THE ANTELOPE VALLEY WATER BANK PILOT BASIN PROJECT: FROM ONE ACRE TO 1600 ACRES

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ABSTRACT

An innovative hydrogeologic investigation and small-scale pilot basin test were conducted to predict the performance of a 123,350,000 m^3 per year groundwater recharge project. The water bank will use approximately 659 hectares of agricultural fields to store surface water in the 46 to 61 meter) thick portion of aquifer that was dewatered by historic groundwater overdraft. Surface trenches and exploration boreholes were constructed at various project area locations to determine sub-surface soil characteristics and deeper vadose zone lithologies. A one-acre 0.4 hectare location representative of the larger Project area was then selected and a pilot basin test implemented to provide a suite of highly detailed subsurface hydraulic property data as well as in-situ flow related data during the test to determine wetting front advancement, subsurface mounding and perching, and vadose zone water and groundwater quality.

Based on several monitoring methods, the recharge was observed to advance 332 feet (101 meters) to the water table within 78 days. Water perching within 0 to 40 meters bgs was intermittent and not sustained during recharge whereas greater mounding was observed at deeper depths. Total dissolved solids and nitrate from historic agricultural operations were observed over California MCLs in suction lysimeter samples; groundwater has remained below all MCLs. Mass balance estimates from field and laboratory data indicate that these antecedent concentrations will be diluted by recharge water to below primary or secondary standard levels within 2 to 5 recharge seasons, respectively.

KEYWORDS

Perching recharge, suction lysimeter, water quality, vadose zone monitoring

INTRODUCTION

The Antelope Valley Water Bank (AVWB, the Project) is located in Kern County near the boundary with Los Angeles County at the western end of the Antelope Valley (Figure 1) and encompasses an area of 1,629 acres (659 hectares). The Project will recharge up to 100,000 acre-feet (123,350,000 m^3) per year (afa) of imported surface water into existing agricultural fields during the off-growing season, and have a total storage capacity of at least 500,000 acre-ft (616,740,000 m^3) of water. This stored water will be recovered when needed using a combination of existing and new wells.

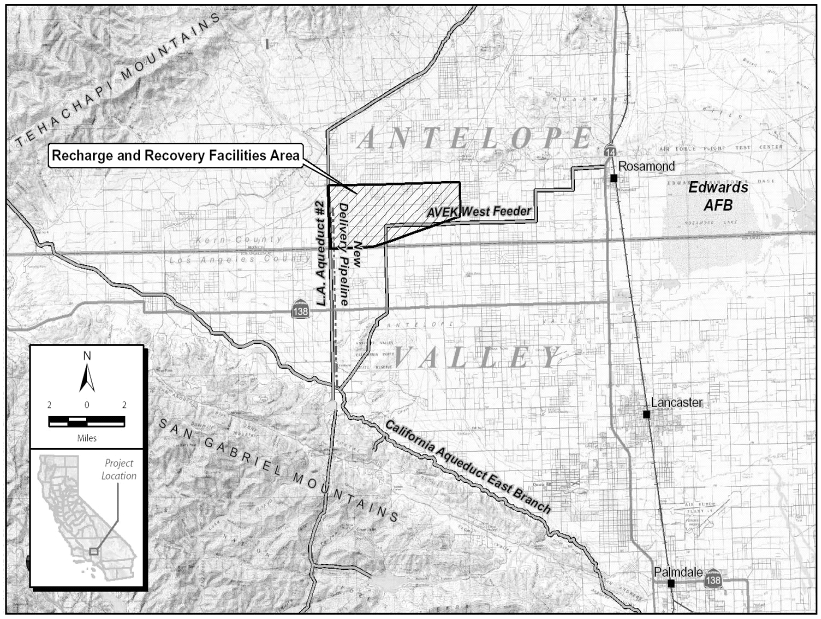

FIGURE 1. Antelope Valley Water Bank Project Area.

