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VOLUME I — REPORT TEXT

HYDROGEOLOGIC ASSESSMENT
OF THE
SAUGUS FORMATION
in the
SANTA CLARA VALLEY
of
LOS ANGELES COUNTY, CALIFORNIA

FOR
CASTAIC LAKE WATER AGENCY
LOS ANGELES COUNTY WATERWORKS DISTRICT NO. 36 — VAL VERDE
NEWHALL COUNTY WATER DISTRICT
SANTA CLARITA WATER COMPANY
VALENCIA WATER COMPANY

FEBRUARY 1988

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February 10, 1988

Mr. Robert Sagehorn, General Manager
Castaic Lake Water Agency
23560 Lyons Avenue, Suite 225
Newhall, California 91321

Job S8701

Subject: Executive Summary
Hydrogeologic Assessment of the
Saugus Formation in the Santa Clara
Valley of Los Angeles County, California

Dear Mr. Sagehorn:

I am pleased to present this Final Volume I report of our hydrogeologic investigation of the Saugus Formation which underlies a large portion of the Santa Clara Valley area of Los Angeles County, California. This study was undertaken to evaluate the Saugus Formation, specifically: local groundwater levels and water quality; its groundwater storage capacity; the thickness of water-bearing strata; and the gross feasibility of further groundwater development from the formation.

Work on this project included collecting and reviewing pertinent data from numerous sources, conducting limited aquifer testing, providing detailed hydrogeologic analyses of available and field-generated data, and writing and preparing this report of investigation. Documenting this report are figures and tables, and a list of references reviewed. A separately bound Volume II of this report, provided in two sections, contains all plates.

Principal conclusions and recommendations include:

1. Alluvial deposits and the Saugus Formation comprise the water-bearing sediments of the Eastern Groundwater Basin of Los Angeles County.

2. The maximum thickness of water-bearing Saugus deposits that contain fresh water varies from 1500 ft northerly of the San Gabriel fault, to 5000 ft southerly of the Holser fault, to 5500 ft in the area between the two faults.

3. Cumulative thickness of potentially usable aquifer sands available to future water wells varies from 400 ft maximum combined thickness northerly of the San Gabriel fault, to 1200 ft maximum cumulative thickness southerly of the Holser fault, to 1400 ft maximum cumulative thickness between the two faults. For these determinations, we have included only the potentially usable sand/gravel aquifers between the depths of 500 ft and: either the base of the Saugus Formation; or the base of fresh water in the Saugus Formation; or a maximum depth of 2500 ft, whichever is shallower.

4. Aquifer transmissivity ranges from 80,000 to 160,000 gpd/ft and is representative of potentially good aquifers. Storativity is low, representative of a confined aquifer system.

5. Recent groundwater level data are available only for the area southerly of the Holser fault; these data show a groundwater flow direction to the northwest. Recent 1987 piezometric surface elevations are 50 to 100 ft above those for 1967, a generally low water level period. The degree to which the two local faults have created barriers to groundwater flow in the Saugus Formation is unknown.

6. Saugus Formation groundwater generally is either of calcium-bicarbonate or calcium-magnesium-sulfate character. Future wells should have acceptable water quality, particularly those located nearer the central portions of the basin.

7. Numerous active and abandoned oil fields exist in the study area. Most petroleum production is from rocks older and stratigraphically below the Saugus Formation. Several oil fields have hydrocarbons and/or high groundwater salinities in at least the lower portion of the Saugus Formation.

8. Usable groundwater in storage is calculated to be approximately 1.41 million ac-ft, representing the volume of groundwater stored only in the potentially usable Saugus aquifers in the 500-foot to 2500-foot depth zone for this study.

9. Principal recharge sources to the Saugus Formation are: direct precipitation on exposed Saugus Formation and terrace deposit materials; and direct infiltration from overlying saturated alluvium within the Santa Clara River channel.

Combined potential recharge from these two sources may range between approximately 20,000 to 22,000 ac-ft/yr in wet periods and 11,000 to 13,000 ac-ft/yr in dry periods. These determinations provide a preliminary estimate of the maxium amount of recharge to the Saugus, and should not be construed as a rigorous determination of the perennial yield of the Saugus Formation.

10. Historically, only 22 wells are known to have been drilled sufficiently deep to produce groundwater from the Saugus Formation. During the historic period of record from 1954 through 1986, local purveyors (NCWD, combined NLF and VWC, and SCWC) have produced a total of approximately 154,000 ac-ft of Saugus Formation groundwater, virtually all from the area south of the Holser fault. Average production for the 33 years of available data has been about 4660 ac-ft/yr.

11. Of the 22 known Saugus Formation wells, 8 were actively producing in 1986. Combined 1986 Saugus Formation production by the local purveyors was 5532 ac-ft. Saugus production by private owners (ranches, industries, etc.) is considered negligible (less than a total of 100 ac-ft/yr).

12. It is hydrogeologically feasible to develop additional groundwater supplies from Saugus Formation aquifers. Production from properly sited and constructed future Saugus wells is not expected to adversely impact the overlying alluvium.

13. General priority locations for new wells are provided, but a detailed evaluation should be conducted prior to drilling on a site-by-site basis. New wells should be spaced at least 1000 ft apart.

New wells in the region southerly of the San Gabriel fault are anticipated to have an operational yield on the order of 1500 to 2000 gpm. Anticipated well depths in this region are between 1500 and 2500 ft. Wells located to the north of this fault will be shallower and will have lower yields.

14. Construction costs for a contractor to drill, case, develop, and test pump one new well on the order of 1500 ft in depth will likely be on the order of $250,000 to $300,000. Additional costs will be for: pumping and chlorination

equipment; electrical equipment and transmission lines; property and/or rights-of-way; and for necessary hydrogeologic services during construction.

15. Groundwater management recommendations are provided in order to establish a more complete groundwater data base for the region.

It has been a pleasure to have worked on this investigation with your agency and the other involved purveyors. This opportunity to have been of service is appreciated.

Very truly yours,

Richard C Slade

Richard C. Slade
Registered Professional Hydrogeologist

TABLE OF CONTENTS

FIGURES

TABLES

PLATES

FIGURES

NOTE: The above Plates are separately bound in Volume II. Volume II consists of two separately bound sections.

INTRODUCTION

GENERAL STATEMENT

Presented in this Volume I report are the findings, conclusions and recommendations of our assessment of the hydrogeologic conditions and the groundwater in storage within the sediments of the Saugus Formation which underlie the environs of the Santa Clara Valley in Los Angeles County, California. As depicted on Figure 1 - Location Map, the 208 square mile, rectangular-shaped base map area includes the entire mapped area of surface exposures of the Saugus Formation. This area extends approximately 16 miles in an east-west direction between Mint Canyon on the east and the Los Angeles-Ventura County line on the west, and approximately 13 miles in a north-south direction between Castaic Dam on the north and San Fernando Pass-Fremont Pass on the south. Situated within this main study area are the communities of Castaic, Canyon Country, Newhall, Saugus, and Valencia.

This Volume I report has been provided with a list of references which have been specifically reviewed and/or cited during the course of this study. Volume II, separately bound, presents the plates which accompany this report.

PURPOSE AND SCOPE

This hydrogeologic study has been undertaken to assess the hydrogeologic conditions within the Saugus Formation which underlies the Santa Clara Valley. Specifically addressed in this report are: anassessment of groundwater levels and water quality within these Saugus Formation sediments; a determination of their groundwater storage capacity; identification of the thickness of potentially water-bearing strata within the

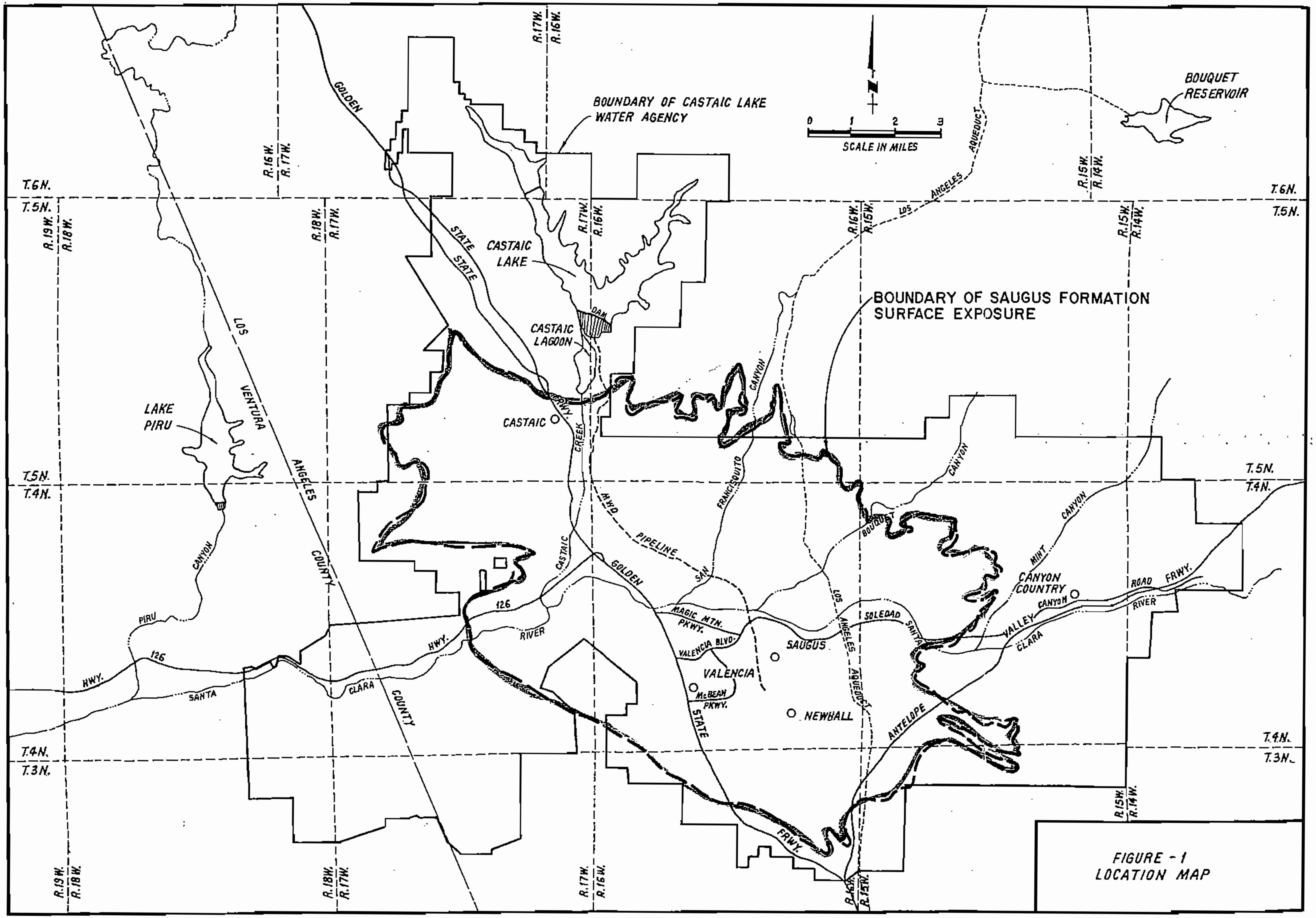


FIGURE - 1
LOCATION MAP

formation; and a determination of the gross feasibility of further groundwater development from these sediments.

This project has been conducted for: the Castaic Lake Water Agency, which has contracts with the State of California to purchase water from the State Water Project in order to wholesale it to the four retail purveyors in the area; and the four retail purveyors of domestic water, these being the Los Angeles County Waterworks District No. 36-Val Verde (LACWWD), the Newhall County Water District (NCWD); the Santa Clarita Water Company (SCWC); and the Valencia Water Company (VWC). The Newhall Land and Farming Company (NLF) is the largest agricultural user of groundwater in the region.

The scope of work for this study was outlined in nine separate tasks in our letter of proposal to Mr. Robert Sagehorn, General Manager, Castaic Lake Water Agency, dated January 26, 1987. This report represents the culmination of work on those nine tasks. A summary of the work tasks for the Saugus Formation study is as follows:

Task 1 - <u>Acquisition of Basic Data</u>
    A. Reports and Geologic Information
    B. Subsurface Data

Task 2 - <u>Preliminary Data Analysis</u>
    A. Surface Geology
    B. Subsurface Geology
    C. Existing Water Wells

Task 3 - <u>Field Reconnaissance and Well Testing</u>
    A. Field Reconnaissance
    B. Conduct Aquifer Tests
    C. Analyze Field Data
    D. Quantify Aquifer Characteristics

Task 4 - <u>Detailed Electric Log Analysis</u>
    A. Use oil well and water well E-logs
    B. Determine total footage of aquifer sands
    C. Provide contour maps of total aquifer thickness

D. Evaluate theoretical salinity from oil well electric logs

Task 5 - Detailed Hydrogeologic Analysis
- A. Evaluate specific capacity and aquifer transmissivity
- B. Identify groundwater flow directions and flow gradients
- C. Ascertain water quality and quality problems
- D. Evaluate relative tendency for corrosion or encrustation in wells
- E. Assess significance of faults on Saugus Formation aquifers

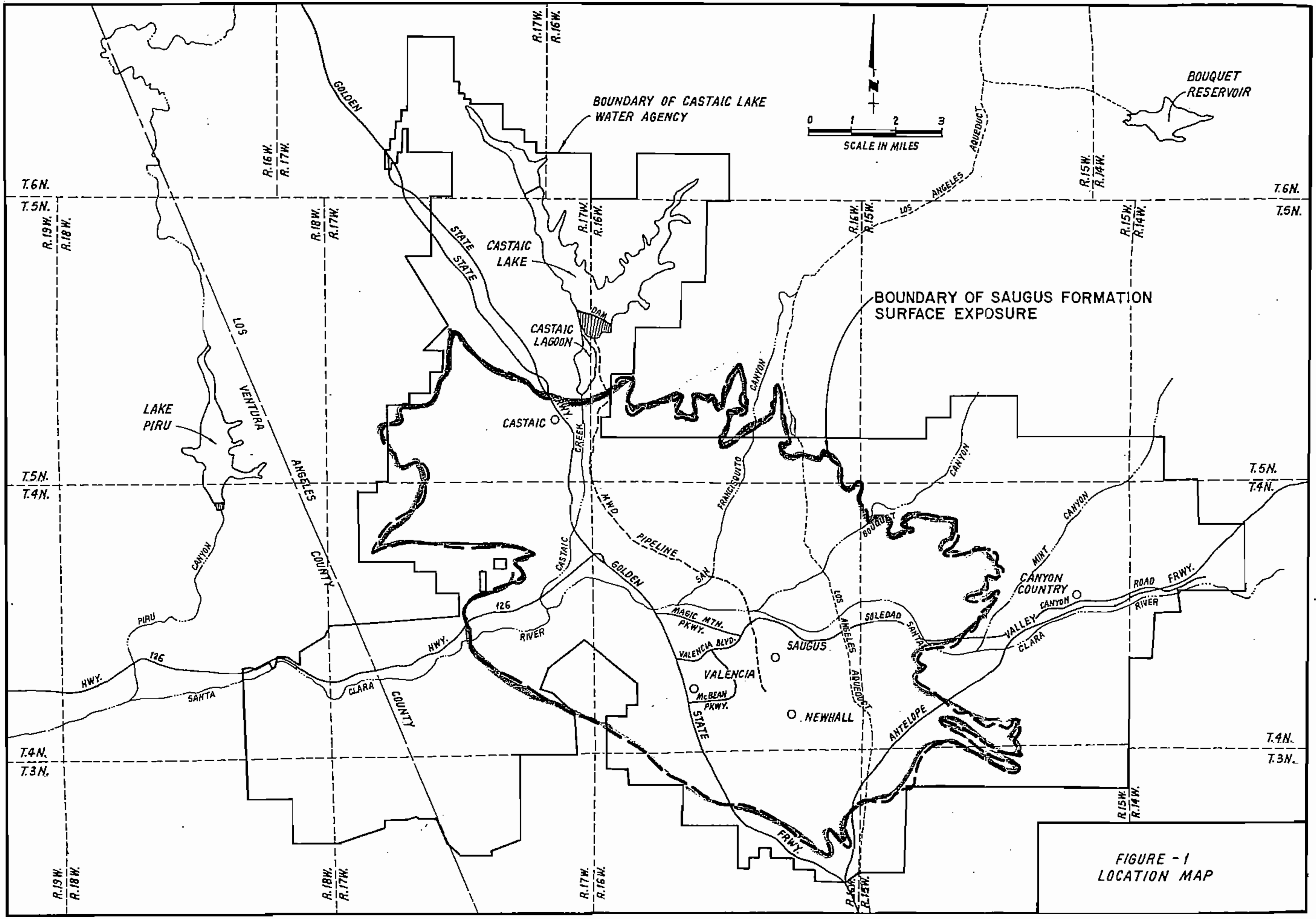
Task 6 - Assessment of Groundwater in Storage
- A. Assign specific yield values
- B. Provide estimates of total and usable groundwater in storage to 2500 feet in depth

Task 7 - Analyses and Reports
- A. Data Analyses
- B. Write and prepare report, with all graphics

Task 8 - Preliminary Well Site Selection
- A. Identify areas within the Saugus Formation for future test holes or wells
- B. Identify areas where wells are not feasible
- C. Provide preliminary design for wells
- D. Provide preliminary guidelines for construction methods

Task 9 - Meetings and Consultation
- A. Prepare for and attend meetings with the water purveyors

Analyses for this project relied on available background data, including reports and electric log data from wildcat oil wells and water wells, and data generated by field work conducted specifically for this project. No subsurface exploration or laboratory testing was conducted for this study. Reports specifically reviewed for this project are shown on the list of References Reviewed.



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    C. Provide contour maps of total aquifer thickness

Field work consisted of conducting 24-hour, constant discharge aquifer tests in five different Saugus Formation wells. Both water level drawdown and recovery data were collected in these wells. These tests were performed between March 4 and April 3, 1987, and provided the basis for our assessment of the aquifer characteristics of transmissivity and storativity.

Throughout the remainder of this report, there will be numerous discussions of water wells in the region. The four retail purveyors in the area utilize wells drilled into the shallow alluvial aquifers and/or the underlying Saugus Formation to meet all or part of their domestic water requirements. Of these purveyors, the Los Angeles County Waterworks District No. 36-Val Verde and the Newhall County Water District are public agencies, while the Santa Clarita Water Company and the Valencia Water Company are privately-owned water companies. The main agricultural user of groundwater, The Newhall Land and Farming Company, is privately owned also. All of these purveyors, with the exception of the Waterworks District, have had one or more wells which produced or still produces groundwater from the Saugus Formation. The Peter Pitchess Honor Rancho (previous known as Wayside Honor Rancho) is a separate entity within the Waterworks District which has relied, and continues to rely upon wells completed only into the shallow alluvial aquifer system of the Santa Clara Valley area. Additional details of the Saugus Formation wells owned by the water purveyors are presented later in this text.

In addition to the aforementioned Saugus Formation wells, there may still exist a few wells historically drilled and/or operated by private landowners, ranches, industries, and/or commercial developments in the region. A determination of the number, location, and current viability of these privately-owned Saugus Formation wells was not within the scope of work for this project. However, it is believed that the vast majority of pumpage from the Saugus Formation is by the retail purveyors and The Newhall Land and Farming Company. Any undocumented pumpage from the Saugus Formation is considered relatively insignificant (a combined total of 100 ac-ft/yr, or less).

Throughout this report and accompanying plates, the terms "wildcat oil wells" and "oil wells" are used interchangeably, for simplicity, with the more technically recognized term "exploration and development oil wells."

This report has been written for the Castaic Lake Water Agency and the four retail water purveyors and with specific application to the hydrogeologic assessment of the Saugus Formation aquifer system within the Santa Clara Valley. The report has been prepared in accordance with the care and skill generally exercised by reputable professionals, under similar circumstances, in this or similar localities. No other warranty, either expressed or implied, is made as to the professional advice presented herein.

AVAILABILITY OF BASIC DATA

Previous Studies. As noted in our recent hydrogeologic investigation of the local alluvial aquifer system (Slade, December 1986), the study area overlies numerous oil fields and there has been a long history of published and unpublished geologic reports and maps dealing with surface and subsurface geologic conditions in the hills and mountains surrounding the Santa Clara Valley. The earliest works date from the period 1902 to 1924 (importantly, Kew, 1924) and provided the initial efforts at naming and mapping the surface exposures of the stratigraphic units and structure in the region.

With the discovery of larger oil fields between the late-1930's and the late-1940's, there was a renewed interest in the geology and the potential for additional petroleum development. Mapping by such workers as Bailey (1954) and Crowell (1954) added considerable detail to the known stratigraphy and to major structures such as the San Gabriel fault. Other particularly significant geologic reports include those by Winterer and Durham for the U. S. Geological Survey (1962) and by Oakeshott (1958) for the California Division of Mines and Geology. Adaptation of the geologic maps provided in these latter reports has permitted the preparation of Plate 3 - Hydrogeologic Map - in this report.

Most importantly, the limits of geologic exposures of the Saugus Formation as utilized on all plates in this report have been updated with the most recently published geologic data available for the area (principally, Nelligan, 1978; Stitt, 1980; Weber, 1982; Saul and Wootton, 1983; Smith, 1984; and Treiman, in press).

Considerable information is available to document much of the history of the oil field development in the greater Santa Clara Valley. The preponderance of these reports have been published by the California Division of Oil and Gas. From its Ventura office, the Division of Oil and Gas maintains comprehensive files on the well histories and geophysical electric logs for the innumerable wildcat and producing oil wells in the region. Electric log data from the repository were updated by review and collection of additional electric log data from local wildcat oil wells from the files of The Newhall Land and Farming Company.

that the locations shown for NC-1 through NC-6 are only approximate due to a lack of data for these wells.

Water Level and Water Quality Data. Long-term accumulations of water level and water quality data are not available for all of the Saugus wells in the region. In general, these data date from the late-1950's or the early-1960's. Virtually no data exist for the oldest known Saugus wells, that is, Newhall County Water District Nos. 1 through 6.

In addition, data gaps of from several months to a few years in duration exist for many of the available records. Scrutiny of the water level data occasionally reveals measurements which are anomalously low and which are considered not to be directly related to climatological fluctuations. Such anomalies are considered to relate to either monitoring error, the reporting of pumping levels or partial recovery levels instead of true static (non-pumping levels), or the monitoring of a water level in a well affected by mutual drawdown interference from another, nearby well.

For our assessment of water level and water quality, we have plotted hydrographs and graphs of total dissolved solids versus time for five Saugus wells, and have prepared water level contour maps for Summer-Fall 1967 and for March 1987. These graphs are discussed later in this report.

Groundwater Extraction Data. Historic groundwater extraction data on an annual basis have been collected from the Newhall County Water District, the Valencia Water Company, the Santa Clarita Water Company, and The Newhall Land and Farming Company. These data have been tabulated for each purveyor and, in addition, have been totalled and graphed versus time to assess any possible connection with long-term water levels and/or water quality in the Saugus Formation with time.

CLIMATE

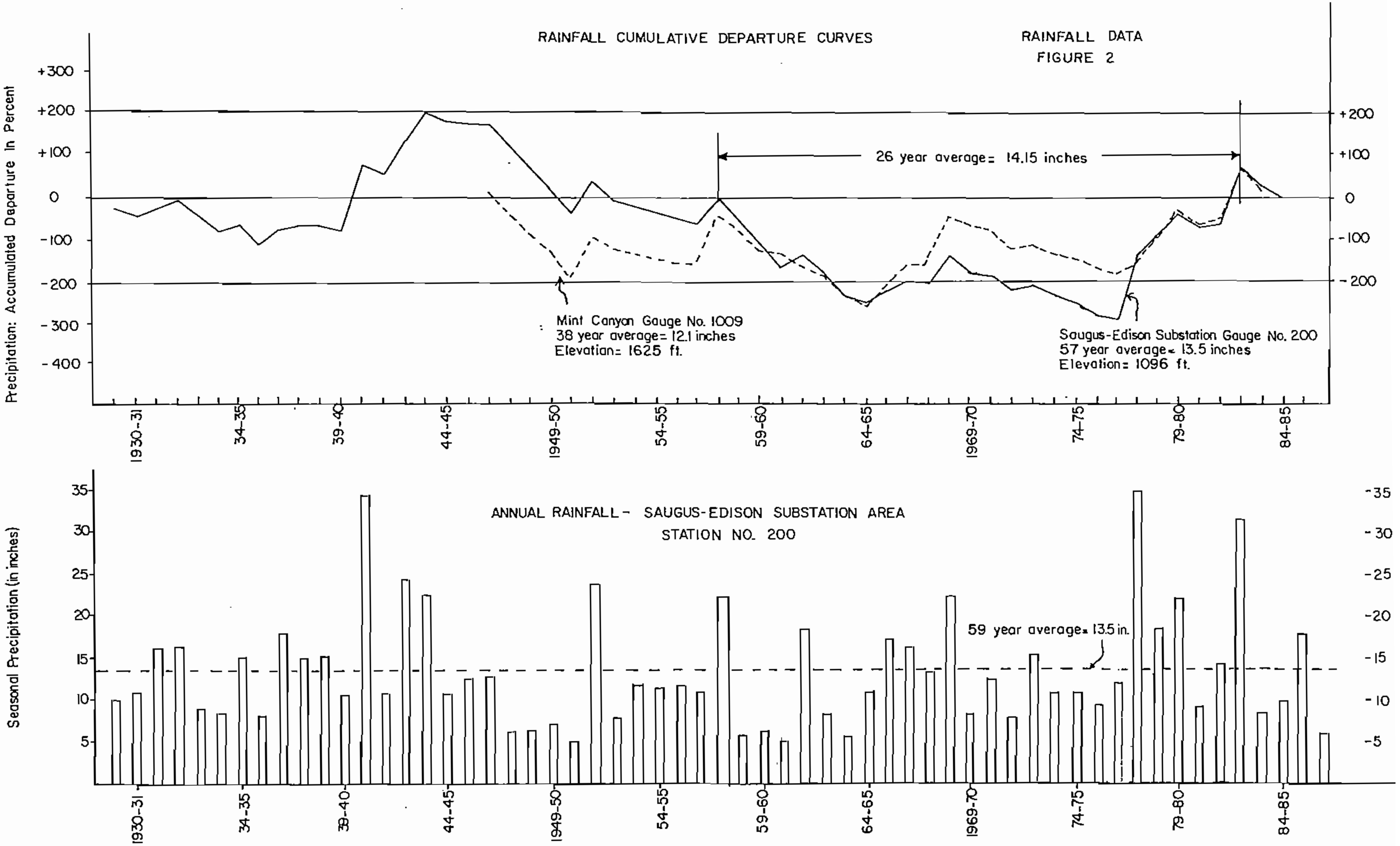
Characterizing the local climate is a semi-arid, Mediterranean-type climate that exhibits long, dry summers and relatively short, wet winters. Valley temperatures typically range from maximums of approximately 100°F in the summer to occasional minimums of approximately 30°F in the winter. Mean monthly temperatures range between approximately 77°F in the summer to 48°F in the winter.

Figure 2 - Rainfall Data - presents a graph of annual precipitation for Los Angeles County Flood Control District Station No. 200 (elevation 1065 ft, near Castaic Junction) for the period 1928-29 through 1986-87; and graphs of the cumulative departure from the mean precipitation for that gage and for Station No. 1009 near Mint Canyon (elevation 1645 ft). Station No. 200 lies near the center of the outcrop area of the Saugus Formation while Station No. 1009 is located near the eastern boundary of this outcrop area.

Average precipitation in the area for the entire Station No. 200 base period is 13.5 inches. Historic high and low rainfall at this gage have ranged between 34.77 inches in 1977-78 (34.43 inches was recorded in 1940-41) and 5.09 inches in 1960-61 (5.25 inches was recorded in 1950-51). Slightly lower averages and totals were recorded by Station No. 1009 during its base period which began in 1946-47. Approximately 80 percent of the average annual precipitation in the valley occurs between November and March. Most notable on Figure 2 is that annual precipitation does fluctuate widely from area to area and from year to year.

The slopes of the cumulative departure curves on Figure 2 also reveal pronounced periods of dry years followed by periods of wet years. No fixed cycle of precipitation is discernible on these graphs, however. For these departure

RAINFALL DATA
FIGURE 2


RAINFALL CUMULATIVE DEPARTURE CURVES

ANNUAL RAINFALL - SAUGUS-EDISON SUBSTATION AREA
STATION NO. 200

curves, a positive slope for the curves indicates above-normal rainfall, while a negative slope indicates below-normal precipitation, regardless of the position of the curve with respect to the ordinate representing the long-term mean (i.e., the zero percent cumulative departure).

For example, the period 1935-36 through 1943-44 on the cumulative departure curve for the Saugus-Edison gage is characterized by positive (upward to the right) slopes; this represents a hydrologically wet period which was characterized by an accumulation of years of average or above average precipitation.

In contrast, the period 1944-45 through 1964-65 on the curves for both rainfall stations displays a protracted, hydrologically dry period that was characterized by an accumulation of generally average or below average rainfall (a negative or downward-sloping curve). Since 1964-65, the curves for both rain gages reveal a generally upward trend up through 1983-84 and, hence, an overall period of excess precipitation.

The cumulative departure curves shown on Figure 2 were adapted directly from our previous report (Slade, December 1986) and are not updated. Any changes required to update these curves would be very slight and are not considered important to the present study. The histogram of annual rainfall at the Saugus-Edison Substation shown on Figure 2 has been updated to include data through the 1986-87 rainfall year.

DRAINAGE

Providing regional drainage across this portion of Los Angeles County, and continuing westerly across Ventura County to the Pacific Ocean, is the Santa Clara River. This river includes a watershed of several hundred square miles and has its headwaters in Soledad Canyon in north-central Los Angeles County.

Principal tributaries draining in a southerly direction to their confluence with the Santa Clara River include, from east to west: Mint Canyon, Bouquet Canyon, San Francisquito Canyon, and Castaic Creek Canyon. Principal tributaries which drain in a northerly direction toward their confluence with the Santa Clara River include, from east to west: Oak Spring Canyon, Sand Canyon, and Potrero Canyon.

The South Fork of the Santa Clara River, which drains in a northerly direction toward its confluence with the main course of the Santa Clara River (just west of Bouquet Junction), has as its main tributaries: Placerita Creek Canyon; Newhall Creek Canyon; and Pico Canyon.

