EXHIBIT D

Bookman-Edmonston
A Division of GEI Consultants

Geotechnical
Environmental and
Water Resources
Engineering

Separation of Antelope Valley into Sub-Basins for Groundwater Management

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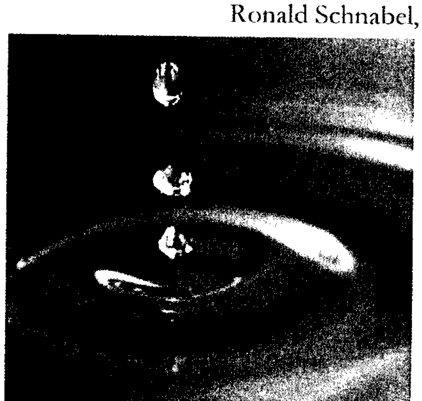

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1 Introduction

On November 29, 2004, Los Angeles County Waterworks District No.40 (District) filed an action against a large number of parties to adjudicate the water rights in the Antelope Valley Groundwater Basin. The District cites the following reasons for filing the action:

- to protect the District's rights to pump and deliver water to the public;
- to protect the Antelope Valley from a loss of the public groundwater supply;
- to prevent degradation of the quality of the public groundwater supply; and
- to prevent land subsidence and higher costs to the public for water.

The Antelope Valley is defined in the complaint as being located in the Mojave Desert in Los Angeles and Kern Counties encompassing about 940 square miles and generally including the communities of Lancaster, Palmdale and Rosamond. The Basin is bounded on the south by the San Gabriel Mountains and on the northwest by the Tehachapi Mountains.

1.1 Scope

The purpose of this report is to address certain aspects of the complaint filed by the District relating to the geology, hydrogeology, groundwater levels, groundwater flow, and to explain how groundwater pumping activity in the Western Antelope Valley sub-basins are not affecting the Lancaster sub-basin, which contains the Palmdale, Lancaster and Rosamond areas. A further purpose of this report is to demonstrate that the western portion of the Antelope Valley should be managed separately from the eastern and southern portions because the actions in the western Antelope Valley have no measurable effect on these other portions of the Antelope Valley and vice versa. From a common sense standpoint and from a groundwater management standpoint they should be considered as separate basins.

The following sections of this report include: Background, Geology, Groundwater Conditions, Potential Groundwater Flow Barriers, Groundwater Levels, and Modeling. The conclusion discusses the current groundwater condition of the Western Antelope Valley and proposes its separate management.

1.2 Background

The Antelope Valley extends approximately 50 miles in a general east-west direction from the vicinity of Quail Lake on the west to Rogers Dry Lake within Edwards Air Force Base on the east. The Antelope Valley drainage basin contains 12 groundwater sub-basins; which according to Bloyd (1967) is "...divided into subdivisions by faults, bodies of consolidated rock, ground-water divides, and, in some instances, by convenient and arbitrary boundaries." Seven of the groundwater sub-basins (also called subunits in earlier reports by Bloyd, 1967 and Thayer, 1946) occur within the Antelope Valley Groundwater Basin as described by Leighton and Phillips, (2003), and Carlson et al (1998). These include the Buttes, Finger Buttes, Lancaster, Neenach, North Muroc, Pearland and West Antelope sub-basins. **Figure 1.2-1** shows the locations of the sub-basins contained in the Antelope Valley Groundwater Basin adjudication boundary. The Antelope Valley Groundwater Basin in this report refers to the sub-basins within the adjudication boundary. These are the Buttes, Finger Buttes, Lancaster, Neenach, North Muroc, Pearland, Oak Creek, Willow Springs, and West Antelope sub-basins. The Gloster, Peerless, and Chaffee sub-basins are included in this report in the Fremont Valley Groundwater Basin. The Antelope Valley Groundwater Basin and the adjacent Fremont Valley Groundwater Basin largely occur within the boundaries of the Antelope Valley-East Kern Water Agency (AVEK) service area, the local water management agency in the Antelope Valley and a State Water Project Contractor.

Groundwater production in excess of natural recharge over the past 80 years has resulted in the lowering of the groundwater levels in the aquifers underlying portions of the Antelope Valley Groundwater Basin. This lowering of the groundwater levels has also led to land subsidence throughout portions of the Lancaster area within the northern portion of the Lancaster sub-basin such that surface fissures have developed at various locations. Subsidence in the adjacent Western Antelope Valley sub-basins (i.e. Neenach, Finger Buttes, and West Antelope sub-basins) is either non-existent (i.e., Finger Buttes, West Antelope sub-basins) or is negligible as in the eastern portion of the Neenach sub-basin adjacent to the Lancaster sub-basin.