Antelope Valley is arid, averaging less than 10-inches (250 mm) rain per year and natural aquifer recharge is considered insignificant. The Valley is a graben, an area that has dropped downward due to movement on the San Andreas and Gerlock faults that bound it. Over time the basin has filled with several thousand feet of alluvial materials eroded from the bounding mountain ranges. The uppermost-unconfined aquifer within these alluvial materials has been partially dewatered up to 200 ft (61 m) by historic over-pumpage for agricultural irrigation. The current water table is located at approximately 330 ft below ground surface.

The project area aquifer is highly transmissive; wells consistently yield more than 1,000 gallons per minute (227,000 liter/sec) and the water quality is excellent. Numerous investigators have evaluated the west end of the Antelope Valley for aquifer recharge projects since the 1940's. The pilot test described herein was designed to conclusively demonstrate that the project area could recharge up to annual and maximum storage capacity design rates.

Project area soils were classified into different textural types via soils mapping, test pit logging and surface sampling. In order to ensure that the pilot test would provide results reasonably representative of the larger Project area, a location was selected with a particle size distribution that is finer textured than 80 percent of the Project recharge area. The pilot test location has also been farmed since at least the 1960s, allowing potential impacts from deep percolation of irrigation water salts to be evaluated.

The pilot test was performed in an approximately 1-acre (04 hectare) bermed corner of a recently farmed field. California State Water Project (SWP) water was used to supply the pilot recharge basin for an initial 5.5 month test period beginning December 19, 2005 and ending June 1, 2006. A second recharge period began on July 24, 2006 and ended in October 2006.

The resulting pilot basin along with local investigation points is shown in plan view in Figure 2. These investigation points were designed to resolve the following important recharge related issues/ questions related to the Project goals:

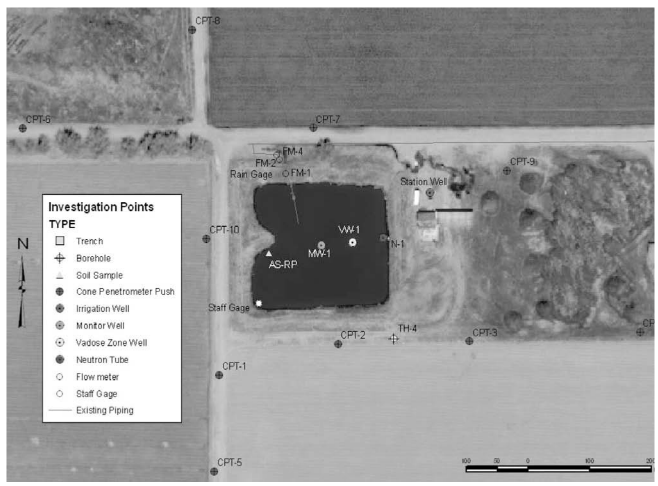

FIGURE 2. Plan view aerial of Pilot Basin.

1) The average achievable recharge rate (acre-ft/day per acre or ft/day).

2) The rate (velocity) at which percolating water moves downward towards the uppermost aquifer.

3) The degree to which percolating water can migrate through and around lower-permeability intervals in the vadose zone and the degree to which perched water conditions may evolve above these intervals.

4) The specific yield (effective porosity) throughout the vadose zone, as a measure of available storage space.

5) Water quality impacts, if any, on the uppermost aquifer, taking into account the initial flush of soluble salts present in the vadose zone naturally and as a result of long-term agricultural irrigation practices.

6) The degree to which pilot test results are representative of the larger Project area.

METHODS

Previous studies included:

- Excavation, sampling, geologic logging, and infiltration testing of 17 soil trenches, 11 to 15 ft (3.3 to 4.6 m) deep at various locations in the Project area.
- Drilling, sampling, geologic logging, and borehole geophysical logging of three exploratory test holes to depths from 398 to 478 ft (121 to 146 m) bgs in the northern portion of the Project area.
- Groundwater sampling and analysis of 2 irrigation wells located in the northern portion of the Project area.