Because the headwater areas of these drainages do not extend into high mountainous areas, and because the local climates preclude the buildup of large snowpacks in the watersheds, flow in all the stream canyons is considered to be ephemeral only and, thus, diminishes rapidly after most rainfall events. Springs, areas of rising water, and even outflows from local wastewater treatment facilities tend to maintain flows even in the summer months in several locations along the Santa Clara River.

LOCAL WATER PURVEYORS

The study area lies within lands served by the Castaic Lake Water Agency. Domestic water purveyors located within the Agency boundary include Los Angeles County Waterworks District No. 36, Newhall County Water District, Santa Clarita Water Company, and the Valencia Water Company. Also included in the present study is The Newhall Land and Farming Company which also owns and operates numerous wells in the region to supply water to meet their agricultural demands. Los Angeles County Waterworks District No. 36 and Newhall County Water District represent public agencies, while the Santa Clarita Water Company and the Valencia Water Company are privately owned.

Table 1 - Summary of Saugus Formation Water Wells - has been prepared to list all known Saugus Formation wells in the region that have been drilled for the above listed purveyors and The Newhall Land & Farming Company (NLF); the list includes one known, privately-owned and -drilled Saugus Formation well (Smiser well). As shown, there have been a total of 22 Saugus wells drilled historically in the study area, including: 12 by NCWD; 5 by NLF; 3 by VWC; one by SCWC; and one by a private owner. The locations of these wells are shown on Plate 1 - Well Location Map.

Notable on Plate 1 is that these 22 wells, with the exception of V-158, have all been drilled southerly of the surface traces of the two faults (San Gabriel and Holser faults) which traverse the study area. Well V-158 was drilled between the two faults. As a result, there are no actual hydrogeologic field test data available from any water wells for the Saugus Formation northerly of San Gabriel fault.

Of particular interest on Table 1 are the following:

a. Historically drilled Saugus wells have ranged in depth, where known, between approximately 370 ft and 2008 ft; most wells are in the general depth range of 1000 to 1500 ft.

b. Uppermost perforations for these wells begin at depths ranging between 29 ft and 950 ft.

c. Any well in the creek channels, as shown on Plate 1, in which perforations begin at a depth of approximately 200 ft or less, is considered to obtain groundwater from the alluvium as well as from the Saugus

TABLE 1 - SUMMARY OF SAUGUS FORMATION WATER WELLS

WELL OWNER	LOCAL NUMBER	STATE NUMBER (T/R-Section)	APPROX. SURFACE ELEV. ft)	TOTAL DEPTH (ft)	DEPTH INTERVAL OF PERFORATIONS (ft)	TYPE OF PERFORATIONS	YEAR AND METHOD OF DRILLING	DEPTH OF CONCRETE SANITARY SEAL (ft)	APPROX. DEPTH SETTING TO TOP OF PUMP BOWLS (ft)	STATUS IN 1986	1986 GROUNDWATER PRODUCTION (ac-ft)
NC	1	3N/16W-2R	1365	Unknown	Unknown	Knife Cut	1944 Cable Tool	Unknown	160	Destroyed	-
NC	2	-11C	1395	Unknown	Unknown	Knife Cut	1940 Cable Tool	Unknown	160	Destroyed	-
NC	3	-11J7	1450	504	230-500 Interspersed	Knife Cut	1930 Cable Tool	Unknown	Unknown	Destroyed	-
NC	4	-11C	1385	570	134-567 Interspersed	Knife Cut	1947 Cable Tool	Unknown	Unknown	Destroyed	-
NC	5	-2B or 4N/16W-35Q	1270	610	135-550. Interspersed	Knife Cut	1948 Cable Tool	Unknown	170	Destroyed	-
NC	6	3N/16W-2L ?	1370	370	120-230, 330-360	Knife Cut	1949 Cable Tool	Unknown	300	Destroyed	-
NC	7	4N/16W-35L1	1252	994	520-974 Interspersed	Knife Cut	1954 Cable Tool	No Cement	261	Active	275.9
NC	8	-35M2	1237	984	342-970 Interspersed	Knife Cut	1954 Cable Tool	No Cement	280	Active	225.3
NC	9	3N/16W-2R2	1352	675	280-591	Louvers	1957 Rotary	81	230	Active Standby Use	116.5
NC	10	4N/16W-34A3	1205	1555	780-1544	Louvers	1961 Rotary	98	320	Active	740.7
NC	11	-27J3	1195	1136	200-1075	Louvers	1973 Rev.Rotary	150	340	Active	2237.0
NC	12	-34A4	1210	1340	485-1280	Louvers	1985 Rev.Rotary	420	No Pump	Inactive	0
NLF	154	4N/16W-27H5	1187	1129	29-1003 Interspersed	Louvers	1960 Rotary	Unknown	270	Destroyed (1982-83)	-
NLF	155	-27R2	1190	1515	108-1468 Interspersed	Louvers	1960 Rotary	Unknown	240	Destroyed (1978-79)	-
NLF	156	4N/17W-13J1	1053	1805	320-1800 Interspersed	Vertical Slots	1961 Rotary	15	210	Active	20 (est.)
NLF	159	4N/16W-33L1	1290	1950	662-1900	Louvers	1962 Rotary	Unknown	500	Inactive	0
NLF	P-2	3N/16W-30	1245	1300	450-1290	*	1958	Unknown	500	Destroyed (1967)	-
V	157	4N/16W-22M1	1150	2008	586-2008	Vertical Slots	1962 Rotary	15	220	Active	779.9
V	158	-17J1	1098	1608	740-1605	Vertical Slots	1962 Rotary	15	-	Destroyed (1984-85)	-
V	160	-21Q1	1099	2000	950-2000	Louvers	1964 Rotary	65	200	Active	1137.4
SC	Lombardi (23)	3N/16W-4R2	1280	1150	260-1130	Unknown	Before 1966 Unknown	Unknown	-	Destroyed (1982)	-
RIVATE	SMISER	3N/16W-4	1300	1000	Unknown	Unknown	1978 Rotary	Unknown	Unknown	Active	Unknown (likely small)

NOTES:
NC = Newhall County Water District
NLF = Newhall Land and Farming Company
SC = Santa Clarita Water Company
V = Valencia

* Knife cut and vertical slots; drilled by cable and rotary

Formation. This would include NC-4, NC-5, NC-6, possibly NC-11, NLF-154,, and NLF-155; there are no perforation data available for NC-1 and NC-2, or for the Smiser well.

d. The deepest perforations in any of the Saugus wells end at a depth of 2008 ft; many wells have perforations ending in the 1000- to 1800-ft depth range.

e. The older Saugus wells (pre-1960) were drilled by the cable tool method and are provided with hydraulically-cut (knife-cut) perforations; a few wells (NLF P-2, V-157, and V-158) have vertical slot perforations; the remaining wells have been drilled by direct rotary drilling methods and are provided with louvered perforations.

f. Though data are limited, most wells have little or no concrete sanitary seal; State laws for domestic water wells require a minimum of a 50-foot deep seal. NC-11 and NC-12, the two newest wells in the group (drilled in 1973 and 1985, respectively) were provided with 150- and 420-foot long cement seals.

g. Of the 22 known wells, 11 are known to be totally destroyed, 8 are active pumpers owned by the purveyors, one is on active/standby use only (NC-9), one has yet to be furnished with a permanent pump (NC-12), and one is inactive (NLF-159). The private Smiser well is considered to be active but its production is likely small.

Table 2 - Historic Saugus Formation Groundwater Production - has been prepared to document all known historic Saugus Formation water well extractions. Data on Table 2 are presented as annual totals for each of the purveyors, by well number. It should be noted that no production data are available at all for NC-1 through NC-6, or for the Smiser well; historic pumpage from these wells and any other private Saugus Formation wells that may exist is considered to be relatively insignificant (a combined total of 100 ac-ft/yr, or less).

Notable from Table 2 data are the following:

TABLE 2 - HISTORIC SAUGUS FORMATION GROUNDWATER PRODUCTION, IN ACRE FEET

CALENDAR YEAR	NEWHALL COUNTY WATER DISTRICT WELLS							THE NEWHALL LAND & FARMING CO. and VALENCIA WATER CO. WELLS						
	No.7	No.8	No.9	No.10	No.11	No.12	NCWD SUBTOTAL	No.154	No.155	No.156	No.157	No.158	No.159	No.160
	Drl.1954	Drl.1954												
1954	275	275					550							
1955	297	297					594							
1956	323	323	Drl.1957				646							
1957	278	278	139				695							
1958	280	165	182				627							
1959	314 est	245 est	160 est				720 est.	Drl.1960	Drl.1960					
1960	352	326	141	Drl.1961			819	903	821					
1961	302	201	68	412			983	882	940	Drl.1961	Drl.1962			
1962	159	27	16	936			1138	721	528	134	749	Drl.1962	Drl.1962	
1963	244	80	25	812			1161	621	538	200	982	126	805	Drl.1964
1964	339	198	37	857			1431	700	951	217	1565	244	1041	135
1965	220	210	90	1071			1591	743	936	80	1379	97	594	830
1966	229	234	47	1091			1601	1092	1787	115	1281	304	634	536
1967	216	401	122	815			1554	287	1111	173	1236	91	515	967
1968	268	420	196	992			1896	523	910	179	864	159	484	1679
1969	413	414	221	760			1808	1132	863	167	828	315	621	1969
1970	312	410	328	1060			2110	961	0	268	0	354	523	2211
1971	373	317	292	1105			2087	816	0	133	1029	131	462	1125
1972	323	373	246	1228			2170	1200	0	117	2188	0	352	1772
1973	366	369	299	843	Drl.1973		1877	75	0	9	1776	96	20	1853
1974	354	431	237	912	30		1964	82	0	0	2001	74	20	1853
1975	352	372	70	1004	187		1985	799	0	0	1852	0	0	1826
1976	332	382	0	634	738		2066	480 est	0	0	1612	0	0	1800
1977	307	467	184	750	170		1878	164	0	20	683	0	0	1265
1978	287	402	9	826	300		1824	0	Dest.	20	1755	0	0	1270
1979	451	613	0	602	658		2324	0	-	20	722	213	0	1702
1980	417	455	0	814	753		2439	0	-	20	635	47	0	1572
1981	396	449	0	905	869		2619	0	-	25	552	200	0	1577
1982	350	319	0	1286	715		2670	Dest.	-	20	824	0	0	574
1983	310	342	0	1155	670		2477	-	-	20	409	0	0	636
1984	355	317	120	1006	1157		2955	-	-	20	668	0	0	806
1985	330	311	192	816	1763	Drl.1985	3432	-	-	20	511	Dest.	0	929
1986	276	225	116	741	2237	0	3595	-	-	20	780	-	0	1137

NOTE: Production records do not exist or are unavailable for NCWD Nos. 1 through 6; these wells were generally small producers and were placed on inactive status by the early-1960's. Dates of destruction for these wells are unknown.

FEET

O. WELLS			SANTA CLARITA WATER COMPANY WELL	TOTAL YEARLY PRODUCTION FROM SAUGUS FM.
.160	P-2	NLF & VWC SUBTOTAL	LOMBARDI (23)	
				550
				594
			Drilling date	646
	Drl.1958		unknown	695
	100	100		727
	140	140		860 est.
	0	1724		2543
	0	1822	No	2805
	0	2132	Data	3270
rl.1964	0	3272		4433
135	0	4853		6284
830	0	4659	0	6250
536	0	5749	200	7550
967	Dest.	4380	395	6329
1679	–	4798	395 est.	7089 est.
1969	–	5895	393	8096
2211	–	4317	691	7118
1125	–	3696	640	6423
1772	–	5629	509	8308
1853	–	3829	529	6235
1853	–	4030	569	6563
1826	–	4477	662	7124
1800	–	3892	585	6563 est.
1265	–	2132	583	4593
1270	–	3025	153	5002
1702	–	2657	0	4981
1572	–	2274	0	4713
1577	–	2354	0	4973
574	–	1418	Destroyed	4088
636	–	1065	–	3542
806	–	1494	–	4449
929	–	1460	–	4892
1137	–	1937	–	5532

a. Available Saugus Formation production records date from 1954.

b. Historic annual production from the Saugus wells has ranged from a low of 550 ac-ft in 1954 to a high of 8308 ac-ft in 1972.

c. Early extractions, prior to 1960, did not exceed 1000 ac-ft/year, but since that time, production volumes have ranged between approximately 2500 ac-ft/yr and 8300 ac-ft/yr.

d. During the period of record (1954 to 1986), a total of 153,820 ac-ft of groundwater have been extracted from water wells in the Saugus Formation. Approximately 38 percent of this total has been produced by NCWD. Combined production from VWC and NLF represents approximately 58 percent of this total volume while the remaining 4 percent was produced by the now-destroyed SCWC-Lombardi well (well 23).

e. Because it is not possible to deduct production volumes from the alluvial portions of the Saugus wells on Table 1 (wells with perforations above approximately 200 ft in depth produce from both the alluvium and the Saugus Formation), we are considering that all production volumes shown on Table 2 to be from the Saugus Formation only.

To illustrate the spatial variability of recent groundwater production from the Saugus Formation, we have prepared Plate 2 - Map of Groundwater Production for 1986. The locations, owners and well numbers for each of the eight Saugus wells that were actively producing groundwater in 1986 are shown on Plate 2, together with their respective production in ac-ft for that year; though likely active in 1986, production data for the privately-owned Smiser well are not available. Total production for 1986 was 5532 ac-ft, and was comprised by 3595 ac-ft from NCWD, and 1937 ac-ft from the combined production from NLF and VWC (see also Tables 1 and 2).

The largest producers in 1986 included NC-11 (2237 ac-ft) which is located along the South Fork of the Santa Clara River, and V-160 (1137 ac-ft) which lies along the south side of the Santa Clara River Valley, approximately one-half mile east of Interstate 5. As noted on Plate 2, there was no Saugus production in 1986 by any wells north of the Holser and San Gabriel faults.

GROUNDWATER BASIN BOUNDARIES

As discussed in detail in Slade (December 1986), the California Department of Water Resources (1980) has established the names and boundary locations for the various groundwater basins along the course of the Santa Clara Valley in both Los Angeles and Ventura Counties. Typical basin boundaries were selected on the basis of such features as faults, groundwater divides, and exposures of bedrock in the hills. Where none of these types of features existed, arbitrary or even political divides were selected as local groundwater basin boundaries.

Based on Department of Water Resources work, the areal extent of the Saugus Formation, which comprises the focus of this investigation, together with the alluvial sediments along the river and major tributaries were placed within the Eastern Groundwater Basin of the Santa Clara River Valley Basin of Los Angeles County. The current mapped exposure limits of the Saugus Formation as shown on Plate 1 differ slightly from those developed by DWR (1980) but have been compiled from more recent and more detailed geologic field mapping by others. In essence, the mapped limits of the Saugus Formation shown on the plates in this report form the northern and southern boundaries of the Eastern Groundwater Basin. Eastern and western boundaries of this basin extend beyond the mapped limits of the Saugus Formation, but only where the groundwater basin consists solely of alluvium.

Also included within this groundwater basin are the alluvial deposits which lie along the Santa Clara River and its major tributaries, and the thin terrace deposits which mantle the flatter ridges on the hills adjoining the various creek channels. These sediments are underlain by the Saugus Formation in much of the region. The exposures of the alluvium (Qal) and the terrace deposits (Qt) in the area are shown on Plate 3 - Hydrogeology Map. Details of the hydrogeologic conditions of these alluvial sediments in the Santa Clara River Valley are presented in a recent report by this investigator (Slade, December 1986). The total surface of the mapped exposures of the Saugus Formation, terrace deposits and alluvium shown on our base maps is 85.56 square miles. Of this amount, alluvium comprises 27.14 sq. mi., terrace deposits have 5.61 sq. mi., while the remaining 52.81 sq. mi. represent exposures of the Saugus Formation.

REGIONAL GEOLOGY

GENERAL STATEMENT

The Eastern Groundwater Basin is part of the eastern Ventura depositional basin, an east-west trending, elongated structural trough which extends from the Santa Clara Valley westward to the Pacific Ocean. With few exceptions, associated geologic structures within the Ventura depositional basin (anticlinal and synclinal folds as well as faults) also trend generally east-west. The eastern part of the Ventura basin, in which the study area is located, is transected by the

STRUCTURAL GEOLOGY

Introduction. The Eastern Groundwater Basin is transected by two major faults, the Holser fault and the San Gabriel fault. The surface traces of these structures are shown on the Hydrogeology Map - Plate 3. Both faults have had a significant impact on the present thickness and continuity of the fresh water-bearing deposits and, in particular, deposits constituting the Saugus Formation.

The location of faults shown on most maps contained in this report represent the surface traces of these faults. Exceptions to this are found later in this report on Plates 5, 6, and 9. These three exceptions generally show the locations of the faults at depth where they intersect the base of the Saugus Formation; these locations differ from the surface traces because the fault planes are not vertical. The surface trace of the western segment of the Holser fault, in the area where the Saugus Formation (map symbol QTs) north of the fault has been offset and juxtaposed in surface outcrops against the Pico Formation (map symbol Tp), south of the fault, is shown on all of the maps in this report. The selection of fault traces, as shown on each individual map (surface traces vs. subsurface traces), was made for the purpose of increasing the usefulness of depth-dependent data relative to the locations of the faults at depth, as well as other considerations.

Holser Fault. The Holser fault is primarily an east-west trending, south-dipping reverse fault where strata south of the fault have been displaced upward relative to the strata north of the fault. The surface trace of the fault, shown on Plate 3, extends from San Martinez Chiquito Canyon eastward to the San Gabriel fault east of Saugus. It is likely that a significant left-lateral component of movement has also occurred such that strata north of the fault have been displaced westward relative to strata south of the fault. Taking into account both the vertical and horizontal components of movement, the Holser fault is best described as a left-lateral reverse fault. The dip of the plane of the fault (inclination downward from the horizontal) is to the south and varies between 45 degrees and 70 degrees, more commonly from 60 to 70 degrees.

Data from oil wells near the western boundary of the study area indicate that correlative rocks of Pliocene age have been offset vertically approximately 5000 feet across the Holser fault. It is evident from the Hydrogeology Map that Saugus strata north of the fault have been juxtaposed against older strata of the Pico Formation south of the fault. The amount of vertical offset of the base of the Saugus Formation in the vicinity of San Martinez Chiquito Canyon is on the order of 4000 feet; over 3100 feet of vertical offset of the base of the Saugus Formation can be inferred from Hydrogeologic Section C-C' - Plate 4. Some of this offset is due to the left-lateral component of movement along the fault. The amount of left-lateral offset of the base of the Saugus Formation, apparent on Plate 3, is about four miles. A comprehensive analysis of the movement history along the Holser fault (or any fault) must take into consideration many geologic as well as geometric factors and is beyond the scope of this report.

The surface trace of the Holser fault has been mapped throughout the region on the basis of its surface expressions (Winterer and Durham, 1962; Nelligan, 1978; and Weber, 1982). Weber's work suggests that the Holser fault comprises a zone of several subparallel faults that project to the ground surface along the general trend of the Santa Clara River in the vicinity of Castaic Junction. The location of the Holser fault in the subsurface is based on data from exploration and development oil wells (Driggs and Sampson, 1951; Winterer and Durham, 1962; Lande, 1964; Nelligan, 1978; and Hill, unpublished, 1984-87). For simplicity, we have mapped the Holser fault as a single strand through the central portion of the Santa Clara basin.

In the western part of the Santa Clara basin, the area where strata of the Saugus Formation north of the fault have been juxtaposed against strata of the Pico Formation south of the fault, the Holser fault undoubtedly forms an effective groundwater barrier at depth. As indicated on Hydrogeologic Section C-C', the difference in elevation of the base of the fresh-water-bearing deposits on opposite sides of the fault may be as much as 1800 feet.

Farther east, in the central part of the basin, where Saugus strata have been juxtaposed against similar Saugus strata across the Holser fault, the fault does not appear to be a significant groundwater barrier. Our opinion is based on the apparent continuity of the fresh water-bearing deposits and, in particular, the continuity of the base of the fresh water-bearing deposits as interpreted from exploration and development oil wells near the fault. Our interpretation is shown on Hydrogeologic Sections D-D' and E-E' - Plate 4, and on Plate 5 - Thickness of Fresh Water-Bearing Deposits.

San Gabriel Fault. The San Gabriel fault is a northwest-trending, steeply-dipping fault in the San Andreas system of right-lateral strike-slip faults. The history of movement along the fault is complex, both in regard to the timing and sense (horizontal vs. vertical) of movement. The surface trace of the fault as shown on Plate 3, trends northwesterly across the central portion of the study area, bisecting the Santa Clara basin. Work by numerous investigators (such as

Crowell, 1954; Oakeshott, 1958; Nelligan, 1978; Schlaefer, 1978; Stitt, 1980; Weber, 1982; Saul and Wootton, 1983; and Ehlig, 1986) reveal that this major structure consists of a series of steeply northeast-dipping faults with primarily right-lateral movement; rocks on the northerly side of the fault have been displaced to the southeast relative to rocks on the southerly side of the fault. Also, rocks on the northerly side of the fault have generally been uplifted relative to rocks on the southerly side of the fault.

As shown on Hydrogeologic Sections D-D', E-E', and F-F', the base of the Saugus Formation northeast of the fault has been uplifted as much as 100 feet to 2600 feet locally relative to the base of the Saugus southwest of the fault. The San Gabriel fault has been mapped through the region because of such strong topographic and geologic expressions as: the fault alignment is very apparent on aerial photographs; it has displaced geologic formations (including the Saugus Formation); it has offset drainage patterns; and it has induced folding in many rock units. Control on the subsurface location of the fault is well documented by data from local oil wells.

Recent work by Ehlig (1986), which includes details of geologic logging of exploratory trenches across the fault, has also corroborated the fact that the fault is a zone of faulting, ranging from a single plane with only minor development of fault gouge, to a zone as much as a half-mile wide containing numerous faults, complex folds and intense shearing and brecciation. This fault is also considered to create at least a partial barrier to groundwater flow as will be discussed later in this text.

Other recent work by Cotton (1986), Kahle (in press), Treiman (in progress) and Weber (in progress), document that the San Gabriel fault has experienced Holocene activity (within the past 10,000 to 11,000 years) although the cause of this activity is still being debated in the geologic community. Reportedly, the fault had its origins during the Middle Miocene epoch (about 15 million years ago) and, since that time, had induced right-lateral offsets in the rocks as great as 40 miles; its overall estimated mapped length is 80 miles.

Several other faults that cut the Saugus Formation have been mapped by previous workers (Winterer and Durham, 1962; Nelligan, 1978; Stitt, 1980; Weber, 1982; Saul and Wootton, 1983; and Smith, 1984). These structures are not shown on Plate 3 because we do not believe that they have a significant impact on the hydrogeologic characteristics of the Saugus Formation. It is not considered prudent, however, to locate a water well on the trace of a known fault as the hydrogeologic characteristics of the rocks may be affected by the fault, locally.

Folds. Several major anticlinal folds (upwarping of strata) and synclinal folds (downwarping of strata) have affected the Saugus Formation as well as older rocks in the Eastern Groundwater Basin. The axes of a few of the more principal of these folds are shown on the Hydrogeologic Map. These locations are based on previous surface and subsurface geological mapping by others (Winterer and Durham, 1962; Nelligan, 1978; Schlaefer, 1978; Stitt, 1980; Weber, 1982; Saul and Wootton, 1983; and Smith, 1984) and on our subsurface mapping of the base of the Saugus Formation.

The axes of major fold structures in the Eastern Groundwater Basin generally trend east-west to northwesterly and plunge toward the central portion of the basin as indicated by the arrows on the fold axes shown on Plate 3. The plunge of a fold is the inclination of the fold axis (the crest of the fold) downward from the horizontal.

In the northeastern part of the basin, the area northeast of the San Gabriel fault, there are at least three major synclines and two major anticlines, all of which plunge in a westerly direction toward the San Gabriel fault. Both the total thickness of the Saugus Formation and the thickness of fresh water-bearing deposits within the Saugus are affected by these folds, as illustrated on Hydrogeologic Sections B-B', E-E', and F-F'. The greatest thickness attained by the Saugus Formation northeast of the San Gabriel fault (approximately 2000 feet) occurs adjacent to the fault and along the synclinal axes (see Plates 3 and 5). The fresh water-bearing deposits of the Saugus Formation attain a maximum thickness of approximately 1500 feet in the area northeast of the San Gabriel fault.

In the central part of the Eastern Groundwater Basin, the area north of the Holser fault and west of the San Gabriel fault, the thickest Saugus strata lie along the axis of a southeasterly-plunging syncline north of and parallel to Hasley Canyon. The syncline turns abruptly to the northeast south of Villa Canyon. Near its eastern terminus, the syncline merges with a southeasterly-plunging synclinal trough that trends through the Castaic Junction area paralleling Interstate Highway 5 and the San Gabriel fault. This synclinal trough coincides with the deepest part of the Eastern Groundwater Basin; the Saugus Formation in this area attains a thickness of about 8500 ft. The fresh water-bearing deposits comprising the upper part of the Saugus in this area attain a maximum thickness of approximately 5500 feet as indicated on the map showing thickness of fresh water-bearing deposits (Plate 5). The southeasterly-plunging anticline whose axis lies south of and parallel to Hasley Canyon is another major structural feature in the area. Beds in the south flank of this structure dip beneath the south-dipping Holser fault as shown on Hydrogeologic Section C-C'.

The major folds in the southwestern portion of the Eastern Groundwater Basin, the area south of the Holser fault and southwest of the San Gabriel fault, include two synclines shown on Plate 3. These structures generally define a broad northwest-plunging trough with its axis oriented parallel to the San Gabriel fault. This trough is shown on Hydrogeologic Sections E-E' and F-F'. In the area immediately south of the Holser fault, the complete Saugus Formation along the axis of the trough attains a maximum thickness of about 7500 feet. The fresh water-bearing deposits comprising the upper Saugus strata in this area attain a maximum thickness of about 5000 feet as shown on Plate 5. Thus, the lower 2500 feet of Saugus strata in this area (i.e., between depths of 5000 and 7500 ft) contain groundwater of unacceptable quality.

The impact of the major fold structures on the hydrogeologic characteristics of the Saugus Formation are considered insignificant except for local areas. For example, the elevation of the base of the Saugus Formation along the crest of an anticlinal fold may be such that a deep well at a specific location would penetrate the base of the Saugus at relatively shallow depths as compared to wells located along the axes of adjacent synclinal folds. Hydrogeologic Section C-C' illustrates this example.

Locally, such as along the southwestern margin of the study area and adjacent to the San Gabriel fault, the Saugus beds are steeply-dipping (as much as 70 degrees or higher) as a result of folding and faulting. Depending on the hydrogeologic characteristics of the Saugus strata in such areas, the lateral movement of groundwater might be affected.

SAUGUS FORMATION

Previous Work. Hershey (1902) recognized non-marine rocks near the town of Saugus which he referred to as the "Saugus division" of the late Pliocene series. Eldrige and Arnold (1907) included these rocks in their Fernando Formation. Kew (1924) divided the Fernando of Eldridge and Arnold (1907) into the early Pliocene Pico Formation and the late Pliocene Saugus Formation. Winterer and Durham (1962) characterized the Saugus of the eastern Ventura depositional basin as including a lower shallow-marine to brackish water member (Sunshine Ranch) and an upper unnamed non-marine member. Oakeshott (1958) had earlier included the Sunshine Ranch as the upper member of his Pico Formation. The nomenclature of Winterer and Durham (1962) is applied to the Saugus Formation for the purpose of this study.

A considerable effort was made during this investigation to define the basal contact of the Saugus Formation in a manner that is consistent throughout the area and to determine the stratigraphic relationship between the Saugus and underlying Pico Formation. Our conclusions are: (1) that the stratigraphic relationship between these formations is not the same throughout the study area; and (2) the distinctions are important in understanding the hydrogeology of the basin.

In order to define the areal extent of the Saugus Formation in the study area, we relied primarily on previous surface geological mapping by Oakeshott (1958), Winterer and Durham (1962), Nelligan (1978), Stitt (1980), Saul and Wootton (1983), and Smith (1984). To define the base of the Saugus

Formation in the subsurface, we relied primarily on our own interpretation and correlation of approximately 200 electric logs and various other data from exploration and development oil wells, and water wells as well as on previous geological investigations by Winterer and Durham (1962), Nelligan (1978), Schlaefer (1978), and Stitt (1980). The total number of electric logs used to define the base of the Saugus Formation (including logs in reports by others) is approximately 800.

Environment of Deposition. Underlying Holocene alluvium (map symbol Qal) and/or terrace deposits (map symbol Qt) in the study area is the Saugus Formation of late Pliocene-early Pleistocene geologic age. As reported by most previous investigators, the Saugus Formation is considered to be primarily of continental (non-marine) origin, having been deposited as channel, floodplain, and lacustrine (lake) sediments and as alluvial fan materials by local ancestral rivers and creeks. Because of their primarily continental mode of origin, Saugus strata, with rare exception, tend to lack definitive fossils. Near its base, the Saugus Formation is reported to contain shallow-water marine fossils locally.

Review of historic and recent literature regarding the Saugus Formation reveals significant disagreement among previous workers regarding the placement of the base of the formation; i.e., principally in regard to its contact with the underlying Pico Formation. The disagreements result from such factors as the similarity in sediment characteristics in the lower Saugus-upper Pico beds, the absence of definitive index fossils in sediments near the contact, and rapid lateral and vertical changes (facies changes) in upper Pico and lower Saugus strata.

Some previous investigators consider the lower portion of the Saugus Formation to be composed of interfingering shallow-water marine to brackish water marine deposits. The interfingering nature of these deposits may have resulted from changes in climate, tectonic uplift and subsidence, and/or minor fluctuations in sea level which caused the sea to alternately transgress and regress upon the surrounding land surface. These deposits are interpreted to grade vertically upward to continental (non-marine) deposits, and downward as well as westerly into deep-water marine strata of the Pico Formation.

The shallow-water marine to brackish water facies of the Saugus is designated the Sunshine Ranch member (the lowermost member) of the Saugus Formation. Some previous workers have chosen to include the Sunshine Ranch member in the upper part of the Pico Formation, but this assignment is generally not followed today. For the purpose of this study, the Sunshine Ranch member comprises the shallow-water marine to brackish water deposits, as well as non-marine deposits, within the lower portion of the Saugus Formation. Due to the gradational and interfingering relationship of the lower Saugus and upper Pico strata, the contact between these formations has been defined and mapped somewhat arbitrarily in the field by previous workers. Such a contact is difficult if not impossible to distinguish on the basis of electric logs of oil wells, especially in the southwestern part of the study area.

