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GEOLOGY & SOILS INVESTIGATION

COUNTY OF LOS ANGELES
DEPARTMENT OF PUBLIC WORKS
MATERIALS ENGINEERING DIVISION

PWS-0190-0001

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ANTELOPE VALLEY GROUNDWATER RECHARGE STUDY
Phase 2

Air Force Site Along Amargosa Creek

Prepared
for

Hydraulics and Water Conservation Division
Los Angeles County

Prepared
by

Geology and Soils Investigations Section
Materials Engineering Division
Department of Public Works
Los Angeles County

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PWS-0190-0002

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TO: Iraj Nasseri
Hydraulics and Water Conservation Division

FROM: M. Johnson
Geology and Soils Investigations
Materials Engineering Division

ANTELOPE VALLEY GROUNDWATER RECHARGE STUDY

In response to your request, we have conducted a geological investigation focusing on potential groundwater recharge at the U. S. Air Force site along Amargosa Creek. The attached report includes the findings of our study.

If you have questions regarding the contents of the report, please contact Lidia Lustig or Ken Leslie at (818) 458-4923.

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ANTELOPE VALLEY
AIR FORCE SITE

I - INTRODUCTION

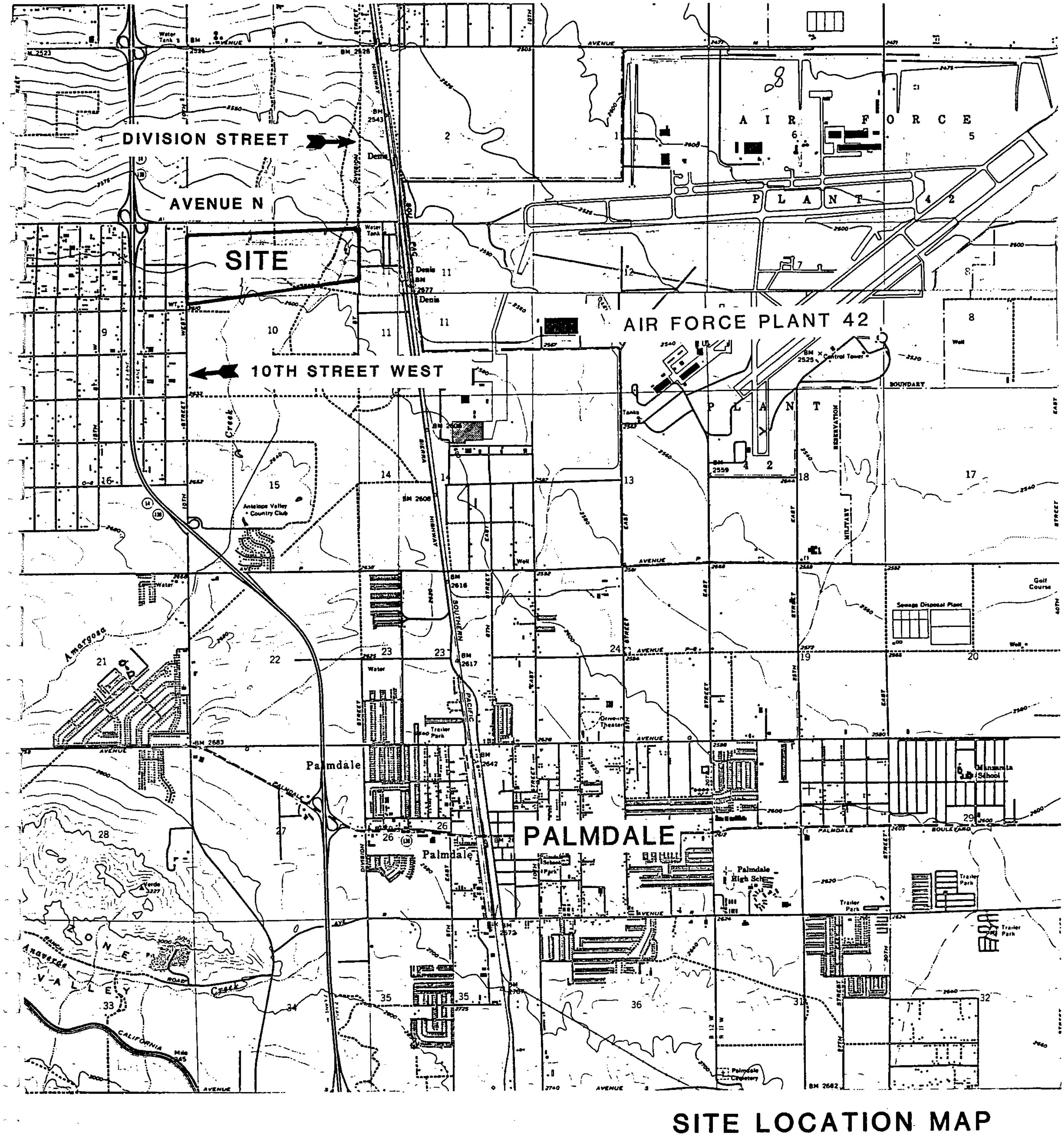
a) Overview

This report presents the findings of the Phase 2 study of potential groundwater recharge of a specific area of Antelope Valley. Phase 1 of the study (dated February 22, 1989) consisted of a preliminary generalized geologic/hydrogeologic investigation of potential recharge of the entire Antelope Valley. Based upon the information contained in the Phase 1 study, the Department's Hydraulic and Water Conservation Division selected the United States Air Force site along Amargosa Creek for further site specific study (see the Site Location Map, Figure 1).

b) Scope of Work

The scope of work for this investigation consisted of acquiring site specific information for evaluating the water recharge potential of the Air Force site. Specifically, the scope of work included:

1. Drilling 3 deep exploratory borings 640 to 800 feet in depth. These borings were preserved as observation wells.
2. Drilling 11 shallow exploratory borings 30 to 70 feet in depth.
3. Casing and gravel packing 5 of the shallow borings for percolation tests.
4. Excavating two exploratory trenches to a depth of 6 feet.
5. Detailed lithologic logging of the deep and shallow borings.
6. Undisturbed and bulk soil sampling of representative earth materials in the deep and shallow borings.
7. Laboratory testing of samples collected.
8. Electric logging of the deep borings.
9. Recording water levels in the deep wells.
10. Permeability testing in the shallow and deep wells and in the 6-foot deep trenches.
11. Pumping test of nearby water supply wells (courtesy of El Dorado Mutual Water Company).
12. Analyzing field and laboratory data.
13. Preparing a geologic map and cross-sections showing geologic units.
14. Preparing this report.



SITE LOCATION MAP

AIR FORCE SITE
AMARGOSA CREEK

SCALE 1" = 4000'

CONTOUR INTERVAL 5 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

UTM GRID AND 1974 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

PWS-0190-0007

FIGURE 1

c) Regional Geology

The most comprehensive discussion of the regional geology of the Antelope Valley can be found in Bloyd (Reference 1, 1967). Phase 1 of this study (1989) summarized the information from Bloyd, and from numerous other studies.

Antelope Valley is an alluviated, fault-controlled valley that locally contains as much as 2000 feet of unconsolidated deposits. Bedrock which underlies the unconsolidated deposits and forms the bordering mountains consists of a variety of metamorphic, igneous and sedimentary rocks ranging in age from Precambrian to Tertiary.

Unconsolidated Quaternary sediments constitute the basin fill in the Antelope Valley. These sediments consist of alluvial fan and lacustrine deposits. The upper alluvial fan deposits, about 600 feet thick, consist of uncemented-unconsolidated, coarse- to medium-grained sand and gravel that become more consolidated and less permeable with depth. Lacustrine sediments were deposited in an ancestral lake that occupied the central portion of the basin. These lake bed deposits, which are buried at depths of a few feet to 600-800 feet, consist of clay and silt up to 400 feet thick, interbedded with layers of coarse sediment up to 20 feet thick.

d) Regional Hydrogeology

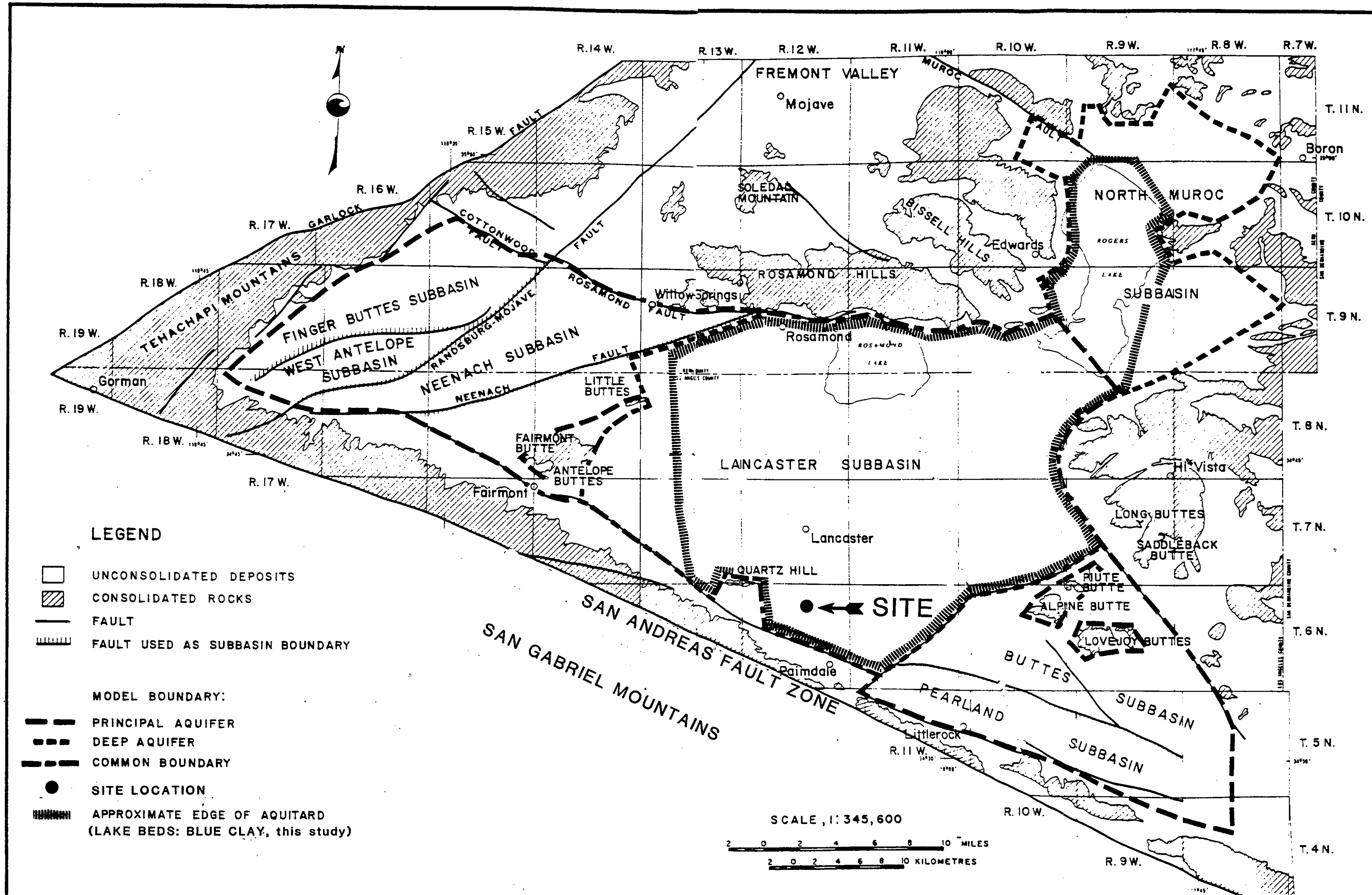
Northwest and northeast trending faults in the Antelope Valley divide the area into subbasins originally proposed by Bloyd in 1967. The U.S. Air Force site along Amargosa Creek is located in the Lancaster Subbasin, the largest in the valley (see Figure 2).