Supplemental work performed to support the pilot test included:

- Particle size distribution testing of 56 near surface soil samples collected from areas outside the pilot test basin, and 2 additional soil samples from within the pilot test basin.
- Cone penetrometer testing to a depth of 60 ft (18 m) at 10 locations around the pilot basin prior to and after 5.5 months of water application.
- Drilling, sampling, geologic logging, instrumenting, and completing the following boreholes within the pilot basin:
    - MW-1, a groundwater monitor well with nested air and water piezometers in the vadose zone.
    - VW-1, a nested vadose zone well with suction lysimeters, and advanced tensiometers at various depths
    - N-1, a neutron logging access tube
- Conducting laboratory physical and hydraulic property tests on borehole drill cuttings and core samples.
- Conducting leaching tests on core samples with leachate water quality analyses.
- Conducting field in-situ saturated hydraulic conductivity testing using borehole permeameter methods in MW-1 water piezometers prior to the pilot basin test.
- Measuring saturated hydraulic conductivity of subsurface materials using atmospheric pressure testing methods with air piezometers in MW-1 and suction lysimeters in VW-1 prior to the pilot basin test.
- Monitoring groundwater levels, temperatures, and electrical conductivity in MW-1 and in vadose zone water piezometers prior to and during the pilot basin test.
- Groundwater quality sampling and analysis of inorganic constituents in MW-1 prior to, during, and following the pilot basin test.

- Monitoring vadose zone matric potentials in VW-1 via prior to, and during the pilot basin test.
- Collecting and analyzing vadose zone water samples from VW-1 during the pilot basin tests.
- Conducting neutron logging in neutron access tube N-1 prior to and during the recharge test.
- Monitoring pilot basin water inflow and calculating outflow as the difference between inflow and evaporation.

RESULTS AND DISCUSSION

Interpretation of data from this work has led to the following conclusions:

Achievable Volumetric Recharge Rates

Daily recharge rates as well as cumulative (rolling average) recharge rates for first 5.5 month period are presented in Figure 3. Evaporative losses ranged from insignificant during certain winter days up to 13% in late May, averaging 3% over the period of the typical recharge season (December through April). The cumulative average recharge rate for the typical recharge season (December through April) was 0.8 ft (0.24 m) per day.

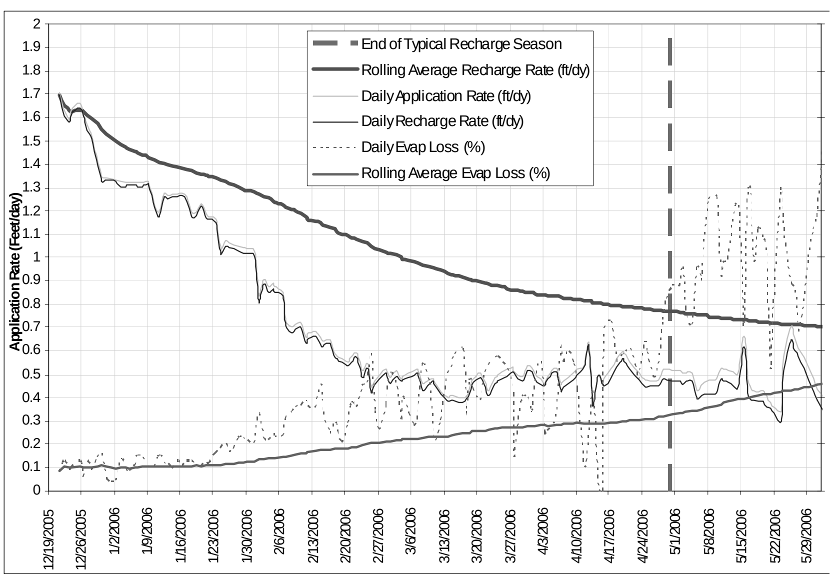

FIGURE 3. Average recharge rates during first 5.5 month recharge period.

Applying the average cumulative recharge rate for a typical recharge season over the full Project area, the Project goal of 100,000 acre-ft (123,350,000 m^3) per recharge per season would have been obtained by mid March (83 days of recharge). Since 80 percent of the Project area is expected to have coarser textured surface soils, and coarser textured soils generally exhibit higher hydraulic conductivities (Todd, 1980), the results summarized above are expected to be conservative for the entire Project area.

Measured Travel Times to the Water Table

Wetting front travel times were estimated from average cumulative recharge rates, matric potential and water content data collected at different depths, and groundwater elevation and EC data in MW-1. Estimated travel times from the pilot basin to the water table range from 74 to 124 days, with average vertical pore velocities of 4.5 to 2.7 ft (1.4 to 0.8 m) per day.

