light of the small net impact on calculated groundwater recharge through a slightly longer (1950-2008) period that ends after a dry year as noted above, the impact of potentially unaccounted water in the unsaturated zone after a single dry year at the end of the base period is minimal.

Data availability, as reflected in the various sections and appendices of this overall Summary Report, is sufficient throughout the period from about 1950 through 2005 for all the purposes reported herein. While not perfect, the available data are sufficient to estimate or calculate the various parameters used to analyze or assess groundwater and related conditions in the AVAA, e.g. precipitation, runoff, land uses, groundwater pumping, groundwater levels, etc.

Cultural conditions in the AVAA have evolved from a predominately agricultural economy for most of the twentieth century, toward a mix of agricultural and suburban land uses that approximated about equal uses of water by about 1990 and continues through the present. A base period from about 1950 to 2005 captures that evolution and, most importantly, includes prevailing current conditions of mixed agricultural and suburban land uses.

Water management conditions in the AVAA have also evolved from sole dependence on groundwater for water supply through the mid-1970's. Since then, there has been a trend toward mixed use of groundwater to meet about two-thirds of water requirements and surface water to meet about one-third of water requirements, with a comparatively small but steadily increasing utilization of recycled water over the last 30 years. A base period from about 1950 to 2005 captures that evolution and, again most importantly, includes prevailing current conditions of integrated groundwater, local and imported surface waters, and recycled water supplies.

The last of the base period criteria is that it **end near the present time**. By doing so, the study period can be used to assess groundwater conditions as they generally exist, rather than as they might have been in some earlier time period. Ideally, then, a study period for estimation of basin yield (and assessment of whether groundwater utilization is within sustainable basin yield) would end in the mid to late 2000-2010 decade.

For reasons related to specific data availability, certain analyses in the overall effort used slightly different base periods (e.g. 1949-2005 and 1951-2005). Ultimately, however, the base periods utilized herein conform to all the accepted criteria for base period selection.

A closing comment on base period selection is that most of the work reflected in this Summary Report was initially undertaken earlier in the overall adjudication partially in anticipation of Phase 3 issues being addressed much earlier. At that time, most of the available data extended only through 2005, with limited data available for 2006. As the work reported herein was extended for the currently scheduled Phase 3, almost all data was available through 2009. Among other small effects, that extended data availability affects the averages and the shapes of the cumulative departure curves in Figures 4.7-1 through 4.7-4, ultimately slightly changing the slopes of the study period lines. The net effect of that extended data set is that the selected base period from about 1950 to 2005 would now be, for the most part, slightly wetter relative to long-term average than was the case prior to the occurrence of the last four years. Specifically, mean streamflow over the base period was about 7 percent wetter than long-term (1924-2009) average, and precipitation at the watershed gages ranged from 1 percent below to 4 percent above long-term (1931-2009) averages. While slightly wetter conditions would be expected to produce a bias toward over-estimated groundwater recharge and basin yield, recalculation of natural groundwater recharge over an extended base period (1950-2008) with closer-to-average stream discharge and precipitation results in a minimal increase (about 200 afy) in natural recharge. In the context of overall precision and the magnitude of recharge and yield values reported herein, revision of base period selection and all subsequent analyses was deemed to be unwarranted.

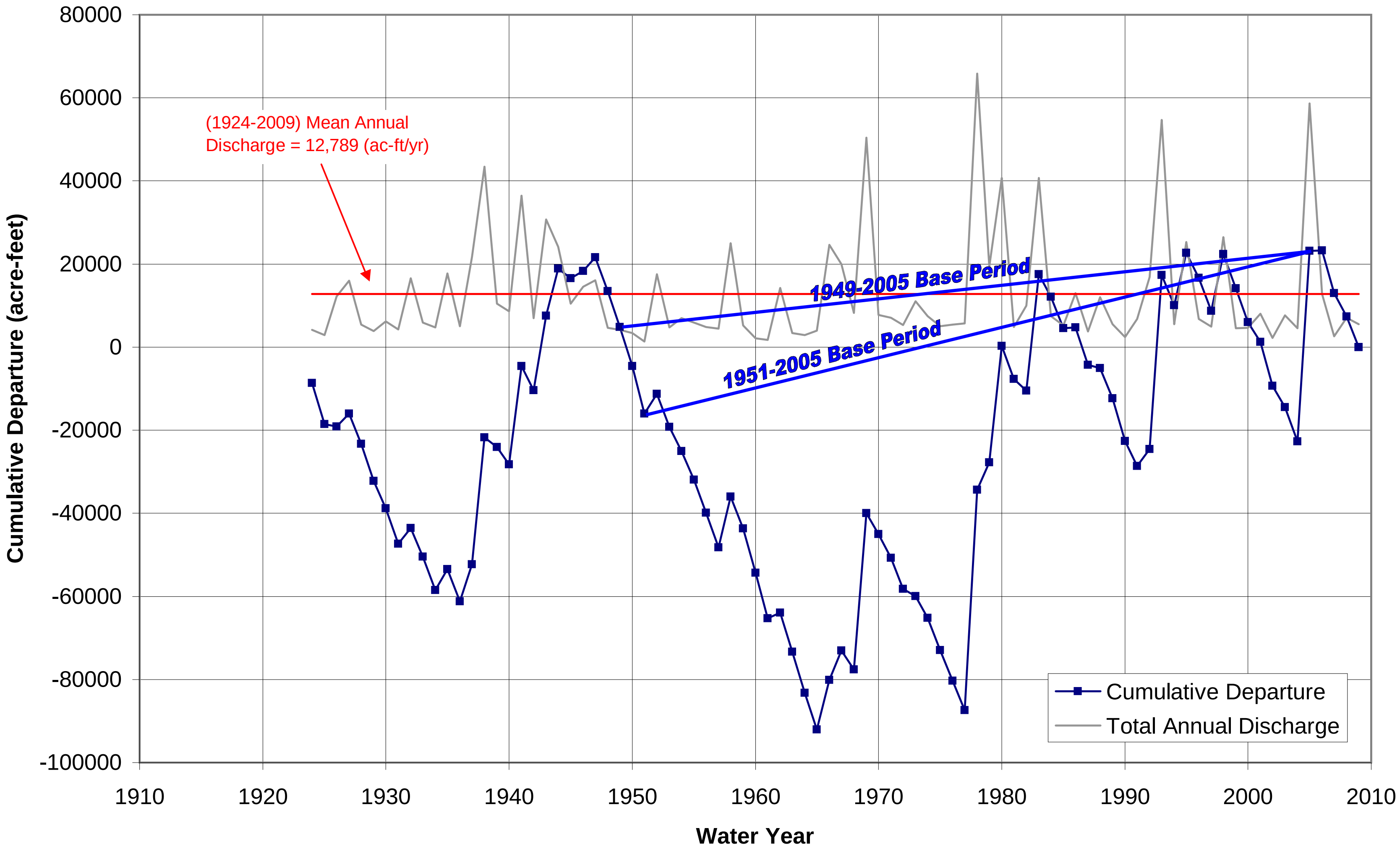

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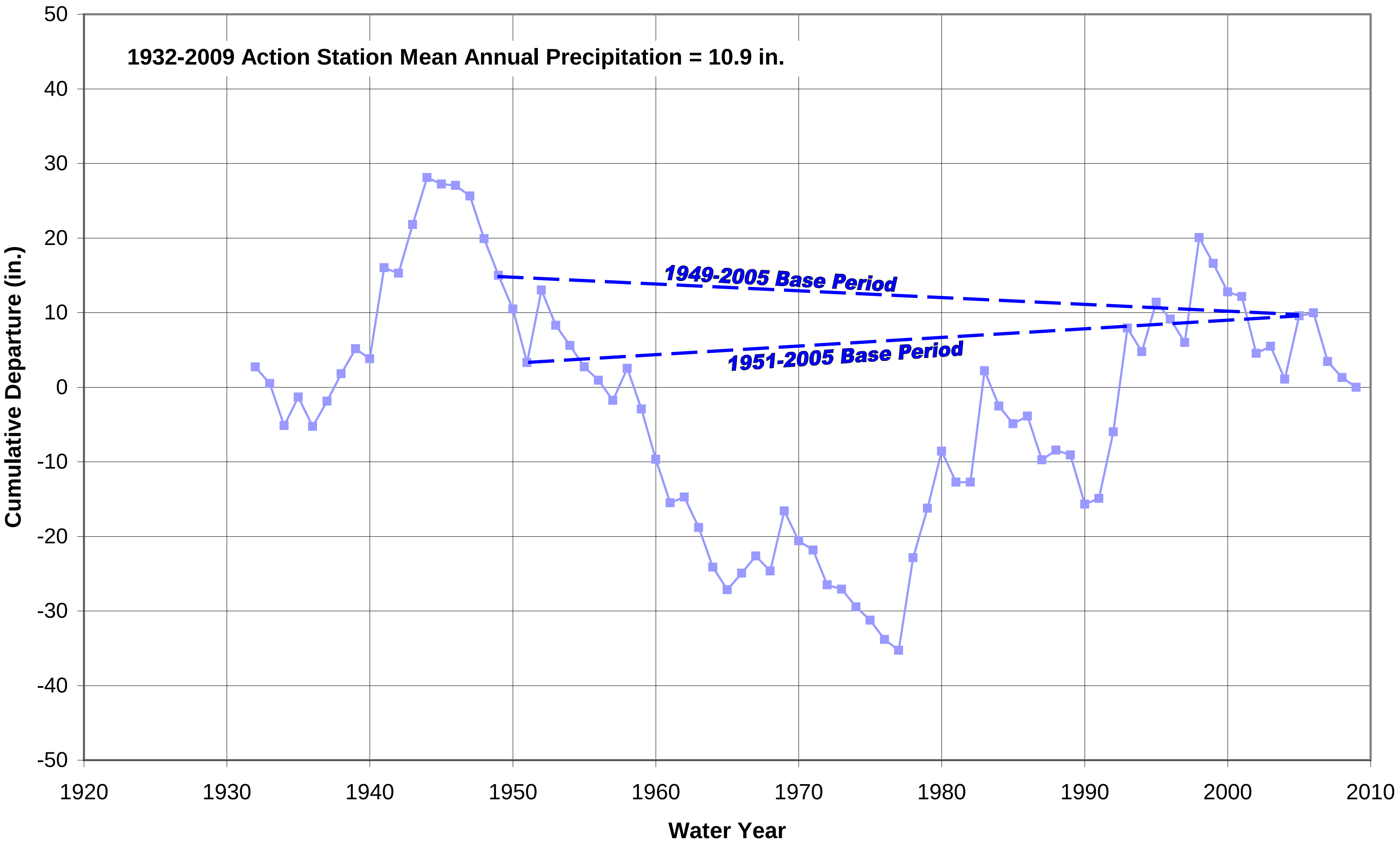
Figure 4.7-1
Base Periods Based on Streamflow
Big Rock Creek Near Valyermo (USGS Site No. 10263500)



Lancaster Wm J Fox Field Gauge precipitation data was used to approximate missing data at Acton Station Gauge.