The Lancaster Subbasin consists of an upper unconfined aquifer and a lower, confined aquifer, separated by an aquiclude (separator) of lacustrine clay and silt. The upper unconfined aquifer, which is between 450 and 600 feet thick, is the main water production zone for the valley. Mostly composed of unconsolidated sand and gravel, it commonly has layers and lenses of clay and silt which produce local semi-perched conditions. The lower, confined aquifer is limited to the areal extent of the lacustrine (lake) deposits. Because of its age and depth of burial, the lower aquifer is more consolidated than the principal upper aquifer.

At the turn of the century, the water table of the upper unconfined aquifer was relatively shallow (60-100 feet deep), and flow from wells onto the surface occurred in the low-lying areas due to artesian conditions. Due to agricultural, industrial and domestic use, the water table has since dropped dramatically in the Lancaster Subunit. Currently, the water table in the City of Lancaster is at a depth of about 350 feet.

II - SUBSURFACE INVESTIGATION

A summary of subsurface exploration performed is provided in the Appendix B, Subsurface Exploration (pages B-1 to B-3).



HYDROGEOLOGIC SUBBASINS OF THE ANTELOPE VALLEY

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1980

FIGURE 2

PWS-0190-0009

III - SITE GEOLOGY

a) Physiography

The site is located approximately 5 miles north of the San Gabriel Mountains, and 3 miles north of the San Andreas Rift zone, in the alluvial fan of Amargosa Creek. The elevation ranges from 2590 to 2610 feet, with a 1% surface grade to the north. The Air Force property dimensions are one mile from east to west and about 1700 feet from north to south, and is bounded by 10th Street West on the west, Avenue N on the north, and Division Street on the east (see Figure 1). Amargosa Creek traverses the westerly portion of the site, and has a steep, up to 8 feet high, western bank that is gently sloping in the east.

The site is in its natural state with sparse native vegetation, which includes scattered Joshua trees and low brush. A thin layer of wind-blown sand mantles the site. A few small concrete slabs mark the locations of former structures.

Access to the site is provided by ungraded dirt roads. The property boundaries are marked by "U. S. Property" posted signs.

b) Site Area Geology

i) Local Geology

Information on subsurface conditions within a few miles of the U.S. Air Force site has been obtained from water wells. The majority of these water wells are owned and operated by Los Angeles County Waterworks Districts Numbers 4 and 34. The wells have been drilled to depths between 690 and 1100 feet.

Available electric logs and drillers' lithologic logs of the wells were used for the interpretation of the local stratigraphy. Consultation with Waterworks' District Consultant Richard Slade (References 12 and 13) facilitated the differentiation of the upper unconfined aquifer, the lower confined aquifer, and the "separator" between them. Figure 3 shows a hydrogeologic cross section based on Waterworks' Division well data, complemented with information from this study.

The upper unconfined aquifer consists of interbedded silty sands and gravels, with occasional "clay" lenses which become more common to the north, near the center of the Lancaster Subbasin.

Below the unconfined aquifer is the "separator", which consists of a layer ranging from 200 feet thick near the hills to the south, to 300 feet thick toward the center of the basin to the north. This separator consists of the fine-grained sediments described as lacustrine (lake) deposits in the literature and it is also defined as an aquiclude. In this study the "separator" will be called the "Blue Clay", a nomenclature that will be used throughout the remainder of this report.

The Blue Clay has been divided into an upper and lower zone, based on grain size of the sediments and geophysical resistivity logs. The upper zone consists of interbedded sand, silt and clay, generally brown or reddish brown in color, with increasing content of finer-grained sediments with depth. Its upper boundary is gradational with the unconfined aquifer and is subject to some interpretation. The lower zone contains predominantly clay, with colors ranging from blue, olive green, to gray green or sometimes brown, and represents the Blue Clay in a strict sense, by the presence of blue colored sediments. This lower zone has been penetrated in the majority of the County wells. Its thickness ranges from 80 feet in the south (at well 34-6) to 125 feet in the north (at well 4-42), thickening basinward. The gradient of its upper boundary is 1 to 2% to the north. The Blue Clay creates confining conditions for the lower aquifer.

The lower confined aquifer consists of interbedded coarse grained sand with clay lenses, and its lower boundary is defined by the presence of bedrock.

ii) U.S. Air Force Site Geology

The upper unconfined aquifer, the focus of this investigation, extends at the Air Force site to a depth of 580 to 620 feet. From this depth to 800 feet, the maximum depth explored, the upper zone of the Blue Clay was encountered. The lower zone was not penetrated, but is interpreted to be immediately below 800 feet (Figure 3).

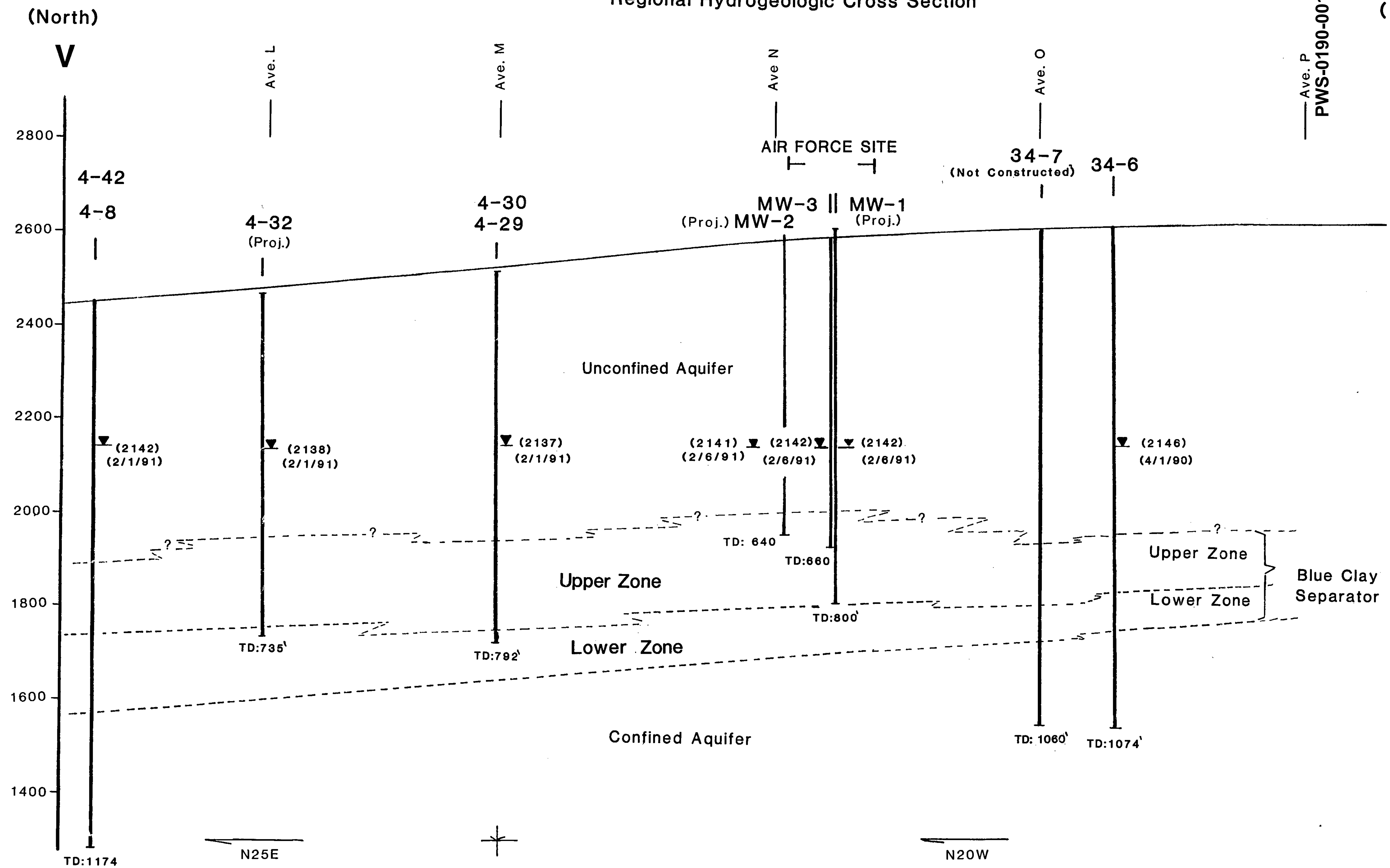
1) Upper Unconfined Aquifer

Within the unconfined aquifer, the shallow borings (B-1 to B-8) defined the detailed stratigraphy of the upper 70 feet. Two general types of units were recognized: one consists of layers of coarser-grained materials (sand, gravel and minor silt); the other, of finer-grained materials (silt, silty sand and clayey sand) is here termed "low-permeability layers".

Below 70 feet, and to a depth of 580-620 feet, the unconfined aquifer was explored by deeper borings MW-1, MW-2 and MW-3.

Logging of these exploratory borings and laboratory grain size analysis of the soil samples indicates that the sediment types are similar from the surface to a depth of 580-620 feet (see laboratory findings in Appendix A). The uniformity of the soils to this depth is also confirmed by the electric logs (see Appendix C). The electric logs show a multitude of thin interbedded sands and "low permeability layers". Detailed lithologic identification and cuttings correlations were not possible due to the fact that the holes were drilled by the rotary wash method with drilling mud.

Regional Hydrogeologic Cross Section



See Plate 8 for Section Loc

PWS-0190-0012

The sediment types of the unconfined aquifer consist of interbedded layers and lenses of silty sand, well graded sand, clayey sand, sandy silt and silty clay. Stratigraphic boundaries between sediment types such as aforementioned "low permeability layers", are gradational to distinct. The predominant sediment type (approximately 60 to 80%) is silty sand.

The following detailed lithologic descriptions characterize the sediments of the unconfined aquifer:

Coarse Layers. The predominant sands are silty, fine to coarse grained, with angular to subangular grains, and very well graded. The percentage of fines ranges from 10 to 30%, with zero to 8% clay. The content of gravel ranges from 1 to 25%, and is mostly fine grained. The maximum gravel clast size encountered was 3 inches in diameter. The gravel consists mostly of schist, granitics and quartz. Unstable minerals in the rock fragments are generally altered to clay.

The grading of the silty sand is generally very high, with a coefficient of uniformity larger than 8, commonly in the 100's, with a maximum of 500 (a coefficient larger than 6 is considered well graded; see Figure 4).

"Low Permeability Layers". Finer-grained sediments occur in lenses that range from one to 10 feet in thickness. These layers have between 30 and 50% fines, with 8 to 35% clay; they range from plastic to non-plastic.