The wetting front was tracked with matric potential and water content data collected at different depths in the unsaturated zone from advanced tensiometers in well MW-1 and neutron logs in well N-1, respectively.

This wetting front response to a depth of 219 ft (66.8 m) is shown Figure 4. Extrapolating these data to 332 ft (101 m) bgs result in travel times of approximately 90 to 120 days and corresponding pore water velocities of 3.7 to 2.8 ft (1.1 to 0.85 m) per day.

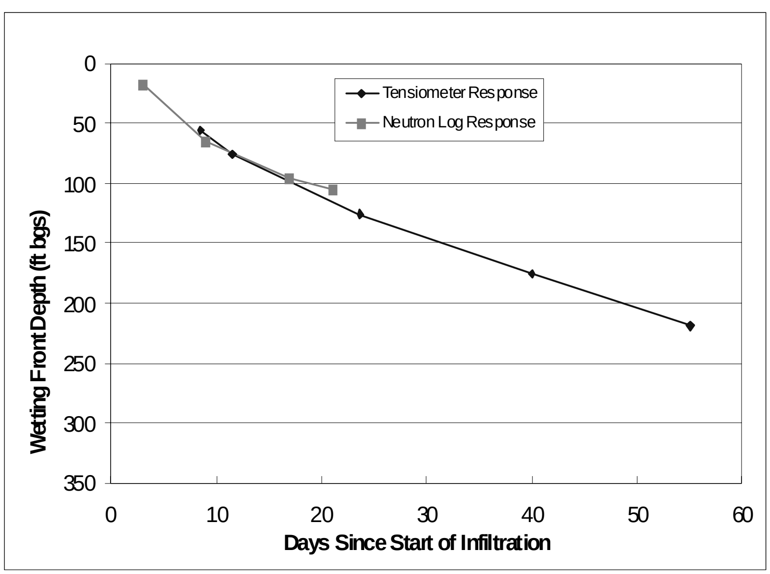

FIGURE 4. Observed wetting front response.

Based on increased water levels in well MW-1, travel times were estimated to range from approximately 81 to 117 days. Observed water level increases were small (approximately 1 ft) and variable between early March and mid April 2006, most likely due to water being flushed from high permeability regions of the vadose zone ahead of the main recharge front.

Average Specific Yield or Effective Porosity

Average specific yield was estimated by two methods from core samples collected from representative textural layers in the subsurface. The first method assumes that the effective porosity is the pore space that drains from a soil core between 0 bars (i.e. saturation) and minus 1/3 bar of matric potential. The second method assumes that effective porosity is the pore space where water flows at hydraulic conductivities greater than 10^{-7} cm/s.

Effective porosity values for core samples collected over a range of depths in the unsaturated zone in wells MW-1, VW-1, and N-1 ranged from 0.07 to 0.21 with average estimated effective porosities of 0.18 and 0.16 for the 1/3 bar and 10^{-7} cm/s methods, respectively (Table 1). These values are consistent with other specific yield estimates of 14% to 20% proposed by other workers who have studied the uppermost aquifer underlying the general Project area (DWR, 1977; USGS, 1978; Psomas, 1998; and USGS, 2003). Moreover, these values indicate there is at least 500,000 acre-ft of storage available in the dewatered portion of the aquifer. It should be noted that the near surface soil sample (MW-1) showed a low effective porosity of 0.07 to 0.09. This value is most likely due to the silty nature and higher moisture retention of that sample.

TABLE 1. Estimated effective porosity of different sample cores

Sample	Saturated Water Content cm^3/cm^3	Volumetric Water Content		Estimated Effective Porosity	
		at 1/3 bar	at K_{unsat} = 10^{-7} cm/s	at 1/3 bar[a]	at K_{unsat} = 10^{-7} cm/sec[b]
MW1	0.28	0.185	0.208	0.095	0.072
NL 286-286.5	0.308	0.129	0.162	0.179	0.146
NL 54-54.5	0.28	0.07	0.097	0.21	0.183
VW 120-121-2	0.267	0.073	0.082	0.194	0.185
VW 160-161-2	0.334	0.144	0.146	0.19	0.188
VW 220-2	0.295	0.106	0.12	0.189	0.175

[a] Effective porosity assumed to be the difference in water content saturation and at 1/3 bar.