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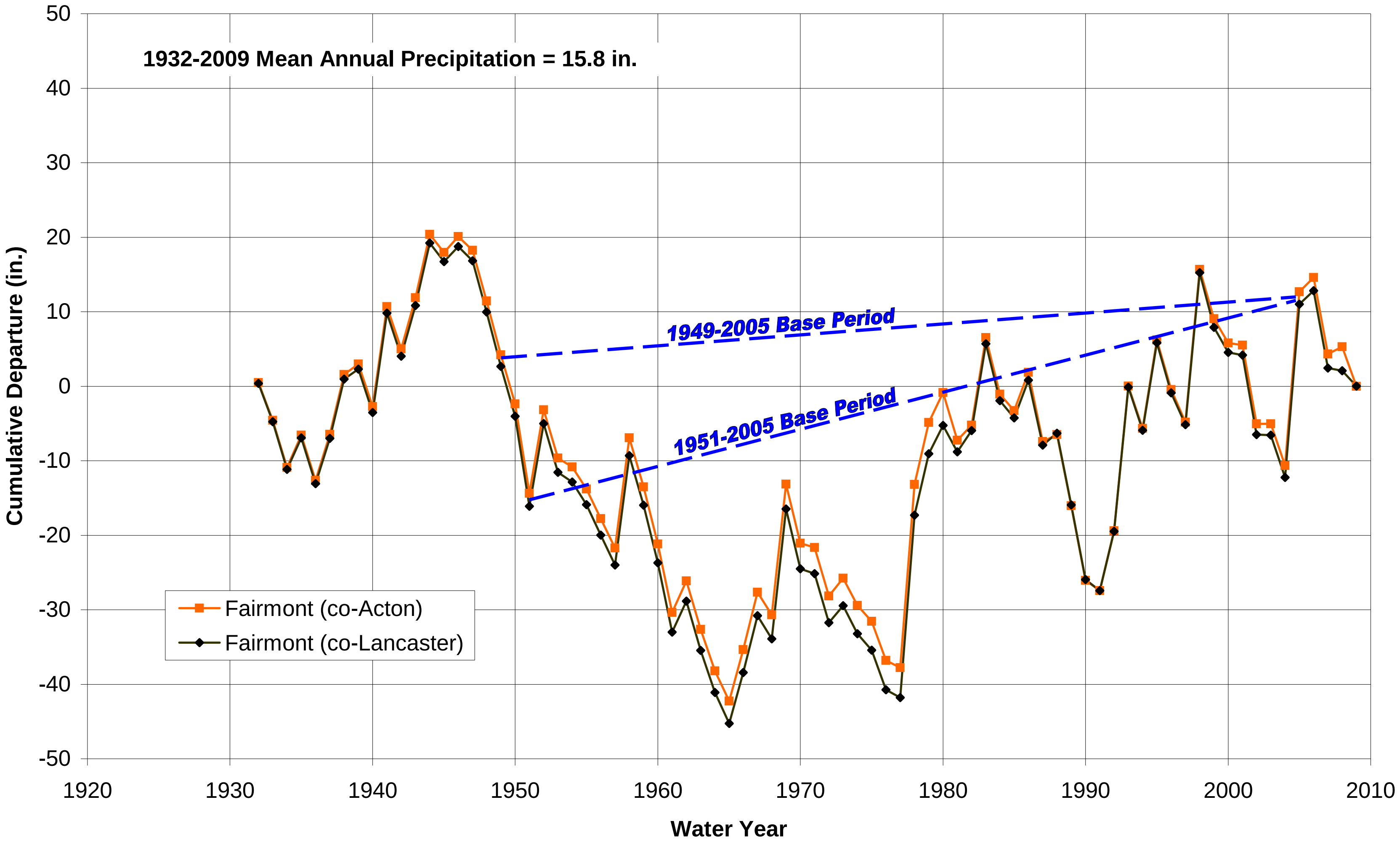
Figure 4.7-2
Base Periods Based on Precipitation (Watershed)
Acton Station Gauge, Antelope Valley



Lancaster Wm J Fox Field Gauge precipitation data and Acton Gauge precipitation data were separately used to approximate missing data at Fairmont Station Gauge.

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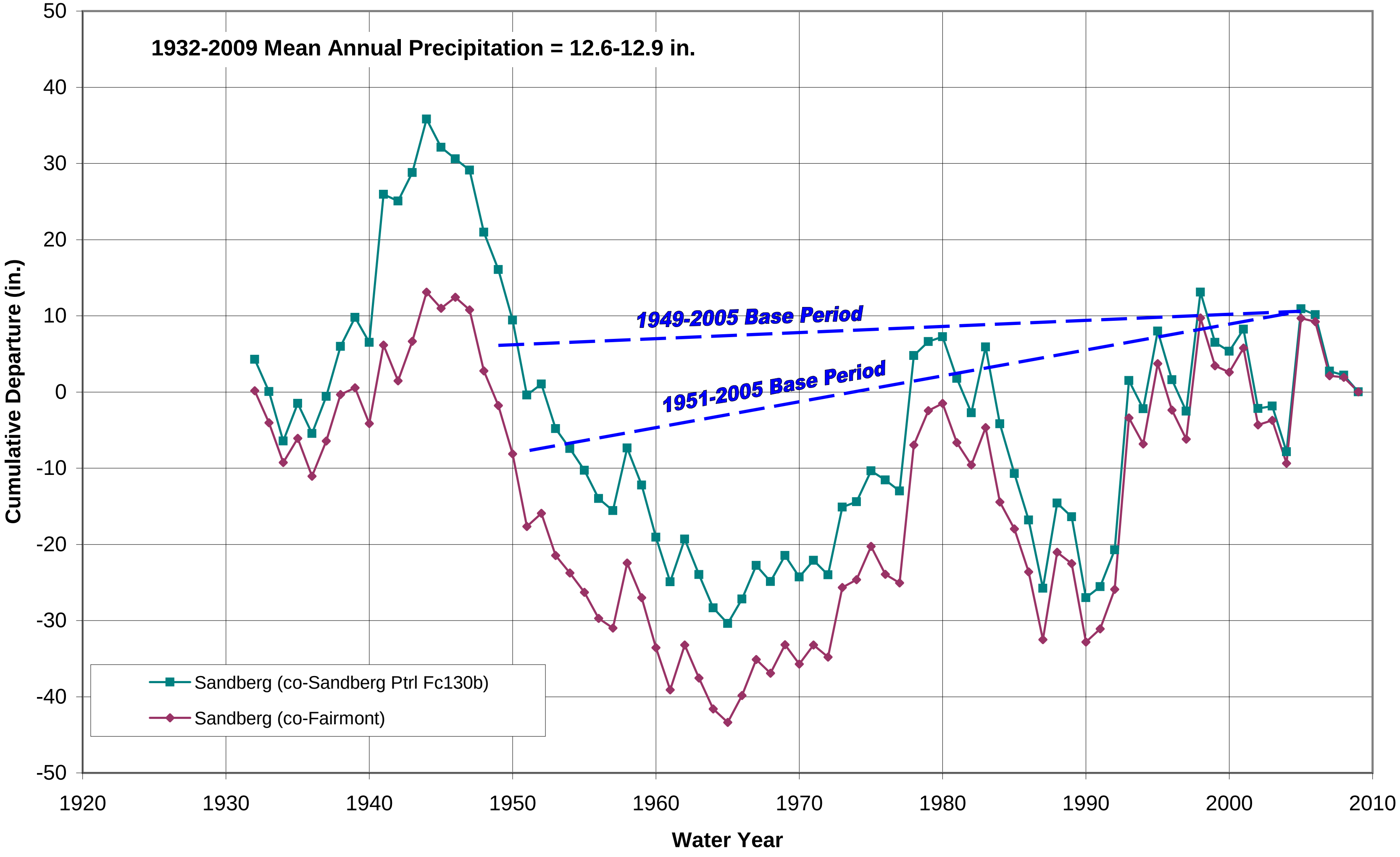
Figure 4.7-3
Base Periods Based on Precipitation (Watershed)
Fairmont Station Gauge, Antelope Valley



Fairmont Gauge precipitation data and Sandberg Ptrl Fc130b Gauge precipitation data were separately used to approximate missing data at Sandberg Station Gauge.

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Figure 4.7-4
Base Periods Based on Precipitation (Watershed)
Sandberg Station Gauge, Antelope Valley

4.8 Precision and Sensitivity

The history of the Antelope Valley Area of Adjudication is well known to have experienced significant agricultural growth through the early to mid 1950's, followed by a period of sustained high agricultural land and water use into the 1970's, followed by a period when agricultural land and water use alternately declined (beginning in the early 1970's) and then increased again (beginning around 1990). The latter period was also marked by a progressive increase in municipal land and water use such that municipal water requirements became essentially equal to agricultural requirements. Throughout the entire early period of agricultural growth, groundwater was the nearly exclusive source of water supply, augmented only by small diversions of local surface water. Only since the 1970's has supplemental water been imported, from the State Water Project, to augment local supplies.

4.8.1 Data Availability and Constraints

As a result of the significant fluctuations in water demands and the evolving nature of water supplies, the AVAA is also well known to have experienced significant fluctuations in groundwater levels and widespread land subsidence. Ultimately however, when an effort to analyze the groundwater and overall water resource system in a place like the AVAA is undertaken, perhaps the greatest challenge derives from data availability (or lack thereof), a common characteristic in most groundwater basins. Overall, while there are sufficient data to assess conditions in the AVAA, much of what is needed to analyze and assess the historical and/or current condition of the basin has often not been directly measured, or has been done so only intermittently. This makes the effort to analyze the system and quantify assessed conditions a significant challenge. Examples of data availability and constraints in the AVAA include:

- precipitation is measured at few locations in the upland areas where it produces runoff and infiltration that, in turn, are the only source of natural groundwater recharge; precipitation records are also of different durations and, for the most part, incomplete for their respective locations;

- stream flow records are limited; there is only one long-term continuous record and two other shorter-term records of sufficient duration for use in assessing long-term runoff into the AVAA where it can infiltrate as natural groundwater recharge; there are no records of surface water flows that reach the dry lake beds and thus do not contribute to natural groundwater recharge;

- there are no data on the consumptive use of water (precipitation) by native vegetation in the watershed;

- groundwater pumping for agricultural irrigation is not metered;

- agricultural land use and cropping patterns are infrequently mapped (about every decade since the 1950’s and not since 1986); estimates of total crop acreages are available for different lengths of time in the Los Angeles (since 1970) and Kern County (since 1994) portions of the AVAA;

- reference data on water use by plants are available for a short period in recent time; published data on individual crop water requirements are not available;

- long-term records of groundwater level measurements are available for most, but not all of the AVAA;

- long-term records of local stream diversions for agricultural and municipal water supply are available;

- groundwater pumping for municipal water supply is measured and, for the most part, metered records of municipal groundwater pumping are available;

- groundwater pumping for rural residential uses is not measured; groundwater pumping for other small individual or small community uses is either not metered or is incompletely recorded and available;

- deep percolation of applied water for agricultural irrigation cannot be practically measured, and there are no published estimates of such return flows in the AVAA;

- deep percolation of applied water for landscape irrigation and other outdoor uses in municipal areas cannot be practically measured, and there are no published estimates of such return flows in the AVAA;

- the respective amounts of indoor and outdoor water uses in municipal (and municipal-type) areas are not metered;

- complete records are available for the importation and use of supplemental water from the State Water Project;

- sporadic data are available on the yields of wells and the related characteristics of the aquifer materials or other subsurface materials beneath and around the AVAA;

- detailed measurements of land subsidence are recorded at several sites throughout the extensive area of subsidence in the AVAA;

- differing amounts of data are available on the amounts of waste water treated at the different water reclamation plants in the AVAA;

- limited anecdotal and measured data are available on sporadic artificial recharge of groundwater.

As a result of the nature of data availability in the AVAA, an effort to assess groundwater and total water resources like that reported herein is necessarily constrained to one that involves some imprecision. Overall, the effort involves a combination of integrating complete data records with interpolation, extrapolation, and estimation of other parameters, all based on as much data as are available, to allow interpretation of the results. Imprecision is ultimately recognized by not reporting exact numbers; rather, using natural groundwater recharge and sustainable groundwater yields as examples, results are reported as rounded numbers, small ranges, or “about” a certain value.

While numerous parts of this overall Summary Report are important to the adjudication issue, the key results are the estimates of natural groundwater recharge and the subsequently dependent estimates of sustainable groundwater basin yield. Recognizing that those would be the key results, and further recognizing that data are incomplete and require interpretation as described above, the approach followed herein was purposely developed to utilize two fully independent methods to estimate natural groundwater recharge. The independent results were ultimately compared and found to reach essentially the “same” conclusion, albeit with respective imprecision that derived from the nature of the two independent sets of data that they used. Recognition of the overall imprecision led to an estimate that a collection of individual estimates around 55,000 to 58,000 afy was “about” 60,000 afy. The subsequent use of the latter value to estimate sustainable yield under native and supplemental water supply conditions also involved utilization of imprecise numbers that derived from interpretation of the types of data as described above. Again recognizing the same overall imprecision, the estimates of sustainable yield are expressed as values “about” 82,000 afy and “about” 110,000 afy under native and current supplemental conditions, respectively. The reader should not interpret the results described herein as exact numbers, or as uniquely “right”; but the reader should also interpret that the results are not so imprecise as to possibly be different by many thousands of afy. The results should ultimately be interpreted as the best possible quantification of the various parameters and their overall integration to describe the water supply, land and water use, and groundwater conditions in the AVAA, given the extent of available information on which to develop such a quantification.