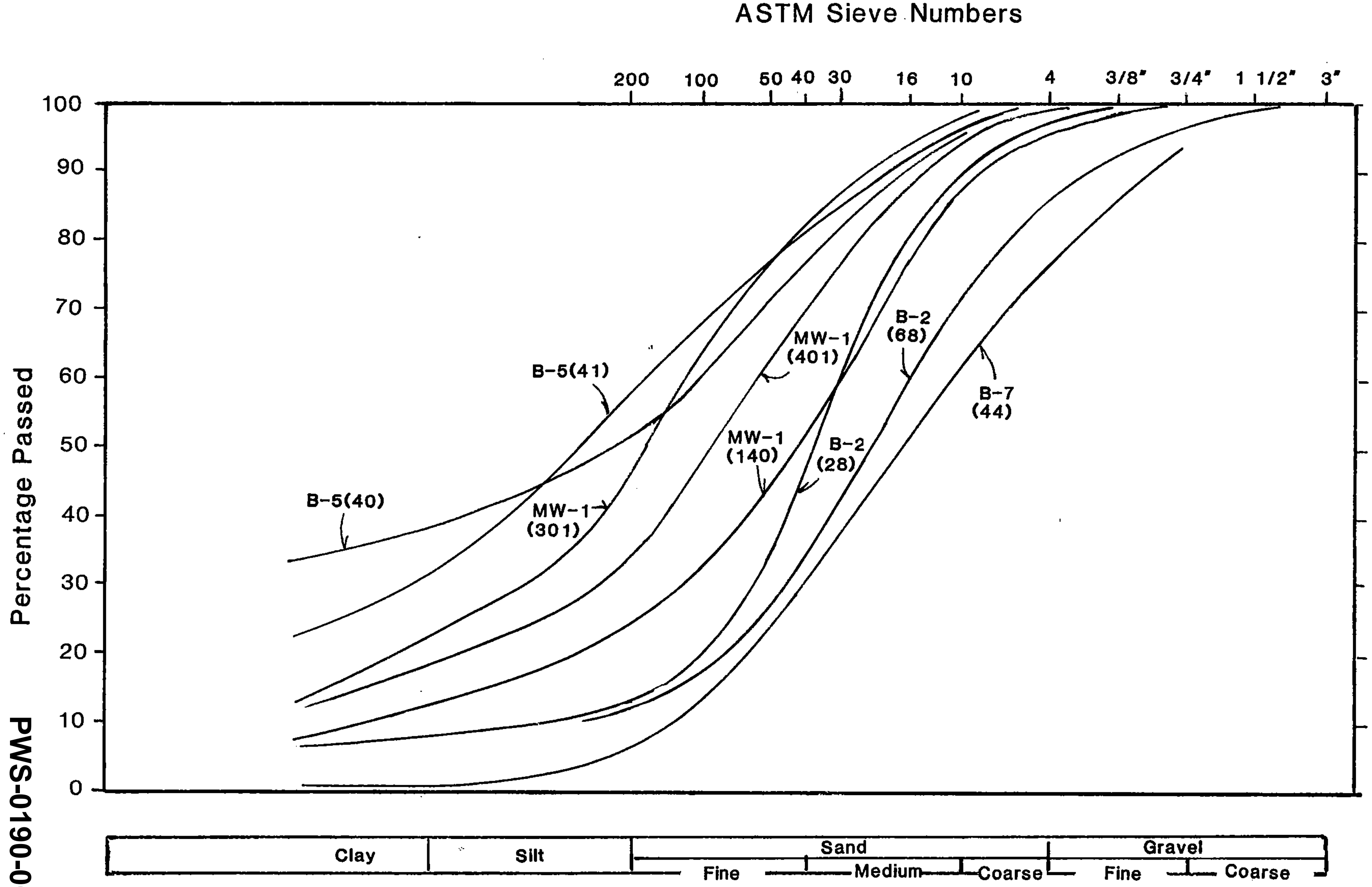
The grain size distribution also shows a very well graded curve, similar to the coarse layers.

Figure 4 shows selected representative grain size curves of the 21 samples analyzed. The grain-size distribution remains similar throughout the depths tested (the deepest in-situ sample was taken at 480 feet). These curves can be used for the design of gravel packs and selection of screen sizes if wells are proposed for the site.

Several geologic cross-sections were compiled, showing correlation of the "low-permeability layers" between the shallow borings (see Plates 2 to 7). Cross-section locations are shown on Plate 1.

The cross-sections show that most of the "layers" are discontinuous and may thin or thicken laterally (both northward and eastward) within a few thousand feet. Some layers, however, are continuous for almost a mile (e.g., cross-section A-A', Plate 2). The thickness and number of "low-permeability layers" decrease towards the eastern boundary of the property. In addition, the low-permeability layers are found at a greater depth towards the

Range of Grain Size Curves for Tested Samples



MW-1 Monitoring Well
B-4 Shallow Boring
(40) Depth (feet)

PWS-0190-0014

FIGURE 4

eastern portion of the site. The "low-permeability layers" are generally less than 10 feet thick and dip uniformly to the northeast at a gradient of less than one degree.

2) Blue Clay

Upper Zone of the Blue Clay

The sediments from 580-620 feet to the total depth explored (800 feet), constitute the upper zone of the Blue Clay. There is considerable fining of the sediments relative to the overlying unconfined aquifer, consisting primarily of silt and clay with subordinate sandy layers. This fining trend can also be recognized in the resistivity logs (Electric Logs, Appendix C). The top of the upper zone differs in each of the monitoring wells, and ranges between 580 to 620 feet deep.

Lower Zone of the Blue Clay

The lower zone was not encountered in the deepest boring, but based on data from wells both north and south of the site, this zone is interpreted to occur immediately below 800 feet (see Figure 3).

IV - SITE HYDROGEOLOGY

a) Surface Flow at Site

Amargosa Creek was described by Johnson (Reference 8) as "the only stream with even moderate flow between Little Rock Creek and the extreme west end of Antelope Valley". This creek traverses the west portion of the site. Most flow along Amargosa Creek is intermittent and is associated with major storm periods. The stream has no gaging stations from its debouchment onto the valley (near Elizabeth Lake Road) to the U.S. Air Force site. Estimates based on point discharge indicate the average yearly flow rate to be between 500 and 800 acre feet. Capital storm discharge for this creek has been estimated at 23,000 cubic feet/second. However, this volume appears to be an overestimation, especially considering that the watershed of Amargosa Creek is only 20 square miles.

b) Permeability of the Unsaturated Zone

The hydraulic conductivity of sediments in the unsaturated zones is not a constant. It is dependent on capillary and gravitational forces and is not easily quantified. The unsaturated hydraulic conductivity is also affected by the water or moisture content, and reaches its maximum at or near saturation. In addition, the theoretical equations for flow in the unsaturated zone are highly complex. The flow equations are non-linear and not subject to easy solutions.

Therefore, the permeability data obtained from permeability tests performed are intended to give a range of values which are representative of a variety of sediment types and moisture contents for the site.

Permeability tests were performed in three depth zones: i) Surface, ii) Surface to 70 feet, and iii) Surface to the water table (about 450 feet).

i) **Surface Percolation Tests**

The surface percolation test trench locations are shown on Plate 1, TP-1 and TP-2. These two trenches were excavated below the topsoil to a depth of 6 feet, where the percolation tests were performed. The materials tested were gravelly sands.

The hydraulic conductivities of the near surface sediments using the percolation method (see A-53) is on the order of 10^{-2} cm/sec, with a range of values from 1.7×10^{-2} to 4.4×10^{-2} cm/sec.

ii) **Ground Surface to 70 Feet** (Shallow Borings)

Permeability tests were performed in the six shallow borings (B-1, B-1A, B-3, B-5A, B-7A, and B-8) in which casing and gravel packs were installed. Falling-head and constant head permeability tests were performed. The results are summarized in Table I.

Some of the falling-head tests were performed to selectively determine the hydraulic conductivity of the "low permeability layers". For example, borings B-1A and B-5A (see Plates 2, 4 and 5, and Table I) were terminated within these "layers" and the test performed only in this interval. The remainder of the falling-head tests were performed to test intervals which contained a composite of sediment types. The calculation methods used for this test (Hvorslev and Auger, A-52 and A-50) are designed for saturated conditions; therefore, the results are considered estimates for the unsaturated conditions of the shallow borings.

The constant-head test (Well Permeameter, A-54) was performed in 3 borings, testing for different stratigraphic intervals. This test is designed for unsaturated conditions.

Table I shows the hydraulic conductivities of the sediments in the shallow borings and indicates that values of 10^{-3} to 10^{-4} cm/sec are representative to a depth of 70 feet. The "low-permeability layers" have hydraulic conductivity values of 10^{-4} and 10^{-5} cm/sec.

Due to the horizontal layering of sediments with variable permeabilities, the values of hydraulic conductivity in a horizontal direction are generally 2 to 10 times larger than those in a vertical direction. The permeability tests performed in the borings measure primarily the horizontal hydraulic conductivity of the sediments, and therefore represent higher values that would be obtained by vertical movement of water, as occurs during percolation from spreading grounds.

TABLE I

PERMEABILITY TESTS OF THE SHALLOW BORINGS

SHALLOW BORINGS	INTERVAL TESTED (Depth in ft.)	MATERIAL TESTED	TYPE OF TEST	DURATION OF TEST (hours)	DATE TESTED	METHOD USED IN CALCULATING HYDRAULIC CONDUCTIVITY	HYDRAULIC CONDUCTIVITY (cm/sec)
B-1A	36-39	Silt layer	Falling head	6	5/24/90	Auger	$1.15x10^{-5}$
B-1A	20-39	Sand & silt	Constant head	2	6/7/90	Well permeameter	$1.0x10^{-3}$
B-1	0-70	Sand & silt	Constant head	1	6/20/90	Well permeameter	$4x10^{-2}$*
B-3	50-70	Sand & silt	Constant head	2.5	7/3/90	Well permeameter	$1.8x10^{-3}$
B-5A	26.5-42.5	Sand	Falling head	1	5/31/90	Hvorslev Auger	$5x10^{-3}$ $7x10^{-3}$
B-5A	35-42.5	Silt layer	Falling head	3	5/31/90	Hvorslev	$6x10^{-4}$
B-5A	18.5-42.5	Sand & silt	Constant head	4	6/5/90	Well permeameter	$8x10^{-4}$
B-7A	0-25	Sand & silt	Constant head	0.5	6/19/90	Well permeameter	$8.4x10^{-3}$
B-8	38-70	Sand & silt	Constant head	3	7/10/90	Well permeameter	$2.7x10^{-4}$

* No pre-saturation

13:TAB

iii) Ground Surface to the Water Table (Deep Borings)

Permeability tests were performed in two of the deep wells. These wells, MW-1 and MW-3, are 800 and 640 feet deep respectively, and both are cased and gravel-packed.

Several falling-head permeability tests were run. Three methods of calculations were utilized: Bouwer and Rice (A-51), Hvorslev (A-52), and the percolation test method (A-53). As shown in Table II, calculated hydraulic conductivities range from a low of 10^{-7} to a high of 10^{-4} cm/sec.

The unreasonably low values obtained with the Bouwer and Rice and with the Hvorslev formulas suggest that these methods are not applicable for unsaturated conditions and for the large boring dimensions tested.

Calculations using the percolation method indicate that the sediments have a hydraulic conductivity of 10^{-4} to 10^{-5} cm/sec. The hydraulic conductivities of the sediments decrease with depth.

Hydraulic conductivities of 10^{-4} to 10^{-5} cm/sec are realistic, as compared with aforementioned hydraulic conductivities of 10^{-3} to 10^{-4} cm/sec of the surficial sediments from 0 to 70 feet. Inasmuch as sediment types in the unsaturated zone show little variation, the lower permeabilities are presumably a consequence of the expected densification with depth.