The Sunshine Ranch member of the Saugus Formation contains fresh water locally as does the upper part of the Pico Formation. For this reason and because more recent workers generally include the Sunshine Ranch strata in the Saugus Formation, the Sunshine Ranch is considered part of the Saugus Formation for the purpose of this study. The Sunshine Ranch member is not differentiated from the rest of the Saugus Formation on the maps or hydrogeologic sections in this report.

It is now clearly understood from previous work by others and from our own investigation that the contact between the Pico and Saugus Formations is, for the most part, gradational, especially in the southwestern part of he study area, and represents a transition from a marine to a continental environment of deposition throughout the region.

The sea in which the strata of the Pico Formation were deposited receded westward in response to tectonic uplift of the area. As the sea retreated, creeks and rivers that developed in the highlands to the north, east, and south carried coarse-grained sediments (sands and gravels) and fine-grained floodplain deposits (fine sands, silts, and clays) and deposited them in the area once covered by the sea. Drainage patterns in the area have changed throughout the long period of deposition of the Saugus Formation, both in response to local tectonic deformation (folding and faulting) and to differences in properties of the rocks (such as resistance to erosion) on which the drainage channels developed.

The coarsest deposits (sands and gravels) of the Saugus Formation were deposited in the main channels comprising the ancient drainage systems. These coarse-grained channel deposits constitute the best aquifers within the present-day Saugus Formation. As the locations of the channels changed during the 3 million-year period of deposition of the Saugus strata, the distribution of the coarse-grained channel deposits also changed, both laterally and vertically (in space and time).

The coarse-grained facies (sands and gravels) of the Saugus Formation can be distinguished from the fine-grained facies (silts and clays) on the basis of their electric log signatures. From our analysis of the electric logs used in this regional study, it is evident that the coarse-grained channel deposits (the best potential aquifers) predominate in some portions of the basin, whereas the fine-grained deposits predominate in other parts of the basin. The lateral transition from predominantly coarse-grained deposits to predominantly fine-grained deposits may occur over relatively short distances in some parts of the basin. Acquisition and interpretation of additional electric logs (if available) from oil wells in the vicinity of future water well sites selected on the basis of our regional study would provide better definition and confirmation of the areas where the coarse-grained deposits predominate.

Plate 6 - Potential Aquifers, Sand Thickness Map - was prepared to show the cumulative thickness of sands and gravels anticipated to be available to yield water to future Saugus Formation water wells; relatively thin isolated layers of sand and gravel, together with all finer-grained siltstone and claystone layers in this 500 to 2500 ft depth zone of interest are not included. This Plate, in a very general sense, defines the principal areas where the ancient Saugus channels have remained approximately in the same locations during the period of time that it took to accumulate the 2000 feet of Saugus strata within the depth zone of interest (500 feet to 2500 feet) of this study. The thickest accumulations of sands as seen on Plate 6 roughly coincide with present-day major river channels, such as the channels of the south fork and main fork of the Santa Clara River and Castaic Creek, southwesterly of the San Gabriel fault.

Plate 6 differs from Plate 5 - Thickness of Fresh Water-Bearing Deposits - in that Plate 5 shows the entire thickness of all Saugus Formation sediments, including siltstone and claystone, which either contain fresh water or, if saturated, would contain fresh water from ground surface to the base of fresh water as interpreted from electric logs. As stated earlier, Plate 5 thickness contours exclude all Saugus strata near the base of the formation which are considered to contain poor quality groundwater on the basis of electric log analyses.

For the purpose of discussing the characteristics of the Saugus Formation, we have subdivided the Eastern Groundwater Basin into three portions which are separated from one another by major faults: a northeastern portion which comprises the area northeast of the San Gabriel fault; a central portion which lies north of the Holser fault and west of the San Gabriel fault; and a southwestern portion which lies south of the Holser fault and west of the San Gabriel fault. These three areas are discussed below under separate headings.

Northeastern Portion, Eastern Groundwater Basin (Northeast of San Gabriel Fault). In the northeastern portion of the Eastern Groundwater Basin, the area northeast of the San Gabriel fault, strata of the Saugus Formation have been deposited unconformably upon older rocks of the Pico, Castaic, Towsley, and Mint Canyon Formations as shown on Hydrogeologic Sections B-B', D-D', E-E', and F-F'. This means that the older strata which underlie the Saugus are not parallel to the Saugus strata; the basal contact of the Saugus is, therefore, an angular unconformity. A period of time elapsed during which the older strata were deformed by folding and faulting before deposition of the Saugus beds commenced.

Because the basal contact of the Saugus with underlying formations is an angular unconformity, the base of the Saugus is, for the most part, easily identified on electric logs of oil wells. Some difficulty arises, however, especially where basal sands and conglomerates of the Saugus Formation overlie sands and conglomerates comprising the upper Pico or Towsley Formation, locally.

According to Stitt (1980), outcrops of the Saugus Formation in the Castaic area are all part of the non-marine Saugus. The Sunshine Ranch lithology (physical character of the rock) was recognized in the subsurface by Stitt but was not differentiated because he could not correlate the Sunshine Ranch member consistently between wells in the area. The upper part of the Saugus Formation in the Castaic area consists of continental (non-marine), red-brown sandstone and conglomerate interbedded with red-green siltstone. The lower part of the Saugus consists of brackish to marine siltstone and conglomerate.

Schlaefer (1978) made a study of the Saugus Formation in the area southeast of Castaic and northwest of Bouquet Canyon, and included the Honor Rancho Oil Field. In surface exposures, the Saugus Formation is composed of light gray, tan to maroon, coarse- to fine-grained, unconsolidated to loosely consolidated, cobble to pebble gravel, sand, and silt. In the subsurface, the shallow marine to brackish water Sunshine Ranch member can be distinguished from the non-marine member by lithologic descriptions from oil well cuttings and cores, and on the basis of electric log characteristics. An electric log signature of jagged, high amplitude resistivity and moderate spontaneous potential distinguishes the non-marine member of the Saugus Formation from the low amplitude resistivity and spontaneous potential of the underlying siltstones of the Sunshine Ranch member.

A basal, massive, fine-grained to medium-grained sandstone and pebble conglomerate of the Sunshine Ranch member rests unconformably on the Pico Formation throughout the western part of the area studied by Schlaefer. The angular unconformity between the Pico and Saugus Formations is locally distinct east of the San Gabriel fault and within the fault zone except where the basal sandstone and conglomerate of the Saugus directly overlie sandstone and conglomerate of the upper Pico Formation.

Smith (1984) made a geologic study to the east of the area investigated by Schlaefer (1978), and included the northeastern part of the Eastern Groundwater Basin east of San Francisquito Canyon and north of Bouquet Canyon. The Saugus Formation in this area rests unconformably on older rocks of the Castaic Formation. Only the upper, coarse-grained facies of the Saugus is present in this area, the Sunshine Ranch member apparently pinches out to the east in the eastern part of the area studied by Schlaefer (1978).

The Saugus Formation in the area studied by Smith is composed entirely of fluvial beds (sediments deposited by streams, rivers, creeks) which in outcrop are buff or tan to brown conglomeratic arkosic (containing primarily quartz and 25 percent or more of feldspar) sandstone, muddy arkosic sandstone, conglomerate, and clayey siltstone. The underlying strata comprising the Castaic Formation are shallow-water marine beds of shale, sandstone, and minor conglomerate. Gypsiferous ($CaSO_4$) clay is present in the upper part of the formation and may be a source of sulfate ions in groundwater, locally.

The southeastern part of the Eastern Groundwater Basin northeast of the San Gabriel fault and south of Bouquet and Plum Canyons has been studied by Nelligan (1978), Saul and Wootton (1983), and Treiman (in progress). Both the non-marine upper Saugus and brackish to marine to non-marine lower Saugus beds are present in the western and southern part of this area. The base of the Saugus in the subsurface, as defined by Nelligan on the basis of electric logs, was adopted (with few exceptions) for this study; the base of the Saugus in outcrop was, for the most part, taken from Saul and Wootton.

In the southeastern part of the basin immediately east of the San Gabriel fault, the Sunshine Ranch member of the Saugus unconformably overlies marine strata of the Towsley and/or Pico Formations (Tt-Tp on Hydrogeologic Sections B-B' and F-F'). These latter rocks are difficult, if not impossible, to differentiate by their electric log character and, therefore, have not been differentiated for this study. Farther to the northeast, the Saugus unconformably overlies the Castaic and Mint Canyon Formations, locally.

According to Saul and Wootton (1983), the basal part of the Sunshine Ranch member consists of a non-marine facies, locally composed of poorly to moderately consolidated arkosic sandstone and conglomerate; beds are generally massive to poorly bedded. The upper part of the Sunshine Ranch consists predominantly of poorly-consolidated, gray-green siltstone and mudstone. Thin beds of white, sandy limestone and nodular limestone are common.

The Sunshine Ranch member is overlain by a generally fine-grained, non-marine unit consisting predominantly of poorly consolidated silty and sandy claystone interbedded with gray arkosic sandstone. This fine-grained facies is overlain by a coarse-grained unit, the lowermost part of the Saugus, composed generally of poorly sorted, gray to light yellow and reddish-brown weathering, sandstone and sandy conglomerate interbedded with minor amounts of sandy siltstone. These rocks are moderately to poorly consolidated, and are lightly cemented with calcium carbonate ($CaCO_3$).

The Saugus Formation in the northeastern part of the Eastern Groundwater Basin northeast of the San Gabriel fault attains a maximum thickness of nearly 2000 feet (refer to Plate 5) in two areas adjacent to and immediately northeast of the fault; these areas coincide with the axes of two major synclines shown on the Hydrogelogy Map, and are located about one-half mile south of Wayside Canyon and one mile east of Bouquet Junction, respectively.

The nearly 2000-foot maximum thickness of the Saugus Formation northeast of the San Gabriel fault is in marked contrast to the 8500-foot maximum thickness of the Saugus southwest of the fault as shown on Plate 5. This difference in thickness is believed to have been primarily the result of uplift and subsequent erosion of upper Saugus strata northeast of the San Gabriel fault in response to a vertical (upward) component of movement (uplift) of the crustal block on the northeast side of the fault relative to the block on the southwest side of the fault. Consequently, as is evident on the Hydrogeologic Sections, the fresh water-bearing Saugus strata northeast of the San Gabriel fault are much thinner than the fresh water-bearing Saugus strata southwest of the fault.

Central Portion Eastern Groundwater Basin - (North of Holser Fault and West of San Gabriel Fault). In the central part of the Eastern Groundwater Basin, the area north of the Holser fault and west of the San Gabriel fault, strata of the Saugus Formation have been deposited disconformably upon older rocks of the Pico Formation (Hydrogeologic Sections A-A' and C-C'). This means that beds within the upper Pico and lower Saugus are essentially parallel to one another. The contact between the formations, however, represents a hiatus, a period of time during which there was no deposition of Saugus strata onto the Pico. Also, there was relatively little deformation (folding and faulting) of the Pico during this period.

The base of the Saugus Formation in the northwestern part of the basin was placed at the top of the marine strata of Pliocene age by Stitt (1980), where paleontological reports were available. This paleontological pick was found to correspond with a reasonably good electric log signature. The base of the Saugus as defined by Stitt was adopted for the northwestern part of the basin for the purpose of this study.

The spontaneous-potential and resistivity curves for rocks in the lower part of the Saugus in the northwestern part of the basin commonly exhibit a gradual upward increase in amplitude, indicating a coarsening-upward vertical sequence from siltstone to sandstone. This characteristic of the Saugus is illustrated by the electric log of wildcat oil well 34Ja on Hydrogeologic Section C-C'. The coarse-grained facies of the upper Saugus becomes much thicker in a southeasterly direction; consequently, the entire portion of the Saugus within the depth zone of interest for this project (500 feet to 2500 feet) becomes generally coarse-grained in a southeasterly direction. Electric log correlation of the Pico-Saugus contact is locally difficult where the upper Pico is conglomeratic.

The upper part of the Saugus Formation in the northwestern part of the basin consists of red-brown conglomerate, sandstone, and red-green siltstone; the lower part is composed of brackish to marine siltstone and conglomerate. The Saugus attains a maximum thickness of approximately 8500 feet in the area of the Santa Clara River, one and one-half miles southwest of Castaic Junction (see Plate 5).

Southwestern Portion, Eastern Groundwater Basin (South of Holser Fault and West of San Gabriel Fault). Strata that comprise the lower part of the Saugus Formation in the southwestern part of the Eastern Groundwater Basin, the area south of the Holser fault and west of the San Gabriel fault, are generally conformable and gradational with strata that comprise the upper Pico Formation. North of the western portion of Pico Canyon, the contact of the Saugus and Pico Formations can be traced for about two miles as an angular discordance. In the vicinity of Placerita Canyon, the Saugus also rests unconformably on the Pico. Elsewhere, the contact is placed rather arbitrarily at the upper limit of the abundantly fossiliferous beds of the Pico Formation. Beds within the lower Saugus Formation generally interfinger with beds within the upper Pico Formation. The non-marine to brackish-water to shallow-water marine sediments in the lower part of the Saugus grade in a southwesterly to westerly direction into shallow-water marine sands and conglomerates in the upper part of the Pico Formation. The marine to brackish strata in the lower Saugus also grade upward to non-marine deposits that comprise the upper Saugus Formation. According to Winterer and Durham (1962) the chief distinction between the Pico and Saugus Formations in the southwestern part of the basin is a change in color of the siltstone beds from olive-gray to light bluish gray in the Pico and to greenish gray in the Saugus.

In the area south of the Holser fault and west of the San Gabriel fault, the Saugus Formation consists primarily of lenticular units of light colored, loosely consolidated, poorly bedded, ill-sorted conglomerate, conglomeratic sandstone, and sandstone alternating with beds of greenish gray siltstone, silty sandstone, and light brown to moderate reddish brown sandy siltstone and claystone. The proportion of greenish gray beds is greater in the lower part; the proportion of reddish brown beds is greater in the upper part of the formation. The maximum thickness of Saugus strata in the southwestern part of the basin (one mile southeast of the interchange of Interstate Highway 5 and Saugus Ventura Road) is approximately 7500 feet. The maximum thickness of fresh water-bearing strata in the same area is about 5000 feet as indicated on Plate 5.

From our interpretation of oil well electric logs, it is apparent that conglomeratic to sandy deposits of the upper Pico Formation as well as strata in the overlying Saugus Formation are fresh water bearing throughout the southwestern portion of the Santa Clara basin. The fresh water-bearing deposits of the upper Pico Formation are discussed in a subsequent section of this report.

PICO FORMATION (South of Holser Fault and West of San Gabriel Fault).

A somewhat surprising result of this study is the recognition of fresh water-bearing sands and conglomerates in the upper part of the Pico Formation in the southwestern portion of the Eastern Groundwater Basin, that is, in the area south of the Holser fault and west of the San Gabriel fault.

According to Winterer and Durham (1962), the Pico Formation consists chiefly of olive-gray and bluish gray siltstone and fine-grained silty sandstone, and light colored sandstone and conglomerate. Concretions (hard nodules) cemented with ankerite, $Ca(Mg, Fe, Mn)CO_3$, are common in the siltstone. However, in the southwestern part of the Eastern Groundwater Basin, south of the Holser fault and west of the San Gabriel fault, the upper part of the Pico is dominantly sandstone and conglomerate. These sediments commonly contain shells of marine mollusks.

OIL AND GAS OCCURRENCE AND PRODUCTION

Historical Development. According to Winterer and Durham (1962), early travelers in California found that the Indians were using oil and tar collected from many natural seeps near the present town of Newhall. By 1850, oil from seeps in Pico Canyon was being distilled at nearby San Fernando Mission to produce lamp oil for lighting purposes. As early as 1869-70, a spring-pole hole was drilled to a depth of 140 feet on the axis of the Pico anticline in Pico Canyon. The well was reported to have flowed from 70 to 75 barrels of oil per day. Not until 1875 was another attempt made to drill a well in the area--a spring-pole hole on the axis of the Pico anticline. This well, which had an initial daily production of two barrels per day is considered to be the beginning of the California oil industry.

The California Star Oil Works Company was organized to develop the oil resources of the Pico Canyon area, and they built the first oil refinery in California (near Newhall) in 1876. Although exploration continued in the area until the early 1900's, no new discoveries of importance were made until discovery of oil and natural gas in the Newhall-Potrero field in 1937.

Since the discovery of the Newhall-Potrero field, ten major oil and gas fields as well as several small oil and gas pools have been developed. The active and abandoned fields are shown later in this report on Plate 10. Although development of existing fields has continued to the present, no new major discoveries have been made since discovery of the Wayside Canyon field in 1962. Exploration has continued intermittently, however, in search of pools on the flanks of existing fields as well as deep pools in the downthrown blocks of major faults (such as the Holser fault), and in other areas of the basin where deep structural or stratigraphic traps for oil have been postulated.

Current-day development of existing oil fields includes: step-out drilling on the flanks of oil pools; drilling of in-field wells to develop deeper pools; workover of existing wells; and secondary recovery projects, such as water-flooding (injecting waste water from oil wells or water from water wells); injection of waste water into waste disposal wells; cyclic-steam injection; diluent injection (using a solvent to mobilize low API gravity oil*); gas-injection; and fire-flooding (involves igniting the hydrocarbons in a producing zone and injecting air to maintain combustion). The Honor Rancho (southeast) field northwest of Castaic Junction is presently being used for storage of natural gas which is injected into abandoned oil and gas producing zones at depth and recovered as needed.

Oil Fields with Shallow Production. Most of the oil and gas production in the Eastern Groundwater Basin area is from deep reservoirs in formations that are geologically older and stratigraphically below the Saugus Formation. Six fields of particular interest to this study have production from relatively shallow reservoirs in the basal part of the Saugus Formation and/or reservoirs in the upper part of the Pico and/or Towsley Formations, immediately below the basal Saugus strata. Table 3 - Summary of Local Oil Fields and Production Zones - lists the active and abandoned oil fields in the area underlain by the Saugus Formation, the formations in which the shallowest oil and(or) gas reservoirs occur, and the average

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*API gravity is the standard American Petroleum Institute method of specifying the density of crude petroleum. The density in degrees API is equal to (141.5/P) minus 131.5 where P is the specific gravity of the oil measured at 60° Fahrenheit.

Table 3
Summary of Local Oil Fields and Production Zones

Oil Field	Shallowest Producing Formation	Average Depth of Shallowest Producing Oil Reservoir (in feet)
Bouquet Canyon (abandoned)	Mint Canyon	2340
* Castaic Hills	Saugus (basal sands)	4000
Castaic Junction	Modelo-Towsley (undifferentiated)	8400
* Charlie Canyon (abandoned)	Saugus (basal sands)	600
Del Valle	Pico	3800
Hasley Canyon	Towsley	4800
Honor Rancho (main area)	Modelo-Towsley (undifferentiated)	3800
Honor Rancho (southeast area)	Modelo	10,000
Lyon Canyon	Modelo	9100
* Newhall (Tunnel Area)	Upper Towsley-Pico (undifferentiated)	600
* Newhall (Elsemere Area)	Upper Towsley-Pico (undifferentiated)	780
Newhall (Townsite Area)	Modelo	2700
Newhall-Potrero	Modelo	6500
Oak Canyon	Modelo	2400
* Placerita	Upper Pico-basal Saugus sands	600
Saugus	Modelo	9500
* Tapia	Upper Pico-basal Saugus sands	1000
* Wayside Canyon sands	Upper Pico-basal Saugus	1500

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* Oil fields with production from sands witin the basal part of the Saugus Formation or from sands immediately underlying the Saugus Formation.

depth of the shallowest reservoirs. The oil fields are shown on Plate 10.

Water wells which are drilled in the vicinity of oil fields with shallow production and which are completed within the lower strata of the Saugus Formation are likely to encounter hydrocarbons or waters with relatively high salinities. Such oil fields and their environs include the Castaic Hills, Charlie Canyon, Newhall (Tunnel Area and Elsemere Area), Placerita, Tapia, and Wayside Canyon fields (refer to Plate 10).

Data obtained from the California Division of Oil and Gas indicate that most of the waste water from oil field operations is disposed of by injection into the underlying rock formations via waste-water injection wells. In the past, however, waste water has been discharged into ponds and allowed to evaporate and to percolate into underlying strata (such as at the Tapia field), or has been discharged into local drainage channels (such as at the Placerita field). The present methods of waste water disposal at the oil fields in the Eastern Groundwater Basin were not investigated in detail as part of this study.

The drilling and completion of water wells in the vicinity of oil fields, where the shallowest producing reservoirs are deep and are well below the total depth of the water wells, may be feasible depending on local oil field completions, abandonment, and waste disposal practices. A comprehensive investigation of the completion and abandonment practices at the various oil fields in the area was beyond the scope of this study.

GROUNDWATER GEOLOGY

GENERAL STATEMENT

Geologic materials depicted on the Hydrogeology Map have been divided according to their relative water-bearing characteristics, that is, to their relative ability to contain, transmit, and yield groundwater to wells. As such, two divisions are recognized: a water-bearing sediment group and a nonwater-bearing rock group. Plate 3 provides the exposures and areal extents of these materials, together with local geologic structure, including representative bedding attitudes and the alignment of major faults and folds.

Depending on water levels, the water-bearing sediments can become saturated, thereby permitting them to provide water to wells. Thus, they constitute the groundwater reservoir of the study area, and, in effect, they are wholly included within the lateral and vertical boundaries of the Eastern Groundwater Basin along the Santa Clara Valley of Los Angeles County.

Water-bearing sediments in the study area are comprised by: undifferentiated alluvial or valley fill deposits which underlie the Santa Clara River and its tributaries; and partially consolidated, older sediments assigned to the Saugus Formation which are exposed on the hills surrounding the river valley and which also underlie the river and its tributaries in the area. Hence, the water-bearing sediments consist of Holocene alluvium (map symbol, Qal), terrace deposits (Qt), and the group of geologically older sediments known as the Saugus Formation (QTs).

ALLUVIAL DEPOSITS

The undifferentiated alluvial-type deposits are Pleistocene to Holocene (Recent) in geologic age and, generally, are exposed in the study area as follows: on the valley floor as floodplain deposits and stream channel deposits; as alluvial fans near the mouths of canyons draining the adjoining hills; as elevated terraces along the margins of the basin; and as terraces in the low foothills which adjoin the main river valley. For the most part, these water-bearing strata are geologically younger, more permeable, less consolidated, and less structurally deformed than the nonwater-bearing, underlying bedrock.

These sediments, as a group, have been penetrated to various depths by the large number of wells in the basin and historically have provided virtually all the groundwater extracted by these wells. Analysis of available drillers' logs clearly reveals that these sediments are composed of extensively interlayered and interfingered mixtures of gravel, sand, silt, and clay, with variable concentrations of cobbles and boulders.

The maximum thickness of alluvium varies along the Santa Clara River, but generally is considered to be on the order of 200 feet. Typically, the alluvium tends to be thickest near the central portion of the river, and thins or pinches out as the flanks of the adjoining hills are approached. Alluvial thicknesses in the tributary canyons are considered to be less than that in the main river valley. The planimetered area represented by the alluvial deposit exposures shown on our base maps is 27.14 sq. mi.

TERRACE DEPOSITS

Terrace deposits (Older alluvium) of late-Pleistocene age has also been mapped in the area by others to include the thin veneer of sediments that have been elevated onto mesas and terraces along the main river valley. These terrace deposits (map symbol, Qt, on Plate 3) are considered to be of the same general composition as Holocene alluvium and were formed in much the same manner. Regional uplift and continued downcutting of the creeks and washes have left these terrace deposits elevated with respect to current stream gradients. In general, the terrace sediments are more deeply weathered and characteristically reddish-brown in color. Because of their topographically elevated position in the study area, these sediments, although potentially water-bearing, are considered to be of very limited use as a water resource; they nearly always lie above the regional water table. The planimetered area represented by terrace deposit exposures shown on our base maps is 5.61 sq. mi.

SAUGUS FORMATION

Groundwater Occurrence, Recharge and Discharge.

Groundwater within the 52.81 sq. mi. surface area of exposures of the Saugus Formation of the Eastern Groundwater Basin occurs under confined (artesian) conditions. Evidence for this includes: the high piezometric levels encountered in the Saugus wells during field testing (in some cases, the piezometric level was as much as a few hundred feet higher than the uppermost level of well perforations); and a value for the aquifer parameter of storativity which is considered to be low and thus representative of typical confined conditions (refer also the the Aquifer Parameters section of this report).

Natural sources of recharge to the Saugus Formation include: infiltration of direct precipitation on the outcrop area of these strata in the hills; deep percolation of groundwater from the saturated portions of the alluvium into Saugus strata, wherever the two formations are juxtaposed; and subsurface inflow from the older rocks adjoining Saugus strata. The relative magnitude of the first two of these possible recharge sources has been quantified for this investigation (refer to Recharge Potential in the Geohydrology Section). Due to a lack of requisite data, the potential recharge to the Saugus from older rocks has not been quantified for this investigation.

Additional, but more limited, sources of recharge to the Saugus are considered man-made and would include: deep percolation of irrigation returns from agricultural acreage located either on terrace deposits overlying the Saugus or on Saugus beds directly; and deep percolation of seepage from unsewered areas on or near the hillsides. Infiltration of wastewater treatment plant effluent is not considered to directly recharge the Saugus because the effluent is released as surface flow to the Santa Clara River within the alluvium.

No artificial recharge operations either by direct surface spreading basins or by deep well injection, have been historically utilized in the hillsides to make use of excess surface runoff for purposes of recharging Saugus aquifers. No water from the State Water Project has been used for artificial recharge purposes either.

Outflow or discharge from the Saugus Formation occurs by water well extractions and subsurface outflow to downstream strata. As previously discussed, the eight active Saugus wells in 1986 produced a total of 5532 acre-feet. Average Saugus production since records became available in 1954 has been about 4660 ac-ft/yr. Pumpage records from the single known privately-owned Saugus well (the Smiser well) were not available to this study; its annual production, if and when active, likely would be less than 100 ac-ft/yr.

Subsurface outflow to older beds below the Saugus Formation likely occurs on the west side of the study area, and mainly into the more permeable units in the upper Pico Formation. The magnitude of this subsurface outflow could not be quantified for this study due to a lack of requisite data. Evapotranspiration from areas of high groundwater or from areas of phreatophytic growth (reeds, etc.) on Saugus strata is considered negligible.

Water Levels. To assess groundwater levels and flow directions in the Saugus Formation, we obtained non-pumping water levels for Saugus wells from the various purveyors and from our own field work, corrected those water levels to a mean sea level datum, and then prepared contour lines for equal elevations of groundwater. In essence, because Saugus aquifers are confined, these water level contours represent the piezometric (pressure) level of the various Saugus aquifers.

Because the existing Saugus wells contain long lengths of continuously perforated casing, groundwater enters the well bore from all strata encountered by the well. Hence, it is not possible to define the head or flow direction for individual aquifers in the region. Also, because there is not an even distribution of Saugus wells in the study area, there are large data gaps, such as in the entire Saugus Formation area northerly of the San Gabriel fault. In such areas, preparing groundwater elevation contours is obviously not possible.

For our assessment of piezometric levels in the Saugus, we have prepared Plate 7 - Contour Map of Generalized

Groundwater Elevations--Summer-Fall, 1967, and Plate 8 - Contour Map of Groundwater Elevations--March, 1987. Plate 7 represents the earliest time period for which adequate water level data were available to construct a water level map; this Summer-Fall, 1967 time period corresponds to a general water level low period in the region. Plate 8 represents the most recently available data and corresponds to a moderately high water level period in the region. Both maps are annotated with the well location, ownership and well number, and the respective piezometric water level elevation.

Data on Plate 7 indicate the following:

a. Only sparse data are historically available and to prepare this map, it was necessary to use data for the summer and fall of 1967.

b. Ten wells were used in the compilation, with nine of these lying south of the Holser fault and one (V-158) lying in the area between the two faults. No water level data exist for the region northerly of the San Gabriel fault.

c. Groundwater elevations (piezometric levels) south of the Holser fault range roughly between 1100 ft near Newhall on the south and approximately 950 ft at well NLF-156 on the northwest near the Holser fault. As seen by the broad arrows on the map, such data suggest a northerly to northwesterly groundwater flow direction for Saugus wells in the vicinity of the South Fork of the Santa Clara River.

d. West of V-160, groundwater appears to follow a more westerly flow direction, subparallel to the trace of the Holser fault.

e. The groundwater gradient in the South Fork region is about 0.005 ft/ft (28 ft/mi), even though localized undulations in the contour values are readily apparent. The reasons for the undulations are not known with certainty, but likely reflect differences in water levels in various wells over the few months' time period of data delineated on the map.

f. A water level low (to elevation 915 ft) is seen at NLF-155, but this likely reflects either a partial recovery level instead of a true fully-recovered, non-pumping level and/or a monitoring error.

g. Our interpretation of the piezometric surface data for V-158, located between the two faults, suggests a northwesterly flow direction for groundwater in this area. It also appears that the Holser fault provides at least a partial barrier to groundwater flow within at least the deeper portions of the Saugus Formation, as evidenced by the different piezometric levels between V-158 on the north and V-160 on the south.

Data on Plate 8 reveal:

a. There are only nine wells for which data exist, these all being located southerly of the Holser fault.

b. No current water level data exist for the area of the Saugus Formation between the two faults or northerly of the San Gabriel fault.

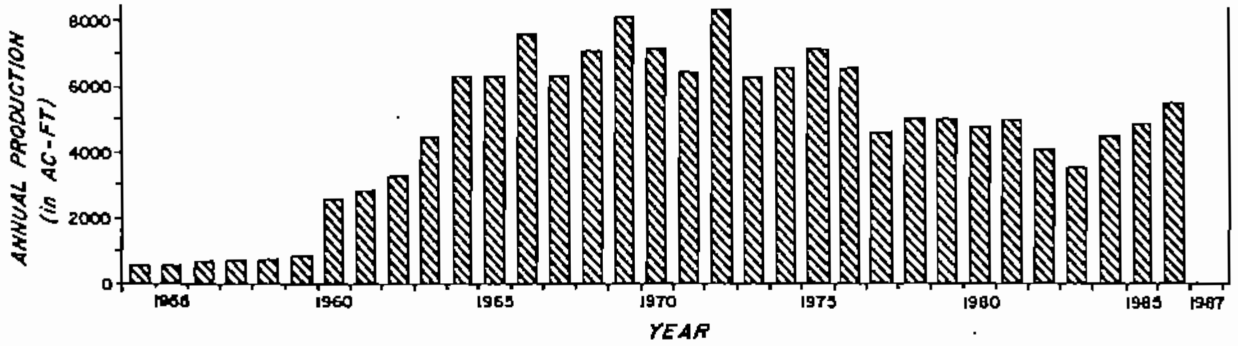
c. Groundwater elevations (piezometric surfaces) near Newhall range from 1300 ft on the south to 1100 ft on the north; groundwater flow direction, as indicated by the broad arrow is to the northwest.

d. The groundwater gradient in the Newhall area is approximately 0.017 ft/ft, or about 90 ft/mi.