2 Geology

The Antelope Valley is located in the western portion of the Mojave Desert Geomorphic Province of California. The Mojave Desert Province generally consists of broad alluvial plains punctuated by isolated low to moderate relief discordant mountains and hills. The highland areas are underlain by a diversity of rock types ranging from Mesozoic granitic rocks to Tertiary sedimentary and volcanic rocks. The alluvial plains generally slope away from the highland areas and terminate at lacustrine playas such as Rosamond and Rogers dry lakes. The active Garlock and San Andreas fault zones form the northern and southern boundaries of the Mojave Desert. Numerous strike slip and low angle reverse (thrust) faults also transect the Mojave Desert. The alluvial plains are chiefly derived from erosion of the Sierra Pelona and San Gabriel Mountains to the southwest, and the Tehachapi Mountains on the northwest. Playa sediments directly underlie Rosamond and Rogers dry lakes. Ancient playa deposits also extend westward and southward from the dry lakes and interfinger with alluvial sediments at depth.

The Antelope Valley Groundwater Basin occurs within the larger Antelope Valley drainage basin, which is bound on the south and southwest by the Sierra Pelona and San Gabriel Mountains, on the northwest by the Tehachapi Mountains, and on the north and east by a series of low hills and buttes. The Antelope Valley drainage basin contains 12 groundwater sub-basins; which according to Bloyd (1967) in referencing the two groundwater basins located within the AVEK service area (i.e., Antelope Valley and Fremont Valley basins), is "...divided into subdivisions by faults, bodies of consolidated rock, ground-water divides, and, in some instances, by convenient and arbitrary boundaries." The five sub-basins located north of the combined Willow Springs Fault and the Rosamond - Bissell hills areas were not considered by Bloyd (1967) and Carlson et al (1998) as part of the Antelope Valley Groundwater Basin.

For the purpose of this report, the Finger Buttes, Neenach and West Antelope sub-basins are herein collectively called the Western Antelope Valley sub-basins. Likewise, the Lancaster, and the North Muroc sub-basins are collectively called the Central Antelope Valley sub-basins, and the Buttes and Pearland sub-basins are collectively called the Southern Antelope Valley sub-basins. The Oak Creek and Willow Springs sub-basins, which are located north of the Willow Springs Fault, are considered separate from the Western Antelope Valley sub-basins.

The Western Antelope Valley sub-basins extend about 27 miles in a general east-northeast direction from the southwestern boundary of the Antelope Valley Groundwater Basin toward the Willow Springs fault where it abuts the Willow Springs sub-basin west of the town of Rosamond. The Neenach fault forms the southern boundary of the Neenach sub-basin where it borders the Lancaster sub-basin.

The Lancaster sub-basin is the largest of the sub-basins comprising the Antelope Valley Groundwater Basin. The Lancaster sub-basin is a largely wedge-shaped area extending 37 miles from east to west and as much as 30 miles in a generally northeast direction from the city of Palmdale to Rogers Dry Lake at Edwards Air Force Base. The sub-basin is bounded on the northwest by the Neenach fault where it abuts the Neenach sub-basin, on the north where it abuts the Rosamond-Bissell Hills area and on the northeast where it abuts the North Muroc sub-basin. The San Gabriel Mountains comprise the southwestern boundary of the Lancaster sub-basin. The southeastern boundary is an unnamed fault where it abuts the Pearland and Buttes sub-basins. The eastern boundary of the Lancaster sub-basin coincides with the Antelope Valley Groundwater Basin boundary.

2.1 Generalized Hydrogeologic Conditions

2.1.1 Western Antelope Valley Sub-basins

Water-bearing sediments underlying the Western Antelope Valley sub-basins largely consist of poorly to moderately consolidated alluvium composed of interbedded layers and mixtures of sand, gravel, silt and clay. Owing to the nature of these deposits, groundwater in the Western Antelope Valley sub-basins largely occurs under unconfined or water table conditions. Groundwater also occurs locally under semi-confined or confined conditions where water-bearing deposits are overlain by laterally discontinuous layers or lenses of fine grained clay and/or silt comprising aquitards that impede the vertical movement of groundwater (Durbin, 1978, Bloyd, 1967) or due to consolidation and/or cementation of the alluvial sediments at depth (Dutcher and Worts, 1963). However, the Western Antelope Valley sub-basins are characterized by a lack of surface lake bed deposits, and little evidence of widespread subsurface lake beds.

Dutcher and Worts (1963), in describing the water-bearing sediments of the Antelope Valley, indicated that there are two distinct aquifer systems in the Lancaster sub-basin, the upper, largely unconfined Principal aquifer and the lower largely confined Deep aquifer system. However, there has been no specific reference to the designation of these two aquifers occurring in the Western Antelope Valley sub-basins in the early literature (Dutcher and Worts, 1963; Bloyd, 1967; Durbin, 1978). These aquifer names have been used for many years and are based on lithologic data from numerous well logs. More recent studies suggest the water-bearing sediments can be divided into three aquifer systems based on chronostratigraphy using paleomagnetic data (i.e., magnetic anomalies) from oriented sediment cores taken from wells drilled into the underlying sediments in the Lancaster sub-basin (Leighton and Phillips, 2003). Further refinement of the new aquifers was based on geophysical logs of wells drilled which show greater consolidation and/or cementation in the water-bearing sediments with depth. The new aquifer system designations in the Antelope Valley Groundwater Basin are: upper, middle and lower as defined by Leighton and Phillips (2003).