As in section ii) above, these values represent the horizontal, and therefore higher, hydraulic conductivity, as compared with the vertical hydraulic conductivity.

c) Permeability and Aquifer Parameters of the Saturated Zone

The principal characteristics of aquifer performance are transmissivity and storativity. Several indirect methods are available to obtain estimated values for transmissivity. These methods are based on grain-size analyses, hydraulic conductivity values, and calculations based on specific capacity of a well. However, only pumping tests provide direct measurement of these parameters. Pumping tests provide results that "most accurately reflect the true hydraulic conditions within an aquifer" (Reference 5).

To perform a pumping test at the site was outside the scope of this phase of the investigation. However, a short pumping test was performed in existing production wells located adjacent to the site. These wells belong to the El Dorado Mutual Water Company and are located near the intersection of Avenue N-8 and 10th Street West, 1700 feet west-southwest of MW-1 (See Plate 8).

Two wells are located at the site, 73 feet apart in a north-south direction. The south well was used as a pumping well, and the north well as the observation well. The table on Page 11 defines the parameters for each well.

TABLE II

PERMEABILITY TESTS
OF THE DEEP BORINGS

DEEP BORING	INTERVAL TESTED (Depth in Feet)	DEVELOPMENT STAGE	MATERIAL TESTED	TYPE OF TEST	DURATION OF TEST (Hours)	DATE TESTED	METHOD USED IN CALCULATING HYDRAULIC CONDUCTIVITY	HYDRAULIC CONDUCTIVITY (cm/sec)
MW-1	46.5-463.7	After Initial Development	Sands and silts	Falling Head	23	8/29-30/90	Bouwer and Rice	1.5×10^{-6}
	"	"	"	"	"	"	Hvorslev	3.5×10^{-7}
	"	"	"	"	"	"	Percolation Test	3.9×10^{-4}
	196.9-463.7	"	"	"	"	"	"	1.8×10^{-4}
	391.6-463.7	"	"	"	"	"	"	5.8×10^{-5}
MW-1	37.5-463.7	After Initial Development	Sands and silts	Falling Head	24.5	8/30-31/90	Hvorslev	1.9×10^{-7}
MW-1	0-384	After Initial and Secondary Development	Sands and silts	Falling Head	7	11/28/90	Bouwer and Rice	6.8×10^{-7}
Mw-3	0-150.1	After Initial Development	Sands and silts	Falling Head	7.5	11/29/90	Bouwer and Rice	1.4×10^{-7}

13:KLTAB2

	North Well (Observation Well)	South Well (Pumping Well)
Total Depth (feet)	600	600
Perforations (feet)	200-500	unknown
Diameter of casing (inches)	14	12
Pump installed	yes	yes
Depth to Static Water Table (feet)	442.2	439.14

The pumping test lasted 143 minutes, with an average discharge of 244 gal/min. The pumping rate fluctuated slightly but remained within 12% of the average rate, ranging from a low of 216 to a high of 251 gal/min. Following the pumping test, a 135-minute recovery test was performed. Calculations of transmissivity from these tests were based on the Cooper-Jacob method.

The time-drawdown curve for the pumping test (Figure 5) shows that the first part of the graph is steeper than the second part, with the inflection point occurring at about 60 minutes. Calculated transmissivity from the first (steeper) curve is lower than that from the second (shallower) curve. The interpretation of this change as an increase in recharge is unlikely, as no source of recharge for the formation is known in the area. A better interpretation is that this deflection is caused by slow drainage (Reference 5, p. 229-230): "The causes of this phenomenon are the great difference between the horizontal and vertical hydraulic conductivity in some sediments ... When pumping begins, the amount of vertical water movement toward the screen is relatively small, but as time passes and the cone of depression widens, a larger percentage of the water moves towards the well vertically, thereby reducing the slope of the time-drawdown curve ... Thus, early data in slow drainage situations do not indicate true aquifer conditions." The higher value of transmissivity (about 60,000 gals/day/ft) therefore is considered more representative for the aquifer.

The time-recovery curve shows an anomalous drop in water level between 5 and 10 minutes (Figure 6), due probably to the rapid backflow of water into the aquifer from the casing of the pumping well when the pump was turned off. This backflow would produce an outward-propagating surge that, when superimposed on the gradually rising water table during the recovery phase, would cause a rapid rise in water level, followed by a slight drop. After 10 minutes, when the transient effects of the surge died out, the graph became a straight line corresponding to a transmissivity of 55,000 gals/day/ft.

PUMPING TEST

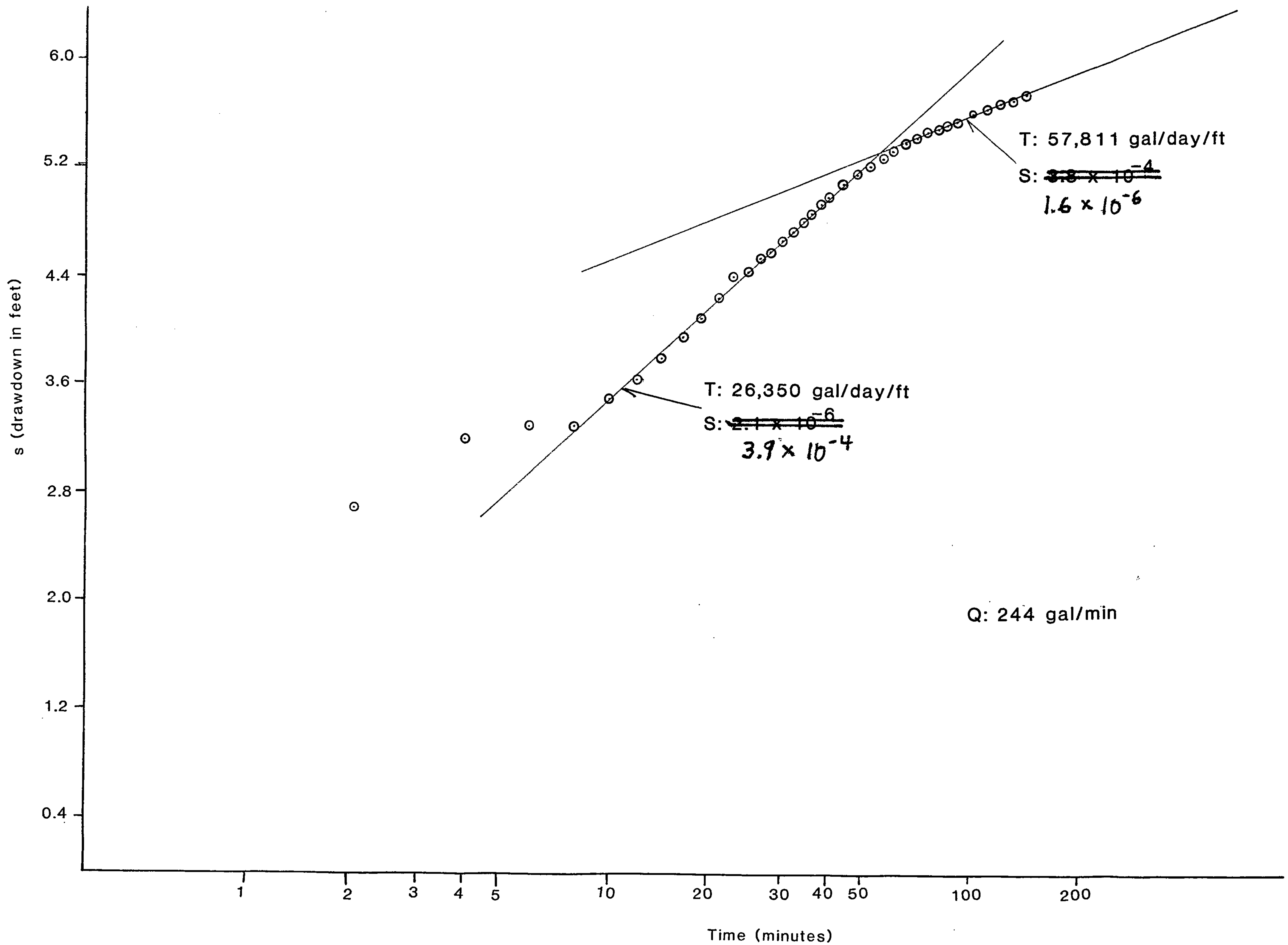


FIGURE 5

RECOVERY TEST

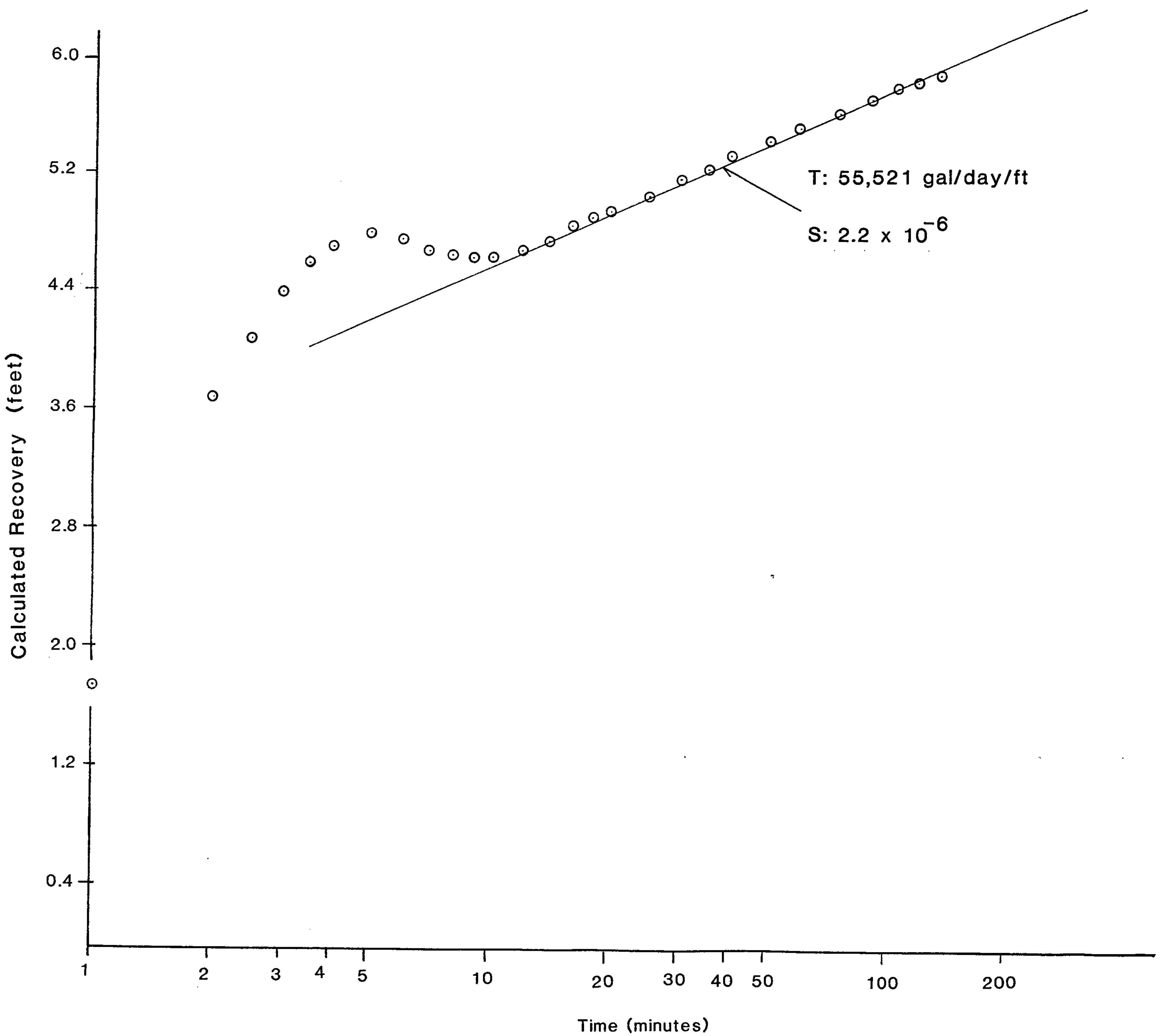


FIGURE 6

The transmissivity value obtained from the time-drawdown graph differs only 4% from that based on the time-recovery data. Because the time-recovery data are more accurate than the drawdown data (measurements are not affected by pump vibrations and variations in pumping rate), data from the recovery test are considered to better characterize the aquifer. The transmissivity value is about 55,000 gal/day/ft.