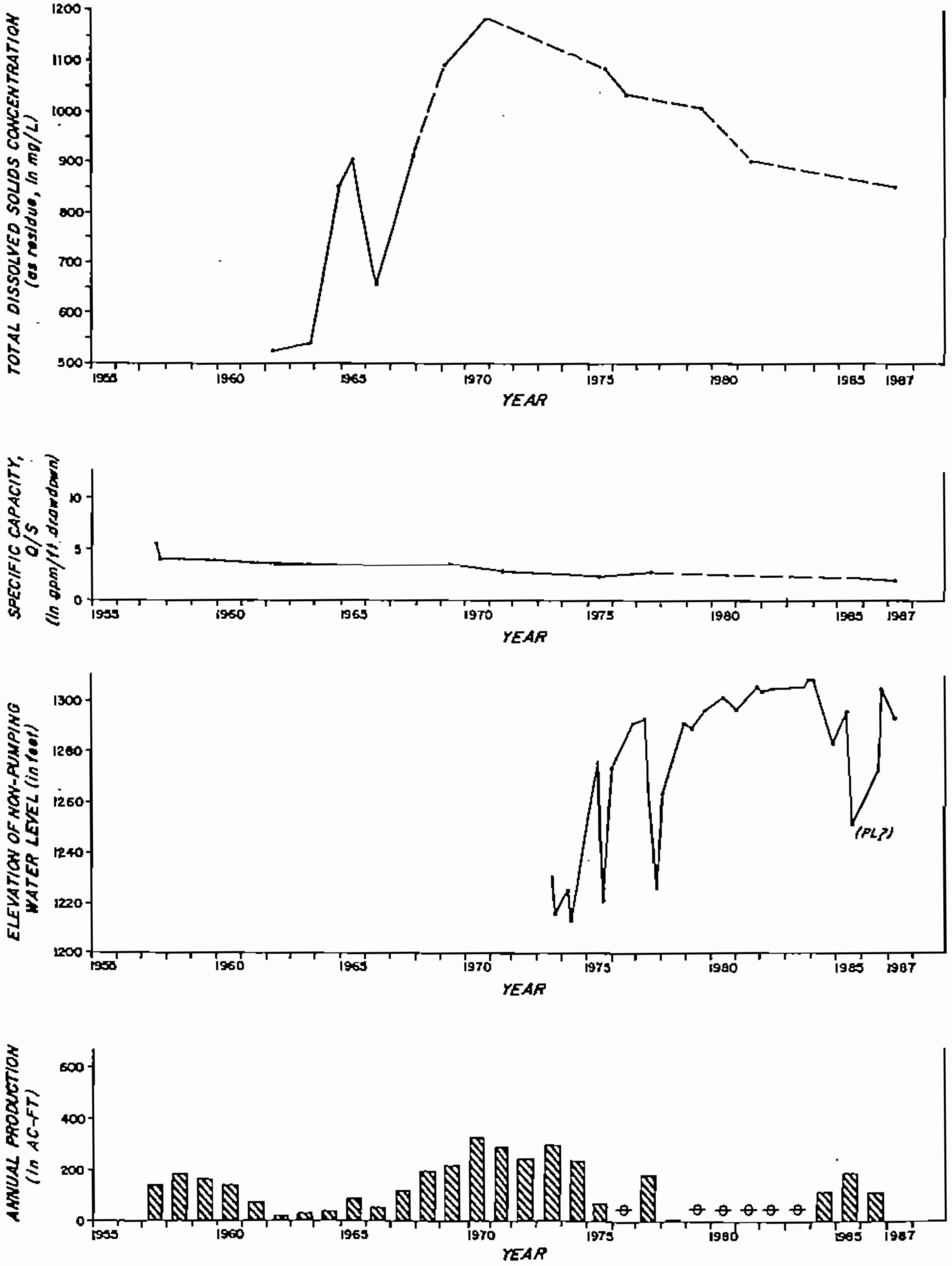
e. Based on sparse data, the groundwater gradient northwest of Newhall appears to flatten noticeably as the Holser fault is approached near well V-160. In the area between Newhall and V-160, groundwater still appears to move northwesterly, but with an apparent gradient of only 0.0037 ft/ft (19 ft/mi).

Hydrographs. Hydrographs from five wells in the region (NC-9 and -10, and V-157, -158, and -160) have been prepared on Figures 4.1 and 4.2 - Histograms of Selected Wells - in order to reveal fluctuations in non-pumping water levels (piezometric water levels) with time. Also shown on these figures are plots of specific capacity vs. time, elevation of

HISTORIC SAUGUS FORMATION PRODUCTION FOR ALL AGENCIES



NEWHALL COUNTY WATER DISTRICT NO. 9



NEWHALL COUNTY WATER DISTRICT NO. 10

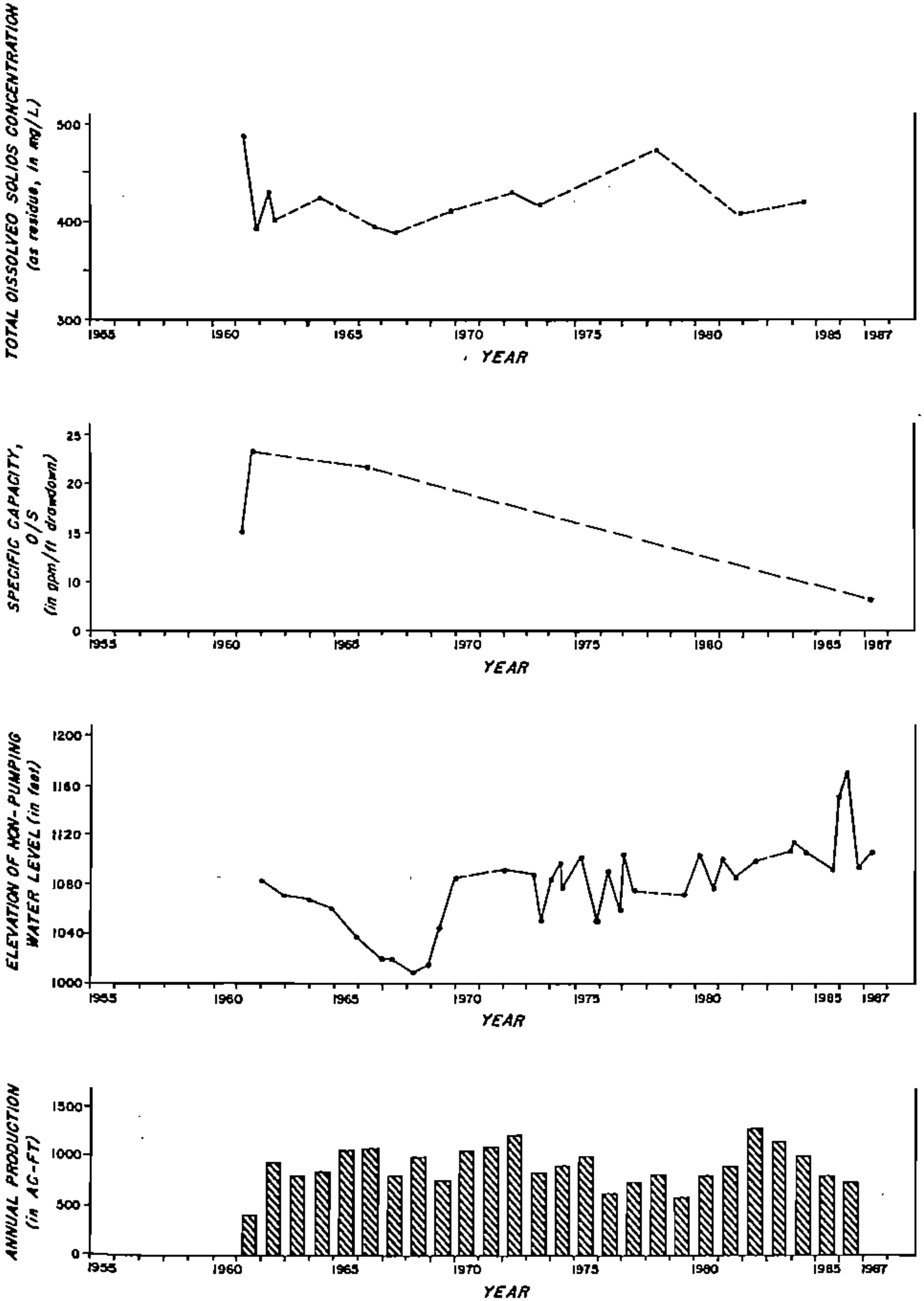
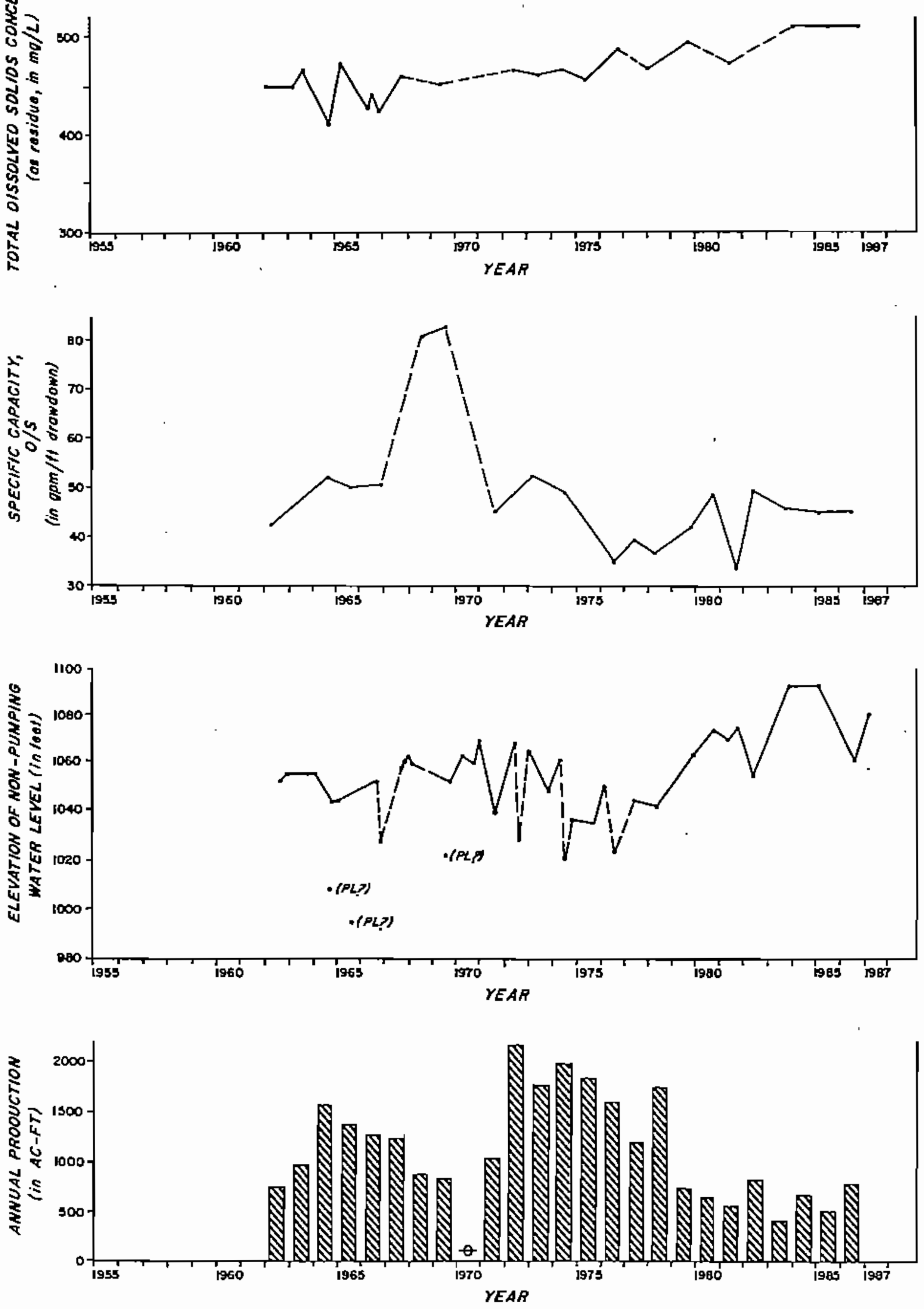
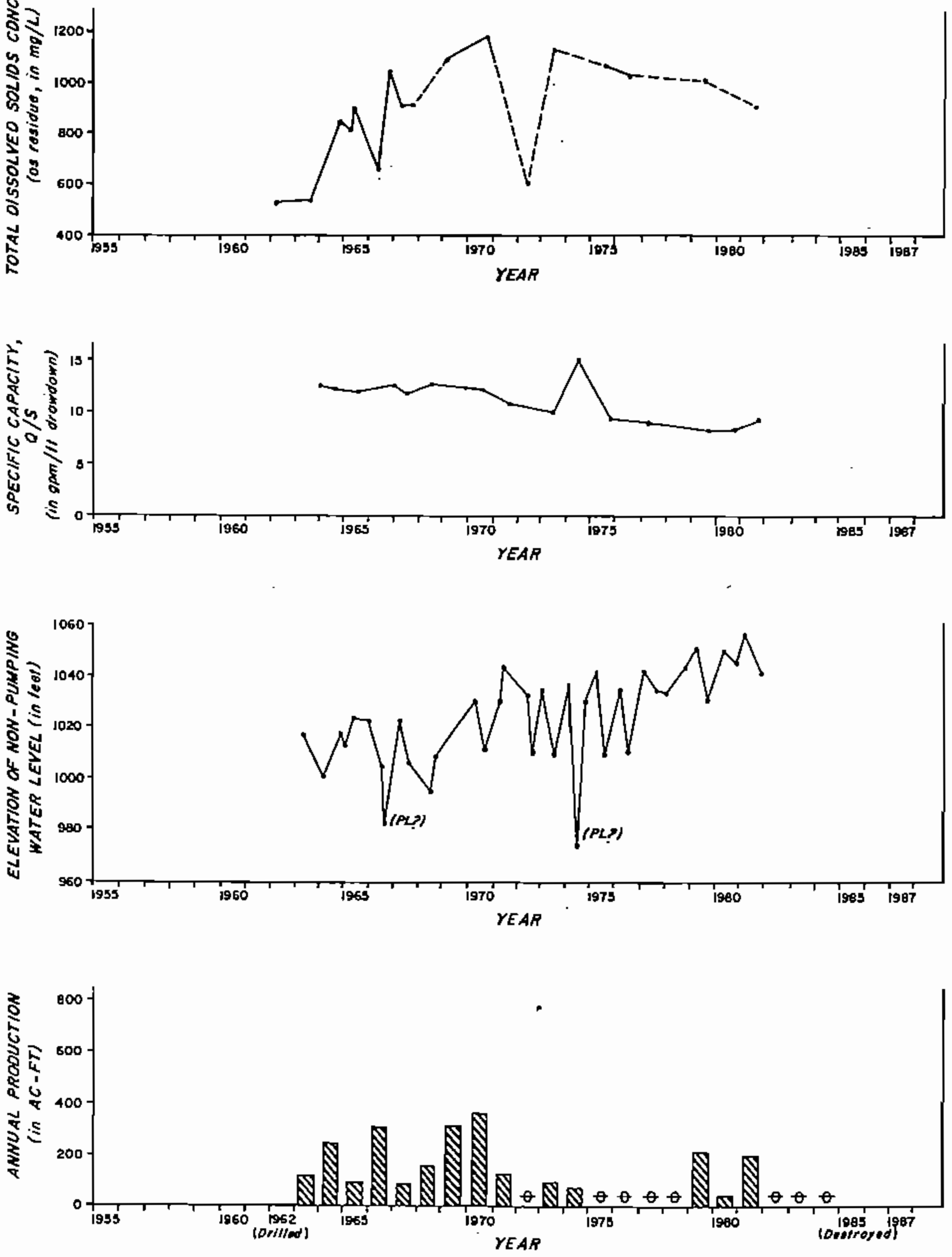


FIGURE 4.1 - HISTOGRAMS OF SELECTED WELLS

VALENCIA WATER COMPANY NO. 157



VALENCIA WATER COMPANY NO. 158



VALENCIA WATER COMPANY
NO. 160

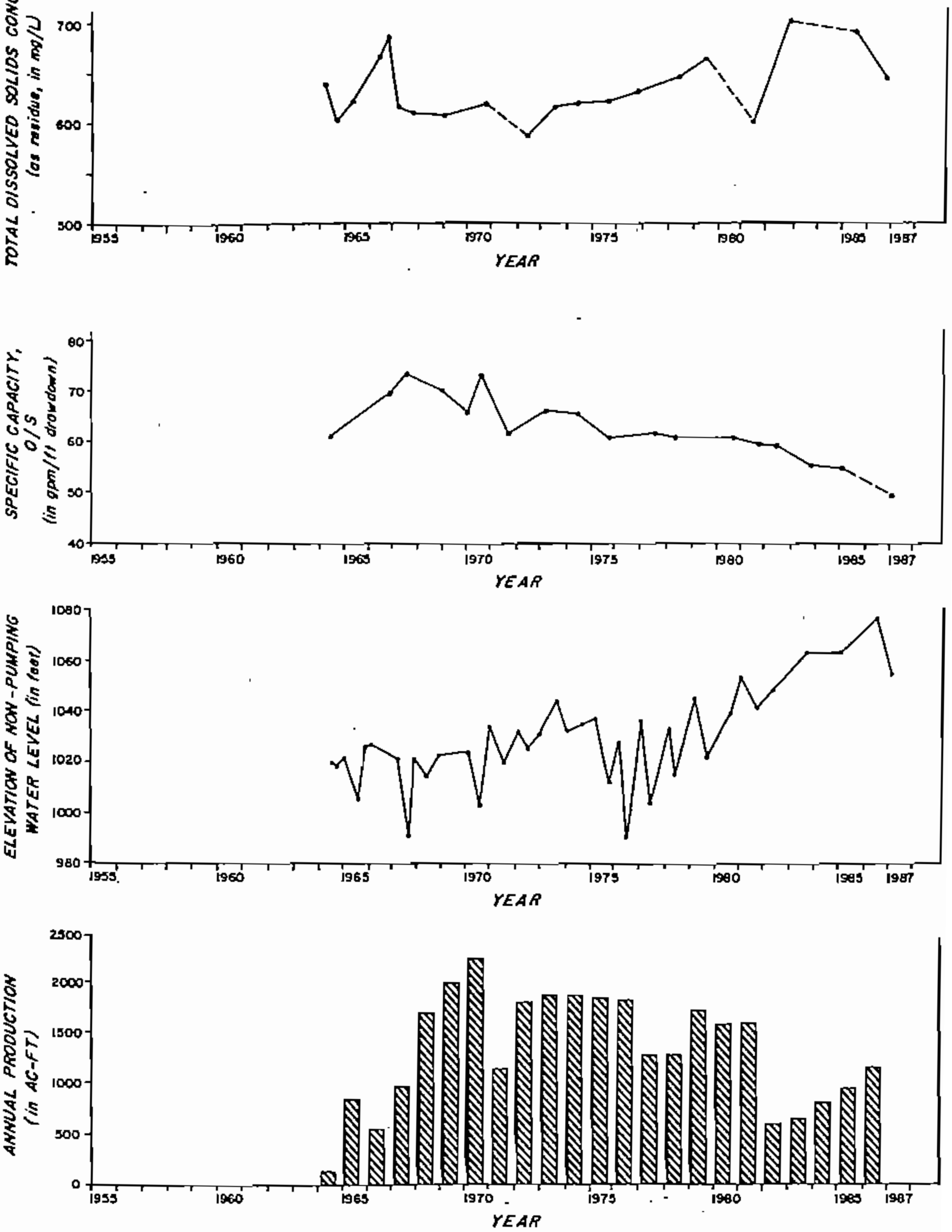


FIGURE 4.2 - HISTOGRAMS OF SELECTED WELLS

non-pumping water levels vs. time, and annual groundwater production for each respective well. For comparison, a histogram of total Saugus Formation groundwater production by all purveyors during the period of record (1954 through 1986) is also shown.

Review of the piezometric water levels vs. time on Figures 4.1 and 4.2 indicates:

a. All five wells display a trend of rising levels during the period of record. None of the records pre-dates the early- to mid-1960's, however.

b. During the period of record, water wevel rises have ranged from roughly 0.5 ft/yr in V-157 to about 4 ft/yr in NC-10.

c. Superimposed on this long-term trend are the seasonal variations in piezometric levels. Typically, spring levels are 20 to 40 feet higher than water levels measured later in the particular year.

d. Certain water level lows (e.g., in 1977 or 1985 in NC-9, or in 1966 or 1974 in V-158) represent pumping levels or partial recovery levels or monitoring errors, and thus are not true non-pumping piezometric levels.

e. There are no definitive trends between water quality or groundwater production and piezometric levels with time displayed on any of the histograms. The reasons for the long-term rise in water levels in each well coupled with the concomitant decline in specific capacity during the same period are unrelated.

Aquifer Parameters. To assess well yields, mutual well drawdown interference and/or well spacing criteria for future wells, it is necessary to first evaluate the water transmitting, or hydraulic properties of the aquifer(s). These properties, which include transmissivity and storativity, are strongly influenced by the arrangement, sorting, shape, and size of the individual sediment grains and intergranular void spaces which comprise the aquifers. Transmissivity (symbol T, in units of gallons per day per vertical foot of aquifer, gpd/ft) and storativity (symbol S, in cubic feet of water per square foot of aquifer per foot of head, ft^3/ft^3, and thus dimensionless) are typically derived from analyses of water level drawdown and recovery tests in pumping and observation wells (i.e., from aquifer tests).

Of the eight Saugus wells known to be actively used in 1986, five wells were selected to be pumping wells for our aquifer test program. Our selection of the wells in which to conduct the aquifer tests for this project was based on numerous factors, including:

a) location and spatial relationship within the groundwater basin and proximity to faults and other potential barriers to groundwater flow;

b) the depth interval of perforated casing;

c) the efficiency, age, and condition of the wells;

d) availability and proximity of potential observation wells; and

e) coordination with the purveyors to consider pumping demand schedules and logistical problems in shutting down/turning on the wells for prescribed periods of time.

The five wells used for our tests were NC-7, -9, and -10, and V-157 and -160. For each pumping well, it had been hoped to utilize other nearby wells (either in the Saugus Formation or in the alluvium) as observation wells during each test in order to collect additional water level data. The principal criteria in selecting potential observation wells would be proximity to the aquifer test pumping well and ensuring that the observation well was not pumping (i.e., that static, non-pumping conditions existed in the observation well throughout the aquifer test).

In most cases, however, it was not possible to utilize observation wells because: there are too few Saugus Formation wells in the region; these wells are generally spaced too far apart to be useful as observation wells; and it was often too difficult to shut down the highly active alluvial wells because of local agricultural demands. Table 4 - Summary of Aquifer Test Data - shows the pumping and observation wells used during the aquifer tests, the dates and durations of the tests, and the quantitative results of these tests using both graphical and computer methods. As shown on Table 4, the five aquifer tests were conducted between March 4 and April 3, 1987. With the exception of V-160, the tested wells were pumped continuously at constant discharge rates for 24 hours, and then shut down and allowed to recover for at least 24 hours. Typical pumping rates were in the range of 256 gpm (NC-9) to 2562 gpm (V-160).

The reader is referred to Appendix A - Aquifer Testing - for additional details of test logistics during the aquifer tests, and for details concerning our quantitative analyses of the data. Individual graphs of the field drawdown and recovery data are presented in Appendix A as Figures A-1 through A-12.

Review of the data on Table 4 reveals the following:

1. T values range from lows of approximately 3000 to 4100 gpd/ft in NC-9 to highs of approximately 157,000 to 182,000 gpd/ft in V-160. NC-9 is the most southerly of the wells tested and is located nearest the edge of the Saugus Formation structural basin; whereas V-160 is the most northerly of the tested wells and is nearest to the center of the structural basin.

2. T values increase toward the center of the structural basin; that is, toward the area of younger Saugus Formation strata, between NC-9 on the south and V-160 on the north.

S8701 - QTs

TABLE 4 - SUMMARY OF AQUIFER TEST DATA

DATE OF TEST	TYPE OF TEST	LENGTH OF TEST (mins)	PUMPING WELL	PUMPING RATE (gpm)	WELL MONITORED	METHOD OF ANALYSIS (1)	AQUIFER VALUES T (gpd/ft)	AQUIFER VALUES S (2) (cu ft/cu ft)	SPECIFIC CAPACITY (gpm/ft)
3/4/87	Drawdown	1440	NC 7	341	NC 7	G	33,300	-	3.1
						C	26,400	-	
		1440	NC 7	341	NC 8	(3)	-	-	
3/5/87	Recovery	1500	NC 7	341	NC 7	G	20,700	-	-
						C	23,300	-	
		1490	NC 7	341	NC 8	(3)	-	-	
3/10/87	Drawdown	1440	NC 10	364	NC 10	G	31,000	-	8.3
						C	28,500	-	
		1440	NC 10	364	NC 12	G	57,500	0.00087	
						C	57,700	0.00091	
3/11/87	Recovery	1480	NC 10	364	NC 10	G	35,300	-	-
						C	36,400	-	
		1490	NC 10	364	NC 12	G	54,000	-	
						G	59,300	0.00080	
						C	61,500	0.00076	
3/17/87	Drawdown	1460	NC 9	256	NC 9	G	4,100	-	1.9
						C	3,700	-	
3/18/87	Recovery	1500	NC 9	256	NC 9	G	3,300	-	-
						C	3,000	-	
3/24/87	Drawdown	720	V 160	2562	V 160	G	169,000	-	49.8
						C	163,000	-	
3/24/87	Recovery	850	V 160	2562	V 160	G	157,000	-	-
						C	182,000	-	
4/1/87	Drawdown	1440	V 157	1347	V 157	(4)	-	-	-
		1440	V 157	1347	V N-68	(5)	-	-	
		1440	V 157	1347	NLF K-2	(5)	-	-	
		1440	V 157	1347	Private (H1)	(5)	-	-	
4/2/87	Recovery	1520	V 157	1347	V 157	G	88,900	-	-
		1530	V 157	1347	V N-68	(5)	-	-	
		1540	V 157	1347	NLF K-2	(5)	-	-	
		1540	V 157	1347	Private (H1)	(5)	-	-	

NOTES: (1) G = Graphical (semi-log) solution; C = "Theisfit" computer program solution.
(2 S value cannot be determined by pumping well measurements; an observation well is required
(3) Not analyzed; observation well NC 8 showed no change due to pumping of NC 7 1200 ft away.
(4) Not analyzed; pumping levels not obtainable due to mechanical problem with well.
(5) Not analyzed; observation wells perforated in alluvium showed no change due to pumping of V 157.
V N-68 = 2000 ft from V 157
NLF K-2 = 1700 ft from V 157
Private (H1) = 2300 ft from V 157

3. The range in values for any particular well results from other factors, including age and condition of the well, types of perforations in the well, chemical precipitates in the well, local aquifer conditions, consolidation and/or cementing in the local sediments, and proximity to the Santa Clara River and to the two major faults in the basin.

The other major aquifer parameter, storativity or storage coefficient (S), cannot be determined directly from water level data from the pumping well alone; monitoring data from observation well(s) near the pumping well are required. As shown on Table 4, the only observation well to display drawdown due to pumping in a nearby well was NC-12. This recently drilled (1985) well is 157 ft from pumping well NC-10 and, at the time of aquifer testing in NC-10, was not yet equipped with its own pump and motor. No drawdown interference was monitored in any of the alluvial wells (N-68, NLF K-2, or private well H-1) which were monitored as observation wells during the aquifer test of Saugus Formation well V-157.

As shown on Table 4, S values ranged from 0.00076 to 0.00091. Storativity is a dimensionless quantity involving a volume of water per volume of aquifer. S values between 0.00005 and 0.005 are considered typical of confined aquifers.

Specific capacity, a measure of the gallons per minute per foot of drawdown in the well (units of gpm/ft) was calculated for aquifer test wells using the final drawdown measurements at the end of the 24-hour pumping tests and the average pumping rate during these constant discharge drawdown tests. Resultant specific capacity values (also listed on Table 4) range from 1.9 gpm/ft to NC-9, to 3.1 gpm/ft for NC-7, to 8.3 gpm/ft for NC-10; and to 49.8 gpm/ft for V-160. Specific capacity for V-157 was indeterminant because a mechanical problem in this well prevented measurement of accurate pumping levels.

Specific capacity values for NC-9 and NC-7 are slightly lower but consistent with those obtained from the most recent available Edison Company efficiency tests (2.3 gpm/ft in 1975 for NC-9 and 3.9 gpm/ft in 1986 for NC-7). At V-160, the current value is somewhat lower than the most recent (1981) Edison test value of 59.7 gpm/ft. The current specific capacity value for NC-10 is considerably lower than the 21.6 gpm/ft value obtained in 1966, the most recent Edison test data available. This large difference is due to a combination of: the aquifer test pumping rate being much lower than the normal operational rate; possible buildup of chemical precipitates in the gravel pack and on the perforations; and possible mechanical problems in the well and/or pump.

To further corroborate the magnitude of the transmissivity, we also used an empirical method, namely, the modified Thiem equation. With this approach, the theoretical value of T is assessed by relating T to the actual specific capacity from well data. For the confined aquifer conditions found within the Saugus Formation, the empirical relationship is approximately:

Theoretical $T = 2000\ Q/s$, where

Q/s = specific capacity
Q = well yield, in gpm
s = amount of drawdown, in ft, created in the well by that pumping rate
2000 = an empirical constant.

Theoretical T values were thus calculated using specific capacity data obtained from our recent aquifer testing. For comparison and to demonstrate the effects of well age and condition, theoretical T values also were calculated for specific capacity data obtained from the earliest available Edison pump efficiency tests (these date from one month to 2-1/2 years after well construction). The following tabulation lists the theoretical T values obtained using these two data sources. These values can be compared to T values computed from actual aquifer tests by reference to Table 4.

