**Final Report**

# SAN DIEGUITO BASIN GROUNDWATER MODEL

**San Diego County, California**

Prepared for:
San Diego County Water Authority
and
San Dieguito Basin Management Task Force

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# Section 1

# INTRODUCTION

The San Dieguito Basin is located along the coast of San Diego County, near the City of Del Mar (Figure 1-1). Historically, there were numerous production wells in the basin. In the early- to mid-1960s, , period of relatively high rates of groundwater production coincided with a period in which no release of surface water was made from Lake Hodges. Resulting water level declines in the basin led to seawater intrusion extending about 2.5 miles inland from the coast. This seawater intrusion adversely impacted groundwater quality, and groundwater production from the basin subsequently declined. Following are sections providing background information on the study, discussions of previous work in the area, physiography, and climate and land use.

## 1.1 Background

This technical memorandum provides an overview of the hydrogeology of the San Dieguito Basin (the "conceptual model" of the basin), and documents construction of a three-dimensional, finite-element, density-dependent, groundwater flow and transport model of the basin. Development of the groundwater model represents Phase 1 of a three-phase project. The overall goal of the three-phase project is to develop a groundwater management plan for the basin and develop design and cost estimates for required management facilities. The intended purpose of the San Dieguito Basin Groundwater Management Study (and Planning Report) is to develop a groundwater management plan and project alternatives to protect, replenish, and improve the groundwater resources of the San Dieguito Basin. In order to replenish and improve the groundwater resources of the basin, the groundwater management study will develop and evaluate groundwater management alternatives, including conjunctive use projects.

The groundwater model developed in Phase I will be utilized in Phases II and III, and for future groundwater management purposes beyond Phase III. Phase II of the three-phase study will investigate the feasibility of alternative groundwater management and conjunctive use projects, including: 1) brackish groundwater development; 2) development of storage capacity within the basin; and, 3) replenishment of groundwater resources with surplus local stream flows, reclaimed water, and/or imported water.

Phase III of the Groundwater Management Study will further develop a recommended project alternative(s) selected by the Task Force based upon Phase II results. In addition, a groundwater management plan will be developed and may be adopted in accordance to the California Water Code (AB3030).

This work was performed under contract to the San Diego County Water Authority (SDCWA), who is acting in partnership with other members of the San Dieguito Groundwater Management Task Force (Task Force). Members of the Task Force include Olivenhain Municipal Water District, the City of Escondido, the City of San Diego, the Rancho Sante Fe Community Services District, the Whispering Palms Community Services District, the Fairbanks Ranch Community Services District, the County of San Diego, the San Elijo Joint Powers Authority, and the San Diego County Water Authority.

This technical memorandum is divided into four sections. Section 1, *Introduction*, provides a brief project overview. Section 2, *Hydrogeology*, presents a description of the hydrogeology of the basin and summarizes previous work. Section 3, *Groundwater Model*, describes the density dependent flow and transport model that was developed for the basin. A users manual for the model is provided as a separate memorandum. A summary discussion of the above work is provided in Section 4, *Discussion and Conclusions*.

## 1.2 Previous Work

Many hydrogeologic studies have been performed in the San Dieguito Basin. California Department of Water Resources reports (DWR; 1949 and 1959) discuss the distribution of geologic units within the basin, typical well yields from the alluvial basin, surface-water/groundwater interaction, and alluvial thicknesses within the basin. Water level and water chemistry monitoring were undertaken jointly in the 1960s by the CDWR and the U.S. Geological Survey (CDWR, 1960 through 1964, 1965 through 1974; U.S. Geological Survey, 1975 through 1981). These data and the earlier reports form the foundation for the work of Izbicki (1983), and the modeling efforts of Huntley and Carroll (1983) and Carroll (1985). The work cited above formed the foundation for the modeling effort conducted as part of this study.

Izbicki (1983) compiled results of previous work and presented water level contour maps, water chemistry maps, and hydrographs of individual wells within the basin. Resulting data interpretations were used to qualitatively assess the potential for using reclaimed wastewater to recharge the basin (Izbicki, 1983). Carroll (1985) compiled much of the same data, reviewed existing lithologic logs to assess variations in sediment type within the alluvial basin, and developed a two-dimensional numerical groundwater flow model of the basin.

Studies conducted by Leighton (1987) and Dudek (1988, 1991) combine qualitative assessments of the engineering and institutional issues related to management of groundwater in the basin with cost comparisons of various alternatives. In addition, these reports present a number of groundwater management alternatives, including seasonal storage of groundwater through injection/production wells, recharge of reclaimed wastewater to decrease basin water salinity, spreading basin recharge, and seawater intrusion protection through both injection wells and slurry walls.

Geophysical (resistivity) surveys conducted by George Jiracek of San Diego State University were reviewed. The survey area was limited to areas west if the eastern most limit of the estuary in areas already intruded by seawater. Because of the low subsurface resistivity (i.e. saline water) the depth of penetration was only about 30 to 50 feet. This was too shallow to be of use for this study.

## 1.3 Physiography

The San Dieguito hydrologic subarea consists of that portion of the surface water drainage system that is tributary to the San Dieguito River downstream of Lake Hodges. The subarea is about 37 square miles (24,000 acres) in area. As herein defined, the San Dieguito Basin (basin) occupies the Holocene age alluvial portion of this subarea. The surface of the basin slopes towards the Pacific Ocean to the west, and ranges in elevation from about 100 feet above mean sea level (ft msl) in the east to 0 ft msl to the west where the basin abuts the ocean. The basin is bounded to the north and south by relatively low hills that reach elevations of about 300 ft msl. These hills are underlain by bedrock material. The basin is bounded to the east by Hodges Dam.

### 1.4 Climate and Land Use

The area is characterized by a Mediterranean climate, with warm dry summers and mild winters. The mean annual temperature is about 55° F. Precipitation within the basin averages between about 11 to 15 inches annually, most of which occurs between the months of November and April. Land use within the basin is primarily agricultural, with local residential developments, and the Del Mar Race Track located along the western most portion of the basin.

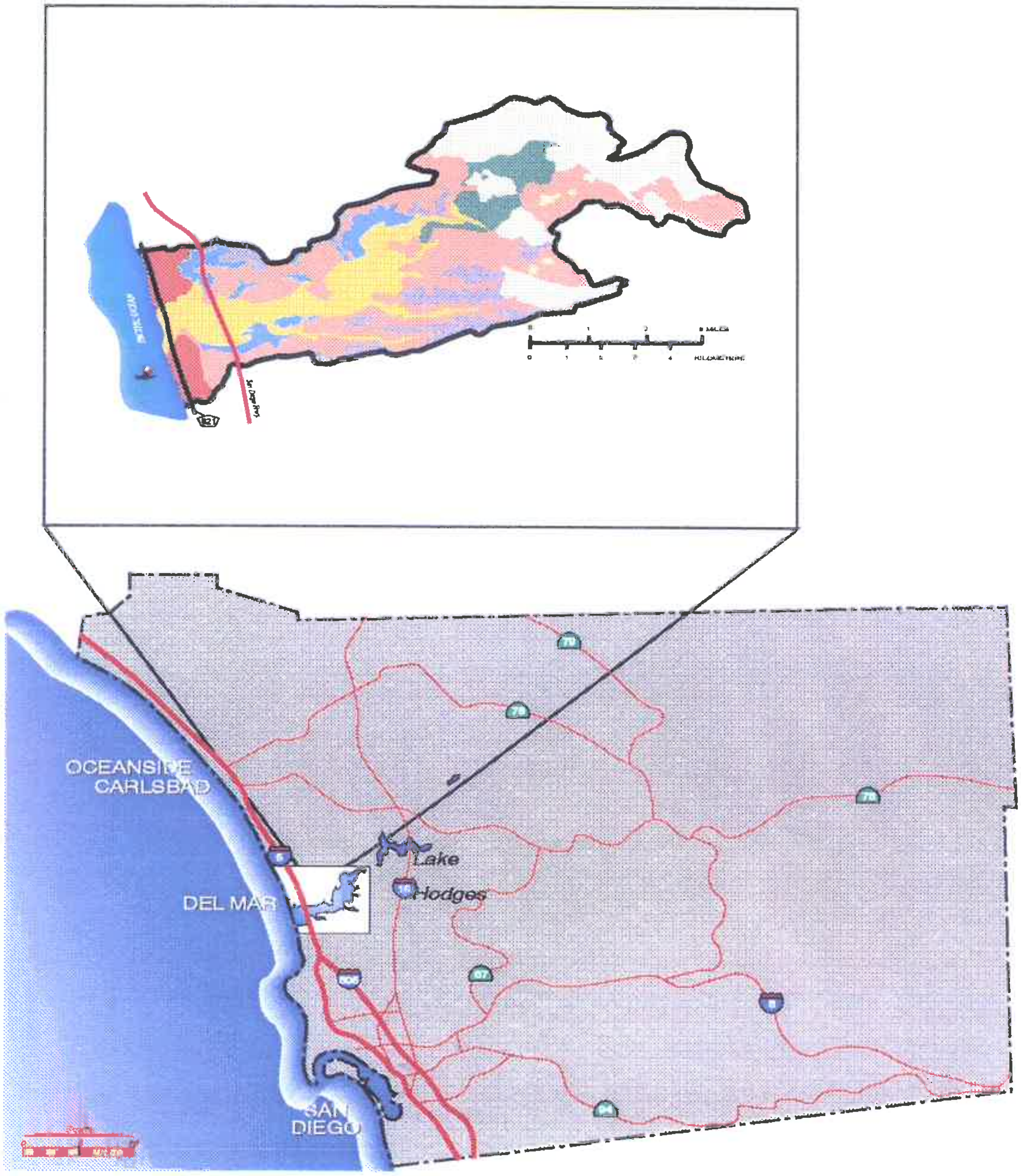

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**Figure 1-1**
**Location Map**

# Section 2

# HYDROGEOLOGY AND CONCEPTUAL MODEL

This section presents a description of the hydrogeology and conceptual model of the San Dieguito Basin. Data used to support this portion of the study included available California Department of Water Resources driller's logs (see separate volume Appendix A), and a number of published sources (see Section 1.2, *Previous Work*).

## 2.1 Hydrogeology

The geologic materials of the San Dieguito Hydrologic area consist of younger and older age Quaternary alluvium, Tertiary age Del Mar Formation and Torrey Sandstone marine sedimentary rocks, and Jurassic/Cretaceous age meta-volcanics (see Figure 2-1; Izbicki, 1983; Huntley and Carroll, 1983; Carroll, 1985). The main aquifer in the subarea is located within the younger Quaternary alluvium, which covers an area of about 6 square miles (3,900 acres) along the river channel (see Figure 2-1). The easternmost portion of the alluvial groundwater basin is filled largely with coarse, permeable sands of fluvial origin that are as much as 125 feet thick (see Figure 2-2; Huntley and Carroll, 1983). Toward the west, these fluvial sands are interbedded with alluvial silts and lagoonal clays, with the amount of sand decreasing substantially toward the coast (Carroll, 1983).