An illustration of the approximate “precision” of the results reported herein can be extracted from a combination of fundamental conservation of mass with defined sustainability, which can be expressed as

$$\text{Inflow (I)} - \text{Outflow (O)} = \text{Change in Storage } (\Delta S)$$

Under sustainable conditions, long-term average inflow equals long-term average outflow and long-term average change in storage is zero; expressed another way, inflow is the sustainable yield and outflow matches inflow. Under non-sustainable conditions, outflow exceeds inflow and storage is depleted by the difference. In the AVAA in recent years, i.e. over the last ten years, groundwater pumping has averaged about 153,000 afy, or about 43,000 afy more than the total sustainable yield reported herein. Over the same time, groundwater storage has declined by a total of about 525,000 af, or at an average rate of about 52,500 afy. While the preceding comparison is simplified, the negative change in storage is consistent with the negative balance between pumping and total sustainable yield over the last ten years. If anything, the preceding might be used to argue that the reported total sustainable yield is slightly high. More importantly, however, the preceding shows that, despite potential debate about "precision", the observed ongoing decline in groundwater storage, which derives from measured groundwater levels, generally supports the basin yield values as reported herein, and also supports a prevailing disparity between pumping and sustainable yield on the order of more than 40,000 afy. In other words, total pumping exceeds the total sustainable yield reported herein by about 35 percent.

4.8.2 Sensitivity

The various individual analyses included in this overall report, which can be considered the components of an overall description of groundwater and water supply conditions in the AVAA, were specifically designed and undertaken to apply generally acceptable methodology to interpret available data and to interpolate, extrapolate, or otherwise estimate other data in order to develop the most probable depiction of historic and current conditions. As much as possible, the overall methodology incorporated the concept of independent checking. The independent approaches to estimating natural recharge are the best example of applying that concept; those two approaches relied on completely different sets of available data, applied different applicable methodologies to interpret that data, and reached independent estimates of natural recharge. The overall methodology then compared the independent results to conclude that, since both approaches concluded about the same estimate, natural groundwater recharge was as reported herein.

In addition to independent checking where possible, the overall methodology incorporated a certain amount of sensitivity analysis, where sensitivity analysis is the examination of how much a result is affected by variations in one or more parameters used to derive that result. In the course of the overall effort reported herein, questions were raised about the effects of various assumptions that went into input parameters, and whether those assumptions might have had a substantial effect on any of the calculated results. Specifically, questions were raised about the sensitivity of results to the following estimated parameters: agricultural irrigation and pumping, return flows of water applied for agricultural irrigation, and return flows of municipal water supply as related to the relative fractions of sewered and non-sewered portions of municipal areas.

Sensitivity analyses were conducted to individually examine the approximate magnitude of net effect on calculated results for each of the questioned parameters. In general, each sensitivity analysis involved changing the questioned parameter, within practical limits, in a direction (increase or decrease) where the impact would be in the direction thought to be of consequence to the results reported herein. For example, in the overall approach reported herein, the estimated natural recharge to the basin would tend to increase if the estimated pumping from the basin were higher than used in the analysis reported herein. On the other hand, estimated return flows have opposing effects on estimated natural recharge and estimated sustainable yield. Overestimates of agricultural return flows would tend to produce a low estimate of natural recharge, so decreasing estimated return flows would produce a higher calculated estimate of natural recharge. But overestimates of agricultural return flows also tend to produce a high estimate of sustainable yield, so decreasing estimated return flows would produce a lower calculated estimate of sustainable yield. To put the preceding in the context of magnitude, each of the individual sensitivity analyses is discussed in the following sections.

4.8.2.1 Agricultural Irrigation and Pumping

The approach and results of the effort to estimate water requirements for agricultural irrigation and groundwater pumping to meet some or all of those requirements are summarized in Section 4.2 and detailed in Appendix D. Sensitivity analysis was undertaken by examining the effect of changing the estimate of applied water on the crop with the highest combination of crop water duty and crop acreage, which is alfalfa. Specifically, the sensitivity of calculated natural recharge to applied water was examined by arbitrarily increasing the applied water duty to 7.5 af/ac/yr. (a 15% increase), and then recomputing natural recharge with all other parameters unchanged. For reference, the base scenario of estimated natural recharge as reported herein is summarized in Table 4.8-1.

As summarized in Table 4.8-2, the net effect of the arbitrary increase in applied water for alfalfa was to increase the calculated estimate of natural recharge from about 56,900 afy to about 58,900 afy, or about a 2,000 afy increase. That increase is insufficient to cause a change in the ultimate estimate, using the independent methods described herein, of about 60,000 afy of natural recharge. Thus, while the estimate of natural recharge has some sensitivity to the estimate of applied agricultural irrigation and pumping, the magnitude of sensitivity is sufficiently small that it does not change the resultant estimate of natural recharge. As a result, the magnitude of sensitivity then has no effect on the subsequent use of estimated natural recharge in the estimating of sustainable groundwater yield.

No attempt was made to quantify the effect of decreasing the estimated water requirement of alfalfa because any substantial decrease (for example, 1 af/ac/yr as was used for the increase above) would bring applied water for alfalfa into an unrealistically low range (5.5 af/ac/yr) for the AVAA.

4.8.2.2 Agricultural Return Flows

The approach and results of the effort to estimate return flows from agricultural irrigation are detailed in Appendix D. Sensitivity analysis was undertaken by examining the effect of arbitrarily reducing the fraction of agricultural return flows from all irrigated crops by the same fraction, 15 percent, used to examine sensitivity to applied water above, and then recomputing natural recharge and sustainable yields with all other parameters unchanged. As summarized in Table 4.8-3, the net effect of the arbitrary decrease in estimated return flows from all applied agricultural irrigation was to increase the calculated estimate of natural recharge from about 56,900 afy to about 67,600 afy, or nearly an 11,000 afy increase. That increase is insufficient to unilaterally cause a change in the ultimate estimate, using the independent methods described herein, of about 60,000 afy of natural recharge. However, since the difference in estimated natural recharge generated by the arbitrary reduction in agricultural return flows is sufficiently large to raise question about its impact on estimated sustainable yield, which is the primary focus of Phase 3 in the AVAA Adjudication, the sensitivity of sustainable yield to agricultural return flows was further investigated as follows.

As noted above, the effect of estimated return flows from agricultural irrigation extends beyond calculations of natural recharge; the return flows also affect estimated sustainable groundwater yield as discussed in Section 4.4. To examine the sensitivity of agricultural return flows through both the estimate of natural recharge and the subsequent estimate of sustainable yield, the preceding result (about 68,000 afy of natural recharge) was utilized with the same 15 percent reduction in agricultural return flows to estimate the net effect on native sustainable yield. Notably, this particular sensitivity analysis was idealistically conducted, i.e. without reconciling where the 15 percent reduction in return flow (deep percolation) would otherwise have gone. For an estimated natural recharge of 68,000 afy (11,000 afy larger than estimated without the arbitrary reduction in agricultural return flows, and 8,000 afy larger than the 60,000 afy rounded estimate used for sustainable yield calculations, all ignoring the independent estimate of 55,000-58,000 afy from the precipitation yield modeling method described in Section 4.1 and Appendix C), the net effect of the 15 percent decrease in all agricultural return flows was to increase the calculated estimate of native sustainable yield from 80,000 afy to about 86,000 afy.

Overall, the calculation of estimated natural recharge is more sensitive to the agricultural return flow fraction than is the calculation of estimated native sustainable yield. Ultimately, however, assuming a large (15%) reduction in agricultural return flows (for sensitivity analysis only, i.e. with no explanation for where the excess applied water might have gone) produces a comparatively smaller (7.5%) calculated increase in sustainable yield.

4.8.2.3 Sewered and Non-Sewered Municipal Water Use

In the earliest stages of the overall analysis reported herein, it was simply assumed that municipal urban areas were sewered, with all indoor water use in those areas then discharged to waste water reclamation plants. It was subsequently recognized, however, that records of inflow and outflow at water reclamation plants did not support such a high fraction of sewering in the overall AVAA. Since there are widely varying and uncommon service areas between those of municipal water purveyors and municipal wastewater collectors, several methods were employed to estimate how much water has been routed to water reclamation plants for treatment and disposal, and how much water has been treated in individual waste treatment systems where it is discharged via leach fields that provide return-flow contributions to groundwater yield. As described in Appendix D, the best interpretation of available data is that, overall in the AVAA, about 70 percent of municipal urban land use areas is sewered; the balance is served by on-site waste treatment and discharge systems. However, in light of how the AVAA has historically developed and is projected to develop, that fraction has logically changed over time, and can be expected to further change in the future. Sensitivity analysis was thus undertaken to assess the relative impact of sewering on the estimates of natural groundwater recharge and sustainable groundwater yield.

In this case, the greatest (increasing) numerical impact would result from returning to the initial assumption that all municipal areas were sewered. As summarized in Table 4.8-4, the net effect of that assumption was to increase the calculated estimate of natural recharge (using the groundwater storage balance method described in Section 4.3 and Appendix E) from about 56,900 afy to about 62,500 afy, or about a 5,600 afy increase. The resultant estimate, when combined with the independent estimate of about 55,000 to 58,000 afy from the precipitation yield modeling method as described in Section 4.1 and Appendix C, suggests that the value of 60,000 afy concluded herein would essentially be bracketed by the respective results. However, while future expansion of sewered municipal areas might lead to an increased estimate of natural recharge, the current state of sewering in the AVAA and the sensitivity of sewered municipal water use do not support a change of the resultant calculated estimate of natural recharge, 60,000 afy.

Table 4.8-1: Base Scenario for Natural Recharge Calculation: Alfalfa AWT of 6.5 af/ac and 100% excess applied water as return flow; M&I urban area 70% sewered

(afy)