THEORETICAL TRANSMISSIVITY (gpd/ft)

Well	From 1987 Specific Capacity Data	From Earliest Edison Test Data
NC-9	3,800	8,000
NC-7	6,200	13,400
NC-10	16,600	46,200
V-157	Not determined	84,800
V-160	99,600	139,200

For NC-9, the 1987 theoretical T is consistent with the actual T values determined from aquifer testing. Recent 1987 theoretical T values for NC-7, NC-10, and V-160 are approximately 25 percent, 50 percent, and 60 percent, respectively, of representative actual T values for those wells.

Theoretical T values for early Edison test data are generally higher and closer to actual aquifer test T values than are the 1987 theoretical T values, thus showing effects of age and condition of the wells. Such conditions as encrustation of the well perforations and of the gravel pack will cause increased head losses (drawdown) in the well and thus reduced specific capacity.

The above values of theoretical T are considered to represent the overall transmissivity of all aquifers penetrated/perforated by the well to its particular total depth. Because aquifer T values are additive, it follows that if wells were drilled into deeper water-bearing zones within the

b. For NC-10, specific capacity data are meager but tend to reveal a continuous decline from 1960-61 to 1987, from a high of approximately 22 gpm/ft to a low of 9 gpm/ft, respectively. Encrustation is suspected to be the cause.

c. In V-157, specific capacity appears to have remained approximately the same with time, even though there have been wide fluctuations from one year to another. Early values in 1961-62 were approximately 40 gpm/ft, while values in the 1980's were on the order of 43 gpm/ft. Large variations (such as in 1970 or 1981) likely relate to errors in water level monitoring (partial recovery levels were obtained, not true non-pumping levels).

d. For V-158, specific capacity declined slightly but continuously with time. Original values in 1963 were about 13 gpm/ft, but by 1981, Q/s had declined to about 9 gpm/ft (roughly a 30 percent decline with time). The high reading of 1974 is a water level monitoring error. Encrustation is the principal reason for the declinining Q/s.

e. Specific capacity in V-160 also has declined steadily with time, from values on the order of 60 to 70 gpm/ft in the mid- to late-1960's to 50 gpm/ft in 1985; encrustation is thought to be the main cause. Early increases in Q/s from 1965 to 1970 may be related to poor well development when the well was initially drilled; subsequent pumping and non-pumping during early years of use actually served to remove additional drilling fluids from the well bore, thus increasing the specific capacity.

f. There does not appear to be any correlation between specific capacity value and trends in TDS, water levels and/or groundwater production versus time for these wells.

Predicted Future Drawdown. Based on representative values for aquifer parameters and pumping rates that were obtained from the aquifer tests, design values for T and S have been assigned in order to establish the magnitude of drawdown interference anticipated in new wells and the magnitude of future well spacing in the area. This method employs the Theis equation which is well documented in the literature and is frequently utilized to define the theoretical distance-drawdown relationships between nearby wells.

Theoretical values have been calculated for drawdown in a single pumping well and for drawdown at radial distances of 1000 and 2000 ft from the pumping well, and for continuous pumping times of three months, six months, and one year. Based on our quantitative analyses of the aquifer test data, we also selected the following representative values for our assessment of distance-drawdown criteria: pumping rates of 500 gpm, 1500 gpm, and 2500 gpm; T values of 40,000 gpd/ft, 90,000 gpd/ft, and 150,000 gpd/ft; and S = 0.0008.

Table 5 - Predicted Future Drawdown - has been prepared to present the results of the calculations using the aforementioned variables. All drawdown data on Table 5 , including that in the pumping well and that at radial distances of 1000 and 2000 ft from the pumping well are assumed to be due only to that single pumping well.

Use of Table 5 for a single pumping well is as follows. For example, for an aquifer transmissivity of 90,000 gpd/ft, one well pumping continuously at 1500 gpm for six months would induce a drawdown in this well (self-induced drawdown) of approximately 43 ft. If the pumping rate were increased to 2500 gpm, the resulting self-induced drawdown would be approximately 72 ft after six months of pumping.

If another pumping well were to be located at either of these distances from the first pumping well, the drawdown influence of the first well at the second site would then be added to the self-induced drawdown at the second site in order to predict future drawdown at that second site. This additive procedure would also apply to any additional drawdown at the first well due to pumping at the second site.

TABLE 5 - PREDICTED FUTURE DRAWDOWN

Transmissivity at Pumping Well (gpd/ft)	Theoretical Drawdown (ft) at 500 gpm 3 mos.	at 500 gpm 6 mos.	at 500 gpm 1 yr.	at 1500 gpm 3 mos.	at 1500 gpm 6 mos.	at 1500 gpm 1 yr.	at 2500 gpm 3 mos.	at 2500 gpm 6 mos.	at 2500 gpm 1 yr.
in Pumping Well									
40,000	30	31	32	90	93	96	151	155	161
90,000	14	14	15	42	43	44	70	72	74
150,000	9	9	9	26	26	27	43	44	45
at 1,000 ft from Pumping Well									
40,000	10	11	12	31	34	37	52	57	62
90,000	5	6	6	15	17	17	26	28	30
150,000	3	4	4	10	11	11	16	18	19
at 2,000 ft from Pumping Well									
40,000	8	9	10	25	28	31	42	47	52
90,000	4	5	5	13	14	16	21	23	26
150,000	3	3	3	8	9	10	14	15	16

Use of Table 5 for multiple well pumpage is as follows. For example, for an aquifer T of 90,000 gpd/ft, one well pumping continuously at 1500 gpm for six months creates a self-induced drawdown of 43 ft and an additional interference drawdown of 17 ft at a radial distance outward from this well of 1000 ft. If an identical well were similarly pumping at this 1000-ft distance, total drawdown in each well would be: its own self-induced drawdown of 43 ft plus the interference drawdown of 17 ft created by pumping the other well; total drawdown is thus 60 ft in each well.

Groundwater Quality. To evaluate the chemical character of Saugus Formation water quality, we have prepared Figures 3.1 and 3.2 - Trilinear Analyses Diagrams. These diagrams are constructed using the relative percentages of the primary cations and anions in the water, with the percentages being based on the total equivalents per million of each major ion as determined in the water laboratory. Data shown on Figures 3.1 and 3.2 date from the late-1970's to 1987 for wells owned by NCWD and/or SCWC (Fig. 3.1), and from the late-1950's to 1985 for wells owned by NLF and/or VWC (Fig. 3.2). It should be noted that several of the wells listed on Figure 3.2 are used for agricultural purposes and, thus, do not require frequent quality testing, and/or have been abandoned and thus are no longer in use at all.

TDS values shown on Figures 3.1 and 3.2 and used elsewhere in this study are for total filterable residues and not the higher values of summation of individual ions as historically reported in the past. This approach is consistent with TDS values currently reported by local laboratories.

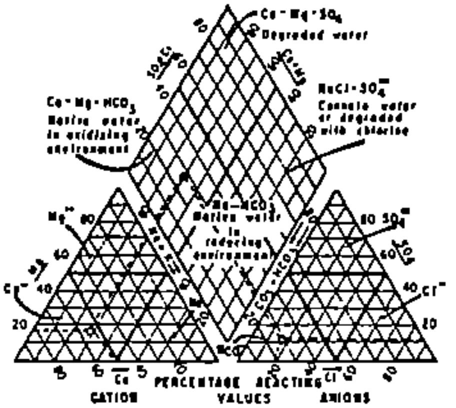
Figure 3.1 data are for six existing Saugus wells owned by NCWD, one destroyed well previously owned by SCWC

S8701

Newhall County Water Dist.
and
Santa Clarita Water Co.

Figure 3.1

TRILINEAR DIAGRAM - Saugus Formation



LEGEND
EXAMPLE OF PLOTTING METHOD

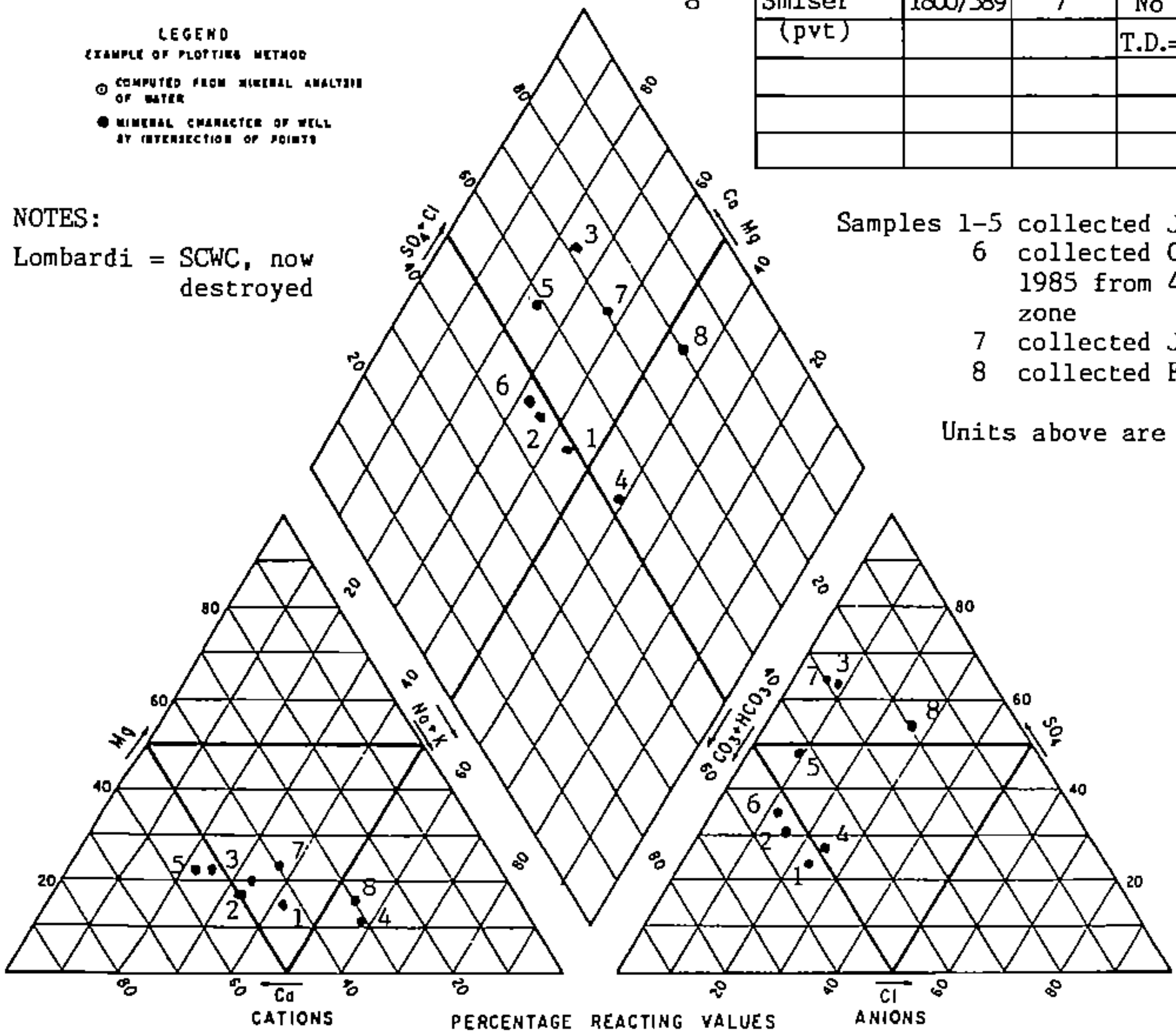
⊙ COMPUTED FROM MINERAL ANALYSIS OF WATER

● MINERAL CHARACTER OF WELL BY INTERSECTION OF POINTS

Symbol	Well	TDS/TH	NO_3	Perfs. (ft)
1	NCWD- 7	478/238	5	520- 974
2	- 8	410/234	5	342- 970
3	- 9	636/380	0	280- 591
4	-10	422/153	3	780-1550
5	-11	552/349	23	200-1075
6	-12	525/281	31	485-1280
	SCWC			
7	Lombardi	766/395	8	260-1130
8	Smiser	1800/589	7	No Data
	(pvt)			T.D.=1000 ft

NOTES:

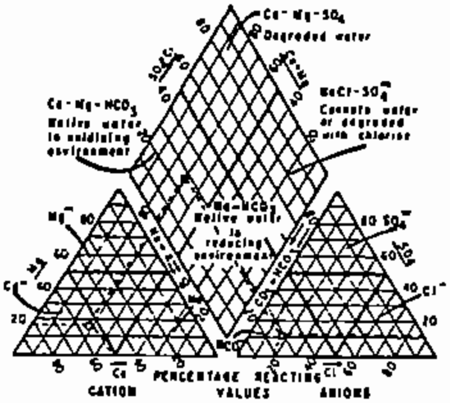
Lombardi = SCWC, now destroyed



Samples 1-5 collected July 1984
6 collected October 1985 from 485-500 ft zone
7 collected June 1977
8 collected Feb. 1987

Units above are mg/l

Figure 3.2
TRILINEAR DIAGRAM - Saugus Formation



LEGEND
EXAMPLE OF PLOTTING METHOD

⊙ COMPUTED FROM MINERAL ANALYSIS OF WATER

● MINERAL CHARACTER OF WELL BY INTERSECTION OF POINTS

Symbol	Well	TDS/TH	NO_3	Perfs. (ft)
1	157	510/252	8	586-2008
2	160	690/403	11	950-2000
3	158	902/471	57	740-1605
4	156	1156/621	13	320-1800
*5	154	1027/593	34	29-1003
6	155	656/349	16	108-1468
7	159	1010/392	0	662-1900
8	P-2	1554/919	20	450-1290

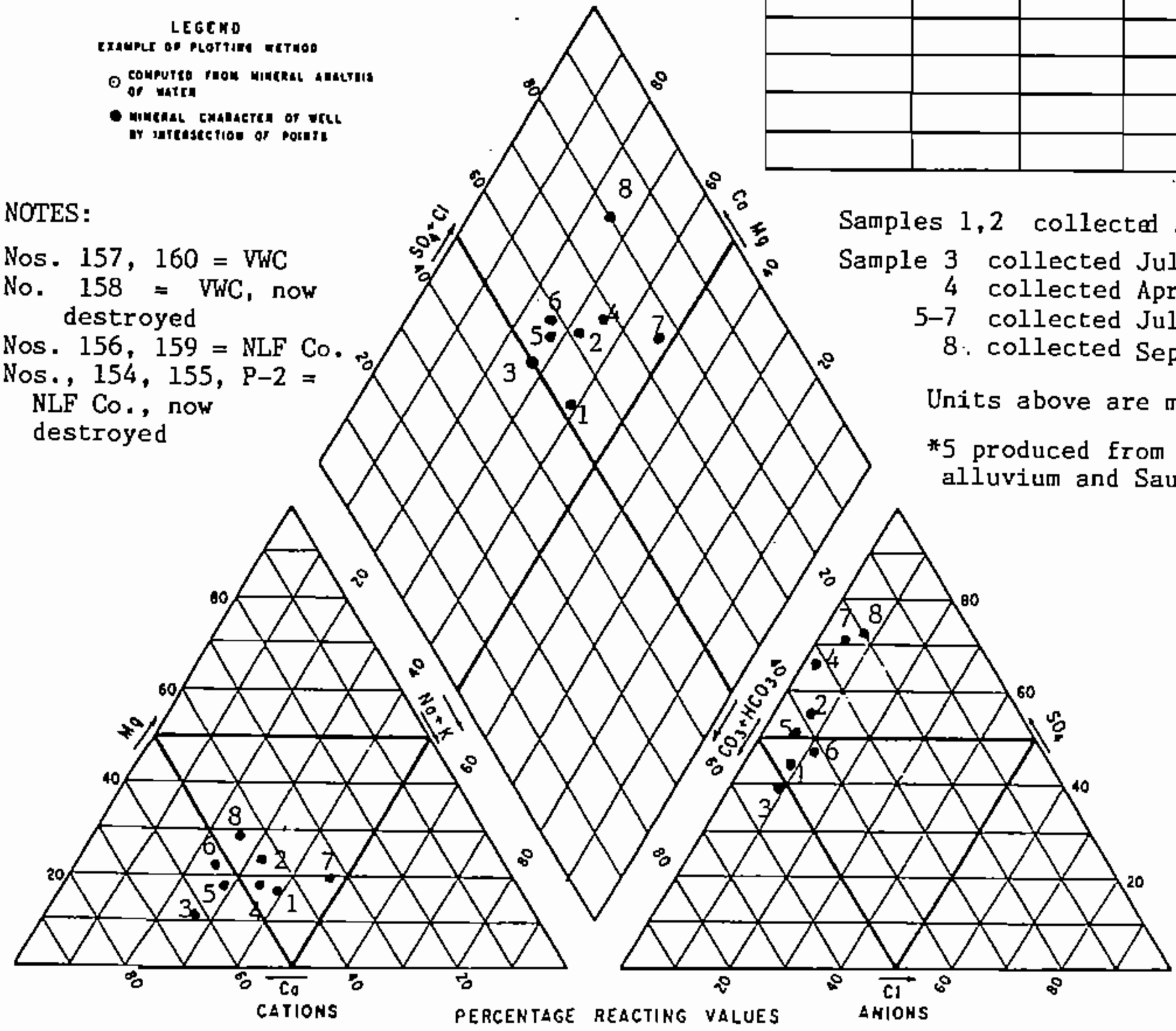
NOTES:

Nos. 157, 160 = VWC
No. 158 = VWC, now destroyed
Nos. 156, 159 = NLF Co.
Nos., 154, 155, P-2 = NLF Co., now destroyed

Samples 1,2 collected Aug. 1985
Sample 3 collected July 1981
4 collected April 1963
5-7 collected July 1964
8 collected Sept. 1959

Units above are mg/l

*5 produced from both alluvium and Saugus Fm.



(Lombardi well), and the only privately-owned well (Smiser well).

a. NC-7, -8, -10 and -12 display a calcium bicarbonate character which is representative of a natural subsurface environment of oxidizing conditions. In such an environment there is good movement and circulation of groundwater. In these wells, total dissolved solids (TDS) and total hardness (TH) are typically on the order of 410 to 525 mg/l and 153 to 281 mg/l, respectively.

b. In contrast, NC-9 and SC-Lombardi, located farther south in the basin, display a calcium-magnesium sulfate (calcium-magnesium sulfate) character on Figure 3.1 which may be representative of natural waters high in sulfate. Field monitoring during aquifer testing of NC-9 in the spring of 1987 detected the presence of a slight hydrogen sulfide odor in the discharge at the well head. There are no available laboratory data to define the concentration of hydrogen sulfide in this well, however. These two wells have TDS values of 636 and 766 mg/l, respectively, and TH values of 380 and 395 mg/l, respectively.

c. The Smiser well (symbol No. 8) is also located near the southern edge of the groundwater basin. It displays a slightly anomalous sodium-chloride sulfate character, possibly related to connate waters deep within the Saugus Formation. Because of its location very near the edge of the basin, and due to its approximately 1000-foot depth, this well probably produces, in part, from the Sunshine Ranch member of the Saugus Formation and likely is very near the top of the Pico Formation in this area. TDS and TH values are very high (1800 mg/l and 589 mg/l, respectively).

d. NC-11 also shows a calcium-magnesium sulfate character, but it is farther out into the basin than NC-9 and SC-Lombardi which have the same character. Its sulfate character, however, is probably not related to the penetration of NC-11 into the basal Saugus (its basinal location and well depth preclude this). Instead, because NC-11 has high perforations (beginning at 200 ft), and no deep cement seal, it obtains some production from the alluvium which is known to have sulfate.

e. NC-10, the well with the deepest level of uppermost perforations (perforations beginning at 780 ft) has a low TDS (422 mg/l) and a very low TH (153 mg/l) compared to the other wells shown on Figure 3.1.

f. None of these wells has a nitrate problem because no values are in excess of the State limit of 45 mg/l.

Data on Figure 3.2 reveals:

a. Wells nearer the center of the basin (such as V-157, -158 and -160) show a slight calcium-magnesium sulfate character, only slightly removed from the calcium bicarbonate character.

b. Wells NLF-159 and P-2 are located near the southern edge of the groundwater basin; they display the same calcium-magnesium sulfate character as other wells in this area (NC-9, SC-Lombardi). Neither well is deep enough to penetrate the full thickness of Saugus strata, however.

c. TDS values are generally high for all wells, ranging approximately between 500 and 1260 mg/l during the period of record; TH values ranged approximately between 250 and 950 mg/l.

d. Uppermost perforations in these wells, as a group, begin at depths below 320 ft, with the exception of NLF-154 (begin at 29 ft) and NLF-155 (begin at 108). The latter two wells, when active, did produce from the alluvium as well as from the Saugus Formation.

e. Gravel packs in the wells rise above the uppermost perforations and continue to near ground surface; where known, cement seals are only very shallow. Hence, these wells may obtain some groundwater from the allivium via leakage down the gravel pack, even though the perforations are deep.

f. V-158 displayed nitrate of 57 mg/l in July 1981, a value which exceeds State limits. However, this is almost certainly due to the lack of a deep cement seal rather than ambient high background levels of nitrate deep in the Saugus Formation.

Graphs of TDS vs. time are presented as histograms on Figures 4.1 and 4.2 for wells NC-9 and -10, and for V-157, -158, and -160. Notable on these TDS vs. time graphs are the following:

a. There appears to be a general increase in TDS in all five wells vs. time.

b. Generally, the amount of TDS increase with time for each well is approximately: 300 to 400 mg/l in Nc-9; 20 to 30 mg/l in NC-10; 50 to 75 mg/l in V-157; 300 to 350 mg/l in V-158; and 40 to 70 mg/l in V-160.

c. With the possible exception of NC-9, these wells display no relationship between increasing TDS values and water level elevations and/or groundwater production. For NC-9, the high TDS values of the early-1970's may correlate with concomitant years of high production in this well coupled with generally low water levels. As water levels decline in this southerly portion of the basin, more of the groundwater produced would be derived from the lowermost portions of the formation and, hence, would result in quality impairment.

To assess the relative potential of the Saugus Formation groundwater to either corrode or encrust steel well casing, the Langelier Calcium Carbonate Saturation Index and the Ryznar Stability Index were calculated for 16 wells from laboratory data dating between 1963 and 1987 (requisite data do not exist for NC-1,-2,-3,-4,-5, or -6, all of which were destroyed years ago). Though the calculations and tabulations are not presented herein, the resulting index values are:

a. +0.02 to +0.70 for the Langelier Index. Here, the larger the positive value, the greater is the tendency for the water to deposit calcium bicarbonate and, hence, cause encrustation; a large negative value indicates a tendency to dissolve calcium bicarbonate (hence, cause corrosion). With this index, the water has a slight tendency to induce encrustation.

b. 6.1 to 7.4 for the Ryznar Index. With this index, low values are considered to be encrustating, while high values tend to indicate corrosive conditions. Ryznar value in the range of 7 to 9 are generally considered to be neither severely corrosive nor heavily encrustating.

Theoretical Water Quality. Estimates of groundwater quality (TDS, total dissolved solids) can be made using data derived from the spontaneous-potential (SP) and resistivity curves of electrical logs (E-logs) of oil and water wells, provided that certain properties of the drilling mud are also known. Various methods are discussed by Mougne (1978, and personal communication, 1987), Guyod (1966), Jones and Buford (1951), and Bryan (1950).

Important properties of the mud include: type of mud, mud weight, viscosity, temperature, and mud resistivity (Rm) and resistivity of the mud filtrate (Rmf). Calculations are made to determine the resistivity of the water (Rw) within the aquifers. The water-resistivity values are then converted to hypothetical salinity values on the basis of experimentally derived resistivity-salinity curves for various types of groundwaters (bicarbonate, sulfate, chloride waters).

Our initial approach was to apply the various methods of estimating water quality (TDS) to the Saugus water wells for which there are electric logs and laboratory data on water chemistry. Unfortunately, the properties of the drilling mud for all but one of the Saugus water wells are not known, so we could not apply the calculations to individual water wells for the purpose of calibrating our method. Therefore, we calculated TDS values using E-logs and mud data from oil wells in the vicinity of the water wells and compared the theoretical TDS values from the oil wells with the known water chemistry from the nearby water wells.

We calculated theoretical TDS values for two different depth zones in the Saugus: a shallow zone (500 feet to 1000 feet in depth) and a deep zone (2000 feet to 2500 feet in depth). These two depth zones were selected to represent both the shallowest and deepest aquifer zones available for casing perforations in potential future water wells. Additional intermediate depth zones were not selected for several reasons. Degraded groundwater quality generally results from either man-influenced, near-surface activities or from deeper natural formation properties. If, for example, both the shallow and deep zones display similar character, an intermediate zone at the same site also can be expected to display a like character. Theoretical quality determinations are intended to be used as general guidelines only. This intended usage as well as the inaccuracies inherent in the method make theoretical quality determinations for intermediate depth zones an unnecessary, and likely unwarranted, level of interpretation.

Results of the theoretical calculations show values from the oil wells ranged from 20 percent lower TDS values than in nearby water wells to 30 percent higher TDS values than in nearby water wells. Our calculated theoretical TDS values, therefore, may be within approximately plus or minus 20 to 30 percent of the actual TDS values. Other factors also affect the accuracy of the TDS calculations.

A minimum of one wildcat electric log, as available, was reviewed for each square mile section of land within the Saugus Formation study area. These well locations and their relative degree of theoretical salinity [TDS, in mg/l or ppm, which is specially shown wherever TDS is less than (<)800 ppm mg/l] for both the shallow depth zone and the deep depth zone, are illustrated on Plate 9 - Theoretical Water Quality. On that plate, regions having TDS <800 ppm in the shallow zone only (500 to 1000 ft) are lightly shaded with a regularly-spaced dot pattern; regions having TDS <800 ppm in the deep zone only (2000 ft to 2500 ft) are hachured; regions having TDS <800 ppm in both the shallow zone and the deep zone are shaded with an irregularly-spaced dot pattern. Finally, regions within the Saugus Formation exposure area that have no data, or that display theoretical TDS >800 ppm in either both depth zones or in the shallow zone where no deep zone exists are left open and unshaded.

Of particular interest on Plate 9 is the following:

a. The region northeasterly of the San Gabriel fault zone has only a limited thickness of Saugus beds; only small portions of the Saugus has theoretical TDS <800 ppm, these occurring mainly near San Francisquito Canyon.

b. In the region between the San Gabriel and Holser faults, large areas have water of generally good quality (<800 ppm) in both the shallow (500 ft to 1000 ft) zone and the deep zone (2000 ft to 2500 ft). In the area north of Hasley Canyon and west of Interstate 5, theoretical TDS values in excess of 800 ppm occur in both the shallow and deep Saugus zones being evaluated.

c. For the region southerly of the Holser fault, groundwater of generally good quality (<800 ppm of theoretical TDS) is also seen to be widespread in both the shallow and deep zone. However, the deep zone area of good quality is less areally extensive, particularly in the region to the west, south, and east of Newhall. In this region, only the shallower Saugus aquifers appear to have theoretical TDS <800 ppm. Also, the region northerly of Pico Canyon and west of Interstate 5 does not display groundwater of theoretical TDS <800 ppm in either the shallow or the deep zone.

In general, the calculated values for theoretical TDS from oil well data are in relatively good agreement with actual TDS values determined from laboratory testing of water well samples for Saugus Formation wells in the Newhall-Saugus area. However, Plate 9 information should be used only as a guide to water quality; water quality is likely to vary locally from that shown on the Plate. For example, the water in water well NLF-156 south of Castaic Junction has measured TDS values as high as 1157 ppm; the perforated interval is from 320 to 1800 feet. Plate 9 indicates that the area around NLF-156 should have <800 ppm of theoretical TDS in both the shallow and deep Saugus aquifers. It should be noted that direct comparison from theoretical TDS to actual laboratory-generated TDS values from existing wells is difficult because most Saugus water wells have either very shallow upper perforations (thus they produce groundwater from the alluvium also) or they have very shallow cement sanitary seals (thus they allow inflow of alluvial groundwater into the gravel pack), or both.

THICKNESS AND DISTRIBUTION OF FRESH WATER-BEARING DEPOSITS

The base of the fresh water-bearing deposits was determined from electric logs (E-logs) of about 250 oil wells scattered throughout the Eastern Groundwater Basin. For the most part, the base of fresh water was identified from the resistivity curves.

In some portions of the basin, the vertical transition from saline (salt water) to fresh water is very abrupt and unambiguous. In other parts of the basin, the transition from salt water to fresh water is gradual and may occur over a vertical distance of hundreds of feet. in such cases, the base of fresh water was chosen, insofar as possible, at the top of the zone of transition from salt water to fresh water.

The reliability of using the E-logs to identify the base of the fresh water-bearing deposits depends on many factors: the properties (mineralogy, cementation, etc.) of the deposits; the type of fluids and gases in the pore spaces (water, oil, gas); the chemistry and resistivity of the drilling mud; formation temperature; the kinds of supplemental data available to the interpreter (well histories, lithologic logs, drilling mud chemistry); and the interpreter's experience in the area or basin of interest. Our approach was to obtain a representative number of E-logs (at least one per square mile, if available), interpret the E-logs, make a preliminary contour map (base of fresh water) to identify areas where data were ambiguous or where additional data were needed, obtain additional E-logs and other data, integrate the new data and reinterpret the E-logs as necessary, re-contour the data and finalize the base of fresh water work map.

Plate 5 shows our interpretation of the thickness of fresh water-bearing deposits within the Eastern Groundwater

Basin. The thickness contour lines are shown only where they fall within the area underlain by the Saugus Formation. As discussed elsewhere in this report, the upper part of the Pico Formation which underlies the Saugus Formation was found to contain fresh water in the southwestern part of the basin, the area south of the Holser fault and west of the San Gabriel fault. Plate 4 - Hydrogeologic Sections - also shows the base of the fresh water-bearing deposits. The fresh water-bearing deposits are thickest southwesterly of the San Gabriel fault: 5500 ft as compared to 1500 ft northeasterly of the fault.

This investigation focused on the future development potential of the deep aquifers within the Saugus Formation. The depth of interest, which ranges from 500 ft to a maximum 2500 ft below ground surface, was chosen on the basis of economic, hyrogeologic, and water quality considerations. The depth zone of interest shown on the Hydrogeologic Sections comprises the fresh water-bearing strata of the Saugus Formation: (1) between the depths of 500 ft and 2500 ft (where the base of the fresh water-bearing Saugus strata is greater than 2500 ft in depth); (2) between 500 ft and the base of the fresh water-bearing deposits within the Saugus Formation (where the base of the fresh water-bearing Saugus strata is less than 2500 ft in depth); or (3) between 500 ft and the base of the Saugus Formation (where the base of the Saugus Formation is less than 2500 ft in depth and the base of the fresh water-bearing deposits is within the Pico Formation which underlies the Saugus Formation).