### 2.1.1 Hydrogeologic Units

To identify hydrogeologic units within basin alluvium, available geologic logs were compiled and lithologies divided into one of 11 categories (see Table 2-1). To aid in correlation, these categories were lumped into six groups based on probable similar hydraulic characteristics (Table 2-1). The location of the wells were digitized, the geologic logs plotted along cross sections, and lithologic correlations then established. Well logs used as part of this study are included as Appendix A (a separate volume). Well locations and cross sections are shown on Figure 2-3. Lithologic symbols are presented in Table 2-1. A fence diagram of the logs is provided as Figure 2-4. Resulting cross sections showing the interpreted layers are presented as Figures 2-5 through 2-11.

Results of the above work indicate the presence of four correlable layers within basin alluvium. From shallowest to deepest these layers are herein termed Layer-1 through Layer-4. Bedrock comprises an additional layer beneath the alluvium. These units form the basis for vertical subdivision of the model grid, and are described below.

**Layer-1** represents the shallowest layer of alluvium, and contains soils and relatively coarse-grained surficial sands. This unit is an aquifer. In the eastern portion of the basin Layer-1 is characterized by relatively coarse-grained materials. Layer-1 was not identified in the west. Thin sand layers and units identified by "soil" designations in DWR well logs locally occur in the west. However, these units have not been correlated with Layer-1 in the east because of sparse well data in the west and the small thickness of sand layers in the west. The unit is typically about 10 to 50 feet thick, but is locally as much as 100 feet thick.

**Layer-2** represents an aquitard consisting of clays and sandy, gravelly, and silty clays. This fine-grained horizon appears below the soils in the west portion of the basin, and below the relatively coarse-grained material of Layer-1 in the eastern portion of the basin. Layer-2 is continuous throughout the basin, typically ranging in thickness between 50 and 100 feet.

**Layer-3** is a coarse-grained aquifer that is relatively thick in the eastern parts of the basin, and present as a series of thin sand layers in the west. Most of the production wells in the basin are screened in Layer-3. Layer-3 is typically about 10 to 50 feet thick, but its bottom is locally poorly defined.

In the eastern portions of the basin, Layer-3 represents coarse-grained materials that underlie Layer-2 and overlie the bedrock. In the western part of the basin, Layer-3 represents horizons of sandy material, with some silts, that underlay Layer-2. Several of these thin sands appear in the western basin, but the well logs show that they appear at a variety of depths and elevations. It is likely that these represent a series of channels eroded through the fine-grained lagoonal deposits. Because the density of well-logs is not great enough to define individual (about 30 ft wide) channels as they meander through the river valley, and because these channels must be continuous in the model to allow hydraulic communication with the ocean, Layer-3 groups a number of these channels together into a single layer, despite their elevation differences.

**Layer-4** represents fine-grained material that appears between the bedrock and Layer-3, particularly in wells 14S/4W-12L1 and 14S/3W-7C2. This horizon becomes coarser toward the east (14S/3W-7C2 and 7C3), so it may act as an aquitard in the west and an aquifer further east. Layer-4 is truncated in the far eastern part of the basin, as all material below Layer-2 is coarse and there is no need to subdivide this unit. Where present, Layer-4 is about 10 to 50 feet thick.

**Bedrock** is present beneath and adjacent to Layer-1 through Layer -4 of the alluvium. Primary bedrock units surrounding the basin consist of Del Mar Formation and Torrey Sandstone. As described in Section 3.1.2, *Vertical Layering of the Model*, a single layer is used to represent bedrock material of the watershed located adjacent to the alluvial portion of the basin. This bedrock layer is connected to Layer-1 of the alluvial basin because work conducted as part of this study suggests that only the shallow portions of the bedrock (primarily Torrey Sandstone) are transmissive. However, it is important to note that water and solutes from the watershed bedrock terrain may still flow into the deeper alluvial model layers after entering Layer-1 of the alluvium. .

### 2.1.2 Hydrogeologic Properties

Based on well yields reported on driller's logs, Izbicki (1983) estimated that the transmissivity of the alluvial aquifer ranged from less than 4,000 square feet per day ($ft^2$/day) to as much as 15,000 $ft^2$/day; however, this approach may underestimate aquifer transmissivity (Razack and Huntley, 1991). Huntley (1984) conducted an aquifer test of a production well located in the Osuna Valley subarea of the San Dieguito basin that resulted in a measured transmissivity of 24,500 $ft^2$/day. Leighton and Associates (1987) cite a Hargis and Associates report (1986) that reports a calculated transmissivity ranging from 1,600 to 3,000 $ft^2$/day from a shallow observation well in Osuna Valley. This value appears relatively low, and is not considered representative of the deeper producing zones, most notably Layer-3.

During calibration of the groundwater model the values of hydraulic conductivity were systematically changed until modeled head and water quality conditions coincided reasonably well with observed conditions. Calibration techniques and results are described in Section 3.4, *Model Properties*

The alluvial aquifer is unconfined throughout most of the basin, with confined conditions occurring in the western parts of the basin where lagoonal clays are interbedded with fluvial sands (Carroll, 1985). Estimates of the volume of groundwater in storage in the alluvial aquifer range from 7,800 acre-feet (ac-ft) (Carroll, 1985) to 50,000 ac-ft (Izbicki, 1983). These estimates are divergent primarily because Carroll (1985) only included portions of the aquifer that contained relatively good quality water. There are no available pumping test estimates of storativity. Estimates of storativity based upon results of modeling are presented and discussed in Section 3, *Groundwater Model,* under Section 3.1.4, *Hydrogeologic Properties.*

## 2.2 Groundwater Movement

The principle sources of recharge to the alluvial aquifer are spillage from Lake Hodges, surface runoff from the surrounding watershed, and subsurface inflow from adjacent marine sedimentary deposits. Historically, there were numerous production wells in the basin (see Figure 2-3). In the early- to mid-1960s, relatively large amounts of groundwater were produced from the alluvium. At the same time, no releases of surface water occurred from Lake Hodges. Resulting water level declines in the alluvium were as great as 50 feet below sea level, and led to seawater intrusion that extended about 2.5 miles inland from the coast (see Figures 2-12 and 2-13; Izbicki, 1983). This seawater intrusion adversely impacted groundwater quality, and groundwater production from the basin subsequently declined.

Significant amounts of surface water were released from Lake Hodges during the late 1970s and early 1980s, resulting in a retreat of the seawater interface. During this time, groundwater elevations within the alluvial aquifer were as much as 30 feet above sea level, and groundwater flowed toward the Pacific Ocean, causing retreat of the seawater interface.

## 2.3 Pre-Model Water Budget Data

A full evaluation of the water budget was not prepared prior to modeling for two primary reasons. First, there was no pumping test data for which to independently estimate the specific yield of sediments within the basin. This precluded the ability to calculate changes in storage, which is a fundamental aspect of a water balance. Secondly, the amount of percolation arising from releases from Lake Hodges was unknown. Because the water budget was developed as part of the modeling process, it is described at more length in Section 3, *San Dieguito Basin Groundwater Model* under Section 3.3, *Groundwater Budget.*

## 2.4 Groundwater Quality

Groundwater quality in the basin is marked by elevated concentrations of total dissolved solids (TDS), ranging from about 1,000 mg/l in the eastern portion of the basin to as much as 27,000 mg/l in the western portion (Figure 2-14; Izbicki, 1983). Elevated concentrations of TDS largely reflect effects of seawater intrusion (Izbicki, 1983). During seawater intrusion events, water levels within hydrogeologic units underlying the estuary are considerably below landsurface, indicating a downward gradient (see Figure 2-12). Because of this downward gradient, the estuary is a source of seawater intrusion to the aquifer. Groundwater quality data indicate relatively elevated concentrations of TDS beneath the estuary that decrease rapidly away from the estuary boundary (Figure 2-14).

The alluvial aquifer is generally underlain by the Del Mar Formation, which consists of relatively well-consolidated, poorly transmissive clays and fine-grained sands saturated with poor quality groundwater (typically 1,500 to 3,000 milligrams per liter [mg/L] TDS). Lateral to the alluvium, the Del Mar Formation is overlain by the more transmissive Torrey Sandstone. The Torrey Sandstone is coarser-grained and more permeable than the older Del Mar formation, but also contains groundwater of relatively poor quality (typically 1,000 to 2,000 mg/L. Groundwater elevations in these units are at least locally higher than the alluvium, and recharge of high TDS water into the alluvial aquifer is significant (Carroll, 1985). Potential problems associated with groundwater development within the alluvial aquifers therefore include upwelling and lateral flow of high salinity groundwaters from the adjacent units as water levels are lowered within the alluvium during pumping. Under equivalent gradients, flow from the Torrey Sandstone would contribute significantly more water to the alluvium than other bedrock units.

## 2.5 Summary of Conceptual Model

In summary, the above data indicate that the major water-bearing unit in the area is Quaternary Alluvium that is underlain and surrounded by bedrock of the Del Mar Formation and Torrey Sandstone. The Del Mar Formation is relatively impermeable and contributes insignificant amounts of water to basin alluvium. The Torrey Sandstone, present in areas adjacent to the basin, is semipermeable and is the primary source of bedrock leakage to the alluvium.

The total thickness of alluvium is about 100 to 150 feet, with the greatest thickness occurring near the western edge of the basin. Geologic log data indicate the presence of four correlable units, herein termed Layer-1 through Layer-4, within the alluvium. Only three of these units are typically present in any given portion of the basin. Layer-3 is present throughout most of the basin, and is the primary water producing unit within the basin. Most wells screened within basin alluvium are screened within this unit. Pumping tests in the Osuna Valley portion of the basin provide transmissivity estimates between 1,600 and 24,500 $ft^2$/day.

The principle sources of recharge to the alluvial aquifer are spillage from Lake Hodges, surface runoff from the surrounding watershed, and subsurface inflow from adjacent marine sedimentary deposits. Groundwater production is an important source of discharge. Water balance calculations for the area were developed during model calibration, and are presented in Section 3.3, *Groundwater Budget.* In the early- to mid-1960s, relatively large amounts of groundwater production combined with no releases of surface water from Lake Hodges resulted in seawater intrusion that extended about 2.5 miles inland from the coast. Decreased production of groundwater from the basin since 1965 in combination with increased releases of water from Lake Hodges has resulted in retreat of the seawater interface.