2.1.2 Lancaster Sub-basin

Water-bearing sediments underlying the Lancaster sub-basin largely consist of poorly to moderately consolidated alluvium composed of interbedded layers and mixtures of sand, gravel, silt and clay. The water-bearing sediments are interbedded with a relatively thick section of fine-grained clays and silts which comprise the lacustrine or lake bed deposits. These deposits separate the water-bearing sediments into at least two distinct aquifer systems, the upper largely unconfined Principal aquifer and the lower largely confined Deep aquifer system (Dutcher and Worts, 1963; Bloyd, 1967; Durbin, 1978). These aquifer names have been used for many years and are based on lithologic data from numerous well logs. More recent studies suggest the water-bearing sediments including the lacustrine deposits can be divided into three aquifer systems based on chronostratigraphy using paleomagnetic data (i.e., magnetic anomalies) from oriented sediment cores taken from wells drilled into the underlying sediments (Leighton and Phillips, 2003). Further refinement of the new aquifers was made based on geophysical logs of wells drilled which show greater consolidation and/or cementation in the water-bearing sediments with depth.

The new aquifer system designations in the Lancaster sub-basin are: upper, middle and lower as defined by Leighton and Phillips (2003). The upper aquifer is largely unconfined except where lacustrine deposits occur at or near the surface such as beneath Rosamond, Buckhorn and Rogers dry lakes. At these locations the upper aquifer is confined. The base of the upper aquifer occurs at an elevation of 1,950 feet above sea level. The middle aquifer is considered a confined aquifer and extends from 1,950 to 1,550 feet above sea level. The lower aquifer is also considered a confined aquifer and extends from 1,550 to 1,000 feet above sea level. The lacustrine deposits occurring within the depth ranges indicated are considered to be part of the designated aquifer. According to Leighton and Phillips (2003, p.25), "Alluvial material at depths below 1,000 ft above sea level was assumed to be well-indurated, impermeable and not a significant part of the regional flow system. Where the altitude of bedrock is above the defined layer bottom, the layer bottom is equal to the altitude of the bedrock." The Lancaster sub-basin is almost entirely underlain by all three aquifers. Ground surface elevations in the Lancaster sub-basin range from about 2,300 feet above sea level at the north to 2,900 feet above sea level at the southwest near the base of the San Gabriel Mountains.

3 Groundwater Conditions

3.1 Groundwater Flow in the Western Antelope Valley Sub-basins

A number of wells have been drilled within the Western Antelope Valley sub-basins (DWR, 1965b). Groundwater levels and flow directions are shown in various studies (Bloyd, 1967; Durbin, 1978; Carlson et al, 1998). Groundwater flow is estimated to be to the east and east-northeast parallel to the Neenach fault (Carlson et al, 1998; Bloyd, 1967). However, in the eastern portion of the sub-basin groundwater flow in the late 1950s and early 1960s is estimated to have changed direction locally to the southeast across the Neenach fault into the adjacent Lancaster sub-basin (Bloyd, 1967; Durbin, 1978). Estimated pre-groundwater development conditions (circa 1915) are shown in Leighton and Phillips (2003) and suggest groundwater flow was east to east-southeast across the Neenach fault west of the town of Rosamond into the adjacent portion of the Lancaster sub-basin northwest of Lancaster. Groundwater inflow was shown to occur across the Randsburg-Mojave Fault in a southeasterly direction from the West Antelope and Finger Buttes sub-basins into the Neenach sub-basin.

3.2 Groundwater Flow in the Lancaster Sub-basin

A large number of wells have been drilled within the Lancaster sub-basin (DWR, 1962, 1965b, 1966). Most of the historic groundwater production in the Antelope Valley Groundwater Basin has been derived from the Lancaster sub-basin (Templin et al, 1995; Leighton and Phillips, 2003).

Groundwater levels and concomitant flow directions over the past 40 years in the Lancaster sub-basin have been presented in various studies (Bloyd, 1967; Durbin, 1978; Carlson et al, 1998). Groundwater originally flowed from the adjacent highlands toward the lowland areas underlain by playa lakebeds (i.e., Rosamond, Buckhorn and Rogers dry lakes) as depicted in pre-groundwater development conditions (circa 1915) in Leighton and Phillips (2003). In the early 1900s, groundwater generally flowed northward from the San Gabriel Mountains across the Buttes and Pearland sub-basins into the Lancaster sub-basin. In the western portion of the Lancaster sub-basin, groundwater flowed northeastward from the San Gabriel Mountains thence eastward nearly parallel to the Neenach fault toward Rosamond Dry Lake. Along the edges of the playa lakes groundwater discharged onto the playa surface as springs (Dutcher and Worts, 1963). However, since the early 1900s, agricultural and more recently urban development has led to sharply increased water demands in the Antelope Valley, in turn, leading to increased groundwater production far in excess of natural recharge.