The Cooper-Jacob method, a simplification of the Theis method, yields transmissivity values that have greater accuracy as duration of pumping increases. Because the pumping test had a relatively short duration, the test data were also analyzed by the Theis method. Analysis by this method gives a transmissivity of about 37,000 gal/day/ft for the aquifer.

In general, long duration pumping tests (72 hours) are recommended for accurately determining the hydraulic properties of unconfined aquifers.

The value for the storage coefficient, based on the time-drawdown curve, is 2×10^{-6}. This low value is more characteristic for a confined aquifer than for an unconfined one. Storage coefficients for unconfined aquifers range from 0.01 to 0.3.

The permeability (or hydraulic conductivity) of the saturated zone can be derived from the relationship $T = K \times b$, where T = transmissivity, K = hydraulic conductivity, and b = the thickness of the saturated aquifer. With values of T ranging from 37,000 to 55,000 gal/day/ft and a value for the saturated thickness of 150 feet, the resulting hydraulic conductivity values range from 1.1×10^{-2} to 1.7×10^{-2} cm/sec.

d) Groundwater Levels, Direction of Groundwater Flow and Hydraulic Gradients of the Unconfined Aquifer

i) Groundwater Levels

1) Site

The three observation wells MW-1, 2 and 3, encountered groundwater of the unconfined aquifer. The water levels are considered to represent the static groundwater table, because no large water extraction area exists close to the site. A series of water level measurements were obtained with an electric sounder in the period from October 1990 to February 1991. The groundwater depths oscillated up to 6 inches in each of the wells; the cause of these variations is not clear.

Depths to groundwater averages 464.1 feet in MW-1, and 444.8 feet in MW-3. Groundwater elevations range from about 2140 to 2142 feet.

A Flood Control District monitoring well (Number FCD-9966, see Plate 1) was constructed in 1940 near Amargosa Creek and Avenue N to a depth of 245 feet. Water levels measured in 1940 were 239 feet below the ground surface. In 1943, due to water level decline, the well went dry and it was subsequently abandoned.

Compared with existing water levels at the site, the water table has declined about 200 feet in the last 51 years, an average of approximately 4 feet per year.

2) Offsite

Several Waterworks District wells where water levels are regularly monitored are located north and south of the Air Force site (see Plate 8).

As reported for several decades and illustrated recently by Slade (1989), a groundwater cone of depression has formed near Lancaster, north of the site, due to high levels of water extraction that have produced overdrafts. Recently (within the past half year), the County Waterworks District has discontinued the pumping of a number of their wells in that area. Comparison of recent and earlier water levels indicates that groundwater recovery is taking place, and since July of 1989. water levels have risen nearly 30 feet. Static water levels within 2 miles north of the site range from 325 to 386 feet below the surface, with elevations between 2131 and 2138 feet.

The two privately owned wells from El Dorado Water Company (see Plate 8) were drilled in 1948 and 1952. In 1948 water levels were monitored at 262 feet below the ground surface; at the present time, water depths are in the order of 440 feet. Paralleling the conditions of the U.S. Air Force site, the groundwater table has declined 181 feet in the last 43 years, an average of about 4 feet per year.

The only water levels available south of the site are from Waterworks Well 34-6, which is perforated in both the upper and lower aquifers and has been pumped intermittently. Depth to water was 471 feet in April of 1990, with a water table elevation of 2149 feet.

Most of the measurements of water levels at the Waterworks wells are performed with an air sounder, which can have a variation of up to 10 feet. Because of the use of this sounding method, and comparable water level elevations between wells, it was not possible to prepare a meaningful water contour map between the site and Lancaster (see Figure 3).

The water elevation at El Dorado Mutual Water Company Wells is about 2170 feet. A difference in elevation of 28 to 30 feet occurs between these wells and the Air Force site. No explanation has been found for these anomalous high water levels.

ii) Direction of Groundwater Flow and Hydraulic Gradient of the Unconfined Aquifer

1) Site

Using depth to water at the three observation wells MW-1, 2 and 3, the flow direction and hydraulic gradient can be determined by solving a three-point problem. Extremely low gradients exist at the site, with water elevation differences being less than 2 feet in a distance of 1200 feet. Therefore, only measurements taken for the three wells on the same day were used, to eliminate any temporal variations.

The hydraulic gradient at the site averages 4 to 5 feet per mile and is directed towards the north-northwest at a N10° to N20° west direction. This is the general direction toward the pumping depression in Lancaster, described above.

2) Offsite

The static water elevation difference between the project site and the down gradient Waterworks wells in Lancaster ranges between zero and 10 feet. In general, the water level measurements indicate a northerly flow with a very low hydraulic gradient, ranging from 1 to 6 feet per mile. Groundwater contours drawn from data for 1958-1965 (Reference 1) and 1973 (Reference 15) also indicate very shallow gradients between Palmdale and Lancaster. Shallow gradients are characteristic of desert environments and are an indication of low levels of groundwater recharge.

The hydraulic gradient south of the site could not be determined with accuracy, because the only well with available static water level measurements (WW 34-6) perforates both aquifers, and therefore may not represent water table levels. The static water elevation in this well approximates that at the U.S. Air Force site (2142 feet).

V - GEOLOGIC HAZARDS

a) Collapsible Soils

"Collapsible soils" refers to a phenomenon also known as hydroconsolidation, near-surface subsidence, and subsidence hydrocompaction. Collapsible soils are defined as unsaturated soils that undergo, after excessive wetting, a great loss of volume, resulting in spontaneous ground subsidence. This collapse can occur with or without additional loading.

Collapsible soils can have diverse origins, but they generally occur in arid and semiarid conditions and are of geologically young age. In the Antelope Valley, the loose, open grain structure of the collapsible soils originates from their mode of deposition. Some of the alluvial fan layers were laid down rapidly as sheet-like mudflows or debris flows, following storms of short duration. The sediment grains in each layer will form a low-density and porous structure, with bonding that will be maintained as the sediment dries out. When subsequent deposition occurs, it may be so rapid that the underlying layer will not become saturated. Layers 100 feet in thickness or more may be built up in this way. When these sediments become saturated, generally as a result of human activities, water produces a radical rearrangement of the loose internal structure of the sand, silt and clay grains, and leads to the collapse of the sediments. Collapsible soils can be found in grain sizes ranging from gravel to clay.

The occurrence of collapsible soils in the Antelope Valley is widespread. It has been especially well documented in areas of residential development where the introduction of irrigation and sewage water has resulted in distress to existing dwellings.

At the Air Force site, six soil samples were tested at selected intervals for consolidation tests (See Table III). Three of them detected over 2%* collapse (decrease in volume), after addition of water. The maximum depth at which collapsible soils were recorded at the site was 45 feet. This indicates that soils have never been saturated at least to that depth.

The delicate, weakly bound in-situ grain structure is readily weakened during field sampling and laboratory testing; consequently, "undisturbed" samples are very difficult to obtain. It is possible therefore, that additional collapsible soil layers underlie the site, and that hydroconsolidation percentages are larger than recorded.

Spreading Grounds and Collapsible Soils

The presence of collapsible soils is an important consideration if spreading grounds are planned for the Air Force site. The near-surface sediments will become saturated and water will migrate laterally (mostly to the northeast), perching on the upper "low permeability layer" located at a depth of about 20 feet. Most probably, several of the collapsible layers will "hydroconsolidate" with a reduction of their thickness and subsequent subsidence of the ground surface.

At the present time the areas surrounding the Air Force site are mostly in a natural condition, with minimal development. However, it can easily be foreseen that development will encroach upon the site in the near future. If the construction of spreading grounds is decided upon, it is strongly recommended that the area be saturated to induce collapse of the sediments under controlled conditions, prior to development. Once the sediments collapse, the hazard is mitigated.

b) Faults and Seismicity

No active or potentially active faults are known to traverse or project to the site. The closest active fault is the San Andreas Fault, located 3.5 miles southwest of the site. The maximum credible earthquake for the southern portion of the San Andreas Fault is a Richter magnitude of 8.5.

* NOTE: The 2% value is commonly used in geotechnical investigations as the threshold value in assessing potential damage to a structure located over these soils.

TABLE III
RESULTS FROM LABORATORY CONSOLIDATION TESTS

Boring	Depth (ft.)	Unified Soil Classification	% Hydroconsolidation
1	5-6.5	SM	1.7
3	10-11.5	SM	2.9
2	28-29.5	SM	1.2
6	29-30.5	SM	3.0
4	44-45.5	ML	4.1
5	64-65.5	SW	1.8

The recurrence interval for a magnitude 8.0 earthquake on the southern portion of the San Andreas Fault is on the order of 150 years. As this section of the fault has not experienced a major earthquake (>8.0) during the past 134 years, an event of this size can be expected during the design life of the recharge installation. During such an event the site is expected to experience a peak horizontal acceleration of approximately 0.7 g. The duration of strong shaking (>.05 g) could last as long as 70 seconds.

c) Liquefaction

The near-surface alluvial soils at the site consist of loosely consolidated silts and sands. If, in a saturated state, these materials are subjected to earthquake shaking during a major seismic event (>8.0 magnitude) they will liquefy. Sand boils and ground fissures are likely to develop, and associated damage to structures and underground installations can be significant.

d) Subsidence

As a result of groundwater withdrawal in the Antelope Valley there has been a concomitant subsidence of the land surface. For the 1955-1967 time period, the ratio of land subsidence to water level decline has been 1:20 (U.S.G.S., 1968, Reference 14).

Studies by the U.S.G.S. (op. cit.) and Los Angeles County (1973, Reference 10), indicate that the primary foci of subsidence in the Lancaster area are centered at Lancaster Blvd. and Sierra Highway, and at Ave J and 70th Street East. As much as 1.5 feet of subsidence has been reported over a 5 year period in these primary subsidence depressions. These locations are approximately 5 miles north and 8 miles northeast of the site, respectively.

Subsidence at the site for a 5 year period, presumably during the late 1950's and early 1960's, was 0.02 feet/year (Los Angeles County, 1961, Reference 9). Subsequent studies (U.S.G.S., 1968, and Los Angeles County, 1973) report approximately 0.1 foot of subsidence between 1955 and 1967 and 0.1 foot of subsidence between 1966 and 1971, respectively. These estimates yield average yearly rates of subsidence at the site of approximately 0.01 to 0.02 foot/year.

VI - DISCUSSION

a) Proposed Spreading Grounds

Results of this investigation indicate that the development of spreading grounds at the site is feasible.