Observed water level data and water quality data indicate that the estuary is a potential source of seawater intrusion. An additional source of poor quality water is the surrounding bedrock formations, particularly the Torrey Sandstone. These bedrock formations contain water with TDS concentrations ranging between about 1,000 to 3,000 ppm

| TABLE 2-1<br>Geologic Log and Model Conductivity Subdivisions | | | |
|---|---|---|---|
| **Symbol** | **Map Color** | **Description** | **Model Parameter** |
| SO | White | Soil | - |
| G | Yellow | Gravel | Gravel |
| SG | Yellow | Interbedded sand and gravel | Sand & Gravel |
| S | Red | Sand | Sand |
| SD | Red | Silty sand | Sand |
| SC | Red | Interbedded sand and clay | 50/50, sand/clay |
| SL | Green | Silt | Silt |
| SS | Green | Interbedded sand and silt | 50/50, sand/silt |
| C | Blue | Clay | Clay |
| GC | Blue | Gravely clay | Clay |
| BD | Gray | Bedrock | - |

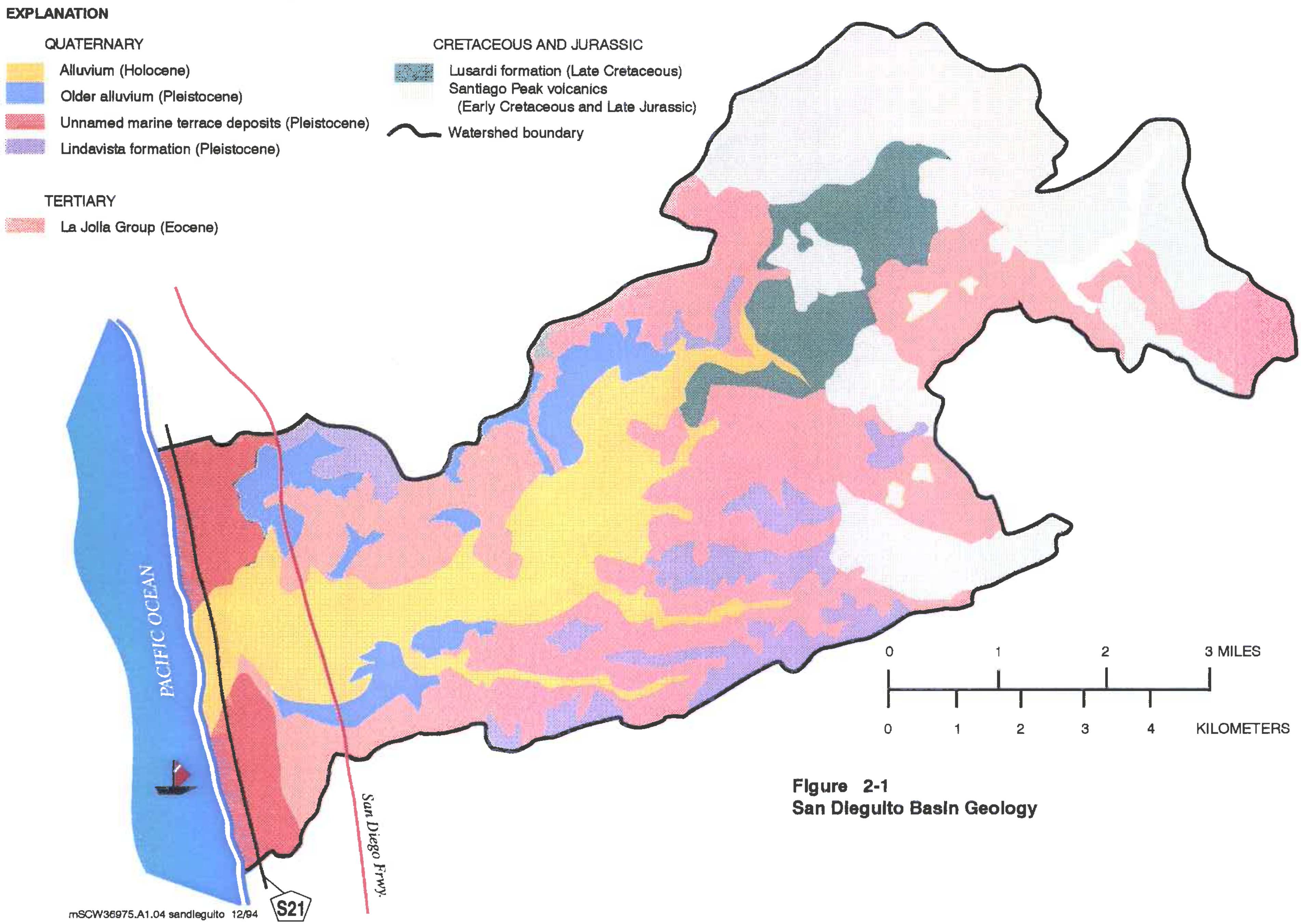


**Figure 2-1**
**San Dieguito Basin Geology**


**Figure 2-2**
**Thickness of Quaternary Alluvium**

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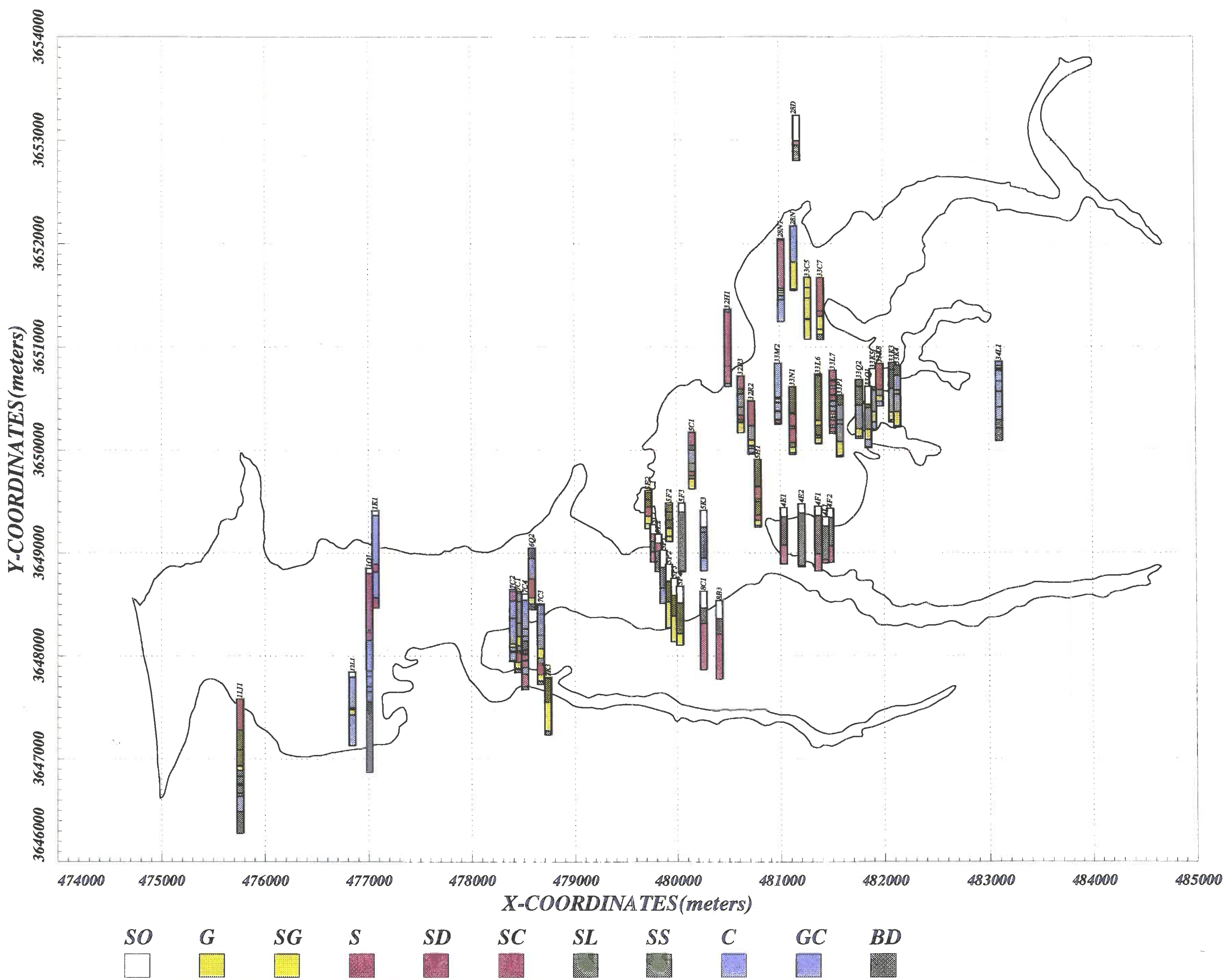
**Figure 2-3**
**San Dieguito Basin**
**Wells Location**