3.3 Potential Groundwater Flow Barriers

As indicated previously, the Antelope Valley Groundwater Basin was, according to Bloyd (1967, p. 19), "...divided into subdivisions by faults, bodies of consolidated rock, ground-water divides, and, in some instances, by convenient and arbitrary boundaries." The following sections describe how several of these faults and consolidated rock features restrict the flow of groundwater in the Western Antelope Valley sub-basins from the Lancaster sub-basin.

3.3.1 The Bedrock Ridge as a Barrier to Groundwater Flow

The most significant impediment to groundwater flow is the occurrence of a less permeable, or impermeable, barrier such as a bedrock high. Antelope and Little Buttes are two such barriers where less permeable bedrock has extended to the surface. Bloyd (1967), in his geologic cross-section (Figure 6) clearly shows the existence of a bedrock barrier in his cross-section at well 8N/14W-15B1. Bloyd's Figure 6 is reproduced as **Figure 3.3.1-1** herein. The Bouguer gravity survey study by Mabey (1960) also shows that the Western Antelope Valley sub-basins are separated from the Lancaster sub-basin by a buried bedrock ridge. The amount that groundwater is affected by this bedrock ridge would depend on groundwater levels.

3.3.2 The Neenach Fault as a Possible Barrier to Groundwater Flow

The boundary between the Neenach sub-basin and the Lancaster sub-basin is currently defined by the Neenach Fault. Weir et al (1965), states that the Neenach Fault is postulated to exist solely on the basis of water level disparities. Bloyd (1967) and Duell (1984) present geologic cross-sections suggesting considerable offset of as much as several hundred feet occurs in alluvial sediments on opposites sides of the Neenach Fault. As indicated on Figure

3.3.1-1 (Bloyd, 1967, Figure 6), the Neenach sub-basin is the downdropped block and contains a greater accumulation and thickness of alluvial sediments relative to the adjacent Lancaster sub-basin along the Neenach Fault. However, geologic mapping by Dibblee (1967) and Ponti et al (1981) indicate there is no surface expression of this Fault, and more recent groundwater level analysis shows that the Neenach Fault may not be a groundwater barrier.

3.3.3 The Randsburg-Mojave Fault as a Barrier to Groundwater Flow

A groundwater level study on the Randsburg-Mojave Fault for this report indicates that the Randsburg-Mojave Fault north of the Kern/Los Angeles County line to the Willow Springs Fault acts as a groundwater flow barrier and impedes groundwater flow from the West Antelope and Finger Buttes sub-basins to the Neenach sub-basin. The Randsburg-Mojave Fault appears to act as a significant groundwater barrier from the Willow Springs Fault to the un-named fault. The un-named fault separates the Finger Buttes sub-basin from the Neenach sub-basin in this area. Although well hydrographs are limited, hydrographs from wells 09N15W-11A01 and 09N15W-12M01, on opposite sides of the Randsburg-Mojave Fault, show a significant difference in groundwater elevation. The groundwater elevation difference was measured at over 400 feet from 1970 to 1976. An offset in groundwater levels of about 300 feet is shown on Figure 3.3.1-1 (Bloyd, 1967, Figure 6), across the Randsburg-Mojave Fault, between wells 9N/15W11A1 and 9N/15W11R1 in 1964.

The Randsburg-Mojave Fault also acts as a groundwater barrier from the un-named fault to the Kern/Los Angeles County line. In this area, the un-named fault separates the Finger Buttes sub-basin from the West Antelope sub-basin. Hydrographs from wells 09N16W-36A01 and 09N15W-30Q01, also on opposite sides of the Randsburg-Mojave Fault, were monitored from about 1985 to 1990, and show a difference in groundwater level of about 80 feet.

South of the Kern/Los Angeles County line, the Randsburg-Mojave Fault does not appear to be a groundwater barrier.

3.4 Groundwater Level Conditions

3.4.1 Groundwater Levels in the Western Antelope Valley Sub-Basins

Hydrographs in the Western Antelope Valley sub-basins show that groundwater levels have been stable since the mid-1980's, coinciding with a reduction in groundwater production for agricultural irrigation. Groundwater levels at well 9N/14W-20B1, located in the eastern portion of the Neenach sub-basin on **Figure 3.4.1-1,** indicate that groundwater levels declined about 108 feet between 1955 and 1984 (Carlson et al, 1998), but have remained stable since that time. Well 9N/15W-26N1 (Figure 3.4.1-1), shows a groundwater decline from 1962 to 1984 of about 100 feet, but levels have risen about 25 feet since 1984. Farther west, well 9N/15W-30Q1 (Figure 3.4.1-1), groundwater levels declined about 57 feet between 1965 and 1986 (Carlson et al, 1998), but have risen about 5 feet since that time.