Perching and Lateral Spreading

Perched water was not observed at any depth prior to commencement of recharge, despite on-going furrow irrigation of the area since the 1960s. This is based on data from the following sources: drill and core logging, cone penetrometer tests (CPT), air and water piezometer monitoring, and advanced tensiometer and neutron logging data. The initial CPT survey data indicated relatively thin and laterally discontinuous fine grained layers are present from 0 to 60 ft (0 to 18 m) below ground surface. However, they were not observed to result in measurable perching or lateral spreading of recharged water in the follow-up CPT survey conducted during recharge operations.

Advanced tensiometers in VW-1 indicate that temporary perching of applied basin water did occur above various fine grained intervals at depths of approximately 55 and 75 ft (17 and 23 m); however these perched zones dissipated within four to six weeks after forming (Figure 5). This conceptual figure also shows that beginning at approximately 130 ft (40 m) bgs, more continuous and thicker fine-grained layers were present and the occurrence and frequency of thicker fine-grained layers increases with depth. These layers created sustained perched water zones throughout the recharge period however, mounding above these layers was limited in depth and dissipated 3 to 12 weeks after cessation of water application. The observed wetting front advancement and limited observed perching indicate that water is able to percolate around/through these deeper fine grained layers and that they should not negatively impact recharge operations.

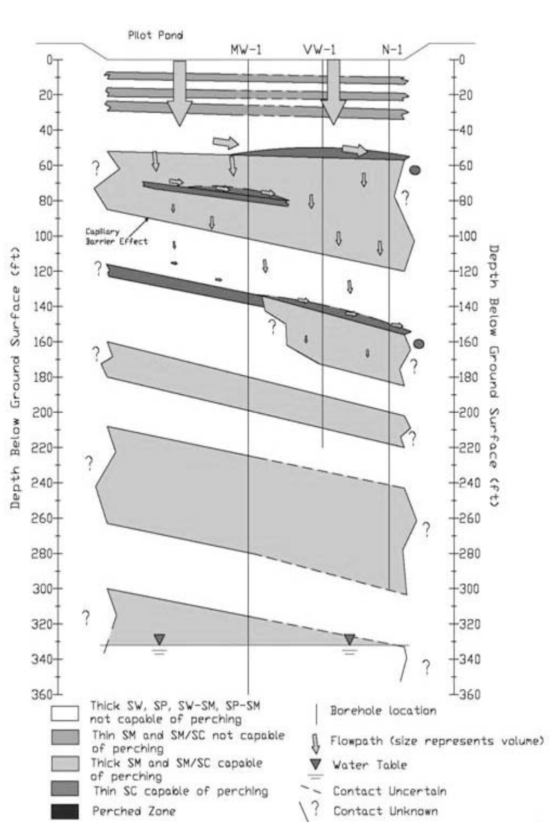

FIGURE 5. Conceptual subsurface lithologic layering.

Although recharge water was observed to reach the water table, it is believed that some water also spread laterally and remains in the deeper vadose zone (i.e.

between 130 to 332 ft (40 to 100 m)). It is expected that full scale recharge operations will cause the water table to rise into and merge with recharge water stored within the deeper vadose zone. Since the groundwater table will be maintained below 130 ft (40 m) bgs through pumping of recovery wells, agricultural operations should not be impaired by recharge operations.

Water Quality Impacts

Prior studies indicated the potential for arsenic and chromium to leach from subsurface sediments during recharge operations. Arsenic was not detected in any of the 66 suction lysimeter (vadose zone) and groundwater samples for this investigation, or in any prior investigations. Chromium was occasionally observed above the California primary Maximum Contaminant Levels (MCL) in the suction lysimeter samples. However, concentrations in water piezometer samples and groundwater have remained at background levels and speciation analyses of lysimeter samples indicated that soluble hexavalent chromium was not present at concentrations greater than 0.013 mg/l. Thus, the high chromium concentrations appear to consist of insoluble (i.e. colloidal) trivalent chromium that was pulled into the suction lysimeter.