		Return Flows									Artificial Recharge		Outflows					Total Outflow	Change in Storage	Total Artificial Recharge	Total Return Flows (Net)	Natural Recharge
		M&I						Recycled	Agricultural		Spreading	Injection	Urban Pumping	Agricultural Pumping	Pumpage to Aqueduct	Other	Total Pumping					
		Urban Area			MWC and RR Areas																	
		Septic tank	Outdoor Irrigation		Septic tank	Outdoor Irrigation																
Study Period	Year	Gross = Net	Gross	Net	Gross = Net	Gross	Net	Gross = Net	Gross	Net	Gross = Net	Gross = Net										
1929-1944	1929	392	317		168	43		0	61,417		0	0	3,241	204,724	0	300						
	1930	421	340		180	46		0	54,034		0	0	3,423	180,112	0	300						
	1931	449	363		193	49		0	51,037		0	0	3,606	170,125	0	300						
	1932	478	386		205	53		0	48,041		0	0	3,788	160,138	0	300						
	1933	507	409		217	56		0	45,045		0	0	3,971	150,150	0	300						
	1934	536	433		230	59		0	42,049		0	0	4,153	140,163	0	300						
	1935	564	456		242	62		0	39,053		0	0	4,335	130,176	0	300						
	1936	593	479		254	65		0	43,383		0	0	4,518	144,611	0	300						
	1937	622	502		266	68		0	47,713		0	0	4,700	159,045	0	300						
	1938	650	525		279	72		0	52,044		0	0	4,882	173,479	0	300						
	1939	679	548		291	75		0	56,374		0	0	5,065	187,914	0	300						
	1940	708	572		303	78		0	60,704		0	0	5,247	202,348	0	300						
	1941	736	595		316	81		0	63,882		0	0	5,430	212,941	0	300						
	1942	765	618		328	84		0	67,060		0	0	5,612	223,533	0	300						
	1943	794	641		340	87		0	70,238		0	0	5,794	234,126	0	300						
	1944	823	664		353	91		0	73,416		0	0	5,977	244,719	0	300						
1945-1950	1945	851	687		365	94		0	76,593		0	0	6,159	255,311	0	300						
	1946	880	711		377	97		0	82,188		3,625	0	6,341	273,960	0	300						
	1947	845	682		362	93		0	89,027		3,625	0	6,049	296,757	0	300						
	1948	929	750		398	102		0	96,749		0	0	6,747	322,497	0	300						
	1949	1,114	900		478	123		0	98,305		0	0	8,296	327,685	0	300						
	1950	891	719		382	98		0	104,303		0	0	6,432	347,676	0	300						
1951-1962	1951	844	681	479	362	93	65	0	108,765	43,383	0	0	6,039	362,549	0	300	368,589	368,889	(278,874)	0	45,133	44,882
	1952	785	634	502	337	86	68	0	107,357	47,713	0	0	5,550	357,856	0	300	363,406	363,706	(278,874)	0	49,406	35,426
	1953	1,297	1,048	525	556	143	72	116	105,949	52,044	0	0	9,821	353,162	0	300	362,983	363,283	(278,874)	0	54,610	29,799
	1954	1,320	1,066	548	566	145	75	109	104,540	56,374	0	0	10,013	348,468	0	300	358,481	358,781	(278,874)	0	58,992	20,915
	1955	1,382	1,116	572	592	152	78	142	103,132	60,704	0	0	10,529	343,774	0	300	354,303	354,603	(278,874)	0	63,470	12,259
	1956	1,859	1,501	595	797	205	81	185	101,724	63,882	0	0	13,088	339,081	0	300	352,169	352,469	(278,874)	0	67,399	6,196
	1957	1,715	1,385	618	735	189	84	171	100,316	67,060	0	0	12,553	334,387	0	300	346,940	347,240	(278,874)	0	70,383	(2,017)
	1958	1,779	1,437	641	763	196	87	70	102,039	70,238	0	0	12,409	340,131	0	300	352,540	352,840	(278,874)	0	73,578	388
	1959	2,164	1,748	664	928	238	91	42	103,762	73,416	0	0	16,745	345,792	0	300	362,536	362,836	(278,874)	0	77,304	6,658
	1960	1,812	1,464	687	777	200	94	26	105,485	76,593	0	0	14,736	351,535	0	300	366,271	366,571	(278,874)	0	79,990	7,707
	1961	2,712	2,190	711	1,162	299	97	23	107,209	82,188	0	0	22,625	357,279	0	300	379,904	380,204	(278,874)	0	86,893	14,437
	1962	3,739	3,019	682	1,602	412	93	41	102,946	89,027	0	0	25,658	351,143	0	300	376,801	377,101	(278,874)	0	95,185	3,043
1963-1970	1963	2,507	2,024	750	1,074	276	102	37	98,684	96,749	0	0	20,776	345,022	0	300	365,798	366,098	(170,219)	0	101,219	94,661
	1964	2,730	2,205	900	1,170	301	123	56	94,421	98,305	0	0	22,514	338,862	0	300	361,377	361,677	(170,219)	0	103,284	88,174
	1965	2,732	2,206	719	1,171	301	98	92	90,159	104,303	0	0	21,475	332,652	0	300	354,127	354,427	(170,219)	0	109,115	75,093
	1966	2,894	2,337	681	1,240	319	93	103	85,896	108,765	0	0	24,141	326,530	0	300	350,672	350,972	(170,219)	0	113,776	66,977
	1967	2,742	2,214	634	1,175	302	86	124	81,634	107,357	0	0	22,873	320,209	0	300	343,082	343,382	(170,219)	0	112,118	61,046
	1968	3,541	2,859	1,048	1,517	390	143	145	77,371	105,949	0	0	26,387	314,087	0	300	340,475	340,775	(170,219)	0	112,342	58,214
	1969	3,719	3,003	1,066	1,594	410	145	154	73,109	104,540	0	0	28,920	307,878	0	300	336,798	337,098	(170,219)	0	111,219	55,661
	1970	3,295	2,661	1,116	1,412	363	152	152	68,846	103,132	0	0	25,863	300,142	0	300	326,005	326,305	(170,219)	0	109,260	46,826
1971-1978	1971	3,528	2,849	1,501	1,512	389	205	150	72,429	101,724	0	0	27,896	308,917	0	300	336,813	337,113	(55,179)	0	108,621	173,314
	1972	3,920	3,166	1,385	1,680	432	189	148	59,466	100,316	0	0	31,196	255,911	0	300	287,108	287,408	(55,179)	0	107,638	124,591
	1973	3,751	3,029	1,437	1,608	413	196	145	58,653	102,039	0	0	29,582	250,227	0	300	279,809	280,109	(55,179)	0	109,175	115,754
	1974	3,629	2,930	1,748	1,555	400	238	143	61,327	103,762	0	0	29,130	257,480	0	300	286,611	286,911	(55,179)	0	111,075	120,656
	1975	3,560	2,875	1,464	1,526	392	200	287	64,039	105,485	0	0	27,891	266,373	0	300	294,263	294,563	(55,179)	0	112,521	126,863
	1976	3,532	2,852	2,190	1,514	389	299	285	52,115	107,209	0	0	28,100	197,077	0	300	225,177	225,477	(55,179)	0	115,028	55,270
	1977	3,153	2,547	3,019	1,351	347	412	283	70,023	102,946	0	0	25,743	266,118	0	300	291,860	292,160	(55,179)	0	111,165	125,816
	1978	3,471	2,803	2,024	1,488	382	276	281	63,991	98,684	0	0	21,452	236,472	0	300	257,924	258,224	(55,179)	0	106,223	96,821
1979-1984	1979	3,705	2,992	2,205	1,588	408	301	279	55,533	94,421	0	0	22,525	190,180	0	300	212,705	213,005	(4,708)	0	102,498	105,799
	1980	3,616	2,920	2,206	1,550	398	301	890	58,345	90,159	0	0	22,147	193,315	0	300	215,462	215,762	(4,708)	0	98,722	112,332
	1981	3,865	3,121	2,337	1,656	426	319	1,303	52,196	85,896	0	0	20,889	160,637	0	300	181,525	181,825	(4,708)	0	95,376	81,741
	1982	3,988	3,221	2,214	1,709	439	302	2,418	44,705	81,634	0	0	24,408	152,229	0	300	176,638	176,938	(4,708)	0	92,265	79,964
	1983	3,265	2,637	2,859	1,399	360	390	1,929	42,747	77,371	0	0	19,711	157,425	0	300	177,136	177,436	(4,708)	0	87,214	85,515
	1984	4,559	3,682	3,003	1,954	502	410	2,046	37,326	73,109	0	0	26,308	139,104	0	300	165,412	165,712	(4,708)	0	85,081	75,923
1985-1991	1985	4,988	4,028	2,661	2,138	549	363	2,239	33,374	68,846	0	0	25,343	118,844	0	300	144,187	144,487	2,139	0	81,234	65,391
	1986	5,771	4,660	2,849	2,473	635	389	2,474	27,371	72,429	0	0	29,936	100,691	0	300	130,627	130,927	2,139	0	86,384	46,681
	1987	6,372	5,146	3,166	2,731	702	432	3,241	21,197	59,466	0	0	31,652	78,727	0	300	110,379	110,679	2,139	0	75,407	37,411
	1988	6,811	5,500	3,029	2,919	750	413	3,349	24,950	58,653	0	0	34,607	89,925	0	300	124,532	124,832	2,139	0	75,174	51,796
	1989	8,288	6,693	2,930	3,552	913	400	6,437	15,488	61,327	0	0	36,944	49,673	0	300	86,618	86,918	2,139	0	82,934	6,122
	1990	8,342	6,736	2,875	3,575	919	392	6,878	15,843	64,039	0	0	34,205	51,052	0	300	85,257	85,557	2,139	0	86,100	1,595
	1991	6,964	5,623	2,852	2,984	767	389	6,657	15,125	52,115	0	0	36,695	62,146	15,658	300	114,499	114,799	2,139	0	71,961	44,976
1992-1997	1992	7,714	6,230	2,547	3,306	850	347	6,308	19,606	70,023	0	0	33,108	77,510	0	300	110,618	110,918	33,467	0	90,245	54,140
	1993	9,565	7,724	2,803	4,099	1,053	382	6,433	16,610	63,991	0	0	38,366	61,654	0	300	100,019	100,319	33,467	0	87,274	46,512
	1994	10,443	8,434	2,992	4,476	1,150	408	6,429	17,198	55,533	0	0	44,233	59,395	0	300	103,628	103,928	33,467	0	80,281	57,114
	1995	10,526	8,501	2,920	4,511	1,159	398	6,877	19,800	58,345	0	0	47,976	68,879	0	300	116,855	117,155	33,467	0	83,578	67,044
	1996	11,707	9,454	3,121	5,017	1,289	426	6,879	22,717	52,196	0	238	49,134	74,152	0	300	123,285	123,585	33,467	238	79,347	77,467
	1997	11,790	9,521	3,221	5,053	1,298	439	7,163	25,419	44,705	0	656	49,240	79,095	0	300	128,336	128,636	33,467	656	72,372	89,075
1998-2005	1998	10,574	8,539	2,637	4,532	1,164	360	7,729	27,019	42,747	0	0	42,626	91,622	0	300	134,247	134,547	(62,145)	0	68,578	3,824
	1999	12,341	9,966	3,682	5,289	1,359	502	7,357	28,216	37,326	0	0	47,318	89,929	0	300	137,247	137,547	(62,145)	0	66,498	8,904
	2000	12,908	10,424	4,028	5,532	1,422	549	7,417	33,363	33,374	5,001	0	47,703	106,667	0	300	154,370	154,670	(62,145)	5,001	63,809	23,715
	2001	13,299	10,740	4,660	5,700	1,465	635	7,824	30,032	27,371	0	0	56,278	101,109	0	300	157,387	157,687	(62,145)	0	59,490	36,052
	2002	13,351	10,782	5,146	5,722	1,470	702	5,723	33,634	21,197	0	0	52,005	120,376	0	300	172,380	172,680	(62,145)	0	51,841	58,694
	2003	13,012	10,508	5,500	5,577	1,433	750	5,033	31,698	24,950	0	0	46,682	116,302	0	300	162,984	163,284	(62,145)	0	54,822	46,316
	2004	13,724	11,083	6,693	5,882	1,511	913	5,011	30,855	15,488	0	0	52,602	111,690	0	300	164,291	164,591	(62,145)	0	47,711	54,735
	2005	13,577	10,964	6,736	5,819	1,495	919	3,070	29,474	15,843	11	558	49,341	102,054	0	300	151,395	151,695	(62,145)	569	45,964	43,017
2006-2008	2006	13,975	11,285	5,623	5,989	1,539	767	1,604	27,398	15,125	0	1,612	42,428	89,445	0	300	131,872	132,172	(38,350)	1,612	43,083	49,128
	2007	14,510	11,717	6,230	6,218	1,598	850	1,900	26,486	19,606	0	857	50,263	79,118	0	300	129,381	129,681	(38,350)	857	49,313	41,160
	2008	13,392	10,814	7,724	5,739	1,475	1,053	1,773	29,670	16,610	0	0	56,839	105,365	0	300	162,204	162,504	(38,350)	0	46,291	77,863
		A		B	C		D	E		F	G	H	I	J	K	L	I+J+K	1 = I+J+K+L	2	3 = G+H	4 = ΣA..F	1+2-3-4

M&I return flows based on 45/55% indoor/outdoor water usage.

Return Flows from M&I septic tanks and Recycled water (A, C, and E) and Artificial recharge (G and H) are not lagged.

Return Flows from M&I outdoor irrigation and Agricultural irrigation are lagged by 15-years (B, D, and F).

Change in storage is the sum of Free drainage and Compaction (M).