Plot date: 14 Dec 94 14:57:37 Wednesday
/gis4/sandieguito/wells.aml




# SAN DIEGUITO WELL LOG PLOT

Figure 2-4

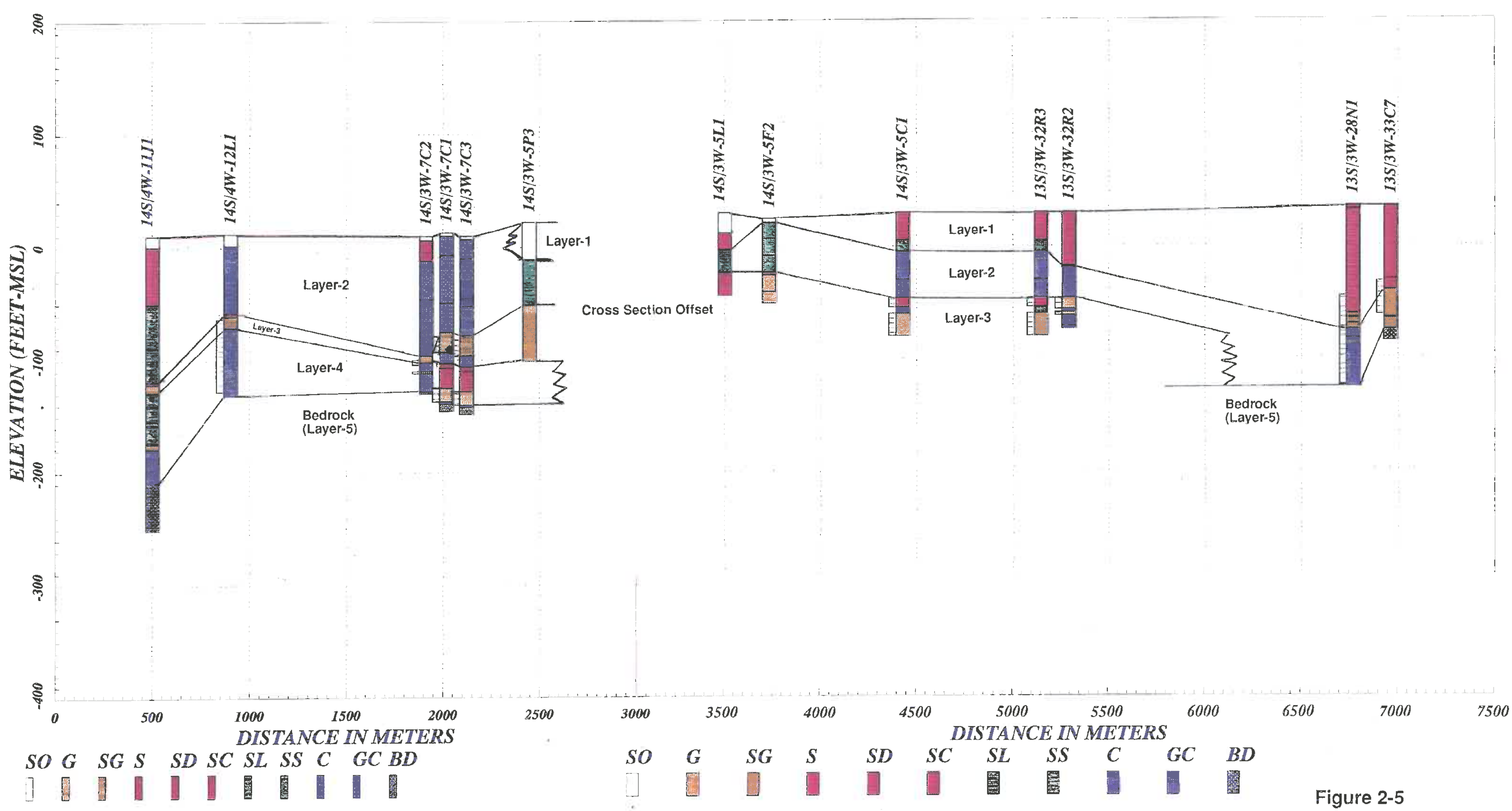
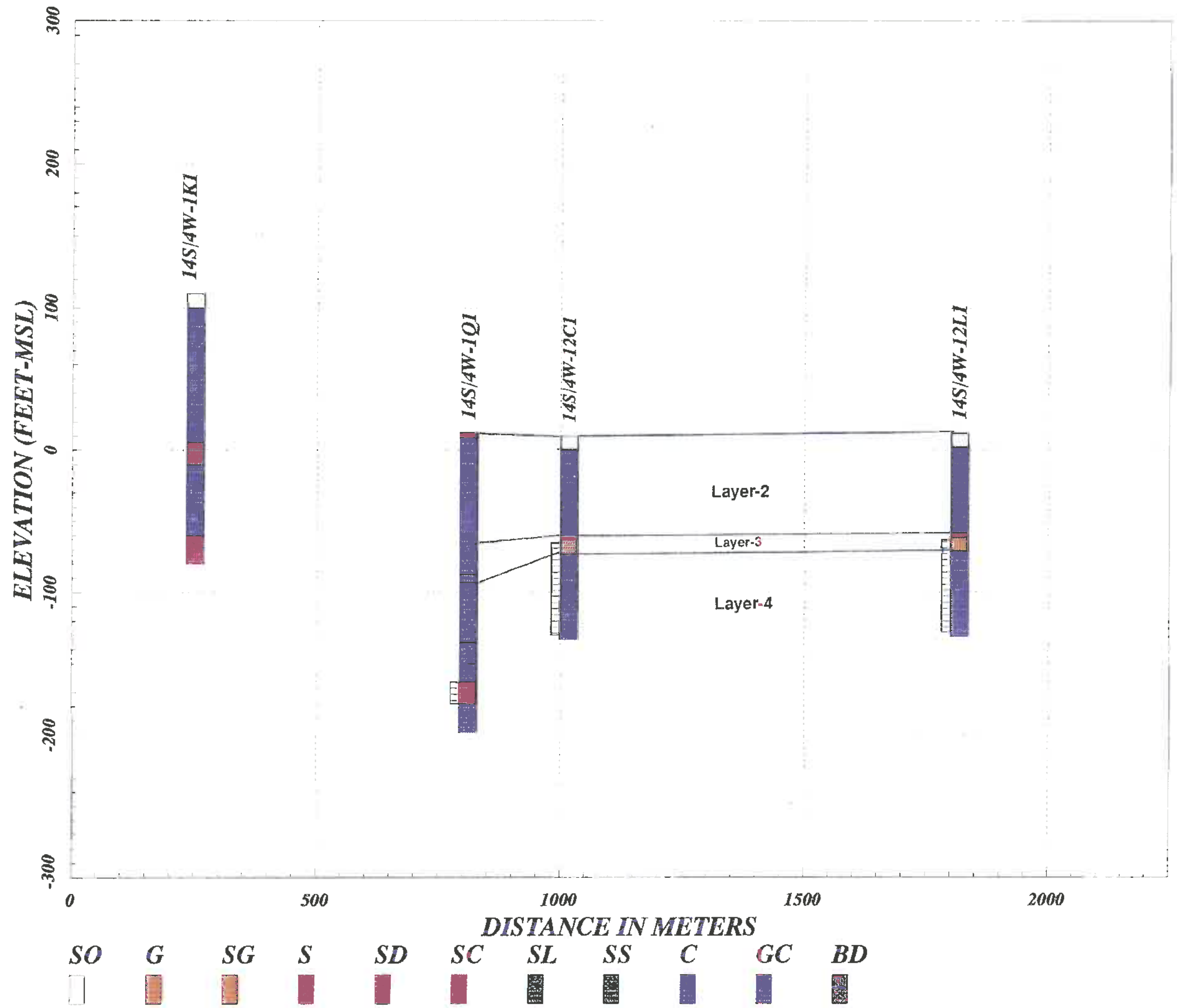