Groundwater levels at well 8N/16W-3F01, located in the western portion of the West Antelope sub-basin on **Figure 3.4.1-2**, indicates that groundwater levels declined about 30 feet from 1965 to about 1980, but since have risen over 5 feet. Well 8N/17W-4D1 located at the very west end of the Antelope Valley (Figure 3.4.1-2) shows that water levels in this area have responded to local recharge and pumping, but have not changed much from the earliest record in 1948.

Wells located in the Lancaster sub-basin, to the west of the bedrock ridge described in Section 3.3.1, also show a pattern of rising groundwater level rise from an earlier low. Wells 8N/14W-10L1 and 8N/14W-18N1 shown on **Figure 3.4.1-3** show that groundwater levels have increased from lower levels and have remained consistent (8N/14W-18N1) or have declined somewhat. Well 8N/14W-10L1 has decline about 15 feet since about 2001 after having raised more than 40 feet from 1983 to 2001. The recent decline in this well is probably related to local pumping near the well, because well 8N/13W-9L1 (Figure 3.4.1-3) does not show the same pattern. Well 8N/13W-9K1 is located east of the bedrock ridge in the Lancaster sub-basin.

3.4.2 Groundwater Levels in the Lancaster Sub-Basin

Increased demand on groundwater resources has caused a concomitant decline in groundwater levels and groundwater flow patterns particularly in the vicinity of large well fields where groundwater production is higher. Recent examples of the changes in groundwater levels caused by increased pumping are shown in Carlson et al (1998), where groundwater flow is generally toward large pumping depressions in the Lancaster-Palmdale area. Groundwater levels at two wells in the Palmdale-Lancaster area, 7N/12W-19R1 and 7N/12W-22K1, show declines of 130 feet between 1951 and 1996 and 95 feet from 1960 to 1996, respectively (Carlson et al, 1998). Groundwater levels at both wells have continued to decline an additional 5.5 feet and 4 feet, respectively, as of 2004. Most of the observed decline occurred before 1980 when groundwater production was primarily used for agricultural irrigation. Since the 1980s, groundwater withdrawals in the Palmdale area have increased due to rapid urban growth. As a result, groundwater levels have declined 33 to 107 feet from 1983 to 1996 at wells 6N/11W-20H1 and 6N/12W-24C1, respectively (Carlson et al, 1998).

In the north-central portion of the Lancaster sub-basin (Lancaster area) land subsidence has occurred over a broad area due to the continued pumping of groundwater in excess of natural recharge in almost every year since the 1920s (Londquist, 1995). As much as six feet of land subsidence occurred between 1926 and 1992 (Galloway et al, 1998; Ikehara and Phillips, 1994) with the bulk of the land subsidence (4 feet) occurring between 1961 and 1991 in and near the City of Lancaster. Figure 8 (from Ikehara and Phillips, 1994 and Leighton and Phillips, 2003) shows measured land subsidence from 1930 – 1992.

3.5 Rate of Groundwater Flow to the Lancaster Sub-Basin from the Western Antelope Valley Sub-Basins

Groundwater flow from the Western Antelope Valley sub-basins to the Lancaster sub-basin is to the east-northeast. Groundwater recharge to the Western Antelope Valley sub-basins occurs from the San Gabriel Mountains to the southwest and from the Tehachapi Mountains to the northwest. Thus, the groundwater that enters the Lancaster sub-basin from the Western Antelope Valley sub-basins comes from the San Gabriel Mountains and Tehachapi Mountains. The time required for this groundwater recharge to reach the Lancaster sub-basin from the San Gabriel Mountains and Tehachapi Mountains is probably greater than 1,000 years as discussed below.

Groundwater level data collected from recently-constructed monitoring wells installed at the proposed Centennial Founders development project suggest groundwater flow is to the east at a gradient of 0.01087 foot/foot (unit-less) at a velocity of about 125 feet per year (ft/yr) toward the western part of the Neenach sub-basin. This groundwater velocity, also known as the discharge velocity, was calculated in part based on the results of aquifer pumping tests conducted at the TRC Well 98 in March 2004 and groundwater level measurements obtained at the recently constructed Centennial monitoring wells. The average discharge velocity (V_s) is calculated based on the Darcian velocity or discharge velocity (V) where:

$$V_s = \frac{K\,i}{n_e}$$

K = horizontal hydraulic conductivity of the aquifer (in feet/day)
= 6.28 ft/day,
i = hydraulic gradient in the direction of the groundwater flow
= 0.01087 (unitless),

And n_e = effective porosity for the mix of soils encountered in the aquifer
= 0.20 (this is a conservative case and thus produces a higher discharge velocity and less travel time).