A comparison of our map of the thickness of fresh water-bearing deposits with data published by the Division of Oil and Gas (D.O.G.) indicates discrepancies in some areas. The D.O.G. publishes data on the base of fresh water-bearing deposits in the areas underlain by oil fields. In some areas, our map indicates that the fresh water-bearing deposits are significantly thicker (deeper) than indicated by the Division of Oil and Gas. The implication is that drilling, completion, abandonment, and waste-water disposal practices at some oil fields and in areas of wildcat exploratory drilling may need to be modified in the future in order to protect the deep fresh-water resource within the Eastern Groundwater Basin.

STORAGE CAPACITY - SAUGUS FORMATION

BACKGROUND INFORMATION

The groundwater reservoir for this study is represented solely by the Saugus Formation of the Eastern Groundwater Basin. Surface exposures for this formation occupy a surface area of approximately 53 square miles (sq.mi.) (the base maps for each plate in this report delineate this outcrop area). In addition, the fresh water-bearing portion of the formation extends to a maximum depth on the order of 5500 ft (in the area between the Holser and San Gabriel faults). As shown on our base maps, an additional 5.61 sq.mi. of area in the basin are mantled by surface exposures of terrace deposits, while the remaining 27.14 sq. mi. of the local groundwater basin are represented by surface exposures of alluvium.

Within a groundwater reservoir having water table conditions, the storage capacity typically represents the total volume of water that can be held in underground storage at a given period of time and that can become readily available for extraction by wells. However, the Saugus Formation displays artesian (confined) groundwater conditions, wherein its aquifers are under pressure. Because of this, the determination of groundwater in storage in these aquifers is not as time dependent as it is for the alluvial aquifers that exhibit water table conditions.

Hence, for the purposes of this study we have calculated the groundwater storage capacity of Saugus aquifers recognizing they are confined. Water levels, as represented by the piezometric surface in wells perforating Saugus aquifers, will rise considerably above the top of the uppermost perforated aquifer zone. In essence, individual sandy aquifers at depth remain "full" and pressurized so long as the piezometric surface remains above the aquifer. Pumping, in essence, causes a pressure reduction (a lowering of the piezometric head) wherein water is "squeezed" from the confined aquifer. It is not until the piezometric surface is lowered to the top of the confined aquifer that groundwater is literally removed from storage in the aquifer.

For this report, we have determined the usable groundwater in storage for the Saugus Formation. Usable groundwater in storage will be defined as the quantity (volume) of groundwater, in acre-feet, that occurs in Saugus aquifers in the study area. To be usable, the water must be economically obtainable to wells (i.e., such items as well yield, drawdown, or drilling depths should not be excessive); and the water must be of satisfactory quality for beneficial use.

Future Saugus wells, as evidenced by several existing wells, should have acceptable well yields and drawdowns. Because of the very uneven distribution of Saugus water wells in the area, there are no quality data for large areas of Saugus exposures. For these exposure areas, we have assessed the theoretical water quality of future wells based on review of existing wildcat oil wells.

Lastly, we have had to select those depth zones within the Saugus Formation to which, using present technology, it is still considered feasible to drill and complete a water well. The maximum thickness of the groundwater reservoir for the Saugus Formation which may contain groundwater of acceptable quality varies from 1500 ft northerly of the San Gabriel fault, to 5500 ft between the San Gabriel and Holser faults, to 5000 ft southerly of the Holser fault (see Plate 5). Even though the aquifers are confined and the resultant piezometric levels from even very deep wells are expected to be within one to three hundred feet below ground surface, we do not believe it is necessary to drill to 5500 ft to get adequate water. Below the depths discussed above are older Saugus strata or other formations which contain groundwater of unacceptable quality.

Furthermore, we have limited our analysis of groundwater in storage to only the sand and/or gravel zones (as noted on electric logs) within the Saugus Formation, and only to such aquifers which occur in our so-called zone of interest, that is, between the depths of 500 ft (the uppermost zones to be perforated, thus precluding interference with any alluvial wells and potential quality degradation from surface contamination) and: 2500 ft; <u>or</u> the base of fresh water within the Saugus Formation; whichever is encountered first.

For our calculations, we also considered the fact that the Saugus Formation is comprised by generally well-bedded strata which vary in grain size and character from shales to siltstones to sandstones to conglomerates. Thus, to calculate groundwater in storage it was considered unreliable to mearly select an average zone of interest thickness for the entire Saugus Formation and to apply this value throughout the study area. Likewise, it was deemed inadvisable to select one value of specific yield for all Saugus strata and to utilize this single value for computational purposes.

METHODOLOGY

To quantify the volume of usable groundwater in storage that is potentially available for extraction, it is necessary to multiply the total volume of potential aquifers by the specific yield of these aquifers. In this assessment, specific yield represents the ratio of the volume of water which can be drained by gravity from a potential aquifer to the unit volume of that stratum. Our procedure for calculating usable storage capacity involved the following steps.

1. Identifying of potential Saugus aquifers.
2. Defining the total thickness of these potential aquifers in the basin.
3. Preparing contours of equal thickness of these potential aquifers in the basin.
4. Subdividing the groundwater basin into individual storage units and thickness zones.
5. Assigning specific yield values to the potential aquifers.
6. Computing the usable groundwater storage capacity (SC), using the formula $SC = AmSy$, where A = surface area of the storage unit, m = thickness of potential aquifers in that unit, and Sy = the assigned specific yield.

POTENTIAL SAUGUS AQUIFERS

Work here involved reviewing at least one electric log, if available, for each square mile section of land within the Saugus Formation boundaries. Based on electric log signatures, we delineated on each log the footage of individual sand or gravel zones only. These relatively coarse-grained strata were thus considered as the only potential aquifers within the Saugus Formation. In this way, we eliminated from consideration of groundwater in storage all remaining portions of the Saugus, i.e., all siltstones, shales, and other fine-grained strata.

For the thickness of a sand or gravel layer to be counted in our calculation, it was determined that the layer had to be at least 10 feet thick; in this way, the layer was considered usable and could receive perforations in a future water well. If the sand or gravel layer was less than 10 ft thick and/or if it were bounded by clays greater than 10 ft thick, it was determined that the sand was isolated and that no future well perforations would be placed here; such a sand layer was also not counted for our calculations. Similarly, sands less than 30 ft in thickness that were bounded by clays more than 30 feet thick were considered isolated also and, hence, were not counted in our total sand footage calculations.

TOTAL THICKNESS OF POTENTIAL AQUIFERS

Using the electric logs, we then totalled the footage of all relatively coarse-grained beds (sands and gravels); this total footage at each well data point then became the total amount (i.e., total thickness) of potential aquifers in the zone of interest available for a future water well at each site.

CONTOURS OF POTENTIAL AQUIFER THICKNESS

For this, it was necessary to plot the location of each electric log data point on a map (Plate 6), together with its total footage of sand as identified from the electric log.

Contour lines of equal sand thickness, in feet, were then prepared as seen on Plate 6. Variations in the locations and patterns of these contours are a direct reflection of such conditions as: changes in both the vertical and horizontal locations of the ancient stream courses which deposited these coarse grained Saugus strata during geologic time; and the effects of faulting and folding of these sediments following deposition.

STORAGE UNITS AND THICKNESS ZONES

Due to the size of the study area, the outcrop area of the Saugus Formation had to be divided into smaller, more easily managed units. To do this, we divided the outcrop area into three main groundwater storage units. Selection of these three units was based on the same boundaries (i.e., the faults) as were our discussions of the Saugus Formation in the Regional Geology section. Hence, Storage Unit No. 1 lies northerly of the San Gabriel fault; Unit No. 2 is located between the San Gabriel and Holser faults; and Storage Unit No. 3 lies southerly of the Holser fault.

To further ease computations and to more readily planimeter surface areas, we then subdivided each storage unit into several individual storage subunits. The surface area of each subunit was then planimetered, with these areas then being summed to define the total surface area of each storage unit.

For example, Storage Unit No. 2 which lies between the San Gabriel and Holser faults, was divided into 15 subunits (Subunit Nos. 1-A through 2-O); these subunits range from 632 acres to 1749 acres in surface area. For simplicity, individual subunit locations and letter designations have not been drafted onto Plate 6.

It was also important to determine the average thickness of potential aquifer sands for each subunit. To do this, we planimetered the surface area in each subunit between the various sand thickness contours on Plate 6. For example, Storage Subunit 2B is traversed by the 0- to 400-foot and the 400- to 800-foot sand thickness contour lines. The area of the thickness zone 0 to 400 feet was planimetered and was assigned an average thickness of 200 feet due to the distribution of data points and contours. The area of thickness zone 400 to 800 feet was planimetered and was assigned an average thickness of 600 feet due to its distribution of data point and contours.

In all, 28 individual subunits were delineated within the three groundwater storage units of the Saugus Formation. Each was further subdivided on the basis of total sand thickness intervals, resulting in forty separate computations to derive the total amounts of usable groundwater in storage in the Saugus Formation.

SPECIFIC YIELD VALUES

Because the Saugus Formation aquifer sands vary horizontally and vertically in location and grain size distribution, it was necessary to assign different specific yield values to these aquifers based on their location in the overall reservoir. Moreover, because of the vertical displacement effects of the proximal faults, it is known that outcrop areas of the Saugus Formation on different sides of these faults are of different age. These age differences were also considered in our assignment of specific yields.

Based on the above, it was our opinion that a realistic range of specific yield values in the various subunits is from a low of 5 percent to a high of 8 percent. By way of comparison, our assignment of specific yield values for the alluvium which overlies the Saugus Formation ranged between 9 and 16 percent (Slade, December 1986).

USABLE GROUNDWATER IN STORAGE

This final step calculated the total estimated volume of usable groundwater in storage in the Saugus Formation by multiplying the total surface area of each storage unit, by the average sand thickness of each sand thickness interval within each of the subunits, by the specific yield value assigned to that sand thickness interval.

Table 6 - Summary of Usable Groundwater in Storage - presents the results of our computations. It identifies the usable quantity (volume) of groundwater in storage in the Saugus Formation between the depth limits of 500 feet and either: 2500 feet; or the base of fresh water within the Saugus Formation, whichever is shallower. As seen on Table 6, the total estimated amount of groundwater in storage in the sands and gravels which constitute the potential aquifers within the Saugus Formation is approximately 1.41 million acre-feet. Storage Unit No. 1 (northerly of the San Gabriel fault) has approximately 130,500 acre-feet of usable groundwater in storage (about 9 percent of the total); Unit No. 2 (between the two faults) and Unit No. 3 (southerly of the Holser fault) each has approximately 641,000 acre-feet of usable groundwater in storage (about 45 percent of the total for each).

In comparison to the calculated 1.41 million acre-feet of usable groundwater in storage in the sand and gravel aquifers of the Saugus, Robson (1972) for the U. S. Geological Survey reported a total storage capacity for the entire Saugus Formation of approximately 6 million acre-feet.

TABLE 6 - SUMMARY OF USABLE GROUNDWATER IN STORAGE

STORAGE UNIT NO.	LOCATION OF STORAGE UNIT	STORAGE SUBUNIT DESIGNATIONS	TOTAL SURFACE AREA (acres)	RANGE OF SAND THICKNESS (ft)	RANGE OF SPECIFIC YIELDS (%)	USABLE GROUNDWATER IN STORAGE (ac-ft)
1	Northerly of San Gabriel fault	1A - 1Db	7,607	0 to 440	7	130,540
2	Between the two faults	2A - 20	13,980	0 to 1400	5-8	641,330
3	Southerly of Holser fault	3A - 3H	16,501	0 to 1240	5-8	641,240
		TOTALS	39,088			1,413,110

RECHARGE POTENTIAL

For the Saugus aquifers to be viable sources of groundwater, they must not only have sufficient groundwater in storage but they must also be capable of being recharged. Potential recharge sources include: deep percolation of direct precipitation on the outcrop area of the Saugus Formation, including deep percolation of precipitation on outcrops of terrace deposits which thinly veneer the Saugus; and direct infiltration from the saturated portions of the alluvium of the Santa Clara River that overlie Saugus strata. The following paragraphs provide our methodology used in assessing the magnitude of each type of potential recharge.

Within the mapped area of Plate 3, the total surface area of Saugus Formation exposures is 52.81 square miles while that of the terrace deposits is 5.61 square miles. This represents a combined surface for the two formations of 58.42 square miles, or 37,390 acres. Review of isohyets (equal precipitation contours) of the 100-year normal precipitation for the region presented in Slade (December 1986, Plate 9), reveals that a reasonable value for average annual precipitation on Saugus and terrace deposits outcrops is approximately 15 inches (1.25 ft). Thus, on a long-term average annual basis, total precipitation falling on Saugus and terrace deposits materials is approximately 46,750 ac-ft/yr.

To evaluate how much of this volume might be available for deep percolation, it is to be recognized that infiltration will vary according to many parameters, such as topography, slope, type and cementation of strata, grain sizes, rainfall intensity, evaporation, transpiration, etc. For the purposes of this project and because definitive values for most of these variables are not available in the literature, it is estimated herein that the long-term average deep percolation is on the order of 10 to 15 percent of the long-term average annual precipitation. Our calculation excludes potential recharge to the Saugus via direct precipitation onto the alluvium in the region.

The second form of potential recharge is direct infiltration into the Saugus from the saturated portions of the alluvium in the Santa Clara River where it directly overlies the Saugus Formation. For this assessment, we are assuming several conditions, including:

1. Direct infiltration from saturated alluvium to the Saugus occurs only from the alluvium of the Santa Clara River; thus, we are excluding the additional recharge that would occur into the Saugus Formation by direct infiltration from the saturated portions of the alluvial deposits of all creek channels that are tributary to the Santa Clara River. That is, we are NOT including in our calculations the potential recharge to the Saugus from saturated portions of the alluvium in such tributaries as Castaic Creek, San Francisquito Canyon, or even South Fork Santa Clara River.

2. Regardless of whether or not surface flow is present in the Santa Clara River, the subjacent alluvium, at least in its lower portion, is always saturated. This is readily recognized by review of hydrogrphs, water level conturs and calculations of groundwater in storage presented for the alluvium in Slade (December 1986); even in the water level lows of 1965 in the alluvium, the lower portions of the Santa Clara River alluvium contained groundwater.

3. Since groundwater levels in the alluvium fluctuate in response to general wet and dry cycles, it was considered important to assess the magnitude of deep percolation from the alluvium in contrasting hydrogeologic periods. As a result, we selected for comparison the historic water level high in the alluvium (April 1945) and the historic water level low in the alluvium (November 1965), based on review of Slade (December 1986).

4. Other conditions incorporated into our assessment were such items as the variations in permeability of the strata, variations in the saturated thickness of the alluvium in different reaches of the river valley, changes in the groundwater gradient along different reaches of the valley, and variations in the width of the valley in the region.

5. The recharge to the Saugus is in the form of repressurization of the confined aquifers; such repressurization will tend to maintain current piezometric levels in wells.

On the long-term average annual basis, results of the requisite calculations show the following:

1. Deep percolation of direct precipitation onto Saugus and terrace deposits outcrops that is available for potential recharge to the Saugus is on the order of 4700 ac-ft/yr to 7000 ac-ft/yr.

2. Maximum direct infiltration from the saturated portions of the river alluvium into the Saugus likely occurred during the water level highs of April 1945 and totaled approximately 15,200 ac-ft/yr.

3. In contrast, the minimum direct infiltration from the saturated portions of the alluvium into the Saugus likely occurred during the water level lows of November 1965 and totaled approximately 6100 ac-ft/yr.

Thus, total potential recharge to the Saugus represents the sum of the deep percolation of direct precipitation and direct infiltration.

Hence, the overall magnitude of potential recharge to the Saugus Formation (i.e., as a re-pressurization of the confined aquifers), recognizing the aforedescribed assumptions and conditions, ranges approximately between: 19,900 and 22,200 ac-ft/yr in water level high periods like 1945; and 10,800 to 13,100 ac-ft/yr in water level low periods like 1965.

WELL CONSTRUCTION

ALTERNATIVE DRILLING METHODS.

There are three basic methods for drilling municipal-supply water wells in the study area. The key issues for each method are summarized as follows:

1. Cable-tool Method: This is one of the oldest methods used for constructing wells. Wells in the study area drilled prior to the mid-1950's were drilled by this method. It is considered to be particularly effective in unconsolidated alluvial deposits containing abundant cobbles and boulders. However, drilling proceeds very slowly by this method and drilling to adequate depths into the Saugus Formation would be very difficult. Additional drawbacks include: because casing is driven continuously as drilling proceeds, perforations must be punched through the casing after the casing is at total depth of the well--this results in irregular perforation openings, poor control of sand, probable formation damage, and inefficient entrance of water into the well; and because steel casing is always in the hole during drilling, no geophysical electric log survey can be conducted, thus precluding accurate definition of aquifer systems.

   Because of these drawbacks, the cable-tool method should not be used for drilling any new wells and thus its further consideration is not deemed appropriate in this report.

2. Direct Rotary Method: This process involves a rotating drill bit and circulating drilling fluids (generally clay-based) to remove cuttings from the borehole; cuttings travel up the borehole in the annular space between the drill pipe and the wall of the borehole.

   This method permits drilling of a small diameter pilot hole (often 8 to 12 inches) which can then be electric logged. With these data, the well screens and gravel pack can be carefully selected, while the pilot hole is being reamed, and then installed to the final depth of the well. Proper screen slot width and gravel pack selection will preclude sanding problems and optimize well efficiency.

Drilling fluids can control unconsolidated deposits in the hole, although concentrations of boulders, particularly at relatively shallow depths, can slow drilling progress noticeably. Penetration rate in more typical alluvial deposits may often be in the range of 15 to 30 feet per hour, while drilling rates in the Saugus Formation may be on the order of 5 to 10 ft/hr. Poor control of drilling fluid additives in the borehole can damage the aquifers and create development problems.

3. Reverse Circulation Rotary Method: This method is similar to the direct rotary process, except: the drilling fluid is often only water, and it is circulated down the annular space between the drill pipe and borehole walls and up the drill pipe with the cuttings in suspension.

   Typical pilot holes are 16 to 18 inches in diameter and permit electric log surveys also. Screens and gravel packs can be designed during reaming operations and then installed in the borehole, thereby providing the same benefits as the direct rotary method.

   Because the reverse process drills a larger diameter pilot hole, the drilling process is generally slower than the direct method: penetration rates of 4 to 8 feet per hour are not uncommon. Furthermore, continuous water supplies for drilling by this method may be as high as 100 to 300 gallons per minute, or more, if the unsaturated deposits in the upper portion of the hole are particularly porous and permeable. Large boulders are also troublesome, particularly if encountered in shallow deposits. Because clay-based mud additives are generally not used as the circulating fluid in reverse-drilled holes, the final completed well is often easier to develop compared to direct mud rotary-drilled holes.

QUALITY SAMPLING

Following geologic logging and electric logging of the pilot hole, two or three potential aquifers will be selected from which water samples will be collected by special techniques within the open borehole. Such down-hole aquifer water sampling is necessary to assess quality at depth.

WELL CASINGS

The next step is the final design of the well casing (the casing completion). This casing completion consists of the pump housing casing, the blank (nonperforated) well casing, and the perforated casing (well screen). Key elements of each are summarized as follows:

1. Pump housing casing: This is the uppermost casing in the well and forms the section within which the pumping equipment will be located. The diameter and depth of the pump housing must be selected to accommodate the desired well yield, the anticipated specific capacity of the well, and the long-term water level (pressure) declines in the basin due to drought. Appropriate casing diameters must be selected to provide adequate clearance for the pump bowls and minimum head losses for uphole water flow.

2. Blank well casing: This is the blank (unperforated) well casing that is situated between the pump housing casing and the well screen. It can also be placed between sections of perforated casing in order to blank-off non-productive aquicludes and/or zones of inferior water quality.

   Blank casing must be selected with appropriate diameters and strengths to meet the anticipated well yields and depth settings of the wells. Corrosion resistance could be a consideration if groundwater quality is adverse.

3. Perforated casing: Casing perforations which provide efficient and sand-free production of groundwater are necessary. Well screens (wire-wrapped, continuous V-shaped slots) or shutter-type (louvered) perforations are the most commonly used varieties in southern California. As stated previously, the down-hole perforating of casing in cable-tool drilling is not considered a viable alternative.

> Casing perforation widths are selected to retain the gravel pack around the casing; the gravel pack is selected to preclude entrance of fine-grained sediments in the formation from entering the well. Casing perforations should be selected to optimize intake area (the open area in the perforations per unit length of casing), thereby minimizing head losses associated with the entrance of water into the well. As with the blank casing, the diameters and strengths of the perforated casing must be selected to meet the anticipated yields and depth settings of the wells.

WELL DEVELOPMENT

Thorough development of the completed well is one of the most critical elements in providing a high-efficiency well. Well development is necessary to: reduce the damage to the aquifers caused by fluid/mud invasion during drilling; and increase the porosity and permeability of the gravel pack and local aquifers by stabilizing them and by removing fine-grained materials from the interstices between the sand/gravel grains.

Development techniques include bailing, swabbing, surge block-simultaneous airlifting, and test pumping. The use of a short surge block with simultaneous airlifting in each section of the well perforations is considered the most effective technique for proper mechanical well development.
Pumping development, by using the deep well test pump to alternately pump and surge, is made especially effective when preceded by the aforementioned mechanical development. In addition, chemical well development is sometimes necessary to help disperse residual wall cake at the borehole/gravel pack interface; this is done by the application of appropriate

chemicals into the well and forcing them out through the perforations and into the gravel pack, generally prior to mechanical development. Chemical development is especially desirable when a clay-based drilling fluid has been used.

CONCLUSIONS AND RECOMMENDATIONS

1.0 FEASIBILITY

Based on review and analyses of existing data and of limited field testing of selected water wells, it is our opinion that it is hydrogeologically feasible to develop additional groundwater supplies from aquifers within the Saugus Formation. Due to the nature of the existing Saugus Formation hydrogeologic data base, it is considered important to drill and test exploratory pilot holes before completing them as permanent water wells.

Average annual volumes of Saugus groundwater production have been determined, as has been the usable volume of groundwater in storage in selected sand and gravel aquifers within the upper, usable portions of this formation. Also defined were the general directions of groundwater flow, current piezometric levels for the artesian system itself, and general aquifer parameters and water quality.

Regions within the Saugus Formation outcrop area have been identified where it is considered most feasible to drill and test these exploratory pilot borings. Should geologic and geophysical logging, and down-hole water quality sampling of these borings validate the findings of this report, then the pilot holes can be immediately reamed out and completed as production water wells. Guidelines for drilling and completing the test holes/wells are provided herein. Once a well site is selected from the priority regions for drilling, a site-specific letter-report should be issued to verify local anticipated conditions which are essential to prepare site-specific, well construction specifications.

It was not within the scope of work for this hydrogeologic assessment of the Saugus Formation to determine its perennial yield. Our preliminary evaluation of the potential recharge to the Saugus should not be construed as a rigorous determination of its perennial yield. Additional hydrogeologic data, and factual data from greater portions of the Saugus outcrop area are needed to obtain a realistic appraisal of its perennial yield.

Though not specifically studied for this project, "banking" of surplus surface water or imported water is not likely as feasible within the Saugus Formation as it is for the alluvial sediments in the valley. Slade; December 1986, provides information on artificially recharging ("banking") within the alluvial deposits.

2.0 DATA BASE FOR SAUGUS FORMATION

2.1 Water Wells. Historically, only 22 wells have been drilled sufficiently deep to produce groundwater from the Saugus Formation. Of this number, only eight were active producers in 1986; one was not yet equipped with a pump; the remaining 13 wells were either destroyed or considered inactive on standby use only.

There are no active wells presently located between the Holser and San Gabriel faults or north of the San Gabriel fault, and no Saugus water wells have ever been drilled north of the San Gabriel fault. No water well has ever fully penetrated the full thickness of the Saugus Formation in the area. The three newest Saugus wells were drilled in 1973, 1978 (a private well), and 1985. All other wells pre-date the mid-1960's.

Of the still usable wells, all were drilled by rotary methods, except two (NC-7 and NC-8), which were drilled by cable tool methods. The rotary-drilled wells generally have louvered-type perforations (two have vertically slotted casing); the cable tool wells have knife-cut perforations. Vertical slots and knife-cut perforations are considered to be antiquated designs. Well screens and/or louvered casings provide more open area, less head loss, and higher well efficiency.

Where data are available, and with the exception of NC-12 (420-foot deep cement seal), none of the usable Saugus wells has a deep cement surface seal. Most seal depths are less than 100 feet in length and, because they have gravel packs which extend up to the base of these seals, it is apparent that some portion of the groundwater production from such wells is from the overlying alluvium.

3.0 HYDROGEOLOGY

3.1 Local Groundwater Basin. Alluvial deposits and the Saugus Formation comprise the water-bearing sediments of the groundwater reservoir of the Eastern Groundwater Basin. River alluvium, which is discussed in detail in a separate report by this investigator ranges in thickness to a maximum of 200 ft. The mapped extent of the surface exposures of the alluvium and terrace deposits is 32.75 square miles.

The Saugus Formation, a series of interbedded sandstone, siltstone and shale strata, underlies the alluvium along the river and its numerous tributaries and is also exposed on the surrounding hills. The mapped extent of Saugus strata in the region is 52.81 square miles.

The base of the Saugus on the northwest, north, and northeast sides of the basin is well defined. It is not as well defined on the southeast, south, and southwest sides of the basin where it interfingers with the marine Pico Formation.

Based on fault blocks created in the basin by the Holser and San Gabriel faults, the study area was divided into three separate regions. The maximum thickness of fresh water-bearing deposits in these regions varies from 1500 ft northerly of the San Gabriel fault, to 5500 between the two faults, to 5000 ft southerly of the Holser fault. In this latter area, it is probable that the upper portion of the underlying Pico Formation locally contains fresh groundwater also.

3.2 Aquifer Sands. Instead of relying on the total thickness of Saugus Formation for its groundwater potential, we determined the total footage of relatively coarse-grained potential aquifers (sand and/or gravel zones, as identified from electric log signatures) throughout the outcrop area of the Saugus, data permitting.

Furthermore, these potential sand/gravel aquifers were tabulated only between the depths of 500 feet and: either the base of the Saugus Formation; or the base of fresh water in the Saugus Formation; or a maximum depth of 2500 ft, whichever is shallower. The 500-foot minimum depth level was selected to preclude interference with groundwater in the shallow alluvium, should future Saugus wells be drilled. The maximum depth level was dependent on local faulting and geology conditions, i.e., on where the three particular Saugus depth zone regions occur relative to the two local faults.

Thus, northerly of the San Gabriel fault, the maximum combined thickness of potential aquifer sands is 400 ft, as identified between a depth of 500 ft and the base of the Saugus Formation. Between the two faults, the maximum combined thickness of potential aquifer sands is 1400 ft, as identified between the depths of 500 ft and 2500 ft. Southerly of the Holser fault, the maximum combined thickness of potential aquifer sands is 1200 ft, as identified between the depths of 500 ft and 2500 ft.

3.3 Groundwater Production. Groundwater production from Saugus strata apparently began in the area in 1954 by NCWD. During the period 1954 through 1986, local purveyors (NCWD, combined NLF and VWC, and SCWC) have produced a total of approximately 154,000 acre-feet of Saugus Formation groundwater. Average production during the 33 years of available data has been about 4660 ac-ft/yr. Virtually all of the historic production has been from the area south of the Holser fault.

Combined production from the local purveyors in 1986 was 5532 ac-ft. Production from the only non-purveyor well in the area (the Smiser well) is not known but is likely less than 100 ac-ft/yr.

3.4 Groundwater Occurrence and Water Levels. Groundwater occurs in the Saugus Formation under artesian (confined) conditions. Thus, water levels in existing or future Saugus wells are (will be) represented by piezometric (or pressure) surfaces that are (will be) as much as several hundred feet above the top of the uppermost well perforations. Pumping reduces the pressure (piezometric level) locally in the Saugus Formation and provides groundwater to the well.

Current 1987 piezometric levels are available only for the area southerly of the Holser fault and show groundwater flows to the northwest. Typical 1987 piezometric surface elevations are from 1200 to 1050 ft above sea level, and thus, are 50 to 100 ft above comparable levels dating from 1967.

Hydrographs show piezometer levels have been rising slowly but steadily in Saugus wells since records began in the mid- to late-1960's. The reasons for this are difficult to define due to a lack of long-term water level data and lack of stress on the entire aquifer system. Some of the rise may be due to increased recharge from the concomitant period of above-average rainfall, and from increased discharges to the river from wastewater treatment plants. Moreover, because some of the wells have shallow gravel packs extending up into the alluvium, it is possible that some of the water level rises actually are occurring as a result of increased recharge to the alluvium which percolates down the pack into the perforations.

Although the two local faults can be expected to form at least partial barriers to groundwater flow (at least in the lower portions of the Saugus), available water level data are inadequate to verify this possibility.

3.5 Groundwater Quality. Saugus Formation quality is either of calcium bicarbonate or calcium-magnesium sulfate character. Near the lateral margins of the basin or near the base of the formation within the basin, the overall quality will deteriorate; increases in TDS, sulphate and even the presence of hydrogen sulfide can be expected in these areas. Future wells to 2500-foot depths appear to have acceptable quality particularly nearer the central portions of the basin. Nitrates and volatile organic compounds are not expected in future, properly constructed wells.

3.6 Aquifer Parameters. Based on our field aquifer tests of efficient wells, aquifer transmissivity is considered to be in the range of 80,000 to 160,000 gpd/ft. Such values are indicative of fair to good aquifers. Storativity values determined from the tests are approximately 0.0007 to 0.0009 ft/ft, and are characteristic of confined systems. Transmissivity is higher in the upper (younger) portions of the Saugus compared to the deeper (older) portions of this formation.

Typical well yields are on the order of 1500 gpm, with specific capacities of 10 to 50 gpm per foot of drawdown. Theoretical T values developed from specific capacity (Q/s) data are approximately 20,000 to 100,000 gpd/ft. Because current specific capacity values are lower than the earliest available Q/s data for each respective well, it is probable that well efficiencies have declined with time; this occurs from encrustation developing on the gravel pack and well perforations and from siltation in and around the gravel pack.