A value of hydraulic conductivity of 10^{-3} to 10^{-4} cm/sec is estimated to be an average for sediments in the upper 100 feet of section. Limitation of these values with reference to unsaturated conditions are described in section IV above. "Low-permeability layers" (see section III) underlie the entire site and will act as temporary barriers to the downward percolation of water. Water will temporarily perch on these layers and flow laterally, mainly in a northeasterly direction, parallel to the inclination of the beds. Because the "layers" pinch out laterally, water will eventually percolate downwards.

The distribution of the "low-permeability layers" (see section III above), changes from west to east. The "layers" are less numerous, deeper, and thinner in the eastern half of the site.

Spreading basins proposed on the western half of the site, west of Amargosa Creek should be shallow, no more than 5 to 8 feet deep, because of the presence of a near-surface "low-permeability layer". This first "layer" occurs about 20 feet below the surface and is approximately 2 feet thick (see Plates 2 through 5). If the excavation for the basin reaches this layer, it should be penetrated to avoid perching and lateral migration of water. No additional "low-permeability layers" occur to a depth of 40 feet.

If the proposed basins are located on the eastern half of the site, east of Amargosa Creek, the recommended invert depth has fewer restrictions, because the first "low-permeability layer" occurs at about 40 feet below the surface.

It is recommended that a large-scale percolation test be conducted prior to construction of the spreading basins. The test plot should be approximately 50' x 50' in area and 5 feet deep.

The recharged water will probably take a long time to reach the water table. A rough calculation for "travel time" based on permeabilities, discloses the following: a) for a hydraulic conductivity of 10^{-5} cm/sec, the water will require approximately 50 years to reach the groundwater table; b) for a hydraulic conductivity of 10^{-4} cm/sec the water will reach the groundwater table in about 5 years. These numbers are based on the values obtained from percolation tests at the site, and also on published studies of percolation rates.

We understand that the short-term recovery of the recharged water is an important consideration for this project. It is evident from the "travel times" that short term recovery is not likely.

b) Proposed Injection Wells

Injection into the saturated zone at a depth of 460 to 600 feet appears feasible from a geologic point of view. The acceptance rate of injected water into the saturated zone is approximately 70% of the pumping extraction rate.

Injection into the saturated zone offers several advantages over spreading basin recharge. There is no time lag between injection and recharge of the groundwater table. In addition, deep injection into the saturated zone avoids potential geologic hazards such as hydroconsolidation and liquefaction of shallow alluvial sediments. The disadvantages of injection include lower overall volume of recharge and the higher capital and maintenance cost.

Deep injection into the saturated zone may be less desirable owing to water quality considerations. We understand that the removal of certain contaminants in the recharged water may require the water to percolate through a certain thickness of unsaturated sediment. Injection into the unsaturated zone at selected depths may allow the recharged water to percolate through the required thickness of sediments and thus remove the aforementioned contaminants. However, the rate of acceptance of recharge water would probably be lower than for injection into the saturated zone.

In addition, maintenance of injection wells in the unsaturated zone is costly and problematic. The effect of alternating wet and dry conditions associated with periodic injection may accelerate bacterial and algal growth, and promote scale buildup on the well screens.

VII - FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

a) Findings

1. The site is part of the Lancaster Subbasin of the Antelope Valley, with an upper unconfined aquifer and a lower confined aquifer, separated by a Blue Clay low permeability "separator".

2. The unconfined aquifer at the site is about 600 feet thick, with a saturated thickness of about 150 feet. This aquifer is underlain by the 200-foot thick upper zone of the Blue Clay. The lower zone of the Blue Clay, which was not encountered to the depth explored, is located at a depth of about 800 feet.

3. Sediments at the site in the unconfined aquifer consist of interbedded silty sand and silt, with thin layers of clay. The sediments are extremely well graded and range from clays to gravels.

4. "Low-permeability layers" were encountered in the shallow subsurface (to a depth of 70 feet). These layers dip gently ($<1°$) to the northeast, are generally 2 to 10 feet thick, and are not laterally continuous.

5. The "low-permeability layers" are expected to exist below 70 feet to the base of the unconfined aquifer.

6. Within the upper 70 feet, the "low-permeability layers" are fewer, thinner, and deeper on the east side of the site, as compared with those on the west side of the site.

7. The sediments in the shallow subsurface (to 70 feet deep) are loosely consolidated and have unsaturated hydraulic conductivities that average 10^{-3} to 10^{-4} cm/sec. The hydraulic conductivity of the "low-permeability layers" is on the order of 10^{-5} cm/sec. These values represent hydraulic conductivities measured in a horizontal direction.

8. The unsaturated hydraulic conductivity of the deep unsaturated portion (below 70 feet) of the upper aquifer, to the water table ($\pm$450 feet) is on the order of 10^{-4} to 10^{-5} cm/sec. These values represent hydraulic conductivities measured in a horizontal direction.

9. Recharge in spreading basins may be limited by the "low-permeability" silt layers which may cause locally perched-saturated conditions.

10. The depth to the groundwater table at the site is on the order of 444 to 464 feet (elevation about 2142 feet).

11. The groundwater table at the site dips gently to the north-northwest at a gradient of approximately 4 to 5 feet/mile.

12. A pumping test performed in nearby privately owned wells resulted in preliminary estimated transmissivity values for the unconfined aquifer ranging from 37,000 to 55,000 gals/day/ft.

13. Calculations based on transmissivity indicate that the hydraulic conductivity of the saturated unconfined aquifer is in the order of 10^{-2} to 10^{-3} cm/sec.

14. There is apparent hydraulic continuity between the groundwater at the site and groundwater in the Lancaster area.

15. The estimated length of time needed for surface or spreading basin recharge to reach the groundwater table is on the order of 5 to 50 years.

16. The soils at the site are subject to hydroconsolidation to a depth of at least 45 feet.

17. An earthquake of Richter magnitude 8.0 or greater can be expected during the design life of the recharge installation, with a peak horizontal acceleration of 0.7 g.

18. The unconsolidated soils at the site, to a depth of about 45 feet, may be subject to liquefaction during a major seismic event, if they become saturated by water recharge.

b) <u>Conclusions</u>

1. Recharge through shallow spreading basins is feasible, with the most favorable location being the east side of the site. Recharge water from spreading basins will take from 5 to 50 years to reach the water table, i.e. before it can be recovered by pumping.

2. Recharge through deep injection below the water table (about 450 feet below ground surface) appears to be feasible, with a recommended maximum injection depth of 600 feet.

c) Recommendations

1. If spreading basins are selected as a means of recharging the groundwater basin, they should: a) be located in the east portion of the site, where the greatest potential for total recharge occurs; and b) be excavated and flooded under controlled conditions in order to induce hydroconsolidation of the subsurface soils prior to development of the site area.

2. A large-scale percolation test should be conducted to further evaluate percolation rates of near-surface sediments. The test plot should be about 50' x 50' in area and a minimum of 5 feet deep.

3. If injection wells are selected for recharging the aquifer, a pilot well and observation wells should be drilled at the site and a minimum 72-hour pumping test should be performed.

4. From a geologic perspective, any location within the site is acceptable for the proposed injection wells.

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LL/KL:sh
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PWS-0190-0032

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APPENDIX A

LOG OF SHALLOW BORINGS

BORING NO. B-1
SHEET 1 OF 2

LOS ANGELES COUNTY ENGINEERING GEOLOGY GROUP
GEOLOGY BORING LOG

Job Description U.S. Air Force - Amargosa Site Date 5-21-90
Job No. Y504940A Logged by K.C.L., L.L. Client Hydraulic/Water Conservation
Elevation 2593 feet Boring Location 800' S/O Ave N, 580' E/O 10th Street West
Drilled by O & M, Bud Mattis Rig Calweld 18" bucket auger Sampling Equip. Bulk/Ring

REMARKS	SAMPLES: BULK	SAMPLES: RING	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
Started drilling @ 11:00 am on 5/21/90			0		Silty Sand, with some coarse sand to gravel sized material, light brown, dry, 40% silt, 55% sand, 5% gravel. Lithology of gravel fraction - quartz, granitics and schists.
		X	5		Becoming coarser @ 5', gravel with max. diameter of ½ to 2", angular, granitics - weathered biotite grains, cobbles, quartzite 2" to 3" max. diameter, angular to subangular.
			10		Silty Sand, light brown, dry, 25% silt, 60% fine to coarse sand, 10-15% gravel, poorly sorted, max. cobble size 2" diameter.
					Grading to a gravely sand, light brown, dry.
			15		
	X		20		Sandy Silt, orange brown, dry, 60% silt, 40% sand, unstable mineral and rock fragments altered to a white clay.
			25		Silty Sand, light brown, dry, some gravel in sample, 15% silt, 80% sand, 5% gravel. @ 25' increase in % gravel in sample. @ 26' silty sand, 30% silt, 70 % sand.
			30		

12:GBORE

LOGGED BY K.C.L., L.L.

DATE 5/21/90

REMARKS	SAMPLES: BULK	SAMPLES: RING	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
			30–36		Silty Sand, light brown, dry, 30% silt, 70% sand, sand fraction ranges from fine to coarse grained, some granules and gravel in sample. @ 34' increase in % gravel in sample, gravel 1 to 2" max. diameter, lithology of gravel, quartz (vein), schists, and granitics.
			36–44		Sandy Silt, orange brown, dry, unstable minerals and rock fragments altered to a white clay material, 60% silt, 40% sand, poorly sorted, angular grains. @ 41' becoming finer (more silty) and more moist with depth.
			44–69		Silty Sand, orange brown, fine to coarse grained sand, angular, slightly moist, 30% silt, 70% sand. Color of sample alternating between orange brown and light brown. @ 54' increase in granule fraction to 10% of sample. @ 57' silty sand, orange brown color, slightly moist. Silty Sand, orange brown, slightly moist, 40% silt, 60% sand, minor granules. Sand content in sample increasing to 70 to 80%.
			69–70		Total depth 69', no groundwater encountered.

12:GBORE1

LOG OF SHALLOW BORINGS

BORING NO. B-2
SHEET 1 OF 2

LOS ANGELES COUNTY ENGINEERING GEOLOGY GROUP
GEOLOGY BORING LOG

Job Description U.S. Air Force - Amargosa Site Date 5/23/90
Job No. Y504940A Logged by K.C.L., L.L. Client Hydraulic/Water Conservation
Elevation 2602 feet Boring Location 1670' S/O Ave N, 630' E/O 10th Street West
Drilled by O & M, Bud Mattis Rig Calweld 18" bucket auger Sampling Equip. Bulk/Ring

REMARKS	SAMPLES: BULK	SAMPLES: RING	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
Started drilling @ 11:15 am on 5/23/90 Hard drilling			0–5		Silty Sand, orange brown, dry, sand ranges from fine to coarse grained, angular, some granules and gravel in sample, silt 30%, sand 70%, granules and gravel < 5%.
			5–15		Becoming coarser @ 5'. Lithology of gravel fraction, predominently schists and granitics. @ 8', percent gravel in sample increasing to 10%, some cobbles up to 3" in diameter, angular to subangular.
			15–20		Silty Sand, orange brown, dry, sand ranges from fine to coarse grained, some granules, silt 20%, sand 75%, granules 5%. @ 17' sample color is light brown.
			20–23		Sandy Silt, orange brown, dry, silt 60-70%, sand 30-40%, minor granules and gravel.
			23–30		Silty Sand, light brown, dry, sand ranging from fine to coarse, minor granules and gravel, silt 10-20%, sand 80%, granules and gravel 5%. @ 26', gravel % in sample increasing to 10-15%, some cobbles, angular, to 2" in max. diameter.