The hydraulic gradient and rate of groundwater flow in the Neenach sub-basin varies from west to east across the sub-basin. Groundwater level data used to compute the hydraulic gradient were taken from 1996 groundwater level contours presented in Carlson et al (1998). In the western part of the Neenach sub-basin the hydraulic gradient was 0.009 and the estimated velocity was 100 ft/yr to the east. In the eastern part of the Neenach sub-basin the hydraulic gradient was 0.0038 and the estimated velocity was about 44 ft/yr. The combined data indicates that under recent (1996) and current (2004) hydraulic conditions; the discharge velocity of groundwater flow is relatively slow across the West Antelope and Neenach sub-basins. For groundwater to enter the Lancaster sub-basin, where it abuts the Neenach sub-basin near Rosamond, from the western edge of the Western Antelope Valley sub-basins near Quail Lake, a distance of about 27 miles, it would likely take as much as 1,140 years using the highest velocity (125 ft/yr), or about 1,600 years using the average (90 ft/yr) of the three flow rates (125, 100 and 44 ft/yr).

4 Groundwater Modeling

This section includes a review of the Antelope Valley groundwater model developed by the United States Geological Survey (USGS). The section also includes results obtained from using the USGS groundwater model for different pumping and recharge scenarios in the Western Antelope Valley sub-basins. These model scenarios were conducted to evaluate what affect, if any, groundwater pumping and recharge has on the Lancaster sub-basin. The following section provides a review of the USGS groundwater model.

4.1 Leighton and Phillips, "Simulation of Ground-Water Flow and Land Subsidence in the Antelope Valley Ground-Water Basin, California" - USGS Water-Resources Investigations Report 03-4016, 2003

This report is the most comprehensive report in the Antelope Valley and is based on a compilation of prior data and reports. The report clearly shows that the historic and future problems in the Antelope Valley occur in the Central area. The abstract of the report reads as follows:

"The ground-water flow system consists of three aquifers: the upper, middle, and lower aquifers. The aquifers, which were identified on the basis of the hydrologic properties, age, and depth of the unconsolidated deposits, consist of gravel, sand, silt, and clay alluvial deposits and clay and silty clay lacustrine deposits. Prior to ground-water development in the valley, recharge was primarily the infiltration of runoff from the surrounding mountains. Ground water flowed from the recharge areas to discharge areas around the playas where it discharged either from the aquifer system as evapotranspiration or from springs. Partial barriers to horizontal ground-water flow, such as faults, have been identified in the ground-water basin. Water-level declines owing to ground-water development have eliminated the natural sources of discharge, and pumping for agricultural and urban uses have become the primary source of discharge from the ground-water system. Infiltration of return flows from agricultural irrigation has become an important source of recharge to the aquifer system.

"The ground-water flow model of the basin was discretized horizontally into a grid of 43 rows and 60 columns of square cells 1 mile on a side, and vertically into three layers representing the upper, middle, and lower aquifers. Faults that were thought to act as horizontal-flow barriers were simulated in the model. The model was calibrated to simulate steady-state conditions, represented by 1915 water levels and transient-state conditions during 1915-95 using water-level and subsidence data. Initial estimates of the aquifer-system properties and stresses were obtained from a previously published numerical model of the Antelope Valley ground-water basin; estimates also were obtained from recently collected hydrologic data and from results of simulations of ground-water flow and land subsidence models of the Edwards Air Force Base area. Some of these initial estimates were modified during model calibration. Ground-water pumpage for agriculture was estimated on the basis of irrigated crop acreage and crop consumptive-use data. Pumpage for public supply, which is metered, was compiled and entered into a database used for this study. Estimated annual pumpage peaked at 395,000 acre-feet (acre-ft) in 1952 and then declined because of declining agricultural production. Recharge from irrigation-return flows was estimated to be 30 percent of agricultural pumpage; the irrigation-return flows were simulated as recharge to the regional water table 10 years following application at land surface. The annual quantity of natural recharge initially was based on estimates from previous studies. During model calibration, natural recharge was reduced from the initial estimate of 40,700 acre-ft per year (acre-ft/yr) to 30,300 acre-ft/yr.

4.2 The USGS Model Used to Evaluate Pumping and Recharge Affects in the Western Antelope Sub-Basins on the Lancaster Sub-Basin.

The USGS calibrated their model to groundwater flow conditions from 1915 through 1995. To make use of the USGS Model, the transient model input files of the USGS Model were first converted by GEI to the GMS-Based Model. Test runs of the GMS-Based Model were performed, and the information described in Leighton and Phillips (2003) was used to verify the model testing results. Three observation wells in or close to the Western Antelope Valley sub-basins were selected to compare the groundwater levels computed by USGS Model and GMS-Based Model. The locations of these three wells are shown in **Figure 4.2-1**. The groundwater levels in these observation wells computed from USGS Model and GMS-Based Model are shown in **Figure 4.2-2 through 4.2-4**. As shown in these Figures, the groundwater levels computed from GMS-Based Model match these computed from USGS Model. Also, the water balance from 1915 through 1995 computed from GMS-Based Model matches the water balance computed from USGS Model.