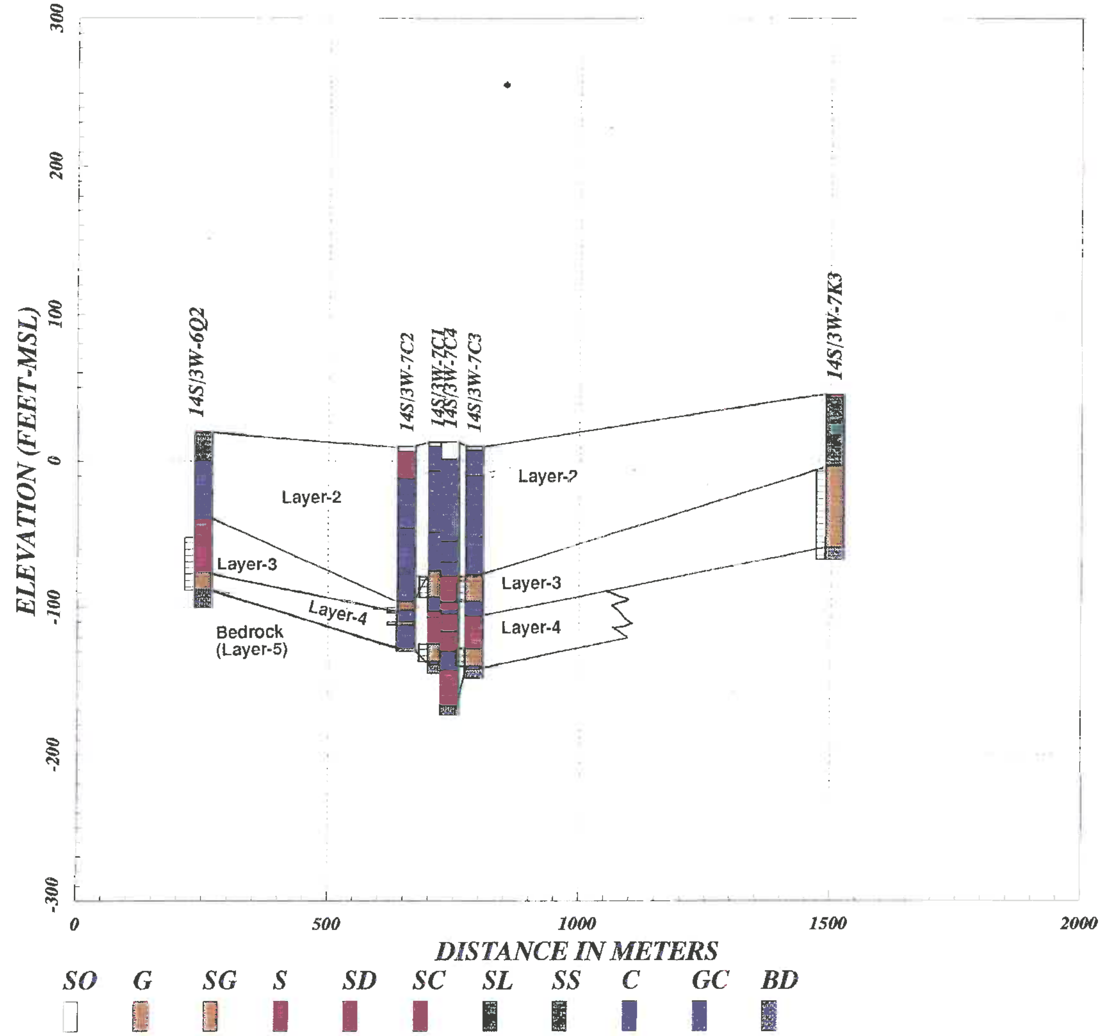

Figure 2-5

CROSS-SECTION A-A' SCALE 1" = 250.00



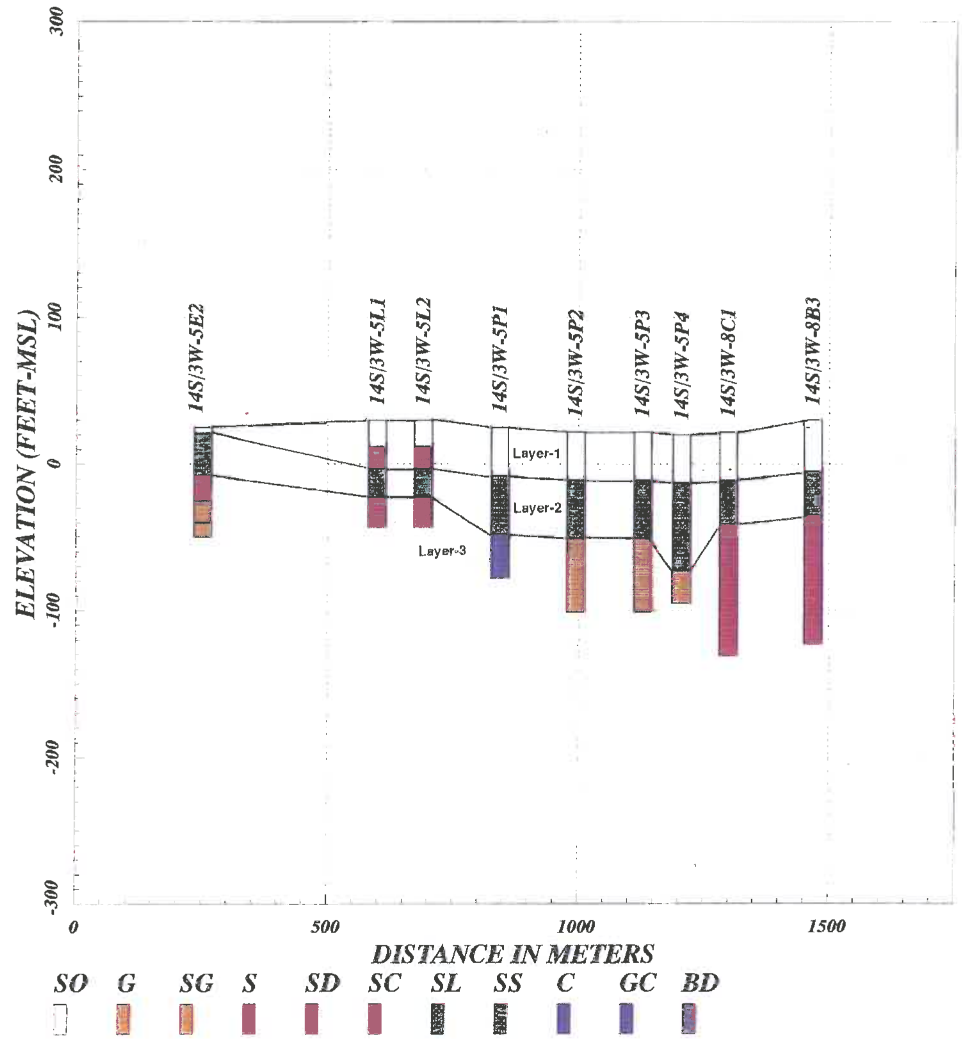

**CROSS-SECTION B-B' SCALE 1"= 250.00**

Figure 2-6



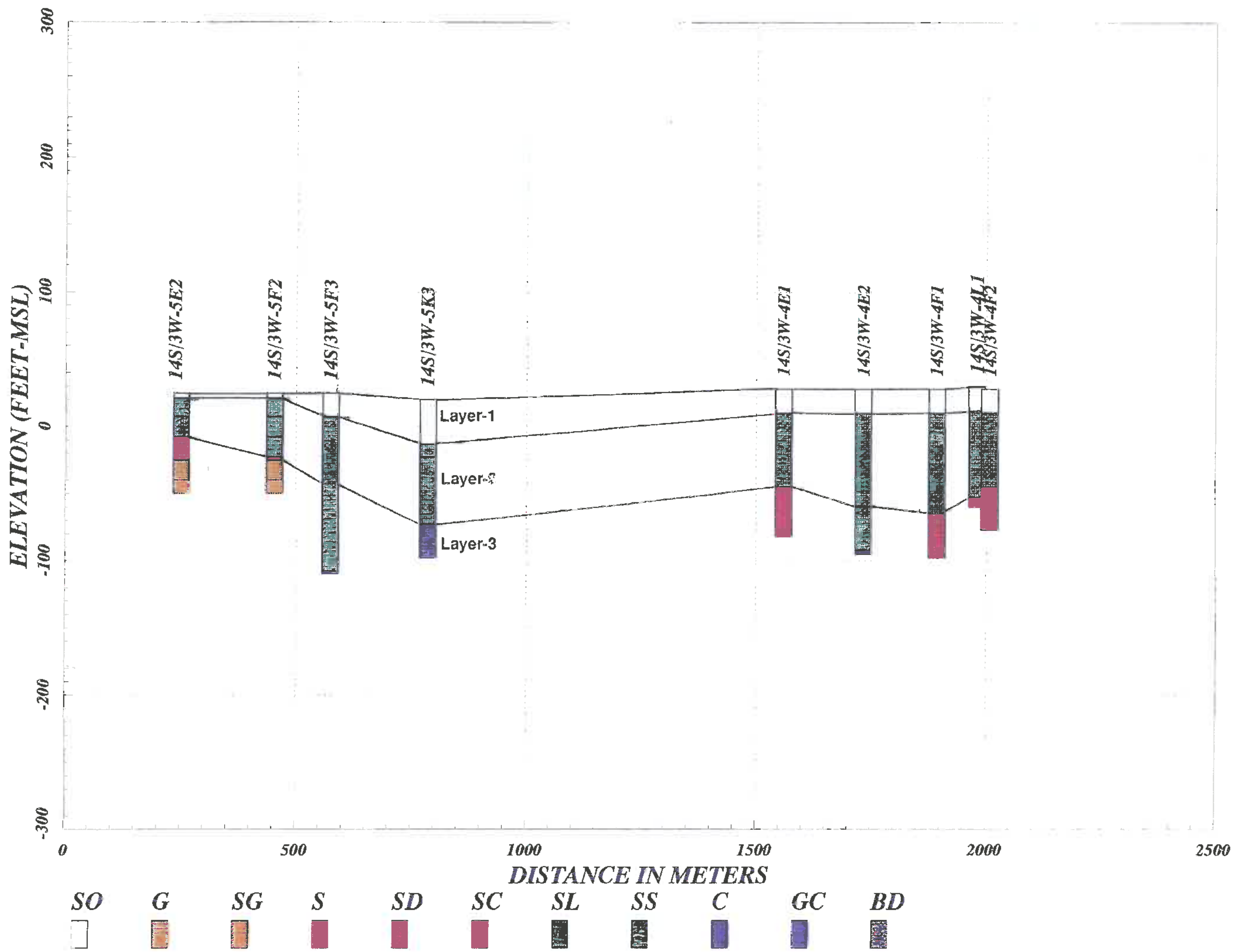

CROSS-SECTION C-C' SCALE 1"= 250.00

Figure 2-7



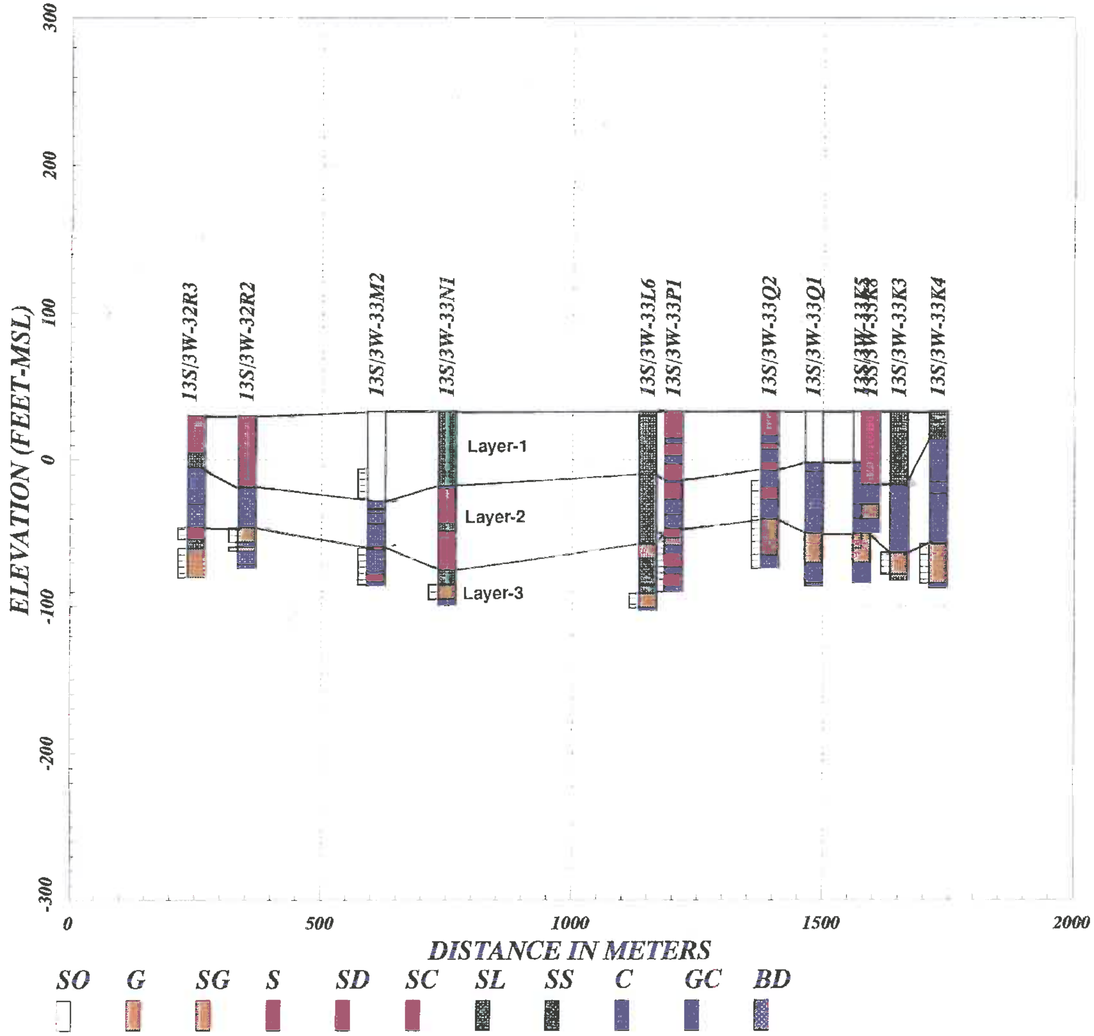

CROSS-SECTION D-D' SCALE 1"= 250.00

Figure 2-8



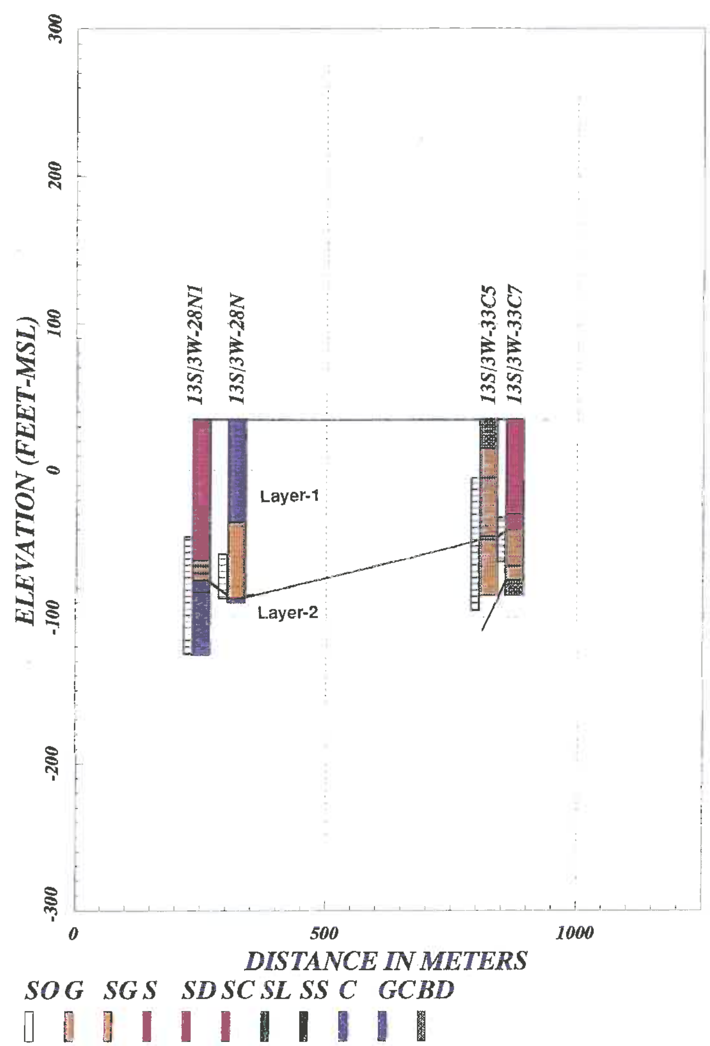

CROSS-SECTION E-E' SCALE 1"= 250.00

Figure 2-9




CROSS-SECTION F-F' SCALE 1"= 250.00

Figure 2-10




CROSS-SECTION G-G' SCALE 1'

Figure 2-11


FIGURE 2-12
SAN DIEGUITO BASIN
OBSERVED WATER LEVELS
1965

Plot date: 29 Mar 95 18:06:35 Wednesday
/gis4/sandieguito/r63st13hcb_new.aml


FIGURE 2-13
SAN DIEGUITO BASIN
OBSERVED WATER LEVELS
1982

Plot date: 29 Mar 95 17:32:13 Wednesday


FIGURE 2-14
SAN DIEGUITO BASIN
OBSERVED TDS
1965

Plot date: 29 Mar 95 17:52:06 Wednesday

## Section 3

# SAN DIEGUITO BASIN GROUNDWATER MODEL

This section describes the groundwater model developed to simulate density-dependent flow and transport of water and TDS in the San Dieguito Basin. The model simulates groundwater flow and transport of TDS while accounting for pressure and density effects. The model was calibrated over the 37-year time period extending from September 1944 through April 1982.

## 3.1 Groundwater Flow Model

### 3.1.1 Model Grid

A finite element grid represents a series of five- and six-sided elements. Hydrogeologic properties, such as hydraulic conductivity, are defined at each element. The model simulates TDS, pressure, and density at each node. Nodes are located in the model at the intersection of element sides. Design of the finite element grid was constrained by seven conditions:

1. The node spacing should be relatively small in areas where future groundwater management activities would likely take place. Because of the dominance of high well yields, better water quality, and coarser shallow deposits, this activity is likely to be concentrated in the eastern portions of the basin.

2. Node spacing should be relatively small near San Dieguito River, as this is an important source of recharge to the basin.

3. Node spacing should be relatively small near El Camino Real, as groundwater west of this point is highly saline. Because of this, potential injection barriers to control sea-water intrusion would likely be located near El Camino Real, and simulation of the injection barrier will require small node spacing.

4. Node spacing should be relatively small near the outer boundaries of San Dieguito Estuary, as this represents not only a constant head boundary, but also a salinity boundary (as the estuary is open to the ocean; see Appendix I for conceptual boundaries). This actually required two areas of small node spacing, because the existing estuary boundary is to be simulated, as well as a proposed estuary boundary resulting from dredging.

5. Nodes should be placed at pumping wells.

6. Element boundaries should follow as closely as possible the alluvium/bedrock boundary around the perimeter of the valley.

7. The model should extend to the watershed boundaries so that it is not necessary to impose an artificial boundary condition at the alluvium/bedrock contact. This allows more accurate definition of leakage from the bedrock terrane into the basin alluvium. There is no need to accurately simulate water levels or water level changes in the bedrock watershed because this area is of no interest from a management perspective. In addition, the conductivity of the bedrock material is two to three orders of magnitude less than alluvial aquifer material (see Table 3-2). Element sizes can therefore be relatively large in this area thereby reducing computing time.

The San Dieguito Basin model grid, shown in Figure 3-1, meets the above constraints. Element sizes are relatively large in bedrock watershed areas (as much as 7,000 ft on a side), but much smaller within the alluvial basin. In the western parts of the basin, and in tributary alluvial fingers, elements are intermediate in size (generally less than 2000 ft on the largest side) because there is less need for detailed information in these areas. In contrast to this, element sizes are reduced to less than 500 ft in the eastern half of the basin, near El Camino Real, near the San Dieguito River, and near the boundaries of the estuary. The grid was designed to allow necessary information to be gained in key areas during simulation of pumping, injection, artificial recharge, and sea-water intrusion.

### 3.1.2 Vertical Layering of the Model

As discussed in Section 2.4.1, *Hydrogeologic Units*, the alluvium has been divided into four units based upon correlable gross lithologies: Layer-1 (shallowest) through Layer-4 (deepest). Vertical layering within the model grid mimics these four layers, with an additional layer along the bottom to represent bedrock. Layer-3 represents the aquifer that supports most of the well production within the basin. Isopach maps of the layers are presented as Figures 3-2 through 3-5. The elevation of the bottoms of Layer-1 through Layer-3 are presented in Appendix B.

A single layer is used to represent bedrock material of the watershed located outside and beneath the alluvial portion of the basin. In areas adjacent to the basin, this bedrock layer is connected to Layer-1 of the alluvial basin because work conducted as part of this study suggests that only the shallow portions of the bedrock (Torrey Sandstone) are transmissive. However, it should be noted that water and solutes from the watershed bedrock terrain may still flow into the deeper alluvial model layers after entering Layer-1 of the alluvium. Similarly, the bedrock unit beneath the alluvium may also leak water and solutes into the overlying layers. This is discussed more at length in Section 3.1.5, *Model Boundaries*.