As expected, nitrate and total dissolved solids (TDS) were present in the vadose zone pore water above MCL and secondary MCL (SMCL) levels due to ancestral agricultural drainage. However, nitrate and TDS concentrations decreased with depth in suction lysimeters and baseline concentrations in groundwater in MW-1 were below MCL and SMCL levels. During recharge, TDS concentrations consistently decreased at all vadose zone depth intervals over time (Figure 6 shows TDS data).

Additionally, concentrations at the water table remained below MCL and SMCL levels as of mid October 2006, approximately 7 months after recharged water first reached the water table.

Mass balance calculations based on laboratory leaching tests and suction lysimeter data indicate that TDS and nitrate concentrations in the vadose zone should be diluted to below SMCL and MCL levels within approximately 2 and 5 recharge seasons, respectively. Mass balance calculations based on the estimated historical deposition of agricultural salts yield estimates of approximately one-half the suction lysimeter estimates under equilibrium mixing assumptions.

After approximately 1.5 recharge seasons of the pilot test, TDS and nitrate are below or slightly above the California MCL and SMCLs. During the life of the project, concentrations in agricultural and recovery wells are not expected to rise above MCL and SMCL levels because of dilution in the vadose zone and within the screened intervals of these wells.

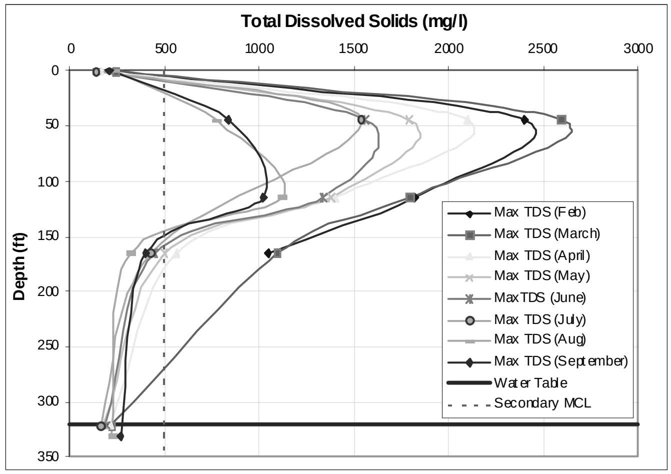

FIGURE 6. Vadose zone TDS concentrations vs. depth over time.

Representativeness of Pilot Recharge Basin Site

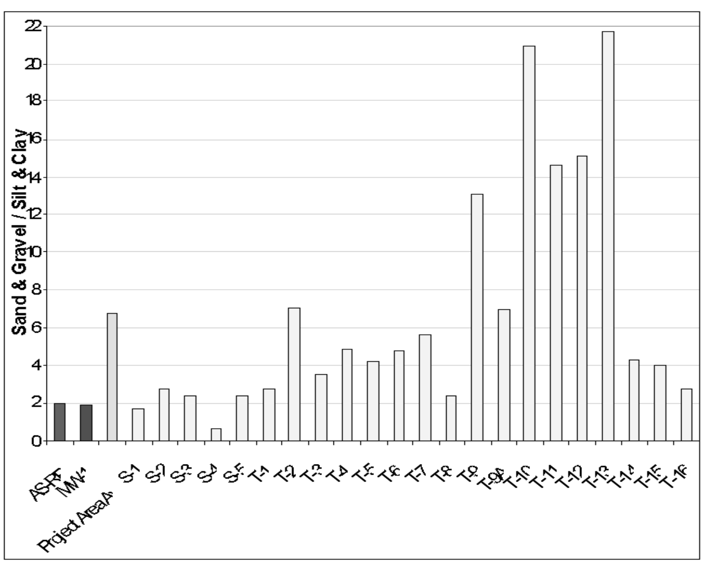

FIGURE 7. Ratio of sand and gravel to silt and clay in surface samples.