4.0 OIL FIELD DATA

Numerous active and abandoned oil fields exist in the study area. A large number of producing, abandoned, and wildcat oil wells have been drilled also; interpretation of electric log data from several hundred of these wells were used to define the thickness of water-bearing deposits, the footage of potential aquifer sands, and the theoretical water quality in future wells.

Oil fields with hydrocarbons and/or high salinities in at least the lower portion of the Saugus Formation include: Castaic Hills, Charlie Canyon, Newhall (Tunnel Area and Elsemere Area), Placerita, Tapia, and Wayside Canyon (refer to locations on Plate 10). Most petroleum production is from rocks older and stratigraphically below the Saugus Formation.

It is also known that secondary recovery is practiced and that waste water injection is performed in several oil fields. A determination of the locations and depths of such practices, and the qualities of such waste waters was beyond the scope of this study. We believe it is important to determine the effects of such practices on the siting and pumping of future Saugus wells.

5.0 USABLE GROUNDWATER IN STORAGE

The calculated amount of usable groundwater in storage is approximately 1.41 million ac-ft. Usable groundwater in storage represents the volume of groundwater stored only in the potential aquifers (sand and gravel layers only) within the Saugus Formation. Our calculations disregard any possible storage in all finer grained layers of claystone, shale and/or siltstone.

These potential aquifers occur beneath a projected surface area of approximately 39,000 acres (61 square miles) within the mapped area on Plate 1. Furthermore, to be considered as usable, these potential aquifers were selected from electric logs and only between the depths of 500 ft (to preclude capturing groundwater from the alluvium) and: the base of fresh water in the Saugus Formation; or a maximum depth of 2500 ft (the deepest existing Saugus well is 2000 ft deep), whichever is shallower.

Current groundwater production (1986) represented only 0.40 percent of the total volume of usable storage in the Saugus Formtion.

6.0 POTENTIAL RECHARGE

Principal recharge sources to the Saugus for our calculations were deep percolation of direct precipitation solely on the outcrop area of the Saugus Formation and terrace deposits; and direct infiltration from saturated alluvium within only the Santa Clara River channel and only where this alluvium directly overlies Saugus strata. Such calculations provided an estimate of the minimum amount of recharge to the Saugus.

17,000/yr

As a preliminary estimate, we believe the combined potential sources from these two sources ranges between approximately 20,000 and 22,000 ac-ft/yr in wet periods and 11,000 to 13,000 ac-ft/yr in dry periods.

Such potential recharge causes a re-pressurization of the confined Saugus aquifers. Historic extractions have caused no discernible or definitive trends in the piezometric levels of graphed wells since records began. Piezometric levels have been rising in wells since the late-1960's, possibly as a result of recharge from years of excess rainfall in this period.

This preliminary assessment of the minimum amount of potential recharge to the Saugus Formation incorporates only portions of the two main forms of deep percolation and recharge into these strata. As such, this preliminary assessment should not be construed as a rigorous determination of the perennial yield of the Saugus, with such determination not being a part of the scope of work.

Furthermore, because so much of the Saugus Formation (both laterally and vertically) contains no active water wells and/or has never contained any water wells, the vast majority of the aquifer system has never been stressed; indeed, for much of the region, there are no definitive hydrogeologic data at all. A meaningful evaluation of the perennial yield of this formation must await, as yet unavailable, long-term water level and water quality data and a data base that includes actual data from wells northerly of the Holser and San Gabriel faults.

It is also noteworthy that the natural losses of groundwater via subsurface leakage from the alluvium into underlying strata, including the Saugus Formation, occur continuously and wherever there are relatively permeable strata underlying saturated alluvium; even in dry years, the lower portions of the alluvium still contain groundwater. The leakage losses are natural and cannot be terminated because it would require an infinite number of wells to totally dewater all of the alluvium on a permanent basis.

In our method of assessing the perennial yield of the overlying alluvium (Slade, December 1986), we considered only the change in water levels vs. groundwater extraction from the alluvium for a specific time period. These water levels are known to change in response to many conditions, including rainfall, basin inflow, and basin outflow (losses). Thence, inherent to the perennial yield assessment of alluvium are the natural losses from the alluvium to the Saugus Formation.

7.0 NEW WELLS

7.1 Priority Locations. Plate 10 - Recommended Drilling Areas - has been prepared on a regional basis to show general locations, on a first-order priority, for new wells. Available data have been analyzed to provide these regional priority locations to be considered for future wells by the purveyors.

However, prior to drilling, it is recommended that a site-specific evaluation be provided of electric logs proximal to any prospective future well site in order to confirm the distribution and continuity of coarse-grained channel deposits. This is also important because zones of deposition of coarse grained Saugus strata are known to have varied widely in geologic time, both vertically and horizontally. Such site-specific subsurface data can be briefly reviewed and summarized in a letter to provide final details for test hole/final well specifications.

If more than one well is desired in a given area, construction should be conducted in phases, with the first well drilled, completed, developed, and thoroughly tested prior to selecting the final sites and design criteria for additional wells in that given area. New wells should be spaced at least 1000 ft apart, based on mutual drawdown interference criteria.

7.2 Anticipated Yields. New Saugus Formation water wells in the region southerly of the San Gabriel fault are anticipated to have an operational yield on the order of 1500 to 2000 gpm. Future yields from wells located northerly of this fault will be less because of the reduced thickness of aquifer sands and because this region is comprised by the lower (older) portion of the Saugus Formation.

Production from future Saugus Formation wells, provided they are properly sited, and constructed with deep cement seals and deep uppermost perforations, is not expected to adversely impact the alluvium.

7.3 Potential Quality Problems. It must be recognized that there are inherent risks in the construction of new wells in this entire region due to the possibility of encountering contaminants in groundwater relating to petroleum occurrences, prior industrial and/or manufacturing facilities, or natural conditions such as the presence of hydrogen sulfide, iron, or manganese. Modern well design, utilizing deep cement sanitary seals and selective placement of well screen, will help preclude potential quality problems that may have affected shallower aquifer zones from surface or near-surface sources.

The opportunity does exist during pilot hole drilling to conduct limited down-hole water sampling of individual aquifers in the open borehole in an effort to determine whether or not contamination exists at the well site; however, collecting conclusive data by this procedure is difficult. That is, such select aquifer sampling is typically conducted by airlifting techniques and can cost on the order of $10,000 to $15,000 per aquifer test zone for mobilization and airlifting alone. Airlifting, however, is not considered appropriate for sampling of volatile organic compounds. Moreover, airlifting typically is conducted at low rates of discharge (100 gpm or so) and for relatively short time periods (less that 3 to 4 hours). Long-term pumping (several hours to a day or more) is not possible in an open borehole under such circumstances due to the risks of collapsing the borehole and losing the sampling equipment.

A contamination plume, if it existed, would have to be virtually at the well site in order to be intercepted by such short-term down-hole sampling. A more distant plume could require hours, days, weeks or even months of pumping at high rates to be intercepted, assuming such a plume exists at all. Naturally occurring inorganic water quality problems should be identified by such testing since these contaminants are within the entire aquifer itself.

7.4 Well Depths and Construction Methods. New wells southerly of the San Gabriel fault are anticipated to be in the range of about 1500 ft to 2500 ft in depth. Wells northerly of this fault will be shallower. Either direct rotary or reverse circulation drilling techniques can be used to drill new wells. Cable-tool drilling is not recommended.

A potential problem will be the availability of water for drilling purposes, especially for the reverse circulation method, which may require 100 to 300 or more gallons per minute of continuous supply. If the direct rotary method is used, particular care must be given to control of drilling fluid properties so as to not induce permanent damage to the aquifers.

Detailed geologic mud logs should be prepared from drill-cuttings data as monitored by field geologists during the drilling. At the completion of the pilot bore, an electric log survey is essential in order to define available aquifers and potential locations for the well perforations.

Due to the possible presence of oil and natural gas (including hydrogen sulfide) within the groundwater basin, it is recommended that gas monitoring devices be used during the drilling of future pilot holes.

7.5 Casing Sizes and Materials. For the anticipated 1500 to 2000 gpm operational yield from each well, new wells can be provided with 18- or 20-inch steel casing to house the pump, and 14- or 16-inch pump bowls. Such casing and pump equipment will minimize friction loss in the casing and could permit short-term pumping at higher yields if supported by aquifer characteristics.

To permit some cost savings, especially in drilling, the blank well casing and well screen placed below the pump housing casing can be reduced to only 14 or 16 inches in diameter. A 2- to 5-foot section of reducer pipe is used to connect the 18- or 20-inch pump housing casing to the lower sections of 14- to 16-inch casing and screen. Existing groundwater quality data for Saugus Formation wells to 2000 feet in depth suggest that new wells will not require the use of special well casing materials.

To optimize well efficiency and open area in the perforated intervals, it is recommended that wire-wrapped, continuous V-shaped slot well screen be used. The uppermost zone of perforations will be placed as deeply as practical in order to preclude potential drawdown and quality problems. Such well screen will also preclude sanding conditions in new wells.

Proper selection and placement of a gravel pack is essential also. The use of a deep cement seal in the annulus (approx. 450 ft in length) is recommended to preclude interference with groundwater in nearby alluvium and to minimize potential for shallow quality problems.

Well screen slot widths and gravel pack grain sizes are to be selected based on analysis and grain size distributionn of the drill cuttings. Total length of well screen is expected to be on the order of 500 to 800 ft. Slot sizes in the 0.050- to 0.080-inch range are anticipated for new wells. Monterey-type, clean, highly rounded and spherical sand is a preferred gravel pack material; a 6 x 12 gradation is anticipated.

7.6 Construction Costs. Approximate costs for a contractor to drill, install casing, develop, and test pump one new well on the order of 1500 ft in depth will likely be on the order of $250,000 to $300,000. A more detailed and refined breakdown of costs can be provided when the site(s) for eventual wells is(are) selected.

In addition to the drilling costs, there also will be costs for the final pumping equipment, chlorination facilities, electrical appurtenances, and transmission lines, property and/or rights-of-way for the new wells, and for required hydrogeologic services during construction.

7.7 Anticipated Well and Aquifer Characteristics. Based on field work data and available existing data collected for this project, the following represent anticipated well and aquifer parameter values for new wells constructed within the recommended drilling areas (Plate 10) and having the anticipated depth and construction features discussed above:

Operational Yield	1500 to 2000 gpm
Total Depth	1500 to 2000 feet
Total Length of Perforated Casing	500 to 800 feet
Specific Capacity	20 to 50 gpm/ft drawdown
Transmissivity	75,000 to 125,000 gpd/ft

8.0 GROUNDWATER MANAGEMENT

To establish more complete groundwater data for the region, we recommend the following:

a. Accurately establish the locations of each well on USGS quadrangle maps.

b. Establish a permanent reference point on all wells from which future depth-to-water measurements can be taken; use a surveyor to obtain accurate elevations for these reference points.

c. Monitor water levels on a regular basis to an accuracy of 0.01 foot (once or twice per month); ensure that these are true static levels, not partial recovery levels, by allowing the well to remain idle for at least 8 hours prior to obtaining the non-pumping water level.

d. When abandoning wells, make sure that accurate records are kept as to which well, its location, etc., and the methods used for abandonment.

e. Verify sanitary seals on active wells to help ensure that water quality meets State standards for domestive usage at all times.

f. Conduct Edison efficiency tests on a regular basis in all wells; consider rehabilitating wells and/or pumps when efficiency and specific capacity decline.

g. Plot water level hydrographs and graphs of specific capacity vs. time for all wells; monitor water for inorganic and organic constituents on a regular basis.

h. Perform operation and maintenance (O & M) on the wells on a regular basis. Such O & M is essential to maintain well efficiency and to return declining specific capacities to their original values. The wells should be periodically surged in order to prevent clogging of the gravel pack by silt or clay.

i. Become cognizant of present and future land use in the area; work with the RWQCB to recognize landfill problems, runoff from hazardous waste sites, and even migration of gasoline from leaky underground service station tanks. Such potential sources of contamination can adversely affect the alluvium and the surface exposures of the Saugus Formation. Locate all industrial dischargers on a map and determine the types and amounts of such discharges.

j. Meet with the State Division of Oil & Gas to establish compatible resource development practices, particularly in the vicinity of those oil fields having shallow hydrocarbon production and/or shallow injection. Such practices could adversely affect the long-term development of groundwater from the Saugus Formation.

The attachments which complete this report are listed in the Table of Contents. Report plates are provided in Volume II.

Respectfully submitted,

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APPENDIX A

AQUIFER TESTING

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AQUIFER TESTING

During the period from March 4 to April 3, 1987, pumping tests were conducted in five of the eight actively pumping purveyor-owned Saugus Formation wells. Based on joint meetings with the involved agencies to resolve local logistical and well usage problems, the following criteria were established for the tests:

1. All pumping and observation wells were to be shut down at least 24 hours prior to the monitoring and testing;
2. Pumping duration was to be 24 hours;
3. Pumping discharge rate was to be kept constant; and
4. Recovery test duration was to be at least 24 hours.

With the exception of V-160, all the tested wells were pumped at a constant discharge rate for 24 hours (1440 minutes) then shut off and allowed to recover for at least 24 hours. During this approximately 48-hour period. drawdown and recovery measurements were taken in the pumping well and, where possible, in the observation wells. In all cases, pumping and observation wells had not been pumped for a minimum of 24 hours prior to the start of test pumping.

V-160 could only be pumped for 12 hours due to a limited storage tank capacity, high pumping rate, and a relatively low water demand on the test day. Also due to water storage and demand limitations, NC-10 was pumped at an average rate of 364 gpm; in normal operation, this well pumps about 1100 gpm.

Pumping rates were maintained as constant as possible in all the wells, with slight adjustments to valving or engine speed (NC-10) as necessary to allow for rate variations due to changes in head, back pressure, and other factors. All pumping and recovery water levels were monitored using a two-wire electric tape sounder and an engineer's tape, measuring the levels below the reference point to ± 0.01 ft.

During each of the pumping tests, the discharge was periodically sampled and tested in the field for temperature and electrical conductivity. Physical observations such as water clarity and odor were noted also.

Wherever possible, attempts were made to utilize proximal wells as observation wells during the aquifer test in order to monitor for any possible drawdown interference effects created by the aquifer test pumping well. As shown on Table 4 in the text, two of the aquifer test wells each had one proximal Saugus Formation observation well, while a third aquifer test well had three proximal alluvial wells in which water level monitoring could be conducted. The remaining 2 aquifer test wells had no nearby observation holes.

As mentioned, only five of the eight Saugus Formation wells active in 1986 were tested in the above methods. The three wells not tested during our field program included: NC-11, which is in nearly constant operation and is located near other agency wells (NC-10, NC-12) and, thus, would not add significantly to the areal data base; NLF-156 which has a small submersible pump and is the sole water source for six or eight homes; and NC-8 which had the pump removed for well survey and rehabilitation.

Data acquired during test pumping and recovery was used to calculate aquifer transmissivity or the aquifer's ability to transmit water. Aquifer transmissivity (T) is defined as the rate of flow in gallons per day through a section of aquifer whose height is the thickness of the aquifer and whose width is one foot, when the hydraulic gradient is one foot. Data analyses were conducted using the Cooper-Jacob modification of the Theis non-equilibrium well formula and the "Theisfit" computer program.

The assumptions inherent in applying the non-equilibrium formula should be emphasized because they are often overlooked which can lead to erroneous results. The assumptions include:

1. The aquifer is homogeneous, isotropic, of uniform thickness, and of infinite areal extent.
2. The well is pumped at a constant discharge rate.
3. The pumped well penetrates the entire aquifer, and flow is everywhere horizontal within the aquifer to the well.
4. The well diameter is infinitesimal so that storage within the well can be neglected.
5. Water removed from storage is discharged instantaneously with decline of head.

These assumptions are seldom entirely satisfied under field conditions; nonetheless, they should be considered when applying these formulas.

The Cooper-Jacob solution may be used to calculate transmissivity when either time elapsed since pumping began is large or when the distance from the well is small. The Cooper-Jacob solution is a semi-logarithmic graphical solution using time and drawdown data. The slope of the resultant line can be used to calculate transmissivity from the formula:

$$T = \frac{264Q}{s}$$

Where: T = transmissivity, in gpd/ft
Q = discharge in gpm
s = change in drawdown over one log cycle, in ft = slope of line

The Cooper-Jacob solution may also be used similarly for recovery tests, graphing a ratio of t/t' (elapsed time since pumping began/elapsed time since pumping ceased) versus residual drawdown data. The formula differs slightly from that shown above in that

$$T = \frac{264Q}{s'}$$

Where: s' = change in residual drawdown over one log cycle, in ft = slope of line.

The "Theisfit" computer program fits the Theis equation to experimental pumping test data by using a least squares procedure. In order to use this drawdown test program for recovery test data, recovery data were input in the form of vertical distance of water level recovery versus time since pumping ceased.

Storativity, or storage coefficient, is a dimensionless quantity involving a volume of water per volume of aquifer (symbol S, in cubic feet of water per square foot of aquifer per foot of head, and thus dimensionless). S is derived from drawdown and recovery test data measured in an observation well that is affected by pumping in a nearby well.

Drawdown and recovery data for the five tested wells are plotted on Figures A-1 through A-12 in this Appendix. Transmissivity values determined from these figures are shown on Table 4 in the text as well as on the figures. Where possible, transmissivity values were used to calculate storativity using the formula:

$$S = 0.3T\ t_o/r^2$$

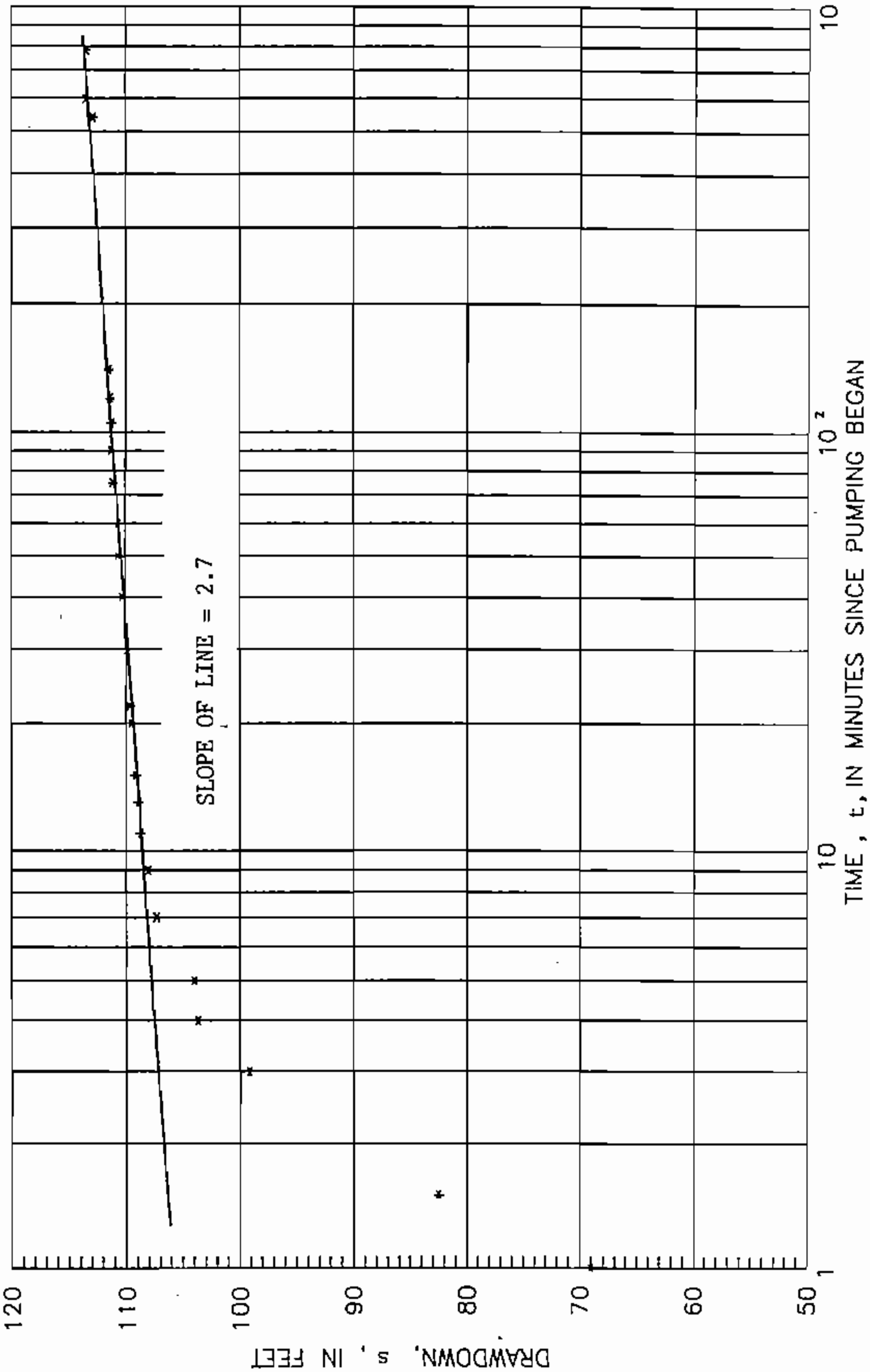
Where:

t_o = time intercept of the straight line at zero drawdown, in days; and
r = distance, in feet, from pumped well to observation well where drawdown measurements were made. 157 ft in this case.

Additionally, the "Theisfit" computer program provided S values from drawdown and recovery data for this well.

S8701

Figure A-1
DATA FOR NC-7

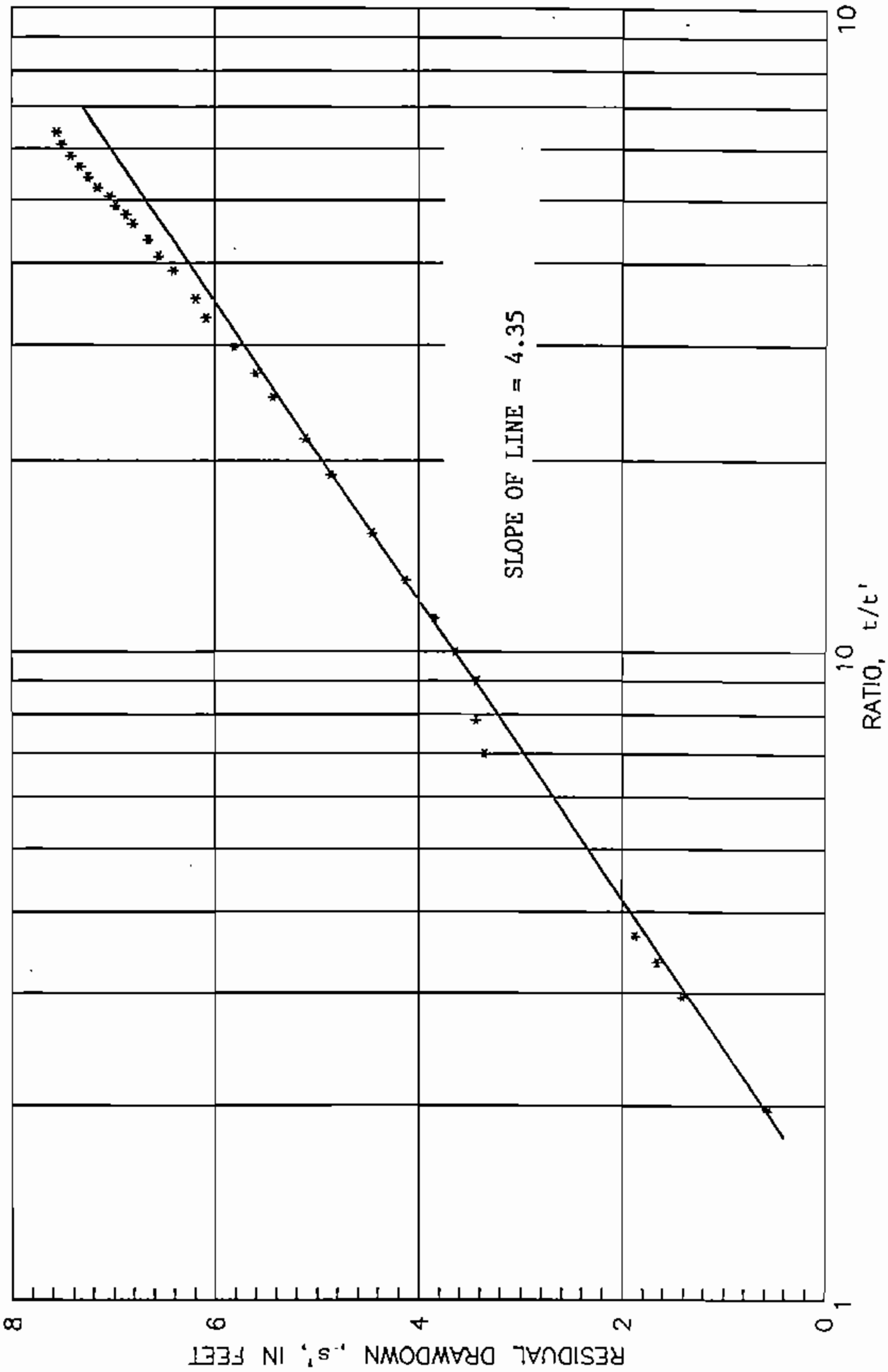


WELL NUMBER : NCWD #7
TYPE AND DATE OF TEST : Drawdown Test, 3/4/87
CALCULATED TRANSMISSIVITY = 33,300 GPD/FT
NON-PUMPING WATER LEVEL = 116.97 FT
PUMPING RATE = 341 GPM

S8701

Figure A-2

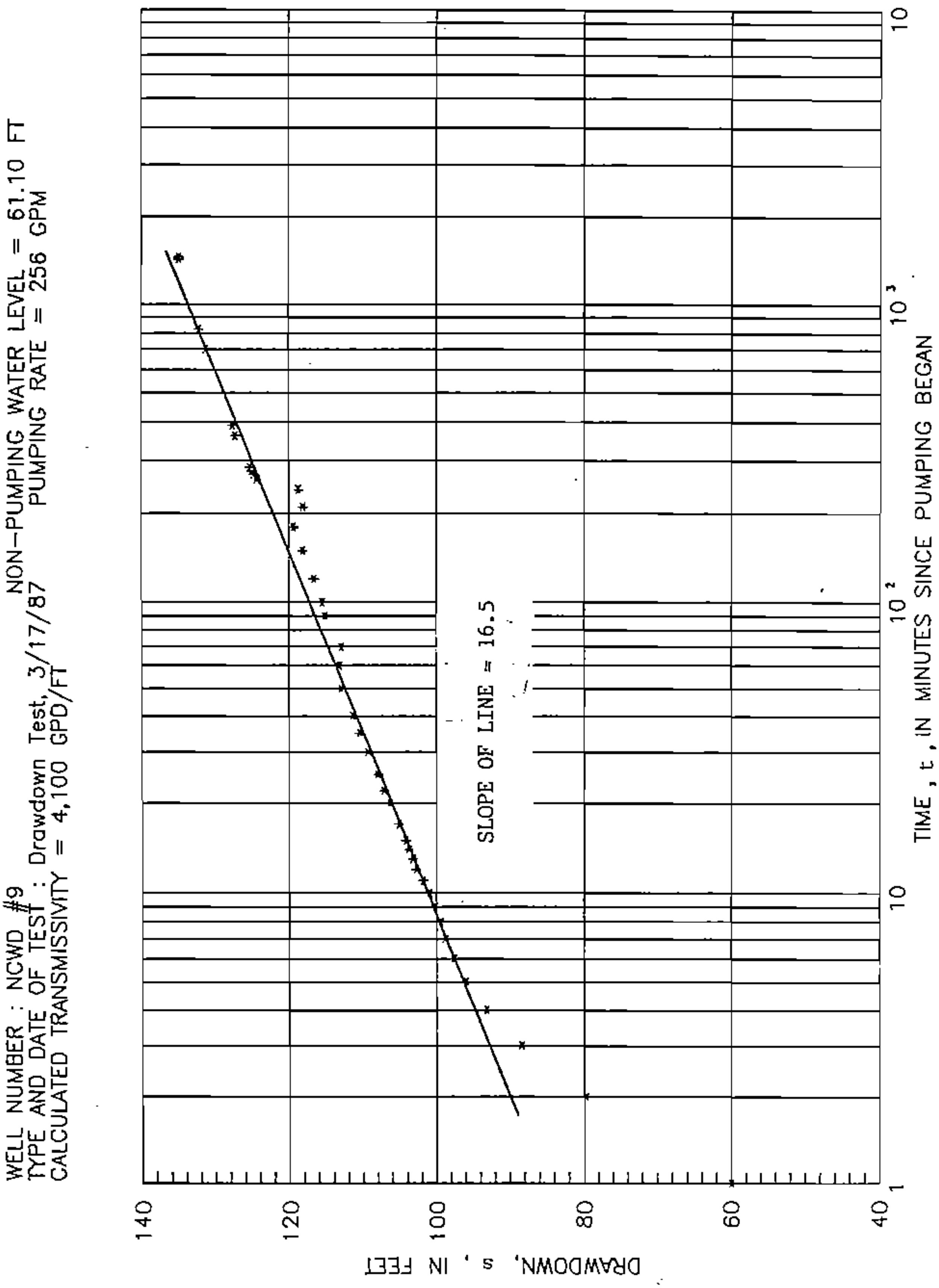
DATA FOR NC-7



WELL NUMBER : NCWD #7
TYPE AND DATE OF TEST : Residual Drawdown 3/5/87
CALCULATED TRANSMISSIVITY = 20,700 GPD/FT
NON-PUMPING WATER LEVEL = 116.97 FT
PUMPING RATE = 341 GPM