Period	Period Length (yr)	Total Outflow (af)	Total Storage Change (af)	Total Artificial Recharge (af)	Total Return Flows (af)	Natural Recharge (afy)
1951-1962	12	4,348,524	(3,346,489)	0	822,342	14,974
1963-1970	8	2,780,733	(1,361,748)	0	872,333	68,332
1971-1978	8	2,261,964	(441,432)	0	881,447	117,386
1979-1984	6	1,130,679	(28,249)	0	561,155	90,212
1985-1991	7	798,198	14,971	0	559,196	36,282
1992-1997	6	684,542	200,801	894	493,096	65,225
1998-2005	8	1,236,702	(497,163)	5,570	458,712	34,407
1951-2005	**55**	**13,241,343**	**(5,459,309)**	**6,464**	**4,648,281**	**56,860**

Table 4.8-2: Base Scenario for Natural Recharge Calculation: Alfalfa AWT of 7.5 af/ac and 100% excess applied water as return flow; M&I urban area 70% sewered

(afy)

		Return Flows									Artificial Recharge		Outflows					Total Outflow	Change in Storage	Total Artificial Recharge	Total Return Flows (Net)	Natural Recharge
		M&I						Recycled	Agricultural		Spreading	Injection	Urban Pumping	Agricultural Pumping	Pumpage to Aqueduct	Other	Total Pumping					
		Urban Area			MWC and RR Areas																	
Study		Septic tank	Outdoor Irrigation		Septic tank	Outdoor Irrigation																
Period	Year	Gross = Net	Gross	Net	Gross = Net	Gross	Net	Gross = Net	Gross	Net	Gross = Net	Gross = Net										
1929-1944	1929	392	317		168	43		0	61,417		0	0	3,241	204,724	0	300						
	1930	421	340		180	46		0	54,034		0	0	3,423	180,112	0	300						
	1931	449	363		193	49		0	51,037		0	0	3,606	170,125	0	300						
	1932	478	386		205	53		0	48,041		0	0	3,788	160,138	0	300						
	1933	507	409		217	56		0	45,045		0	0	3,971	150,150	0	300						
	1934	536	433		230	59		0	42,049		0	0	4,153	140,163	0	300						
	1935	564	456		242	62		0	39,053		0	0	4,335	130,176	0	300						
	1936	593	479		254	65		0	43,383		0	0	4,518	144,611	0	300						
	1937	622	502		266	68		0	47,713		0	0	4,700	159,045	0	300						
	1938	650	525		279	72		0	52,044		0	0	4,882	173,479	0	300						
	1939	679	548		291	75		0	56,374		0	0	5,065	187,914	0	300						
	1940	708	572		303	78		0	60,704		0	0	5,247	202,348	0	300						
	1941	736	595		316	81		0	63,882		0	0	5,430	212,941	0	300						
	1942	765	618		328	84		0	67,060		0	0	5,612	223,533	0	300						
	1943	794	641		340	87		0	70,238		0	0	5,794	234,126	0	300						
	1944	823	664		353	91		0	73,416		0	0	5,977	244,719	0	300						
1945-1950	1945	851	687		365	94		0	76,593		0	0	6,159	255,311	0	300						
	1946	880	711		377	97		0	82,188		3,625	0	6,341	273,960	0	300						
	1947	845	682		362	93		0	89,027		3,625	0	6,049	296,757	0	300						
	1948	929	750		398	102		0	96,749		0	0	6,747	322,497	0	300						
	1949	1,114	900		478	123		0	98,305		0	0	8,296	327,685	0	300						
	1950	891	719		382	98		0	104,303		0	0	6,432	347,676	0	300						
1951-1962	1951	844	681	479	362	93	65	0	108,765	43,383	0	0	6,039	362,549	0	300	368,589	368,889	(278,874)	0	45,133	44,882
	1952	785	634	502	337	86	68	0	107,357	47,713	0	0	5,550	357,856	0	300	363,406	363,706	(278,874)	0	49,406	35,426
	1953	1,297	1,048	525	556	143	72	116	105,949	52,044	0	0	9,821	353,162	0	300	362,983	363,283	(278,874)	0	54,610	29,799
	1954	1,320	1,066	548	566	145	75	109	104,540	56,374	0	0	10,013	348,468	0	300	358,481	358,781	(278,874)	0	58,992	20,915
	1955	1,382	1,116	572	592	152	78	142	103,132	60,704	0	0	10,529	343,774	0	300	354,303	354,603	(278,874)	0	63,470	12,259
	1956	1,859	1,501	595	797	205	81	185	101,724	63,882	0	0	13,088	339,081	0	300	352,169	352,469	(278,874)	0	67,399	6,196
	1957	1,715	1,385	618	735	189	84	171	100,316	67,060	0	0	12,553	334,387	0	300	346,940	347,240	(278,874)	0	70,383	(2,017)
	1958	1,779	1,437	641	763	196	87	70	102,039	70,238	0	0	12,409	340,131	0	300	352,540	352,840	(278,874)	0	73,578	388
	1959	2,164	1,748	664	928	238	91	42	103,762	73,416	0	0	16,745	345,792	0	300	362,536	362,836	(278,874)	0	77,304	6,658
	1960	1,812	1,464	687	777	200	94	26	105,485	76,593	0	0	14,736	351,535	0	300	366,271	366,571	(278,874)	0	79,990	7,707
	1961	2,712	2,190	711	1,162	299	97	23	107,209	82,188	0	0	22,625	357,279	0	300	379,904	380,204	(278,874)	0	86,893	14,437
	1962	3,739	3,019	682	1,602	412	93	41	106,594	89,027	0	0	25,658	354,792	0	300	380,450	380,750	(278,874)	0	95,185	6,691
1963-1970	1963	2,507	2,024	750	1,074	276	102	37	105,980	96,749	0	0	20,776	352,318	0	300	373,095	373,395	(170,219)	0	101,219	101,957
	1964	2,730	2,205	900	1,170	301	123	56	105,365	98,305	0	0	22,514	349,807	0	300	372,321	372,621	(170,219)	0	103,284	99,118
	1965	2,732	2,206	719	1,171	301	98	92	104,751	104,303	0	0	21,475	347,244	0	300	368,720	369,020	(170,219)	0	109,115	89,686
	1966	2,894	2,337	681	1,240	319	93	103	104,137	108,765	0	0	24,141	344,771	0	300	368,912	369,212	(170,219)	0	113,776	85,218
	1967	2,742	2,214	634	1,175	302	86	124	103,522	107,357	0	0	22,873	342,098	0	300	364,971	365,271	(170,219)	0	112,118	82,934
	1968	3,541	2,859	1,048	1,517	390	143	145	102,908	105,949	0	0	26,387	339,624	0	300	366,011	366,311	(170,219)	0	112,342	83,751
	1969	3,719	3,003	1,066	1,594	410	145	154	102,294	104,540	0	0	28,920	337,063	0	300	365,983	366,283	(170,219)	0	111,219	84,846
	1970	3,295	2,661	1,116	1,412	363	152	152	101,679	103,132	0	0	25,863	332,975	0	300	358,838	359,138	(170,219)	0	109,260	79,660
1971-1978	1971	3,528	2,849	1,501	1,512	389	205	150	102,886	101,724	0	0	27,896	339,374	0	300	367,270	367,570	(55,179)	0	108,621	203,771
	1972	3,920	3,166	1,385	1,680	432	189	148	86,093	100,316	0	0	31,196	282,539	0	300	313,735	314,035	(55,179)	0	107,638	151,218
	1973	3,751	3,029	1,437	1,608	413	196	145	83,709	102,039	0	0	29,582	275,282	0	300	304,864	305,164	(55,179)	0	109,175	140,810
	1974	3,629	2,930	1,748	1,555	400	238	143	85,077	103,762	0	0	29,130	281,230	0	300	310,360	310,660	(55,179)	0	111,075	144,406
	1975	3,560	2,875	1,464	1,526	392	200	287	87,226	105,485	0	0	27,891	289,559	0	300	317,450	317,750	(55,179)	0	112,521	150,050
	1976	3,532	2,852	2,190	1,514	389	299	285	75,281	107,209	0	0	28,100	220,243	0	300	248,343	248,643	(55,179)	0	115,028	78,436
	1977	3,153	2,547	3,019	1,351	347	412	283	97,275	106,594	0	0	25,743	293,370	0	300	319,112	319,412	(55,179)	0	114,813	149,420
	1978	3,471	2,803	2,024	1,488	382	276	281	90,875	105,980	0	0	21,452	263,356	0	300	284,807	285,107	(55,179)	0	113,520	116,409
1979-1984	1979	3,705	2,992	2,205	1,588	408	301	279	81,230	105,365	0	0	22,525	215,877	0	300	238,402	238,702	(4,708)	0	113,443	120,551
	1980	3,616	2,920	2,206	1,550	398	301	890	84,047	104,751	0	0	22,147	219,017	0	300	241,164	241,464	(4,708)	0	113,314	123,442
	1981	3,865	3,121	2,337	1,656	426	319	1,303	75,086	104,137	0	0	20,889	183,527	0	300	204,415	204,715	(4,708)	0	113,616	86,390
	1982	3,988	3,221	2,214	1,709	439	302	2,418	63,485	103,522	0	0	24,408	171,009	0	300	195,418	195,718	(4,708)	0	114,154	76,856
	1983	3,265	2,637	2,859	1,399	360	390	1,929	59,155	102,908	0	0	19,711	173,833	0	300	193,544	193,844	(4,708)	0	112,751	76,386
	1984	4,559	3,682	3,003	1,954	502	410	2,046	51,539	102,294	0	0	26,308	153,317	0	300	179,625	179,925	(4,708)	0	114,266	60,951
1985-1991	1985	4,988	4,028	2,661	2,138	549	363	2,239	45,894	101,679	0	0	25,343	131,364	0	300	156,707	157,007	2,139	0	114,067	45,078
	1986	5,771	4,660	2,849	2,473	635	389	2,474	37,418	102,886	0	0	29,936	110,738	0	300	140,674	140,974	2,139	0	116,841	26,271
	1987	6,372	5,146	3,166	2,731	702	432	3,241	31,202	86,093	0	0	31,652	88,732	0	300	120,384	120,684	2,139	0	102,035	20,788
	1988	6,811	5,500	3,029	2,919	750	413	3,349	34,170	83,709	0	0	34,607	99,145	0	300	133,752	134,052	2,139	0	100,230	35,961
	1989	8,288	6,693	2,930	3,552	913	400	6,437	22,669	85,077	0	0	36,944	56,855	0	300	93,799	94,099	2,139	0	106,684	(10,446)
	1990	8,342	6,736	2,875	3,575	919	392	6,878	23,115	87,226	0	0	34,205	58,323	0	300	92,528	92,828	2,139	0	109,287	(14,320)
	1991	6,964	5,623	2,852	2,984	767	389	6,657	21,987	75,281	0	0	36,695	69,008	15,658	300	121,361	121,661	2,139	0	95,127	28,673
1992-1997	1992	7,714	6,230	2,547	3,306	850	347	6,308	26,534	97,275	0	0	33,108	84,438	0	300	117,546	117,846	33,467	0	117,497	33,815
	1993	9,565	7,724	2,803	4,099	1,053	382	6,433	23,545	90,875	0	0	38,366	68,589	0	300	106,954	107,254	33,467	0	114,157	26,563
	1994	10,443	8,434	2,992	4,476	1,150	408	6,429	24,088	81,230	0	0	44,233	66,285	0	300	110,518	110,818	33,467	0	105,979	38,306
	1995	10,526	8,501	2,920	4,511	1,159	398	6,877	26,893	84,047	0	0	47,976	75,972	0	300	123,948	124,248	33,467	0	109,280	48,435
	1996	11,707	9,454	3,121	5,017	1,289	426	6,879	29,804	75,086	0	238	49,134	81,239	0	300	130,373	130,673	33,467	238	102,236	61,665
	1997	11,790	9,521	3,221	5,053	1,298	439	7,163	32,911	63,485	0	656	49,240	86,587	0	300	135,827	136,127	33,467	656	91,151	77,787
1998-2005	1998	10,574	8,539	2,637	4,532	1,164	360	7,729	34,320	59,155	0	0	42,626	98,922	0	300	141,548	141,848	(62,145)	0	84,986	(5,283)
	1999	12,341	9,966	3,682	5,289	1,359	502	7,357	36,633	51,539	0	0	47,318	98,346	0	300	145,664	145,964	(62,145)	0	80,710	3,109
	2000	12,908	10,424	4,028	5,532	1,422	549	7,417	42,083	45,894	5,001	0	47,703	115,387	0	300	163,090	163,390	(62,145)	5,001	76,329	19,915
	2001	13,299	10,740	4,660	5,700	1,465	635	7,824	37,840	37,418	0	0	56,278	108,917	0	300	165,194	165,494	(62,145)	0	69,537	33,812
	2002	13,351	10,782	5,146	5,722	1,470	702	5,723	41,593	31,202	0	0	52,005	128,334	0	300	180,339	180,639	(62,145)	0	61,846	56,647
	2003	13,012	10,508	5,500	5,577	1,433	750	5,033	38,959	34,170	0	0	46,682	123,563	0	300	170,245	170,545	(62,145)	0	64,042	44,358
	2004	13,724	11,083	6,693	5,882	1,511	913	5,011	38,558	22,669	0	0	52,602	119,392	0	300	171,994	172,294	(62,145)	0	54,893	55,256
	2005	13,577	10,964	6,736	5,819	1,495	919	3,070	36,548	23,115	11	558	49,341	109,129	0	300	158,470	158,770	(62,145)	569	53,235	42,820
2006-2008	2006	13,975	11,285	5,623	5,989	1,539	767	1,604	34,139	21,987	0	1,612	42,428	96,186	0	300	138,613	138,913	(38,350)	1,612	49,945	49,006
	2007	14,510	11,717	6,230	6,218	1,598	850	1,900	33,283	26,534	0	857	50,263	85,915	0	300	136,178	136,478	(38,350)	857	56,241	41,030
	2008	13,392	10,814	7,724	5,739	1,475	1,053	1,773	36,394	23,545	0	0	56,839	112,089	0	300	168,928	169,228	(38,350)	0	53,226	77,652
		A		B	C		D	E		F	G	H	I	J	K	L	I+J+K	1 = I+J+K+L	2	3 = G+H	4=ΣA..F	1+2-3-4