### 3.1.3 Density Considerations

The San Dieguito Basin Groundwater model simulates groundwater pressures, density, and the concentration of TDS. For presentation purposes, groundwater pressures have been converted to the equivalent freshwater head. Freshwater heads are used to present the simulation results because they provide a common reference density. The freshwater head represents the groundwater head of essentially freshwater, and is calculated by:

$$H_f = P/[(Ro)(g)] \quad (3\text{-}2)$$

where,

$H_f$ = freshwater head
P = water pressure
Ro = density of freshwater
g = coefficient of gravity

Alternatively, head could have been represented by calculating the head at the actual density at each node, instead of using the freshwater head. This head is also calculated using equation 3-2, except that the actual density at each point in the model (at each timestep) is used rather than the freshwater density. Because the density change from freshwater to seawater is very small, the difference between these two estimated heads is very small. For example, Figure 3-6 shows the concentration, freshwater head, and head at the calculated salinity for a node within the basin. The heads can be seen to be within about two feet of one another, even when the concentration of TDS in the water approaches seawater (TDS = 35,000 mg/L).

Freshwater heads can be used to evaluate groundwater flow directions when the TDS is about 5,000 mg/L or less. At concentrations greater than about 5,000 mg/L, the variation in density must be considered, and groundwater gradients must be evaluated using flow vectors. The direction the vector points represents the direction of groundwater flow, and the length of the vector the relative velocity.

Flow vectors for Layer-3 for 1977 (the end of a drought) are presented in Figure 3-7. The vectors indicate that seawater is moving eastward under the estuary, towards the main portion of the basin. The overall eastward movement of groundwater is striking, indicating large-scale seawater intrusion of the basin. Groundwater is being drawn towards the pumping centers in the west, and flow velocities increase significantly near constrictions in the basin. Pumping centers are typically marked by a radial arrangement of vectors pointing towards the center of pumping.

### 3.1.4 Hydrogeologic Properties

As discussed in Section 2.1.1, *Hydrogeologic Units*, lithologies presented on DWR driller logs were originally placed into one of 11 lithologic categories. These categories were then grouped into five hydrostratigraphic units (four for the alluvium and one representing bedrock) that were used for numerical modeling purposes (see Table 2-1). The four alluvial hydrostratigraphic units are: 1) gravel/sand, 2) sand, 3) silt/sand (assumed 50/50), and 4) clay. The relative percentages of each of these four units within each of the model layers was calculated for each well. These percentages were then used to interpolate values to the center of each element where no log data were available. An inverse distance weighting routine was used for the interpolation. Appendix C contains raw data for the percentage of each of the four units on a well-by-well basis, along with contour maps showing the interpolated distribution of these percentages within each model layer. Contouring was performed in ARC/INFO using the lattice contour routine.

The interpolated values of the percentage of gravel/sand, sand, silt/sand, and clay form the basis for calibrating or otherwise changing aquifer properties within the model. Values of hydraulic conductivity (K) and specific yield (Sy) are automatically assigned to each of the elements based upon: 1) a user-defined estimate of these properties for each of the four alluvial units; and, 2) the interpolated percentages of each of the units. K and Sy values therefore representing weighted averages. An example should help clarify this process. Assume that a particular element within Layer-3 has interpolated values of zero percent gravel/sand, 55 percent sand, 25 percent silt/sand, and 20 percent clay (these values are "hardwired" into the model). A modeling/calibration run might assume user-defined K values for these lithologies of 500 ft/day, 150 ft/day, 50 ft/day, and 0.1 ft/day, respectively. The model will automatically calculate the K value via the following formula:

$$K_{element} = [(0.0)(500)+(0.55)(150)+(0.25)(50)+(0.2)(0.1)]/3 = 32 \text{ ft/day}$$

Similar calculations occur for every element within the alluvial basin portion of the model. During calibration, K and Sy estimates for the units were manually adjusted in this fashion in an iterative process with the goal of fitting simulated groundwater levels to historical levels (see Section 3.2, *Calibration Results*). Additional information regarding the mechanical aspects of changing K and Sy are contained in *San Dieguito Basin Groundwater Model Users Manual.* Watershed and "Layer-5" bedrock hydraulic conductivity and specific yield values are assumed to be constant. For the calibrated model, both of these bedrock units have a hydraulic conductivity value of 0.1 ft/d, with a specific yield of 0.02.