12:GBORE

BORING NO. B-2
SHEET 2 OF 2

LOGGED BY K.C.L., L.L.

DATE 5/23/90

REMARKS	SAMPLES: BULK	SAMPLES: RING	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
			30		Silty Sand, light brown, dry, sand ranging from fine to coarse grained, some granules and gravel, silty 10-20%, sand 70-80%, granules and gravel to 10%.
			35		
	X	X			Sandy Silt, orange brown, dry, silt 60-70%, sand 30-40%, unstable mineral grains and rock fragments altered to a white clay material.
			40		
					Becoming more sandy at depth.
			45		
Sand running from bucket					Silty Sand, light brown, slightly moist, sand fine to coarse grained, silt 20%, sand 70-75%, scattered gravel (less than 3%), loose.
			50		
					Becoming coarser grained with depth.
			55		
	X	X			Percent gravel in sample increasing to 10%, cobbles, angular, up to 2" to 2½" in max. diameter.
					Sample color change - becoming more orange brown.
			60		Lithology of gravels, predominantly schists with some quartz (vein), quartzite, granitics and anorthosite?
					Silty Sand, orange brown to light brown, slightly moist, sand fine to coarse grained, silt 20%, sand 70%, scattered gravels to 5 to 10%.
			65		
Drilling completed @ 5:15 pm			70		

12:GBORE1

Total depth 70', no groundwater encountered

LOG OF SHALLOW BORINGS

BORING NO. B-3
SHEET 1 OF 2

LOS ANGELES COUNTY ENGINEERING GEOLOGY GROUP
GEOLOGY BORING LOG

Job Description U.S. Air Force - Amargosa Site Date 5/24/90
Job No. Y504940A Logged by K.C.L., L.L. Client Hydraulic/Water Conservation
Elevation 2585 feet Boring Location 720' S/O Ave N, 2990' E/O 10th Street West
Drilled by O & M, Bud Mattis Rig Calweld 18" bucket auger Sampling Equip. Bulk/Ring

REMARKS	SAMPLES (BULK / RING)	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
Started drilling @ 9:00 am on 5/24/90.		0		Silt, minor sand, light brown, very dry, no coarse material, wind blown material.
				Silty Sand, light brown, dry, most sand in the fine to medium size class, minor granules and gravel, silt 20-30%, sand 60-70%, granules and gravel< 5%.
Running sand from bucket.		5		
Hole caving badly @ 6-10'.				Sand becoming coarser with depth and less silty.
	Bulk, Ring	10		Silty Sand, light brown, dry, silt 20-30%, sand 60-70%, minor granules and gravel.
Much caving. Contamination from higher sand rich zones.		15		@ 18' granules and gravel fraction increasing to 5-10% gravel up to 3" in diameter, angular, lithology of gravel-schists, granitics and vein quartz.
		20		@ 23' sample grading to fine to coarse sand with minor silt, light brown, dry.
	Bulk	25		Sandy Silt, orange brown, dry, silt 60%, sand 30%, granules and gravel 5-10%, becomes more sandy @ 26.5'.
		30		Silty Sand, orange brown, dry, minor gravel, silt 20-30%, sand 60-70%, gravel 10%.

12:GBORE

PWS-0190-0039

BORING NO. B-3
SHEET 2 OF 2

LOGGED BY K.C.L., L.L.

DATE 5/24/90

REMARKS	SAMPLES: BULK	SAMPLES: RING	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
Material sticks in bucket.			30		Silty Sand, orange brown, dry, becomes coarser and less silty with depth.
					Silty Sand, orange brown to light brown, slightly moist, 20-30% silt, 60-70% sand.
			35		Silty Sand, orange brown, slightly moist, 35% silt, 40-60% sand, 5-10% granules and gravel, unstable mineral grains and rock fragments altered to clay material. Dense to very dense.
			40		
			45		Silty Sand, orange brown, slightly moist, lower % of silt than in 35-42' zone.
					Silty Sand, orange brown, slightly moist, silt 40-50%, sand 50-60%.
					Sandy Silt, orange brown, slightly moist, silt 60-70%, sand 30-40%.
			50		Gradational change to a silty sand, reddish brown, predominantly fine to coarse sand with silt, some pea gravel, silt 20-30%, sand 70-80%, gravel 5%.
			55		@ 54' scattered gravel in silty sand sample, gravel up to 2" in max. diameter, 2-3% of sample. Silty Sand Color change to yellowish brown.
			60		@ 60' silty sand, reddish brown, thin layer. @ 62' silty sand, coarse sand with gravel up to ½" in diameter, 3% of sample.
			65		Silty Sand, reddish brown, silt 10-15%, sand predominantly medium to coarse grained. Thin layer 6".
			70		

12:GBORE1

Total depth 70', no groundwater encountered, caving.

LOG OF SHALLOW BORINGS

BORING NO. B-4
SHEET 1 OF 2

LOS ANGELES COUNTY ENGINEERING GEOLOGY GROUP
GEOLOGY BORING LOG

Job Description U.S. Air Force - Amargosa Site   Date 5/29/90
Job No. Y504940A   Logged by L.L., S.L.   Client Hydraulic/Water Conservation
Elevation 2605 feet   Boring Location 2040' S/O Ave N, 1390'E/O 10th Street West
Drilled by O & M, Bud Mattis   Rig Calweld 18" bucket   Sampling Equip. Bulk/Ring

REMARKS	SAMPLES BULK	SAMPLES RING	DEPTH (feet)	LITHOLOGIC DESCRIPTION
			0	Sandy Silt, moderate yellow brown, scattered gravel to ½" diameter, loose.
			5	Silty Sand, moderate yellow brown, silt 40%, sand 60% fine to coarse grained, loose, slightly moist.
				Silty Sand, dark yellowish brown, silt 20-30%, sand fine to coarse, 3% gravel up to 2" diameter, angular to subangular.
			10	Gravelly Sand, moderate yellow brown, gravel 20%, sand fine to medium 65-70%, silt 10-15%, loose.
				Silty Sand, moderate yellow brown, sand medium to coarse 80-90%, silt 10-20%.
			15	
				Scattered gravel up to 1" max. diameter, 2-3%, loose.
			20	Silty Sand, moderate yellow brown, medium dense.
				@ 23' thin layer of silt, 3 to 4" thick.
			25	Silty Sand, same as above.
				Sandy Silt, moderate yellow brown, 50% silt, sand fine to coarse, med. dense.
			30	Silty Sand, same as above.

12:GBORE

PWS-0190-0041

BORING NO. B-4
SHEET 2 OF 2

LOGGED BY L.L.,S.L..

DATE 5/29/90

REMARKS	SAMPLES: BULK	SAMPLES: RING	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
			30		Silty Sand, same as above.
					Sandy Silt
			35		Silty Clayey Sand, abundant white altered feldspar grains, marker bed? Medium dense to dense, semi-indurated, medium to coarse grained.
			40		Silty Sand, moderate yellow brown, medium to coarse grained.
			45		Sandy Silt, yellowish brown, 50% silt, increase in silt content with depth to almost 100% silt, interbeds of silty sand.
					@ 46', gradational change to silty sand from 50% -50% to 60% sand, 40% silt.
			50		Silty Sand, moderate yellow brown, sand fine to coarse 80%, silt 20%, loose, slightly moist.
			55		Gravelly Sand, moderate yellow brown, sand fine to coarse, gravel up to ½" diameter, 5% of sample, loose.
					Silty Sand, scattered gravel 5-10%, fine to granules, gravel up to 1" in diameter.
			60		Silty Sand, moderate yellow brown, sand fine to coarse, silt 15%, loose.
			65		Silty Sand, moderate brown, same as above.
			70		Total depth 70', no groundwater encountered.

12:GBORE1

LOG OF SHALLLOW BORINGS

BORING NO. B-5
SHEET 1 OF 2

LOS ANGELES COUNTY ENGINEERING GEOLOGY GROUP
GEOLOGY BORING LOG

Job Description: U.S. Air Force - Amargosa Site Date: 5/30/90
Job No.: Y504940A Logged by: S.L., L.L. Client: Waterworks L.A.C.D.P.W.
Elevation: 2587 feet Boring Location: 670' S/O Ave N, 2020' E/O 10th Street West
Drilled by: o & M, Bud Mattis Rig: Calweld 18" bucket Sampling Equip.: Bulk/Ring

REMARKS	SAMPLES BULK	SAMPLES RING	DEPTH (feet)	LITHOLOGIC DESCRIPTION
Started drilling @ 8:00 am on 5/30/90			0	Sandy Silt, moderate yellow brown, soft, sand 15%.
				Silty Sand, moderate yellow brown, sand fine to medium grained, silt 15-20%, medium dense.
			5	Silty Sand, moderate yellow brown, sand fine to coarse grained, granules 3% subangular to angular grains.
			10	Silty Sand, moderate yellow brown, fine to coarse grained, more fines than @ 5', silt 20%, poorly sorted.
	X	X		Silty Sand, moderate yellow brown, fine to medium, silt 10%, poorly sorted. @ 10.5' sand, moderate yellow brown, fine to medium, moderate sorted, silt 10-15%.
			15	Silty Sand, moderate yellow brown, sand fine to coarse, poorly sorted, granules and pebbles 5%, silt 15%, loose.
			20	Silty Sand, moderate yellow brown, sand fine to medium, moderate sorted, 10-15% silt.
			25	Sandy Silt, moderate-dark yellow brown, grains very fine to fine, moderately well sorted, silt 60-70%, more plastic, medium dense, moist. Becoming less silty 50% with depth.
				Sand, moderate yellow brown, fine to coarse, poorly sorted, granules 3%, silt 10%.
			30	Silty Sand, dark yellow brown, fine to medium grained, moderate sorted 3% granules, 25% silt, moist.

12:GBORE

PWS-0190-0043

LOGGED BY S.L., L.L.

DATE 5/30/90

REMARKS	SAMPLES: BULK	SAMPLES: RING	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
			30		Silty Sand, same as above.
					Sand, dark yellow brown, fine to med. gravel, 10% silt, mod. sorted, moist.
			35		Sand, mod. yellow brown, fine to coarse grained, 10% silt, poorly sorted.
					Same
					Sand, slightly finer than @ 35'.
					Silty Sand, dark yellow brown, very fine to fine grained, silt 30%, moist, well sorted. Becoming more silty with depth.
			40		Sandy Silt, dark yellow brown, silt 50%, very fine to fine grained, moist.
					@ 39.5' clay rich zone 6" thick.
					@ 40' Clayey sand, light brown, moist, weathered feldspar grains.
					@ 41' Clayey silt, mod. yellow brown, moist, hard, 10-20% sand.
			45		@ 43' Clayey silt, decreasing clay content, stiff to hard.
					Silty Sand, mod. yellow brown, silt 30%, mod. well sorted, subangular to angular.
					Same as above, fine to coarse grained, poorly sorted, coarsening downward, slightly moist, < 3% granules.
Sand flowing from bucket.			50		@ 48' Silty Sand, very fine to coarse grained, poorly sorted, silt 25%.
					@ 50', same, very loose, 20% silt.
					Sand, fine to coarse grained, 5-10% silt, poorly sorted, subangular to angular, 3% granules and small pebbles.
			55		Silty Sand, mod. yellow brown, fine to very coarse grained, poorly sorted, 5% pebbles - mostly 1", silt 20%.
					@ 56' grading to sand, less silty.
					@ 57' Silty sand, dark yellow brown, fine to very coarse grained, abundant white feldspar grains, silt 20-30%, minor pebbles.
			60		Same
					Sand, mod. yellow brown, fine to medium grained, mod. sorted, few white grains, silt 10%, angular to subangular.
					@ 62' same, fine to coarse grained, poorly sorted.
					@ 63' same, 5% pebbles (< 1") and granules.
			65		@ 66' same.
					@ 64' same, fine to medium grained, silt 15-20%.
			70		Total depth 70', no groundwater encountered.