Three scenarios were simulated using the GMS-Based Model to estimate the hydraulic impact under different what-if conditions. These three scenarios are described as follows:

1. Decrease of net pumping by 20% in part of the Lancaster sub-basin to see the effects on the groundwater levels in the Western Antelope Valley sub-basins

2. The impact of artificial recharge in the Western Antelope Valley sub-basins on the Lancaster sub-basin

3. Increased pumping in the Western Antelope Valley sub-basins to see the effects on the Lancaster sub-basin

Scenario 1: The impact of net pumping decreased by 20% in the Lancaster sub-basin

The groundwater flow was simulated using pumping rates reduced by 20% from the wells in the western part of the Lancaster sub-basin. The locations of wells with pumping rates reduced by 20% are shown in **Figure 4.2-5**. The original pumping rates and 20% reduced pumping rates of all wells in this area from 1915 through 1995 are shown in **Figure 4.2-6**. The groundwater level changes in 1995 after pumping rates are reduced by 20% are shown in **Figures 4.2-7 through 4.2-9** for model layer 1, 2, and 3, respectively. As shown from these figures, the groundwater level in all three layers would be 60 to 70 feet higher in the central part of the Lancaster sub-basin in 1995 if pump rates were reduced by 20%. The 70 feet higher groundwater level in 1995 represents the accumulative effect of reduced pumping rates for 80 years from 1915 through 1995. The groundwater levels north of the Neenach

Fault would be 20 to 40 feet higher in 1995 in all three layers. The model also shows that the reduced pumping does not increase the groundwater levels in the western half of the Western Antelope Valley sub-basins. Groundwater levels do increase in the eastern half of the Western Antelope Valley sub-basins.

<u>Scenario 2: The impact of artificial recharge in the Western Antelope Valley sub-basins</u>

A recharge of 3,600 af/yr was added in one model cell in layer 1 as shown in **Figure 4.2-10** from 1915 to 1995 (80 years) for a total of 288,000 af. The area of a model cell is one mile by one mile. In the USGS Model (Figure 11, Leighton and Phillips, 2003), the unknown (also known as the un-named) fault was set up in the south and east sides of this model cell. The unknown fault is believed to actually pass through the area of this recharge cell, and any artificial recharge would be located east of this fault. Therefore, the unknown fault was moved to the north and west sides of this recharge cell in this model simulation as shown in Figure 4.2-10. The groundwater level changes in 1995 after 3,600 af/yr were added into the model are shown in **Figures 4.2-11 through 4.2-13** for model layer 1, 2, and 3, respectively. As shown from these figures, the groundwater level would be 200 feet higher in 1995 in the area around the layer 1 cell where the 3,600 af/yr recharge was assigned. The model simulated the period of 80 years from 1915 through 1995, therefore, the average groundwater rising is about 2.5 feet per year in this model cell of layer 1. As shown in these figures, there is no groundwater level rises west of the bedrock ridge. This indicates that the impact of the simulated increased recharge in the Western Antelope Valley sub-basins to the Lancaster sub-basin east of the bedrock ridge is negligible.

<u>Scenario 3: The impact of pumping increase in the Western Antelope Valley sub-basins</u>

To stress the groundwater model, and to determine what the added stress affects would be on the Lancaster sub-basin, an imaginary well with a constant pumping rate of 3,000 af/yr was added to one model cell in layer 1 as shown in **Figure 4.2-14**. As in scenario 2, the unknown fault actually passes through the model cell, and the well with the pumping rate of 3,000 af/yr would be located east of this unknown fault. Therefore, the unknown fault was moved to the north and west sides of this recharge cell in this model simulation as shown in Figure 4.2-14. The groundwater level changes after 3,000 af/yr of pumping for 80 continuous years

(240,000 af total) from the added well are shown in **Figures 4.2-15 through 4.2-17** for model layer 1, 2, and 3, respectively. As shown from these figures, the groundwater level would be 280 feet lower in 1995 in the layer 1 cell where 3,000 af/yr of additional pumpage is assigned. This 280 feet groundwater level drop in 1995 represents the accumulative effect of adding a pumping rate of 3,000 af/yr for 80 years from 1915 through 1995. In other words, the average groundwater level drop due to adding this 3,000 af/yr pumpage is about 3.5 feet per year in the model cell. The deepest drop of groundwater level in layers 2 and 3 in 1995 would be 150 feet.