### 3.1.5 Model Boundaries

The lateral boundaries of the model are no-flow boundary, except for the nodes along the ocean (Figure 3-1). The lateral no-flow portions of the boundary prohibit groundwater from entering or exiting the model. This type of lateral boundary is considered appropriate because it coincides with the watershed divide. In the estuary area, groundwater elevations at nodes within the estuary have a prescribed head of sea level, and a held concentration of 35,000 mg/L.

Difficulty was encountered when constructing the model ocean boundary. When all the nodes along this boundary were given a held head of zero (sea level) and held concentration of 35,000 mg/L (the concentration of seawater) the model would either not run or would give erroneous results (TDS concentrations more than 35,000 mg/L). It is believed that this was caused by a "numeric convection cell" being set up between the held nodes and adjacent nodes. The only way found to remedy this situation was to allow the uppermost nodes to remain as held heads of zero (sea level) and held concentration of 35,000 mg/L, while making underlying nodes no-flow. Because the ocean boundary is at a relatively great distance from areas of potential management interest this boundary should not significantly impact model results. Indeed, the estuary appears to be the main source of seawater during seawater intrusion events (see, for example, Section 2.4, *Groundwater Quality).* For the reasons presented above, the no-flow condition of the lower nodes along the ocean boundary should not affect the Task Force's use of the model.

The lowermost layer of the model throughout the entire domain is bedrock. Bedrock has been divided into two categories: watershed bedrock and "Layer-5" bedrock (see also the *Model Users Manual*). Layer-5 refers to bedrock present beneath basin alluvium. In the eastern portion of the alluvium, because only three alluvial layers are present, the fourth layer of the model is actually bedrock. In the western portion of the alluvial basin, in areas where all four alluvial layers are present, bedrock is indeed the fifth layer. In the watershed, the base of the model is the bottom of the first (and only) layer.

The concentration of TDS in the watershed bedrock layer is held at 3000 mg/L, and leaks into the basin at variable rates depending upon the local gradient across this boundary. Because of the large amounts of precipitation falling on the watershed, significant leakage can occur into the basin from the watershed bedrock. The bedrock beneath the basin ("Layer-5") may also leak water into the basin when gradients are appropriate. Initial TDS concentrations within "Layer-5" bedrock were determined as part of steady state calibration, and then allowed to vary during the simulation. Because of relatively small vertical gradients and low vertical hydraulic conductivity, this unit tends to leak little water into the alluvial basin.

Recharge and discharge to the San Dieguito River is incorporated through a river package, which simulates the effects of flow between the San Dieguito River and the aquifer. The package basically provides for a head-dependent flux type boundary condition at specified nodes. When the river is turned "on" (a command supported by the user interface), water can flow into or out of the river. When the river is turned "off," water may only flow out of the basin, into the river.

Flow from the river to the aquifer occurs when there is water in the river (typically when discharges from Lake Hodges occur, see Table 3-1), and the water level in the river is above the groundwater head. Flow from the aquifer to the river occurs when the groundwater elevation near the river is greater than the elevation of the base of the river. Flow between the aquifer and river occurs at 59 nodes located along the river (Figure 3-1). Flow between the river and aquifer at each river node is given by:

$$Q_{riv} = [(K)(L)(W)][(H_{riv} - h)/M] \qquad (3\text{-}1)$$

where,

$Q_{riv}$ = flow between the river and aquifer (units of feet$^3$/day)
K = hydraulic conductivity of the streambed material (units of feet/day)
L = river length associated with a node (units of feet)
W = river width associated with a node (units of feet)
$H_{riv}$ = head in the river (units of feet)

h = aquifer head (units of feet)
M = thickness of riverbed (units of feet)

During model calibration, the hydraulic conductivity of the streambed was varied to allow sufficient recharge and discharge from the river. The final value of streambed hydraulic conductivity is relatively high because it is believed there are few places along the river where recharge is limited by the ability of the streambed sediments to conduct water. Recharge from the river is primarily limited by groundwater levels in the aquifer, and occurs when water levels in the alluvium are fairly deep. When the basin is full (i.e., groundwater elevations are close to the bottom of the river), little if any recharge occurs from the river because there is a small gradient between the head in the river and the aquifer head. A listing of nodes numbers for the estuary, river, and ocean boundaries are provided in Appendix J.

## 3.2 Calibration Results

Calibration of the San Dieguito Basin model proceeded in three phases:

1. **Steady-state calibration** of groundwater levels to 1982 levels.
2. **Transient calibration** of groundwater levels, using the period of September 1944 through April 1982.
3. **Sea-water intrusion simulation**, again for the period of September 1944 through April 1982.

Principle model properties and input adjusted during the calibration included hydraulic conductivity of the four lithology groups for each layer, storage coefficients, and river leakance. Calibrated values of hydraulic conductivity are summarized in Table 3-2. During calibration, the hydraulic conductivity of the sand and sand/gravel were the primary values altered (i.e., values for clay and silt were not appreciably altered). Values for these lithologies were varied between about 100 and 1,000 ft/day. Transmissivities of the alluvial layers based on calibrated conductivities are shown in Figures 3-8 through 3-11. As discussed in Section 2.1.2, *Hydrogeologic Properties,* a pumping test of a production well in the Osuna Valley provided a transmissivity estimate of 24,500 $ft^2$/day. This correlates extremely well with the total (Layer-1 through Layer-3) model transmissivity in this area of 25,000 $ft^2$/day.

Specific yield varies within each layer (but not between each layer) based on the percentage of each sediment type. In the calibrated model, sand is assigned a specific yield of 0.1, sand/gravel is 0.15, silt is 0.05, and clay is assigned a specific yield of 0.01. The elastic (confined) storage coefficient is uniformly specified as 0.0001/foot, and was not varied due to the lack of data. Because this value is relatively small, it is eclipsed by specific yield as the sediments of Layer-1 and Layer-2 dewater and fill during pumping and recharge. Because the pumping test discussed above was not conducted with a suitable monitoring wells, an estimate of storage coefficient was not made. In the watershed, the hydraulic conductivity is assigned a value of 0.1 ft/d, and specific yield 0.02. Calibration is discussed at length below.

### 3.2.1 Steady-State Calibration

The first phase of calibration involved adjustment of model parameters to match, as closely as possible, steady-state groundwater levels from the model to groundwater levels measured in the basin in 1982. The 1982 water levels were chosen because precipitation and runoff had been above normal for the previous four years, and the basin was essentially full. The model was executed as a simple groundwater flow code during this stage – – no solute transport was simulated, and fluid density was treated as constant. Calibration focused largely on adjustment of aquifer hydraulic conductivity.

Early simulations did not treat the upper reaches of the San Dieguito River as a boundary condition. Initial runs resulted in simulated groundwater levels that were 20 to 40 feet above the measured groundwater levels in the basin. Aquifer hydraulic conductivity was increased, particularly in layers three and four, until simulated groundwater levels were within five to ten feet of the measured 1982 groundwater levels. Simulated water levels were, in all cases, above the measured water levels. A final step in this calibration involved setting the San Dieguito River to be a constant head boundary. With groundwater levels above the river elevation, this made the San Dieguito River a hydraulic sink, and brought simulated groundwater levels down to the measured 1982 groundwater levels.

It should be noted that the measured groundwater levels in 1982 do not truly represent a "steady-state" situation, merely a time period when the groundwater basin is full and water levels are controlled by discharge to the San Dieguito River. Therefore, those water levels provide a good starting point (initial head) for the transient simulation of the 1944 to 1982 period. Calibration of those 1982 water levels, however, particularly once the San Dieguito River is added as a constant-head boundary, is relatively insensitive to aquifer hydraulic conductivity. Because of this insensitivity, aquifer hydraulic conductivity was re-visited during the third phase of calibration, simulation of sea-water intrusion.

### 3.2.2 Transient Calibration of Groundwater Levels

The period 1944 to 1982 was chosen as a transient calibration period. This period includes a dry period of 1944 to 1977, when groundwater recharge was minimal both from precipitation and from Lake Hodges releases. Groundwater levels in the basin declined almost continuously during this dry period. The period 1978 to 1982 was a period of above-normal precipitation recharge and yearly releases from Lake Hodges, which brought water levels back up to the original 1945 groundwater levels. To simulate the San Dieguito River, which acts only as a source or a sink when Lake Hodges is releasing water, but only as a sink when Lake Hodges is not releasing water to the river channel, a river package was added to the model. For this phase of the modeling, the model was used as a groundwater flow model without solute transport and assuming constant fluid density.

During the transient calibration, adjustments primarily to specific yield were made to achieve a match between measured water level changes and those predicted by the model. Because no field values are available, values considered reasonable based on experience in similar basins were used. River recharge parameters (riverbed permeability and thickness) were also adjusted, as was the duration of recharge so that the amount of water recharged to the aquifer from the San Dieguito River was less than the amount of water released from Lake Hodges.

During the initial runs, simulated water levels did not decline as much as was measured between 1945 and 1965, and recharge from the San Dieguito River in 1952 exceeded the amount of water released from Lake Hodges. Riverbed permeability was decreased, as was the duration of simulated releases to limit recharge from San Dieguito River. Basinwide specific yield was reduced to increase the simulated water level drawdown in the period of 1945 to 1965. As previously stated, specific yield was adjusted by changing the values of the various lithologies. Aquifer hydraulic conductivity was not changed during this calibration phase.

### 3.2.3 Simulation of Sea-Water Intrusion

The final phase of calibration was a test of the values of hydraulic conductivity and specific yield by simulating the sea-water intrusion that occurred in the basin in the dry period of 1944 to 1978. Our calibration target was the water quality mapped by the U.S. Geological Survey in the basin in 1965. To calibrate against this target, the model was run as a density-dependent, solute transport code, using the same aquifer parameters as in the previous calibration efforts. The first simulation predicted very high salinity water intruding eastward into the basin to Osuna Valley, farther east than had been observed in the 1965's. Hydraulic conductivity was decreased in Layer-1 and Layer-3 (the two aquifers) to limit the extent of sea-water intrusion, resulting in a good match between the measured water salinities in 1965 and those simulated by the model. At the same time, the decrease in aquifer hydraulic conductivity increased the predicted drawdown in the aquifer to match those measured in 1965. This simulation was considered a key calibration step, with resulting values of hydraulic conductivity reasonable and now better justified.

### 3.2.4 Assessment of Calibration

As previously discussed, results of a pumping test of a production well in the Osuna Valley provided a transmissivity estimate of 24,500 $ft^2$/day, which correlates extremely well with the total model transmissivity in this area of 25,000 $ft^2$/day. In addition, the final calibration of the San Dieguito Basin model resulted in good matches between simulated groundwater fluctuations and measurements of groundwater fluctuations between 1944 and 1982, as well as good matches between simulated and measured water qualities. In the western portion of the basin water levels reported by the U.S. Geological Survey (Izbicki, 1983) for well 14/03-5N1 show groundwater declining to about -10 to -20 ft msl in the 1960 to 1965 time period, which has been match well by the simulated water levels in corresponding node 30719 (Figure 3-12). The basin model predicts water levels at node 30719 to start at 20 ft msl in 1945, decline to -25 ft msl in 1965, continue declining to -40 ft msl in 1977, then recover to

20 ft msl in 1982 (Figure 3-12). Water level measurements were not available for the 1977 time period, but it is logical that water levels would continue to decline from 1965 to 1977 as there was little recharge and no release of water from Lake Hodges.