Data indicate that near surface soils (upper 10 ft) in the Pilot basin area are finer grained than soils underlying approximately 80 % of the full scale Project area. For example Figure 7 shows that the 2 pilot basin surface samples (AS-RP and MW-1) contain significantly less sand and gravel and more silt and clay than 19 of the other 22 surface samples collected throughout the Project area. Since there is typically an inverse correlation between the amount of fines and the hydraulic conductivity of porous media, the pilot basin test likely provides a conservatively low estimate of the infiltration capacity of near surface soils within the Project.

The subsurface lithologic conditions and recharge performance in the northern portion of the Project area should also be applicable to the central and southern portions of the Project area where exploratory and monitoring wells were not drilled for the following reasons.

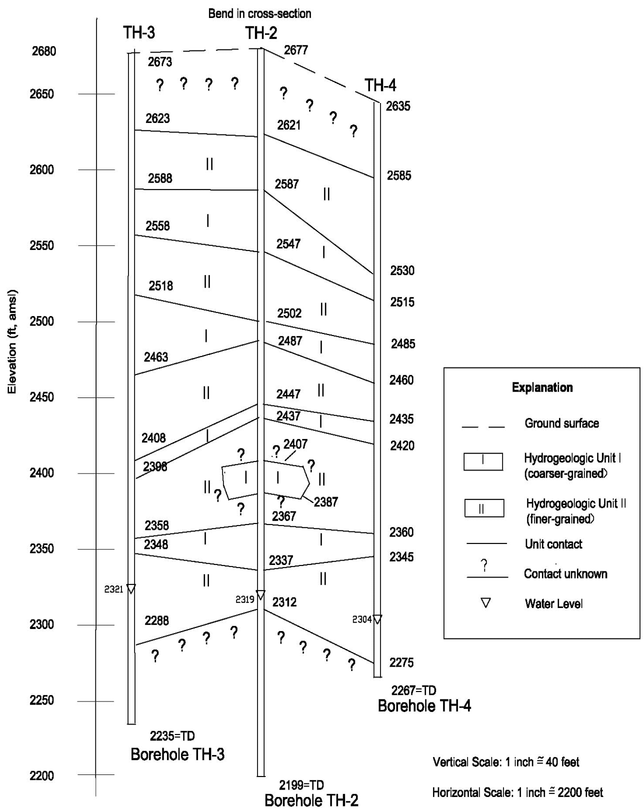

FIGURE 8. East-west lithologic cross section through northern Project area.

- Nearly all irrigation wells spread over the Project area are perforated between 250 and 1000 ft (76 to 305 m) bgs and support pumping from 1000 to 2000 gpm (227,000 to 450,000 l/s) indicating that the deeper subsurface saturated sediments are coarse-grained and highly permeable throughout the Project area.
- Previous studies (Bloyd, 1967a and b) suggest that the overlying unsaturated sediments will also be similar or coarser-grained in texture throughout the Project area.

CONCLUSIONS

The Antelope Valley Water Bank pilot test has demonstrated that water can be recharged to the water table at rates that exceed project requirements and that recharge and nearby agricultural operations should not be impaired by perching of percolating water. Based on other Project area surface and subsurface data, the pilot test results appear to provide a conservative indication of performance of the larger Project area. This test also corroborates specific yield assumptions that were used to previously estimate an available storage capacity of 500,000 acre-feet (616,740,000 m^3) in the dewatered portion of the aquifer.

Suction lysimeter water quality data showed that that arsenic was non-detect and that although chromium occasionally exceeded the MCL, the majority of chromium was insoluble (trivalent) chromium that had been pulled into the suction lysimeter. As expected, nitrate and TDS are present in the vadose zone at significant levels due to prior agricultural operations. Mass balance estimates indicate that vadose zone TDS and nitrate concentrations should be diluted to below SMCL and MCL levels within 2 to 5 recharge seasons. During this time, concentrations in agricultural and recharge recovery wells are not expected to rise above the SMCL and MCL levels because of dilution that will occur in the lower vadose zone and across several hundred feet of well screen within the aquifer below the recharge zone. As of February 2007, arsenic, chromium, TDS and nitrate concentrations in groundwater immediately below the pilot basin have remained below SMCL and MCL levels.

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