The drop of groundwater levels near the southern edge of the bedrock ridge is about 1 to 3 feet in 1995. The average annual drop for 80 years from 1915 through 1995 at the north end of the Neenach sub-basin is less than half an inch in this area. This indicates that an increase of pumpage of 3,000 af/yr in this area of the Western Antelope Valley sub-basins will not affect the groundwater level in the Lancaster sub-basin east of the bedrock ridge.

Results from these three model scenarios support the conclusion that the pumping and recharge of the Western Antelope Valley sub-basins has little impact to the Lancaster sub-basin east of the bedrock ridge.

4.3 USGS Model Sensitivity Tests, Limitations, and the Removal of the Neenach Fault.

Leighton and Phillips (2003) did sensitivity analysis on the USGS model to determine the sensitivity of the model to changes in model input parameters. For sensitivity simulations one input parameter was changed at a time, while all other parameters were held constant. The sensitivity of the model was evaluated by comparing water levels and subsidence from the sensitivity simulations with those from the calibrated transient-state model at the end of the transient period (1995).

Results to the sensitivity analysis done by Leighton and Phillips (2003) indicate that the model is sensitive to different parameters in different areas. The model was generally most sensitive to changes in hydraulic conductivity and specific yield. From the sensitivity analysis it is possible to see what model parameters have the greatest affect on the model and estimate what limitations the model may have.

The model limitations were discussed by Leighton and Phillips (2003), who state that the model is only an approximation of the actual aquifer system and it does not exactly simulate the system. However, Leighton and Phillips (2003, p.74) also state that "A ground-water flow model is a valuable tool for testing the conceptualization of the ground-water flow system and for predicting the response of the system to changes in aquifer stresses." This would suggest that the model can then reliably be used to predict that changes in the system under the different scenarios discussed in Section 4.2 above.

One sensitivity analysis not done by Leighton and Phillips (2003) for the USGS model was the removal of the Neenach Fault as a possible groundwater barrier. The impact of eliminating the Neenach Fault on the groundwater levels in the western and central parts of the Antelope Valley Groundwater Basin was done as sensitivity analysis of the different what-if conditions discussed in Section 4.2. The location of Neenach Fault is shown in **Figure 4.3-1**. The GMS-Based Model (see Section 4.2), after eliminating the barriers representing the Neenach Fault, was used to simulate the impact of Neenach Fault on the groundwater flow. The groundwater level changes after eliminating the Neenach Fault in 1995 are shown in **Figures 4.3-2 through 4.3-4** for model layer 1, 2, and 3, respectively. As shown from these figures, the groundwater level drops about 1 to 5 feet north of the Neenach Fault area and rises about 1 to 5 feet south of the Neenach Fault area in layer 1 and layer 2. In layer 3, the groundwater level drops 5 to 15 feet in the area one mile north from the Fault and rises 5 to 15 feet from the area one mile south from the Fault. This result suggests that if the Neenach Fault is removed as a hydraulic barrier, the impact to the scenarios performed in Section 4.2 above would be negligible.

5 Conclusions

5.1 Western Antelope Valley Sub-Basins and "Overdraft"

The Antelope Valley is a very large groundwater basin stretching over 50 miles from the east to west. Most of the historical pumping in the Antelope Valley Groundwater Basin, the problems with declining groundwater levels, and the land subsidence are all occurring in the central and northeastern parts of the Antelope Valley near or in the Lancaster and Palmdale areas. Most of the Western Antelope Valley sub-basins have not experienced any land subsidence. Only minor subsidence occurs in the very northeastern part of the Neenach sub-basin. Hydrographs show that groundwater levels are either stable or have been rising, and the Western Antelope Valley sub-basins do not show an "Overdraft" condition (see Section 3.4.1).

Groundwater pumping in the Lancaster sub-basin is not currently affecting the Western Antelope Valley sub-basins. It is clear from Leighton and Phillips (2003), and from the modeling work discussed in Section 4.2, that pumping in one area has little or no affect on the other area. Recharge in the western area does nothing to solve the problems in the central area. This information is substantiated by the long travel times it takes for groundwater to move from the Western Antelope Valley sub-basins to the Lancaster sub-basin and from the modeling work. In Section 3.5 it was estimated that travel times, from the western area of the Western Antelope Valley sub-basins where recharge occurs, to the Lancaster sub-basin would take over a 1,100 years.

5.2 Western Antelope Valley Sub-Basins Management

The groundwater problems in the Antelope Valley are for the most part limited to the central portion of the basin where water level declines indicate continuing overdraft and associated land subsidence. The only solution to over pumping and subsidence in the Lancaster sub-basin is to reduce the net extraction of groundwater in that area. Due to the large area of the Antelope Valley Groundwater Basin, and the relatively slow movement of groundwater, management actions in the Western Antelope Valley sub-basins would have only negligible affect on the Lancaster sub-basin east of the bedrock ridge as discussed in Sections 3.5, 4.2, and 5.1.

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