M&I return flows based on 45/55% indoor/outdoor water usage.
Return Flows from M&I septic tanks and Recycled water (A, C, and E) and Artificial recharge (G and H) are not lagged.
Return Flows from M&I outdoor irrigation and Agricultural irrigation are lagged by 15-years (B, D, and F).
Change in storage is the sum of Free drainage and Compaction (M).

Period	**Period Length (yr)**	**Total Outflow (af)**	**Total Storage Change (af)**	**Total Artificial Recharge (af)**	**Total Return Flows (af)**	**Natural Recharge (afy)**
1951-1962	12	4,352,172	(3,346,489)	0	822,342	15,278
1963-1970	8	2,941,251	(1,361,748)	0	872,333	88,396
1971-1978	8	2,468,342	(441,432)	0	892,391	141,815
1979-1984	6	1,254,368	(28,249)	0	681,543	90,763
1985-1991	7	861,306	14,971	0	744,271	18,858
1992-1997	6	726,966	200,801	894	640,301	47,762
1998-2005	8	1,298,944	(497,163)	5,570	545,577	31,329
1951-2005	**55**	**13,903,349**	**(5,459,309)**	**6,464**	**5,198,759**	**58,888**

Table 4.8-3: Base Scenario for Natural Recharge Calculation: Alfalfa AWT of 6.5 af/ac and 85% excess applied water as return flow; M&I urban area 70% sewered
(afy)

		Return Flows									Artificial Recharge		Outflows					Total Outflow	Change in Storage	Total Artificial Recharge	Total Return Flows (Net)	Natural Recharge
		M&I						Recycled	Agricultural		Spreading	Injection	Urban Pumping	Agricultural Pumping	Pumpage to Aqueduct	Other	Total Pumping					
		Urban Area			MWC and RR Areas																	
Study Period		Septic tank	Outdoor Irrigation		Septic tank	Outdoor Irrigation																
	Year	Gross = Net	Gross	Net	Gross = Net	Gross	Net	Gross = Net	Gross	Net	Gross = Net	Gross = Net										
1929-1944	1929	392	317		168	43		0	52,205		0	0	3,241	204,724	0	300						
	1930	421	340		180	46		0	45,929		0	0	3,423	180,112	0	300						
	1931	449	363		193	49		0	43,382		0	0	3,606	170,125	0	300						
	1932	478	386		205	53		0	40,835		0	0	3,788	160,138	0	300						
	1933	507	409		217	56		0	38,288		0	0	3,971	150,150	0	300						
	1934	536	433		230	59		0	35,742		0	0	4,153	140,163	0	300						
	1935	564	456		242	62		0	33,195		0	0	4,335	130,176	0	300						
	1936	593	479		254	65		0	36,876		0	0	4,518	144,611	0	300						
	1937	622	502		266	68		0	40,556		0	0	4,700	159,045	0	300						
	1938	650	525		279	72		0	44,237		0	0	4,882	173,479	0	300						
	1939	679	548		291	75		0	47,918		0	0	5,065	187,914	0	300						
	1940	708	572		303	78		0	51,599		0	0	5,247	202,348	0	300						
	1941	736	595		316	81		0	54,300		0	0	5,430	212,941	0	300						
	1942	765	618		328	84		0	57,001		0	0	5,612	223,533	0	300						
	1943	794	641		340	87		0	59,702		0	0	5,794	234,126	0	300						
	1944	823	664		353	91		0	62,403		0	0	5,977	244,719	0	300						
1945-1950	1945	851	687		365	94		0	65,104		0	0	6,159	255,311	0	300						
	1946	880	711		377	97		0	69,860		3,625	0	6,341	273,960	0	300						
	1947	845	682		362	93		0	75,673		3,625	0	6,049	296,757	0	300						
	1948	929	750		398	102		0	82,237		0	0	6,747	322,497	0	300						
	1949	1,114	900		478	123		0	83,560		0	0	8,296	327,685	0	300						
	1950	891	719		382	98		0	88,657		0	0	6,432	347,676	0	300						
1951-1962	1951	844	681	479	362	93	65	0	92,450	36,876	0	0	6,039	362,549	0	300	368,589	368,889	(278,874)	0	38,625	51,389
	1952	785	634	502	337	86	68	0	91,253	40,556	0	0	5,550	357,856	0	300	363,406	363,706	(278,874)	0	42,249	42,583
	1953	1,297	1,048	525	556	143	72	116	90,056	44,237	0	0	9,821	353,162	0	300	362,983	363,283	(278,874)	0	46,803	37,606
	1954	1,320	1,066	548	566	145	75	109	88,859	47,918	0	0	10,013	348,468	0	300	358,481	358,781	(278,874)	0	50,536	29,371
	1955	1,382	1,116	572	592	152	78	142	87,662	51,599	0	0	10,529	343,774	0	300	354,303	354,603	(278,874)	0	54,364	21,365
	1956	1,859	1,501	595	797	205	81	185	86,466	54,300	0	0	13,088	339,081	0	300	352,169	352,469	(278,874)	0	57,817	15,778
	1957	1,715	1,385	618	735	189	84	171	85,269	57,001	0	0	12,553	334,387	0	300	346,940	347,240	(278,874)	0	60,324	8,042
	1958	1,779	1,437	641	763	196	87	70	86,733	59,702	0	0	12,409	340,131	0	300	352,540	352,840	(278,874)	0	63,042	10,923
	1959	2,164	1,748	664	928	238	91	42	88,198	62,403	0	0	16,745	345,792	0	300	362,536	362,836	(278,874)	0	66,292	17,670
	1960	1,812	1,464	687	777	200	94	26	89,663	65,104	0	0	14,736	351,535	0	300	366,271	366,571	(278,874)	0	68,501	19,196
	1961	2,712	2,190	711	1,162	299	97	23	91,127	69,860	0	0	22,625	357,279	0	300	379,904	380,204	(278,874)	0	74,565	26,766
	1962	3,739	3,019	682	1,602	412	93	41	87,504	75,673	0	0	25,658	351,143	0	300	376,801	377,101	(278,874)	0	81,831	16,397
1963-1970	1963	2,507	2,024	750	1,074	276	102	37	83,881	82,237	0	0	20,776	345,022	0	300	365,798	366,098	(170,219)	0	86,707	109,173
	1964	2,730	2,205	900	1,170	301	123	56	80,258	83,560	0	0	22,514	338,862	0	300	361,377	361,677	(170,219)	0	88,538	102,920
	1965	2,732	2,206	719	1,171	301	98	92	76,635	88,657	0	0	21,475	332,652	0	300	354,127	354,427	(170,219)	0	93,470	90,739
	1966	2,894	2,337	681	1,240	319	93	103	73,012	92,450	0	0	24,141	326,530	0	300	350,672	350,972	(170,219)	0	97,461	83,292
	1967	2,742	2,214	634	1,175	302	86	124	69,389	91,253	0	0	22,873	320,209	0	300	343,082	343,382	(170,219)	0	96,015	77,149
	1968	3,541	2,859	1,048	1,517	390	143	145	65,765	90,056	0	0	26,387	314,087	0	300	340,475	340,775	(170,219)	0	96,450	74,107
	1969	3,719	3,003	1,066	1,594	410	145	154	62,142	88,859	0	0	28,920	307,878	0	300	336,798	337,098	(170,219)	0	95,537	71,342
	1970	3,295	2,661	1,116	1,412	363	152	152	58,519	87,662	0	0	25,863	300,142	0	300	326,005	326,305	(170,219)	0	93,790	62,296
1971-1978	1971	3,528	2,849	1,501	1,512	389	205	150	61,564	86,466	0	0	27,896	308,917	0	300	336,813	337,113	(55,179)	0	93,362	188,572
	1972	3,920	3,166	1,385	1,680	432	189	148	50,546	85,269	0	0	31,196	255,911	0	300	287,108	287,408	(55,179)	0	92,590	139,638
	1973	3,751	3,029	1,437	1,608	413	196	145	49,855	86,733	0	0	29,582	250,227	0	300	279,809	280,109	(55,179)	0	93,869	131,060
	1974	3,629	2,930	1,748	1,555	400	238	143	52,128	88,198	0	0	29,130	257,480	0	300	286,611	286,911	(55,179)	0	95,511	136,221
	1975	3,560	2,875	1,464	1,526	392	200	287	54,433	89,663	0	0	27,891	266,373	0	300	294,263	294,563	(55,179)	0	96,698	142,686
	1976	3,532	2,852	2,190	1,514	389	299	285	44,298	91,127	0	0	28,100	197,077	0	300	225,177	225,477	(55,179)	0	98,947	71,351
	1977	3,153	2,547	3,019	1,351	347	412	283	59,519	87,504	0	0	25,743	266,118	0	300	291,860	292,160	(55,179)	0	95,723	141,258
	1978	3,471	2,803	2,024	1,488	382	276	281	54,393	83,881	0	0	21,452	236,472	0	300	257,924	258,224	(55,179)	0	91,421	111,624
1979-1984	1979	3,705	2,992	2,205	1,588	408	301	279	47,203	80,258	0	0	22,525	190,180	0	300	212,705	213,005	(4,708)	0	88,335	119,962
	1980	3,616	2,920	2,206	1,550	398	301	890	49,593	76,635	0	0	22,147	193,315	0	300	215,462	215,762	(4,708)	0	85,198	125,856
	1981	3,865	3,121	2,337	1,656	426	319	1,303	44,367	73,012	0	0	20,889	160,637	0	300	181,525	181,825	(4,708)	0	82,491	94,626
	1982	3,988	3,221	2,214	1,709	439	302	2,418	37,999	69,389	0	0	24,408	152,229	0	300	176,638	176,938	(4,708)	0	80,020	92,209
	1983	3,265	2,637	2,859	1,399	360	390	1,929	36,335	65,765	0	0	19,711	157,425	0	300	177,136	177,436	(4,708)	0	75,608	97,120
	1984	4,559	3,682	3,003	1,954	502	410	2,046	31,727	62,142	0	0	26,308	139,104	0	300	165,412	165,712	(4,708)	0	74,114	86,889
1985-1991	1985	4,988	4,028	2,661	2,138	549	363	2,239	28,368	58,519	0	0	25,343	118,844	0	300	144,187	144,487	2,139	0	70,907	75,718
	1986	5,771	4,660	2,849	2,473	635	389	2,474	23,265	61,564	0	0	29,936	100,691	0	300	130,627	130,927	2,139	0	75,520	57,546
	1987	6,372	5,146	3,166	2,731	702	432	3,241	18,018	50,546	0	0	31,652	78,727	0	300	110,379	110,679	2,139	0	66,487	46,331
	1988	6,811	5,500	3,029	2,919	750	413	3,349	21,207	49,855	0	0	34,607	89,925	0	300	124,532	124,832	2,139	0	66,376	60,594
	1989	8,288	6,693	2,930	3,552	913	400	6,437	13,165	52,128	0	0	36,944	49,673	0	300	86,618	86,918	2,139	0	73,735	15,321
	1990	8,342	6,736	2,875	3,575	919	392	6,878	13,467	54,433	0	0	34,205	51,052	0	300	85,257	85,557	2,139	0	76,495	11,201
	1991	6,964	5,623	2,852	2,984	767	389	6,657	12,856	44,298	0	0	36,695	62,146	15,658	300	114,499	114,799	2,139	0	64,144	52,794
1992-1997	1992	7,714	6,230	2,547	3,306	850	347	6,308	16,665	59,519	0	0	33,108	77,510	0	300	110,618	110,918	33,467	0	79,742	64,643
	1993	9,565	7,724	2,803	4,099	1,053	382	6,433	14,118	54,393	0	0	38,366	61,654	0	300	100,019	100,319	33,467	0	77,675	56,111
	1994	10,443	8,434	2,992	4,476	1,150	408	6,429	14,619	47,203	0	0	44,233	59,395	0	300	103,628	103,928	33,467	0	71,951	65,444
	1995	10,526	8,501	2,920	4,511	1,159	398	6,877	16,830	49,593	0	0	47,976	68,879	0	300	116,855	117,155	33,467	0	74,826	75,796
	1996	11,707	9,454	3,121	5,017	1,289	426	6,879	19,309	44,367	0	238	49,134	74,152	0	300	123,285	123,585	33,467	238	71,517	85,297
	1997	11,790	9,521	3,221	5,053	1,298	439	7,163	21,607	37,999	0	656	49,240	79,095	0	300	128,336	128,636	33,467	656	65,666	95,781
1998-2005	1998	10,574	8,539	2,637	4,532	1,164	360	7,729	22,966	36,335	0	0	42,626	91,622	0	300	134,247	134,547	(62,145)	0	62,166	10,236
	1999	12,341	9,966	3,682	5,289	1,359	502	7,357	23,983	31,727	0	0	47,318	89,929	0	300	137,247	137,547	(62,145)	0	60,899	14,503
	2000	12,908	10,424	4,028	5,532	1,422	549	7,417	28,358	28,368	5,001	0	47,703	106,667	0	300	154,370	154,670	(62,145)	5,001	58,803	28,721
	2001	13,299	10,740	4,660	5,700	1,465	635	7,824	25,528	23,265	0	0	56,278	101,109	0	300	157,387	157,687	(62,145)	0	55,384	40,157
	2002	13,351	10,782	5,146	5,722	1,470	702	5,723	28,589	18,018	0	0	52,005	120,376	0	300	172,380	172,680	(62,145)	0	48,661	61,874
	2003	13,012	10,508	5,500	5,577	1,433	750	5,033	26,943	21,207	0	0	46,682	116,302	0	300	162,984	163,284	(62,145)	0	51,080	50,059
	2004	13,724	11,083	6,693	5,882	1,511	913	5,011	26,227	13,165	0	0	52,602	111,690	0	300	164,291	164,591	(62,145)	0	45,388	57,058
	2005	13,577	10,964	6,736	5,819	1,495	919	3,070	25,053	13,467	11	558	49,341	102,054	0	300	151,395	151,695	(62,145)	569	43,587	45,394
2006-2008	2006	13,975	11,285	5,623	5,989	1,539	767	1,604	23,289	12,856	0	1,612	42,428	89,445	0	300	131,872	132,172	(38,350)	1,612	40,814	51,396
	2007	14,510	11,717	6,230	6,218	1,598	850	1,900	22,513	16,665	0	857	50,263	79,118	0	300	129,381	129,681	(38,350)	857	46,373	44,101
	2008	13,392	10,814	7,724	5,739	1,475	1,053	1,773	25,219	14,118	0	0	56,839	105,365	0	300	162,204	162,504	(38,350)	0	43,800	80,354
		A		B	C		D	E		F	G	H	I	J	K	L	I+J+K	1 = I+J+K+L	2	3 = G+H	4 = ΣA..F	1+2-3-4