12:GBORE1

LOG OF SHALLOW BORINGS

BORING NO. B-6
SHEET 1 OF 2

LOS ANGELES COUNTY ENGINEERING GEOLOGY GROUP
GEOLOGY BORING LOG

Job Description U.S. Air Force - Amargosa Site Date 6/4/90
Job No. Y504940A Logged by K.C.L. Client Waterworks L.A.C.D.P.W.
Elevation 2588 feet Boring Location 1580' S/O Ave N, 4200' E/O 10th Street West
Drilled by O & M, Bud Mattis Rig Calweld 18" bucket Sampling Equip. Bulk/Ring

REMARKS	SAMPLES: BULK	SAMPLES: RING	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
Started drilling @ 9:45 am on 6/4/90. 0-5 ft. sand running from bucket. Caving badly @ 2-6'.			0		Silty Sand, moderate yellow brown, dry, mainly fine to medium grained. Becoming more silty at 3'.
			5		Silty Sand, silt 15%, sand 80%, minor granules and gravel, gravel - angular, dominated by quartz and schists.
Caving 9-13'. Sand running from bucket.			10		Silty Sand, same as above, silt 15-20%, sand 70-80%, minor granules and gravel.
			15		
Sand running from bucket @ 18' 11:00 am Breakdown Begin again at 11:35 am @ 22' sand staying in bucket.			20		Becoming more silty, finer grained sand. Silty Sand, moderate yellow brown, slightly moist, silt 15%, sand 80%, granules to gravel 5 to 10%.
Sand running in bucket.			25		
		■	30		Granules/gravel % increasing in sample to 20%.

12:GBORE

LOGGED BY K.C.L.

DATE 6/4/90

REMARKS	SAMPLES (BULK / RING)	DEPTH (feet)	LITHOLOGIC DESCRIPTION
Sand staying in bucket.	Ring at 30	30	Silty Sand, moderate yellow brown, slightly moist sand 70-80%, silt 15-20%, granules and gravel 10-15%.
	Bulk at 35	35	Silty Sand With Minor Clay, light brown, slightly moist, well sorted, unstable mineral grains and rock fragments altered to a white clay, silt 40%, sand 50-60% minor granules and gravel. Increasing clay content in sample with depth, slightly moist to moist.
Having to dig sample out of bucket.		40	
Sand running in bucket.		45	Silty Sand, moderate yellow brown, slightly moist, sand 70%, silt 15-20%, minor granules and gravel.
		50	
		55	Silty Sand With Minor Clay, light brown, moist to slightly moist, well sorted, silt 40%, sand (fine) 50-60%.
Sand running in bucket.			Silty Sand, light brown, moist to slightly moist, sand 60%, silt 30-35%, minor granules and gravel.
		60	@ 60' minor silt/sand lense.
			Sample changing to moderate yellow brown color.
		65	
Finished drilling @ 2:40 pm on 6/4/90.	Ring at ~67		Same as above.
		70	Total Depth 70', no groundwater encountered.

12:GBORE1

LOG OF SHALLOW BORINGS

BORING NO. B-7
SHEET 1 OF 2

LOS ANGELES COUNTY ENGINEERING GEOLOGY GROUP
GEOLOGY BORING LOG

Job Description: U.S. Air Force - Amargosa Site | Date: 6/5/90
Job No.: Y504940A | Logged by: S.L. | Client: Waterworks, L.A.C.D.P.W.
Elevation: 2580 feet | Boring Location: 640' S/O Ave N, 4300' E/O 10th Street West
Drilled by: O & M, Bud Mattis | Rig: Calweld 18" bucket | Sampling Equip.: Bulk/Ring

REMARKS	SAMPLES: BULK	SAMPLES: RING	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
Started drilling @ 8:27 am on 6/5/90.			0		Silty Sand
Sand running from bucket.			5		Silty Sand, moderate yellow brown, sand fine to medium grained, silt 20%, poorly sorted, grains angular to subangular. Same, 5 % angular granules.
Sand running from bucket.			10		Silty Sand, dark yellow brown, sand fine to medium, silt 25%, granules 5%, poorly sorted, granules angular to subangular. @11' same with more pebbles, subangular ½ to 2" in diameter, 5%. @12' Gravelly sand, mod. yellow brown, sand fine to coarse, silt 25%, granules 5%, pebbles 5-10%, poorly sorted. @13' becoming siltier, less gravelly, 3% pebbles.
			15		Gravelly Sand, fine to coarse sand, silt 15%, pebbles 10%, schists granitics. @18' same, pebbles increasing to 15-20% of sample, pebbles angular to subangular to ¼" in diameter.
			20		@20' Silty sand, sand very fine to medium, mod. sorted, few granules. Silty Sand, moderate yellow brown, sand fine to coarse, granules 3%, poorly sorted.
			25		Silty Sand, moderate yellow brown, getting finer grained with depth, silty 25-30%, slightly moist. Silty Sand, getting less silty, sand fine to medium, granules 5%, few pebbles, poorly sorted.
			30		

12:GBORE

BORING NO. B-7
SHEET 2 OF 2

LOGGED BY S.L.

DATE 6/5/90

REMARKS	SAMPLES BULK	SAMPLES RING	DEPTH (feet)	LITHOLOGIC DESCRIPTION
			30	Silty Sand, sand fine to coarse, silt 15%, granules 5% poorly sorted.
			35	Silty Sand, moderate yellow brown, sand fine to medium, silt 40%, moderately sorted.
				Gravelly Sand, gravel 10%, gravel ½ to 2" in diameter.
			40	Silty Sand, becoming siltier with depth, sand very fine to medium, silt 30-40%, moderately sorted.
				Silty Sand, same, silt 30-40%.
				Silty Sand, moderate yellow brown, sand 25% medium to coarse, silt 10%, moderately well sorted.
			45	Silty Sand, dark yellow brown, becoming coarser with depth, sand fine to coarse, silt 15-20%, gravel 5%, gravel ½ to 2" maximum diameter, pebbles of quartz, schists and granitics.
				Same, with 10% gravel ½ to 2" in diameter, angular to subangular.
			50	Clayey Sandy Silt, mod. yellow brown, stiff, mod. plastic, sand v. fine to coarse.
				Sandy Silt, cleaner, less plastic, sand v. fine to medium.
				Silty Sand, mod. yellow brown, sand v. fine to fine, silt 20%, well sorted, slightly moist.
			55	Same, silt 40%, mod. plastic, slightly more moist.
				Same, silt 25%, less plastic, less moist.
Sand flows from bucket.				Silty Sand, mod. yellow brown, sand fine to medium, silt 15-20%, mod. sorted.
			60	Same, sand fine to coarse, silt 15%, gravel 3%, angular, poorly sorted.
				Same, sand fine to medium, silt 20%, granules 3%, mod. sorted.
				Same
Finished drilling at 1:35 pm on 6/5/90.			65	Same, sand fine to coarse, silt 10-15%, poorly sorted.
				@68' Silty sand, sand very fine to fine, silt 20-30%, slightly plastic, slightly moist, mod. well sorted.
			70	@70' same. Total Depth 70', no groundwater encountered. CAVING

12:GBORE1

LOG OF SHALLOW BORINGS

BORING NO. B-8
SHEET 1 OF 2

LOS ANGELES COUNTY ENGINEERING GEOLOGY GROUP
GEOLOGY BORING LOG

Job Description U.S. Air Force - Amargosa Site Date 6/6/90
Job No. Y504940A Logged by L.L., S.L. Client Waterworks L.A.C.D.P.W.
Elevation 2594 feet Boring Location 850' S/O Ave N, 1400' E/O 10th Street West
Drilled by O & M, Bud Mattis Rig Calweld 18" bucket Sampling Equip. Bulk/Ring

REMARKS	SAMPLES: BULK / RING	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
		0		Sandy Silt, yellow brown.
				Silty Sand, yellow brown, sand fine to coarse, silt 20-30%, dry loose.
		5		Decrease in silt content to 15%, scattered gravel 3%, moderate yellow brown, damp.
				Sand, sand coarse, silt 10-15%, granules 3%, poorly sorted, damp, loose.
		10		
Sand flowing from bucket.				Gravelly Sand, yellow brown, gravel ½ to 2" in diameter, silt 10-15%, loose.
		15		Sandy Silt to Silty Sand, moderate yellow brown, sand fine to 40%, soft to firm.
				@16.5', Gravelly sand, sand coarse, granules 3%, poorly sorted.
		20		Increase in silt content to 20%.
				Sandy Silt, sand fine 50%, silt 50%, bedded with coarse silty sand.
Sand flowing from bucket.				@22.5' Silty sand, silt 10-15%, gravel fine 3-5%.
		25		Sandy Silt, sand 30%, silt 70%.
Sand flowing from bucket.		30		Silty Sand, moderate yellow brown, increasing sand content in sample with depth, silt 30-40%, gravel 3% up to 1" in diameter, loose.

!:GBORE

BORING NO. B-8
SHEET 2 OF 2

LOGGED BY L.L., S.L.

DATE 6/6/90

LITHOLOGIC DESCRIPTION

REMARKS	SAMPLES: BULK	SAMPLES: RING	DEPTH (feet)	GRAPHIC LOG	LITHOLOGIC DESCRIPTION
			30		Silty Sand/Sandy Silt, sand fine, gravel 3%.
Sand flowing from bucket.					Silty Sand, sand fine to coarse, silt 30%, loose, dry.
Major caving @ 30'.			35		Silty Sand, moderate yellow brown, sand fine to coarse, silt 20-30%, granules 5%, mod. to poorly sorted.
					Silty Sand, sand coarsing with depth, silt 10-20%, granules 3% angular.
			40		Silty Sand, sand fine, silt 40% well sorted.
					Silty Sand, mod. yellow brown, sand fine to medium, mod. sorted, 25% silt.
			45		Gravelly Silty Sand, sand fine to coarse, silt 15%, pebbles 10% ½ to 2" diameter, poorly sorted.
					Silty Sand, sand fine to coarse, silt 10-15%, gravel 5%, poorly sorted.
					Silty Sand, same.
			50		Silty Sand, similar to sample @49', silt 20-25%, granules 3%.
					Same
			55		@54.5 Sandy Silt, cohesive, plastic, stiff, slightly moist. @56' same, slightly less silty.
			60		Silty Sand, moderate brown to moderate yellow brown, sand fine to coarse, silt 15%, granules 5%, poorly sorted, white grains, weathered feldspar grains.
					Gravelly Silty Sand, gravel 10%, ½ to 2", cobbles few 4-8".
			65		Silty Sand, moderate yellow brown, sand fine to coarse, silt 10%, mod. to poorly sorted.
Finished drilling @ 5:20 pm on 6/6/90.					Silty Sand, light brown, sand fine grained, well sorted, slightly plastic. @68' grades to more clayey. @69' less clayey.
			70		Total Depth 70 feet, no groundwater encountered.

12:GBORE1