Figure A-3

DATA FOR NC-9



S8701

Figure A-4
DATA FOR NC-9

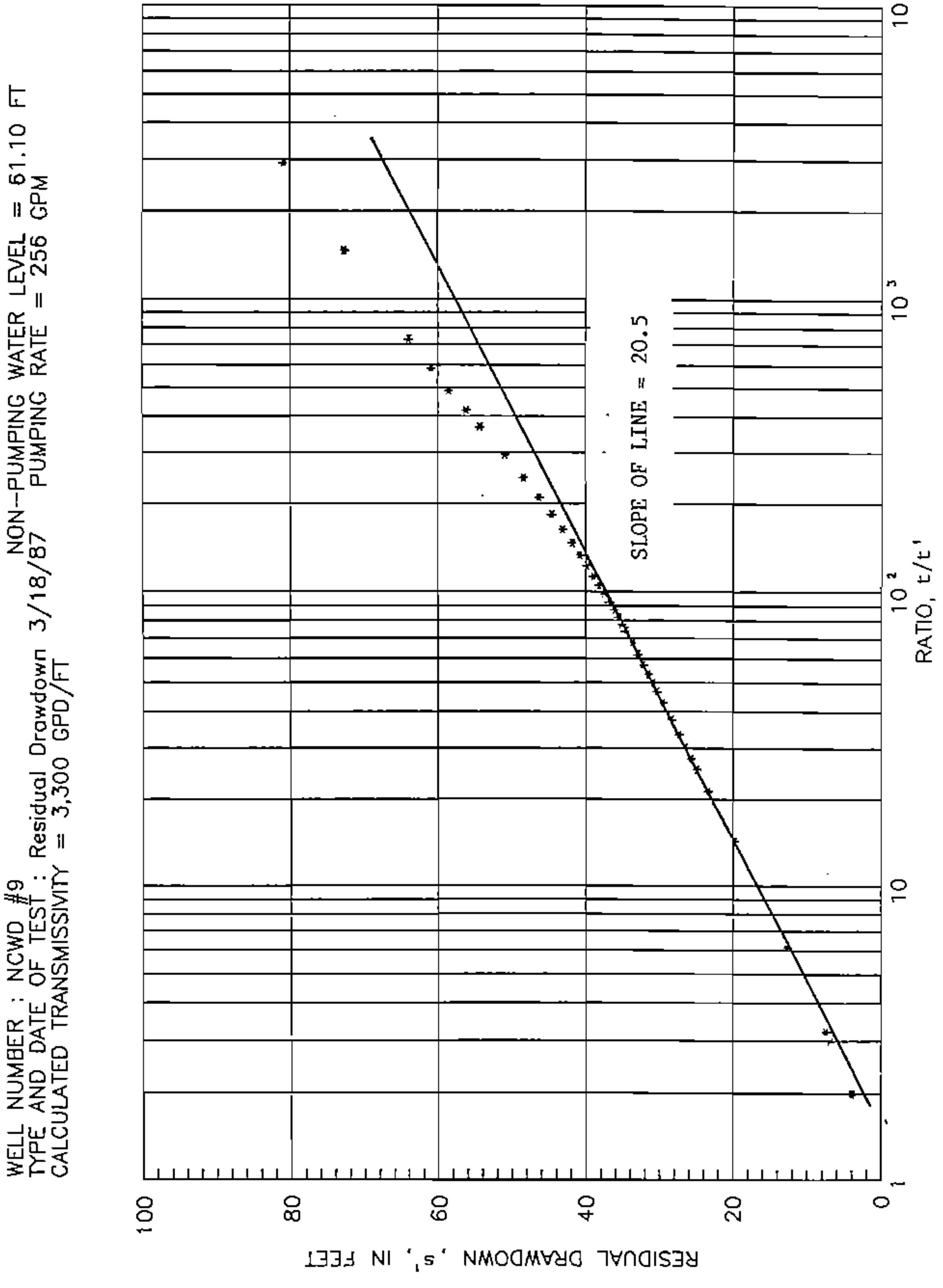


Figure A-5

DATA FOR NC-10

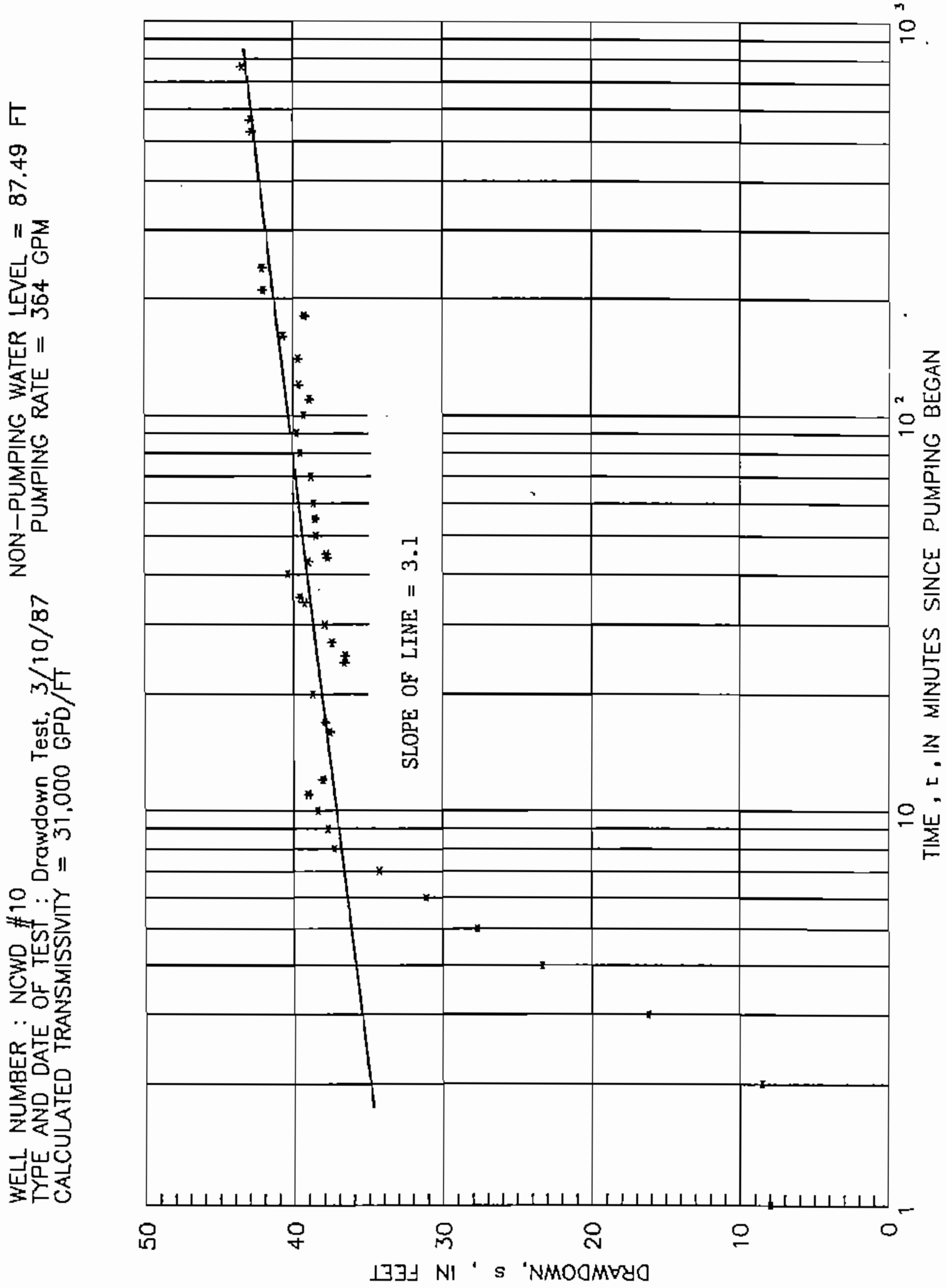
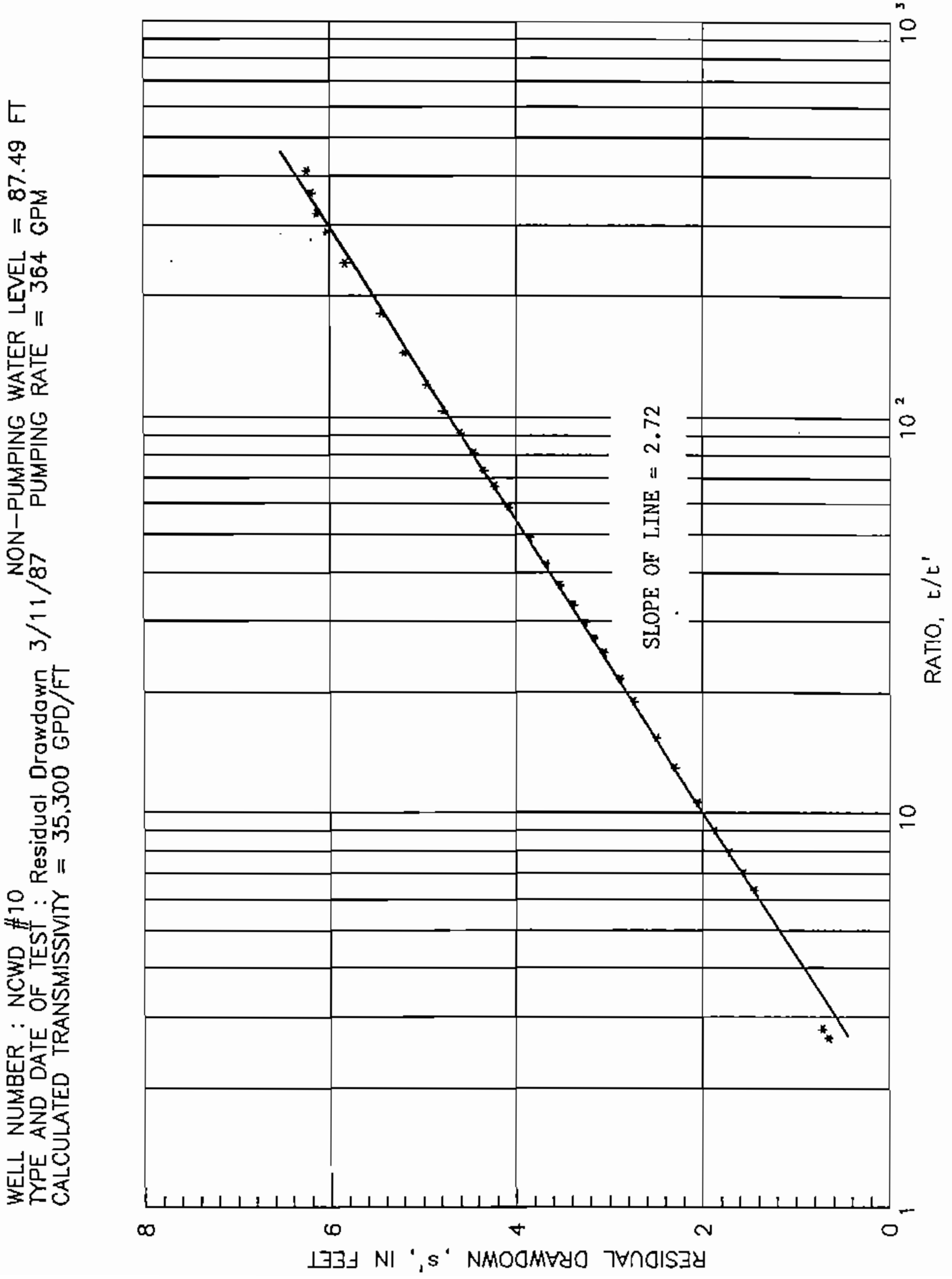


Figure A-6
DATA FOR NC-10



S8701

Figure A-10

DATA FOR V-157

WELL NUMBER : VWC #157
TYPE AND DATE OF TEST : Residual Drawdown 4/2/87
CALCULATED TRANSMISSIVITY = 88,900 GPD/FT
NON-PUMPING WATER LEVEL = 70.52 FT
PUMPING RATE = 1347 GPM

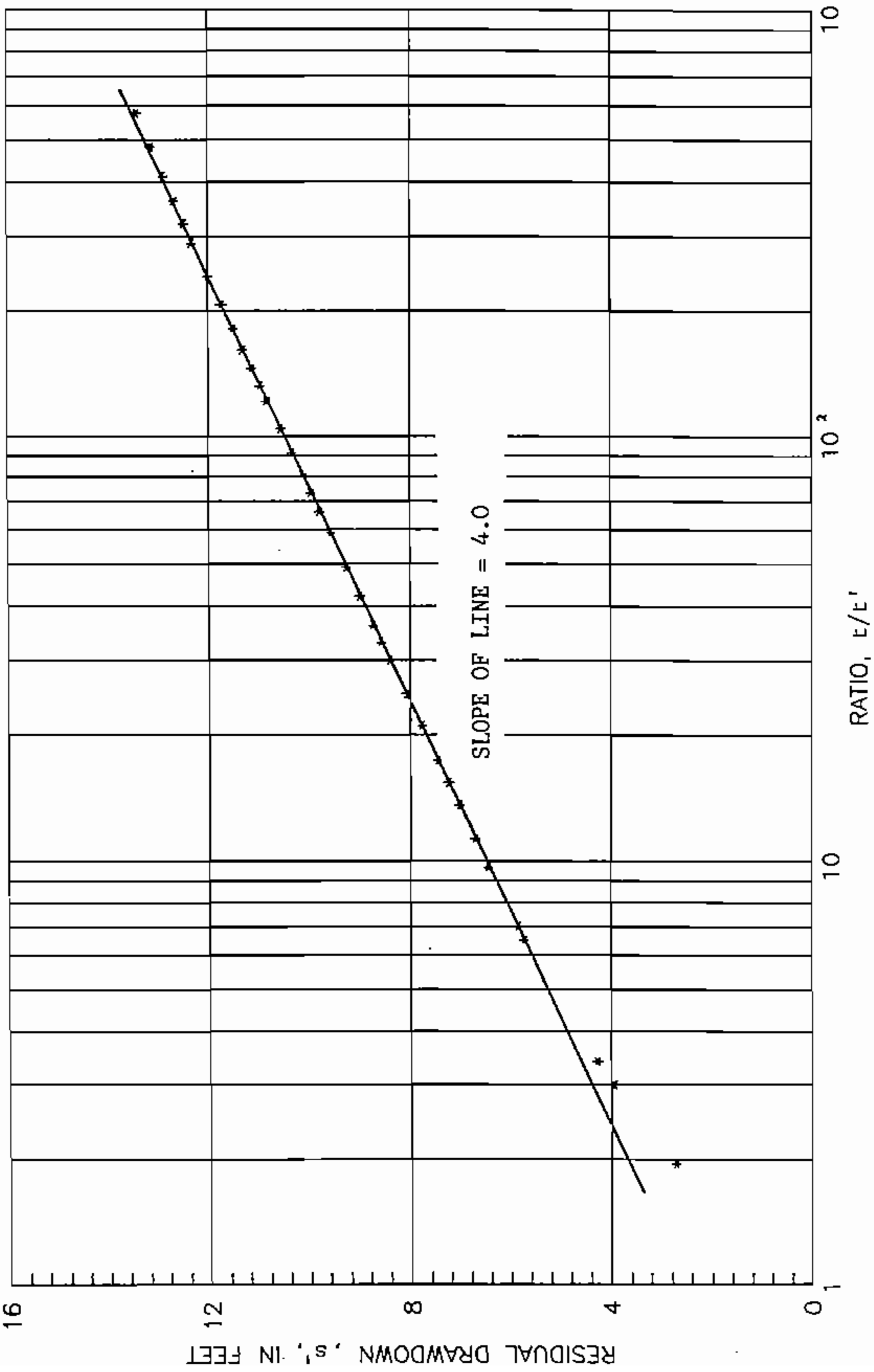


Figure A-7

DATA FOR NC-12

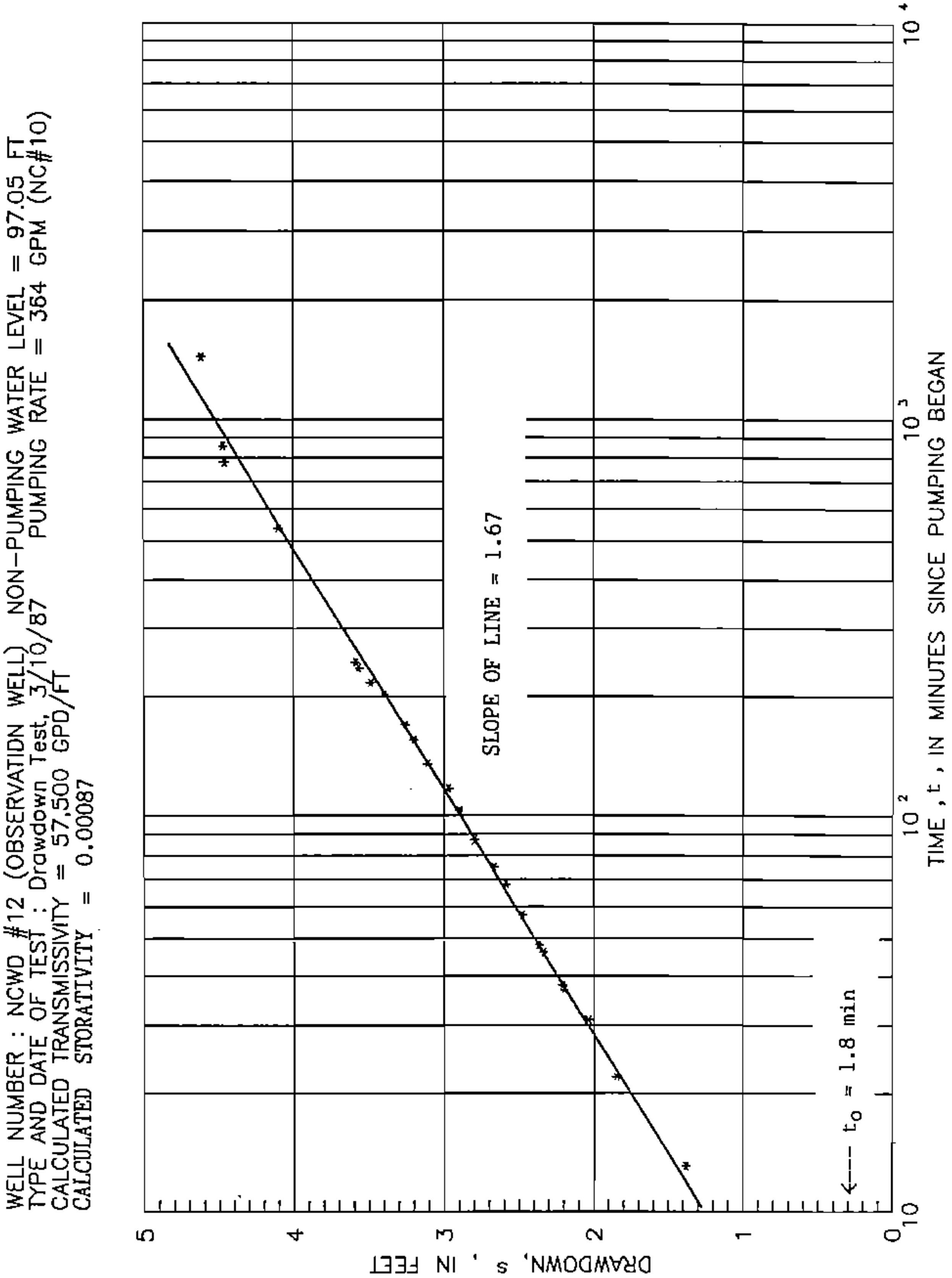


Figure A-8

DATA FOR NC-12

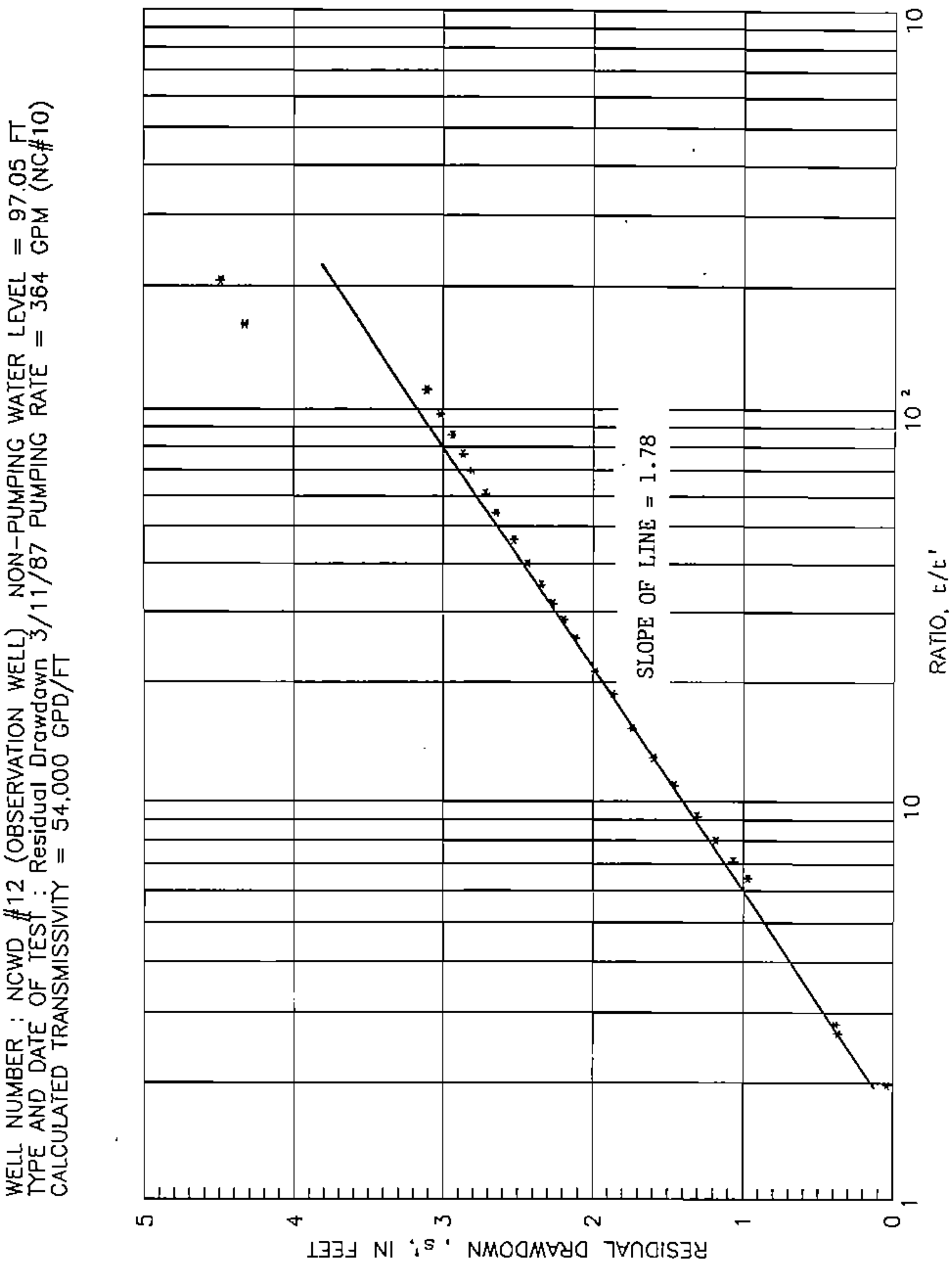
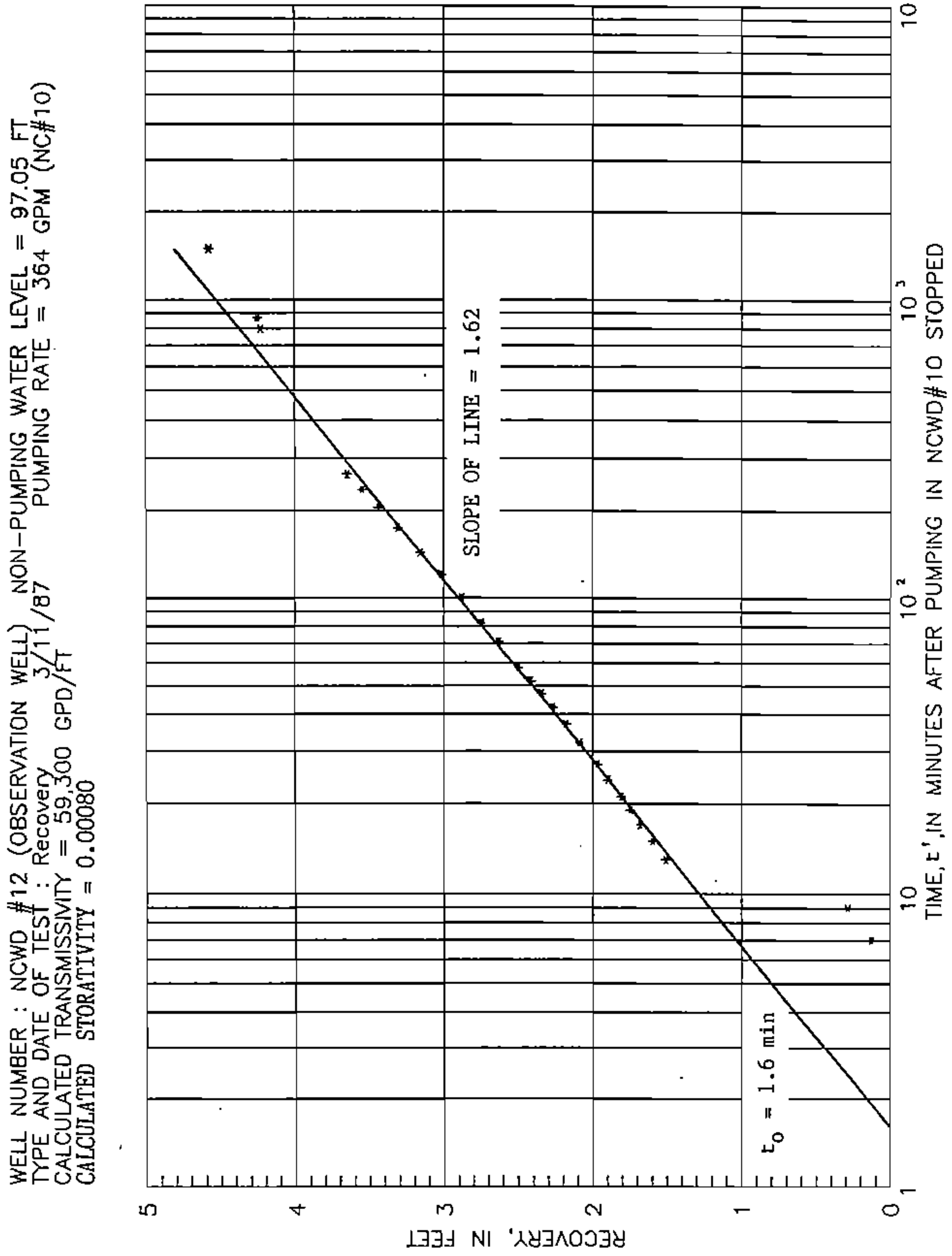


Figure A-9

DATA FOR NC-12



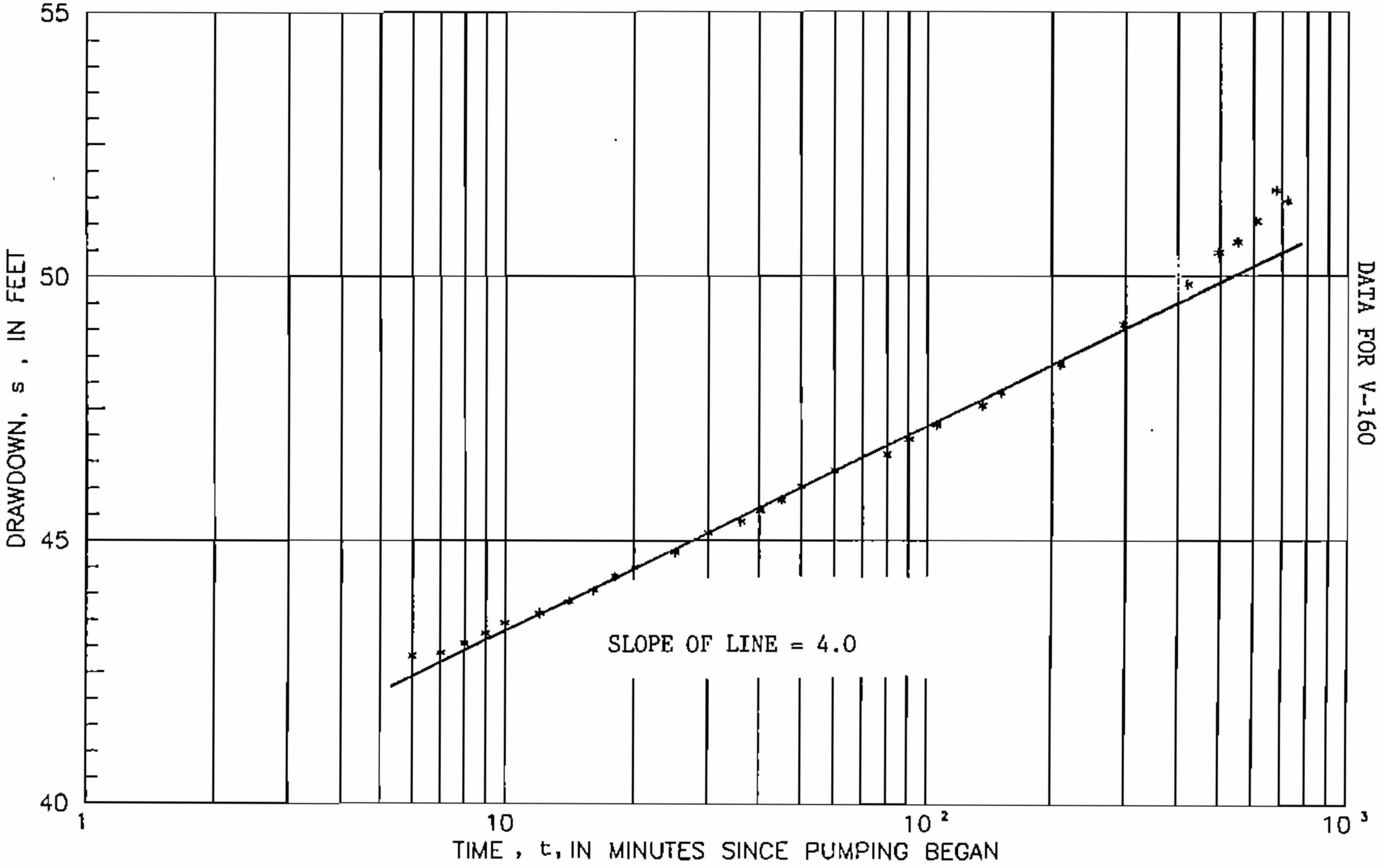
S8701

Figure A-11

DATA FOR V-160

WELL NUMBER : VWC #160
TYPE AND DATE OF TEST : Drawdown Test, 3/24/87
CALCULATED TRANSMISSIVITY = 169,100 GPO/FT

NON-PUMPING WATER LEVEL = 45.11 FT
PUMPING RATE = 2562 GPM



S8701

Figure A-12

DATA FOR V-160