M&I return flows based on 45/55% indoor/outdoor water usage.

Return Flows from M&I septic tanks and Recycled water (A, C, and E) and Artificial recharge (G and H) are not lagged.

Return Flows from M&I outdoor irrigation and Agricultural irrigation are lagged by 15-years (B, D, and F).

Change in storage is the sum of Free drainage and Compaction (M).

Period	**Period Length (yr)**	**Total Outflow (af)**	**Total Storage Change (af)**	**Total Artificial Recharge (af)**	**Total Return Flows (af)**	**Natural Recharge (afy)**
1951-1962	12	4,348,524	(3,346,489)	0	704,948	24,757
1963-1970	8	2,780,733	(1,361,748)	0	747,968	83,877
1971-1978	8	2,261,964	(441,432)	0	758,122	132,801
1979-1984	6	1,130,679	(28,249)	0	485,767	102,777
1985-1991	7	798,198	14,971	0	493,664	45,644
1992-1997	6	684,542	200,801	894	441,377	73,845
1998-2005	8	1,236,702	(497,163)	5,570	425,967	38,500
1951-2005	**55**	**13,241,343**	**(5,459,309)**	**6,464**	**4,057,814**	**67,596**

Table 4.8-4: Base Scenario for Natural Recharge Calculation: Alfalfa AWT of 6.5 af/ac and 100% excess applied water as return flow; M&I urban area 100% sewered

(afy)

		Return Flows									Artificial Recharge		Outflows					Total Outflow	Change in Storage	Total Artificial Recharge	Total Return Flows (Net)	Natural Recharge
		M&I						Recycled	Agricultural		Spreading	Injection	Urban Pumping	Agricultural Pumping	Pumpage to Aqueduct	Other	Total Pumping					
		Urban Area			MWC and RR Areas																	
Study		Septic tank	Outdoor Irrigation		Septic tank	Outdoor Irrigation																
Period	Year	Gross = Net	Gross	Net	Gross = Net	Gross	Net	Gross = Net	Gross	Net	Gross = Net	Gross = Net										
1929-1944	1929	0	317		168	43		0	61,417		0	0	3,241	204,724	0	300						
	1930	0	340		180	46		0	54,034		0	0	3,423	180,112	0	300						
	1931	0	363		193	49		0	51,037		0	0	3,606	170,125	0	300						
	1932	0	386		205	53		0	48,041		0	0	3,788	160,138	0	300						
	1933	0	409		217	56		0	45,045		0	0	3,971	150,150	0	300						
	1934	0	433		230	59		0	42,049		0	0	4,153	140,163	0	300						
	1935	0	456		242	62		0	39,053		0	0	4,335	130,176	0	300						
	1936	0	479		254	65		0	43,383		0	0	4,518	144,611	0	300						
	1937	0	502		266	68		0	47,713		0	0	4,700	159,045	0	300						
	1938	0	525		279	72		0	52,044		0	0	4,882	173,479	0	300						
	1939	0	548		291	75		0	56,374		0	0	5,065	187,914	0	300						
	1940	0	572		303	78		0	60,704		0	0	5,247	202,348	0	300						
	1941	0	595		316	81		0	63,882		0	0	5,430	212,941	0	300						
	1942	0	618		328	84		0	67,060		0	0	5,612	223,533	0	300						
	1943	0	641		340	87		0	70,238		0	0	5,794	234,126	0	300						
	1944	0	664		353	91		0	73,416		0	0	5,977	244,719	0	300						
1945-1950	1945	0	687		365	94		0	76,593		0	0	6,159	255,311	0	300						
	1946	0	711		377	97		0	82,188		3,625	0	6,341	273,960	0	300						
	1947	0	682		362	93		0	89,027		3,625	0	6,049	296,757	0	300						
	1948	0	750		398	102		0	96,749		0	0	6,747	322,497	0	300						
	1949	0	900		478	123		0	98,305		0	0	8,296	327,685	0	300						
	1950	0	719		382	98		0	104,303		0	0	6,432	347,676	0	300						
1951-1962	1951	0	681	479	362	93	65	0	108,765	43,383	0	0	6,039	362,549	0	300	368,589	368,889	(278,874)	0	44,289	45,726
	1952	0	634	502	337	86	68	0	107,357	47,713	0	0	5,550	357,856	0	300	363,406	363,706	(278,874)	0	48,620	36,212
	1953	0	1,048	525	556	143	72	116	105,949	52,044	0	0	9,821	353,162	0	300	362,983	363,283	(278,874)	0	53,313	31,097
	1954	0	1,066	548	566	145	75	109	104,540	56,374	0	0	10,013	348,468	0	300	358,481	358,781	(278,874)	0	57,672	22,235
	1955	0	1,116	572	592	152	78	142	103,132	60,704	0	0	10,529	343,774	0	300	354,303	354,603	(278,874)	0	62,088	13,641
	1956	0	1,501	595	797	205	81	185	101,724	63,882	0	0	13,088	339,081	0	300	352,169	352,469	(278,874)	0	65,540	8,055
	1957	0	1,385	618	735	189	84	171	100,316	67,060	0	0	12,553	334,387	0	300	346,940	347,240	(278,874)	0	68,668	(302)
	1958	0	1,437	641	763	196	87	70	102,039	70,238	0	0	12,409	340,131	0	300	352,540	352,840	(278,874)	0	71,799	2,167
	1959	0	1,748	664	928	238	91	42	103,762	73,416	0	0	16,745	345,792	0	300	362,536	362,836	(278,874)	0	75,140	8,822
	1960	0	1,464	687	777	200	94	26	105,485	76,593	0	0	14,736	351,535	0	300	366,271	366,571	(278,874)	0	78,177	9,519
	1961	0	2,190	711	1,162	299	97	23	107,209	82,188	0	0	22,625	357,279	0	300	379,904	380,204	(278,874)	0	84,181	17,149
	1962	0	3,019	682	1,602	412	93	41	102,946	89,027	0	0	25,658	351,143	0	300	376,801	377,101	(278,874)	0	91,446	6,781
1963-1970	1963	0	2,024	750	1,074	276	102	37	98,684	96,749	0	0	20,776	345,022	0	300	365,798	366,098	(170,219)	0	98,713	97,167
	1964	0	2,205	900	1,170	301	123	56	94,421	98,305	0	0	22,514	338,862	0	300	361,377	361,677	(170,219)	0	100,554	90,904
	1965	0	2,206	719	1,171	301	98	92	90,159	104,303	0	0	21,475	332,652	0	300	354,127	354,427	(170,219)	0	106,383	77,825
	1966	0	2,337	681	1,240	319	93	103	85,896	108,765	0	0	24,141	326,530	0	300	350,672	350,972	(170,219)	0	110,882	69,871
	1967	0	2,214	634	1,175	302	86	124	81,634	107,357	0	0	22,873	320,209	0	300	343,082	343,382	(170,219)	0	109,376	63,787
	1968	0	2,859	1,048	1,517	390	143	145	77,371	105,949	0	0	26,387	314,087	0	300	340,475	340,775	(170,219)	0	108,801	61,755
	1969	0	3,003	1,066	1,594	410	145	154	73,109	104,540	0	0	28,920	307,878	0	300	336,798	337,098	(170,219)	0	107,500	59,380
	1970	0	2,661	1,116	1,412	363	152	152	68,846	103,132	0	0	25,863	300,142	0	300	326,005	326,305	(170,219)	0	105,965	50,122
1971-1978	1971	0	2,849	1,501	1,512	389	205	150	72,429	101,724	0	0	27,896	308,917	0	300	336,813	337,113	(55,179)	0	105,092	176,842
	1972	0	3,166	1,385	1,680	432	189	148	59,466	100,316	0	0	31,196	255,911	0	300	287,108	287,408	(55,179)	0	103,718	128,511
	1973	0	3,029	1,437	1,608	413	196	145	58,653	102,039	0	0	29,582	250,227	0	300	279,809	280,109	(55,179)	0	105,424	119,505
	1974	0	2,930	1,748	1,555	400	238	143	61,327	103,762	0	0	29,130	257,480	0	300	286,611	286,911	(55,179)	0	107,447	124,285
	1975	0	2,875	1,464	1,526	392	200	287	64,039	105,485	0	0	27,891	266,373	0	300	294,263	294,563	(55,179)	0	108,961	130,423
	1976	0	2,852	2,190	1,514	389	299	285	52,115	107,209	0	0	28,100	197,077	0	300	225,177	225,477	(55,179)	0	111,496	58,802
	1977	0	2,547	3,019	1,351	347	412	283	70,023	102,946	0	0	25,743	266,118	0	300	291,860	292,160	(55,179)	0	108,012	128,970
	1978	0	2,803	2,024	1,488	382	276	281	63,991	98,684	0	0	21,452	236,472	0	300	257,924	258,224	(55,179)	0	102,753	100,292
1979-1984	1979	0	2,992	2,205	1,588	408	301	279	55,533	94,421	0	0	22,525	190,180	0	300	212,705	213,005	(4,708)	0	98,793	109,504
	1980	0	2,920	2,206	1,550	398	301	890	58,345	90,159	0	0	22,147	193,315	0	300	215,462	215,762	(4,708)	0	95,106	115,949
	1981	0	3,121	2,337	1,656	426	319	1,303	52,196	85,896	0	0	20,889	160,637	0	300	181,525	181,825	(4,708)	0	91,511	85,606
	1982	0	3,221	2,214	1,709	439	302	2,418	44,705	81,634	0	0	24,408	152,229	0	300	176,638	176,938	(4,708)	0	88,277	83,953
	1983	0	2,637	2,859	1,399	360	390	1,929	42,747	77,371	0	0	19,711	157,425	0	300	177,136	177,436	(4,708)	0	83,948	88,780
	1984	0	3,682	3,003	1,954	502	410	2,046	37,326	73,109	0	0	26,308	139,104	0	300	165,412	165,712	(4,708)	0	80,521	80,482
1985-1991	1985	0	4,028	2,661	2,138	549	363	2,239	33,374	68,846	0	0	25,343	118,844	0	300	144,187	144,487	2,139	0	76,247	70,379
	1986	0	4,660	2,849	2,473	635	389	2,474	27,371	72,429	0	0	29,936	100,691	0	300	130,627	130,927	2,139	0	80,614	52,452
	1987	0	5,146	3,166	2,731	702	432	3,241	21,197	59,466	0	0	31,652	78,727	0	300	110,379	110,679	2,139	0	69,035	43,783
	1988	0	5,500	3,029	2,919	750	413	3,349	24,950	58,653	0	0	34,607	89,925	0	300	124,532	124,832	2,139	0	68,363	58,607
	1989	0	6,693	2,930	3,552	913	400	6,437	15,488	61,327	0	0	36,944	49,673	0	300	86,618	86,918	2,139	0	74,646	14,410
	1990	0	6,736	2,875	3,575	919	392	6,878	15,843	64,039	0	0	34,205	51,052	0	300	85,257	85,557	2,139	0	77,759	9,937
	1991	0	5,623	2,852	2,984	767	389	6,657	15,125	52,115	0	0	36,695	62,146	15,658	300	114,499	114,799	2,139	0	64,998	51,940
1992-1997	1992	0	6,230	2,547	3,306	850	347	6,308	19,606	70,023	0	0	33,108	77,510	0	300	110,618	110,918	33,467	0	82,531	61,854
	1993	0	7,724	2,803	4,099	1,053	382	6,433	16,610	63,991	0	0	38,366	61,654	0	300	100,019	100,319	33,467	0	77,709	56,077
	1994	0	8,434	2,992	4,476	1,150	408	6,429	17,198	55,533	0	0	44,233	59,395	0	300	103,628	103,928	33,467	0	69,838	67,557
	1995	0	8,501	2,920	4,511	1,159	398	6,877	19,800	58,345	0	0	47,976	68,879	0	300	116,855	117,155	33,467	0	73,051	77,571
	1996	0	9,454	3,121	5,017	1,289	426	6,879	22,717	52,196	0	238	49,134	74,152	0	300	123,285	123,585	33,467	238	67,639	89,175
	1997	0	9,521	3,221	5,053	1,298	439	7,163	25,419	44,705	0	656	49,240	79,095	0	300	128,336	128,636	33,467	656	60,581	100,866
1998-2005	1998	0	8,539	2,637	4,532	1,164	360	7,729	27,019	42,747	0	0	42,626	91,622	0	300	134,247	134,547	(62,145)	0	58,004	14,398
	1999	0	9,966	3,682	5,289	1,359	502	7,357	28,216	37,326	0	0	47,318	89,929	0	300	137,247	137,547	(62,145)	0	54,156	21,245
	2000	0	10,424	4,028	5,532	1,422	549	7,417	33,363	33,374	5,001	0	47,703	106,667	0	300	154,370	154,670	(62,145)	5,001	50,901	36,623
	2001	0	10,740	4,660	5,700	1,465	635	7,824	30,032	27,371	0	0	56,278	101,109	0	300	157,387	157,687	(62,145)	0	46,190	49,351
	2002	0	10,782	5,146	5,722	1,470	702	5,723	33,634	21,197	0	0	52,005	120,376	0	300	172,380	172,680	(62,145)	0	38,490	72,046
	2003	0	10,508	5,500	5,577	1,433	750	5,033	31,698	24,950	0	0	46,682	116,302	0	300	162,984	163,284	(62,145)	0	41,810	59,329
	2004	0	11,083	6,693	5,882	1,511	913	5,011	30,855	15,488	0	0	52,602	111,690	0	300	164,291	164,591	(62,145)	0	33,987	68,459
	2005	0	10,964	6,736	5,819	1,495	919	3,070	29,474	15,843	11	558	49,341	102,054	0	300	151,395	151,695	(62,145)	569	32,387	56,594
2006-2008	2006	0	11,285	5,623	5,989	1,539	767	1,604	27,398	15,125	0	1,612	42,428	89,445	0	300	131,872	132,172	(38,350)	1,612	29,108	63,102
	2007	0	11,717	6,230	6,218	1,598	850	1,900	26,486	19,606	0	857	50,263	79,118	0	300	129,381	129,681	(38,350)	857	34,804	55,670
	2008	0	10,814	7,724	5,739	1,475	1,053	1,773	29,670	16,610	0	0	56,839	105,365	0	300	162,204	162,504	(38,350)	0	32,900	91,254
		A		B	C		D	E		F	G	H	I	J	K	L	I+J+K	1 = I+J+K+L	2	3 = G+H	4=ΣA..F	1+2-3-4

M&I return flows based on 45/55% indoor/outdoor water usage.

Return Flows from M&I septic tanks and Recycled water (A, C, and E) and Artificial recharge (G and H) are not lagged.

Return Flows from M&I outdoor irrigation and Agricultural irrigation are lagged by 15-years (B, D, and F).

Change in storage is the sum of Free drainage and Compaction (M).

Period	**Period Length** **(yr)**	**Total Outflow** **(af)**	**Total Storage Change** **(af)**	**Total Artificial Recharge** **(af)**	**Total Return Flows** **(af)**	**Natural Recharge** **(afy)**
1951-1962	12	4,348,524	(3,346,489)	0	800,933	16,758
1963-1970	8	2,780,733	(1,361,748)	0	848,174	71,351
1971-1978	8	2,261,964	(441,432)	0	852,903	120,954
1979-1984	6	1,130,679	(28,249)	0	538,157	94,046
1985-1991	7	798,198	14,971	0	511,661	43,073
1992-1997	6	684,542	200,801	894	431,350	75,517
1998-2005	8	1,236,702	(497,163)	5,570	355,925	47,256
1951-2005	**55**	**13,241,343**	**(5,459,309)**	**6,464**	**4,339,102**	**62,481**

V. Groundwater Resource Conditions

Based on the detailed analyses of surface water and groundwater resources, land use and associated water requirements, and water supply availability and utilization, groundwater resource conditions in the Antelope Valley Area of Adjudication (AVAA) can be summarized in three categories:

- groundwater pumping has long exceeded the sustainable yield of the groundwater basin; and groundwater pumping continues to exceed the current sustainable yield of the basin, by about 40,000 afy over the last decade;
- as a result of pumping in excess of sustainable yield, groundwater storage has been significantly depleted, by more than five million acre-feet since 1951; ongoing pumping in excess of sustainable yield has resulted in ongoing declining groundwater levels and associated ongoing depletion of groundwater storage, by an average of more than 50,000 afy over the last ten years;
- up to about six feet of land subsidence has resulted from historical lowering of groundwater levels and the associated depletion of groundwater storage in the central part of the basin.

Under generally current cultural conditions related to land and water use in the AVAA, the combination of natural recharge and return flow contributions to groundwater recharge from the use of both native and supplemental water supplies will support total groundwater pumping of about 110,000 afy on a sustainable basis (no chronic depletion of groundwater from aquifer storage). Since the mid-1990s, under a range of cultural conditions that result in that sustainable yield, and without regard to any allocations of sustainable yield among types of pumpers, average groundwater pumping has consistently exceeded the total sustainable yield of the basin, by about 15,000 to 25,000 afy in the late 1990's to more than 40,000 afy over the decade from 2000 through 2009.

The long-term history of groundwater pumping in the AVAA is illustrated in Figure 4.2-6. Total groundwater pumping for agricultural and municipal-type uses has been in the range between about 150,000 and 175,000 afy, or about 60 to 70 percent of total water supply, for the period of generally stable land and water use conditions since 2000. For the respective periods used to estimate the sustainable yield of the AVAA groundwater basin under fairly recent cultural conditions in the basin, total pumping has consistently exceeded sustainable yield. In the late 1990's, over the five year period prior to the initial filing of the current adjudication, average pumping exceeded sustainable yield by about 20,000 afy. With increased pumping since then, average pumping over the last decade has exceeded sustainable pumping by about 40,000 afy. For historical reference, over a short period from the late 1980's through the mid 1990's, groundwater pumping was between about 88,000 and about 117,000 afy; however, for several decades prior to that, total pumping was consistently in the range of about 150,000 afy to more than 350,000 afy, all far in excess of any estimate of sustainable yield.

As a result of long-term historical and recent pumping above the sustainable yield, total groundwater storage in the AVAA has been significantly depleted, by about 5,600,000 af since 1951, most notably evidenced by lowered groundwater levels. The magnitude of historical groundwater level decline is not uniform throughout the AVAA but, where located beneath and to the south of the Rosamond and Rogers dry lake beds, has resulted in subsidence of the land surface by more than six feet in some areas of the AVAA.

Subsidence of the ground surface, eccentrically centered to the south of the Rosamond and Rogers dry lake beds, has occurred in the AVAA as a result of a combination of geologic conditions (extensive, compressible, fine-grained lacustrine deposits in that part of the AVAA) and the historical lowering of groundwater levels as described above. Subsidence has been occurring in the basin since about 1930, indicating that pumping has exceeded sustainable yield since at least that time, and has continued to the present as pore pressures within the thickest aquitards slowly equilibrate with lower heads in the aquifer units. The magnitude and spatial extent of historical land subsidence has ranged from about one to more than six feet of permanent subsidence over an area that covers about one-third of the entire basin. The most damaging effects of the historical land subsidence have been the occurrence of ground fissures in areas of differential land subsidence (e.g. at Edwards Air Force Base).