Similarly, measured groundwater levels for well 13/03-33L3, in the eastern portion of the basin, show groundwater elevations starting at about 20 ft msl, and declining to -40 ft msl in 1965 (Figure 3-13). Simulated groundwater levels for corresponding node 30988 start at 20 ft msl, decline to -38 ft msl by 1965, continue to decline to -55 ft msl in 1977, then recover to 20 ft msl in 1982. The model does a very good job of matching the few measured groundwater levels available for the basin (see Figure 3-14).

The simulated extent of sea-water intrusion in 1965 also matches measurements of water quality in 1965 published by the U.S. Geological Survey (Figure 3-15). Though water quality is somewhat irregularly distributed in the basin, both the model and the field measurements show that water salinity in the westernmost part of the basin was 15,000 to 20,000 mg/L throughout the simulation period, dominated by the effects of both the ocean and the estuary that act as constant concentration boundary conditions in the model. Further to the east, the model predicts that the 3000 mg/L concentration contour extended a distance of about 3.5 miles from the coast in 1965, which is closely matched by the 3610 mg/L measurement of salinity in well 14/03-5K2. Increased recharge in the 1978 to 1982 period pushed the sea-water front westward, which was accurately simulated by the model.

Available data on measured water levels were compared with simulated values to quantitatively assess the degree of calibration. Measured water levels are available for Spring 1965 and Spring 1982 from the USGS (Izbicki, 1983). These data are presented in Table 3-4 and summarized in Figures 3-16 through 3-18. Simulated data for January 1982 (Figure 3-18) more closely mimic observed water levels than April 1982 data (Figure 3-17). This may reflect field water level measurements obtained sometime between the model output periods (i.e. field water level measurements made after timestep 28 [January 27, 1982] but before timestep 29 [April 28, 1982]).

Compiled data indicate a mean absolute error of four to seven feet for Spring 1965 and 1982 data (Table 3-4). This indicates a good calibration, especially when viewed in light of the approximate 60 foot change in water levels during this time interval (equivalent to an error across this range of about 7 to 12 percent; see Figures 3-20 and 3-21). Data from 1965 have a greater frequency of differences (also known as "residuals") greater than 10 feet relative to 1982 data, but only two values are greater than 11 feet (Table 3-4). Differences greater than 10 feet are generally distributed throughout the basin, but are somewhat more common in the Osuna Valley area (see residuals plot, Figure 3-19). This probably reflects greater pumping stress in this area, and may also reflect, at least in part, inaccurate estimates of pumping. In addition, errors in estimation of hydraulic properties (K and Sy) become more apparent under greater pumping stresses. In either case, the models predictive capabilities over this relatively wide range of operating water levels appears to be about 10 feet or less.

Additional water level simulation results for Layer-3 for 1952, 1966, 1977, 1979, and 1982 are provided in Appendix D. Water level contours are presented for Layer-3 because this layer is the main aquifer in the basin. Results of TDS transport simulations for Layer-3 for 1952, 1966, 1977, 1979 and 1982 are provided in Appendix E.

### 3.2.5 Sensitivity Analysis

Sensitivity analyses were performed to evaluate potential affects of parameter uncertainty. Figures 3-20 and 3-21 indicate that a factor of two difference in hydraulic conductivity may lead to differences in simulated head of as much as 10 feet. This difference is maximum during periods of low water levels. Identical changes in specific yield result in similar changes in water level elevations (Figures 3-24 and 3-25). The chemical hydrograph data indicate that doubling hydraulic conductivity or halving specific yield results in unreasonable changes in seawater intrusion (see Figures 3-22 and 3-26, and Appendices G and H). Halving hydraulic conductivity or doubling specific yield does not produce totally unreasonable results (see Figure 3-22 and 3-26 and Appendices G and H).

The sensitivity analysis provides information regarding the reasonableness of aquifer parameter estimates. For example, hydraulic conductivity is not twice the calibrated value, and specific yield not one-half the calibrated value. In addition, the Osuna Valley pumping test transmissivity estimate of 24,500 $ft^2$/day correlates extremely well with the calibrated model transmissivity in this area of 25,000 $ft^2$/day, suggesting that the calibrated values of hydraulic conductivity are reasonable. As discussed below in Section 3.4, *Discussion*, , potential errors in the estimates of specific yield and/or pumpage are intimately linked, with errors in one leading to compensation by the other parameter. For example, if actual pumping was double that used in the model, specific yields would have to be doubled to produce the same observed change in water levels from 1945 to 1965. Groundwater recharge rates affect specific yield estimates in a similar fashion.

## 3.3 Groundwater Budget

The primary components of inflow into the model are recharge from the San Dieguito River, recharge from precipitation, and inflow from the estuary and ocean. The primary components of outflow from the basin are pumping, outflow into the estuary or ocean, and discharge to the San Dieguito River. Irrigation return flows are not accounted for in the model because agricultural irrigation is largely fed by wells, and the total amount of groundwater pumping was estimated during this study. "Refining" the recharge rate estimate by assuming that some pumped water returns to the aquifer via return flow (basically amounting to lower net pumpage) is therefore inappropriate. In the discussion below, the groundwater budget for the entire model area, including the watershed is presented. The water budget is summarized in Table 3-3.

### 3.3.1 Inflows

Recharge from the San Dieguito River occurs when Lake Hodges discharges sufficient amounts of water, or sufficient rainfall occurs, to generate surface flows in the river. During the simulation period of 1945-82, these conditions occurred in 1952, 1978, 1979, 1980, 1981, and 1982/83. The amount of water recharged during these periods ranged from about 1,000 to 11,000 acre-feet per recharge period.

Recharge from precipitation occurs from rainfall percolating into the subsurface and migrating into the saturated zone. Recharge from precipitation was estimated using a soil moisture budget approach, as discussed in Appendix F. Because there are insufficient data to estimate variable infiltration rates based on soil type or landuse, recharge from precipitation is applied uniformly throughout the model area. Areas that have been paved or otherwise covered are considered to be sufficiently distributed (non-localized) that they do not affect percolation on a scale recognizable by the model.

Inflow from the estuary and ocean occurs when groundwater levels in the alluvial basin approach and/or decline below sea level. In the simulation period, this primarily occurs during the drought period during the 1960s and early- to middle-1970s. During this period, groundwater levels in the eastern portion of the basin decline to tens of feet below sea level, and an eastward gradient developed from the estuary towards pumping wells located to the east. The estuary provides a greater source of seawater than the ocean boundary because the estuary is closer to the pumping wells than the ocean, and the model opens to the ocean within a relatively narrow gap. Water chemistry data supports this view: the estuary ends near Gonzales Canyon, and water quality (especially TDS) markedly changes away from this point (see, for example, Izbicki, 1983, Figure 12).

### 3.3.2 Outflows

Precise data are not available regarding the history of groundwater production from the basin wells. Pumping rates were estimated from discussions with landowners and from estimates of water usage based on assumed agricultural demands. Because of the lack of pumpage data, it was assumed that pumping rates were constant throughout the modeling period, and that all pumping occurred from Layer-3. Total average annual pumping from the basin (as currently modeled) is 1,338 AFY, and is distributed as follows:

> **Whispering Palms.** Seven wells, each pumping at a rate of 10,025 cubic feet per day (cfd; 52 gpm). Total annual production from all seven wells: 588 AF. The wells are located at nodes: 30686, 30711, 30623, 30793, 30695, 30775, and 30746.
>
> **Chino Farms**. One well pumping at a rate of 17,901 cfd (93 gpm). Total annual production from this well: 150 AF. The well is at node 30978.
>
> **Griset well.** Two wells, each pumping at a rate of 35,802 cfd (186 gpm). Total annual production from both wells: 600 AF. The wells are located at nodes 30988, and 30985.

Discharge to the San Dieguito River occurs when the groundwater elevation at the river is higher than the elevation of the river base. This condition primarily occurs after periods of significant recharge. The model's ability to simulate river discharge is limited by a lack of accurate river elevation data, and the fact that the base elevation of the western end of the river is very close to sea level. Because the held heads of the estuary are within about five feet or less of the estimated river base elevation, the aquifer may discharge to the river in the model when, in fact, little or no discharge naturally occurs. This does not, however, limit the overall use of the model - - the purpose of the estuary boundary is to supply a source of seawater, not to fully simulate the effects of the river/estuary interaction. The estuary, as modeled, provides the main source of seawater when groundwater elevations decline during the drought periods.

Discharge to the estuary occurs when groundwater levels near the estuary are above sea level. Discharge to the ocean occurs when groundwater levels directly east of the ocean boundary are above sea level. Because the model opens to the ocean at a relatively narrow gap, and because groundwater levels directly east of the ocean generally remain near sea level due to the presence of the estuary, discharge to the ocean is typically smaller than discharge to the estuary.

The water budget for each model time step during the simulation period is summarized in Table 3-3. The primary source of inflow to the basin is precipitation, and the primary discharge is pumpage. The water budget summary in Table 3-3 represents a net positive balance, or net recharge, of about 22,000 AF over the model period. Storage declines steadily through about 1978 (Figure 3-20). A sudden increase in basin storage coincides with large amounts of river recharge related to increased releases from Lake Hodges (Figure 3-20, Table 3-1, and Table 3-3).

### 3.4 Discussion

The user of the San Dieguito Model, as presently calibrated, should be aware of several limitations. Historical pumping data for the basin are very limited. The three major water users identified by discussions with water agencies and water users in the basin are: 1) agricultural pumping by Griset in the Osuna Valley portion of the basin, 2) agricultural pumping by Chino Farms in the Osuna Valley portion of the basin, and 3) pumping for golf course irrigation within Whispering Palms golf course. According to Griset (personal communication, 1992) his pumping continued unchanged from 1945 to 1982, but ceased in 1982. Pumping was estimated at 600 acre-ft yr. Chino Farms reports that their average irrigation rate continues to be about 150 acre-ft/yr. Pumping for golf course irrigation was estimated by multiplying an assumed consumptive use of 3 acre-ft/acre/yr by the golf course area, to arrive at a total pumping rate of 588 acre-ft/yr.

Actual groundwater production may have been more or less than the 1,338 acre-ft/yr used in the simulation. The net result is that the actual specific yield in the basin may be somewhat more or less than that used to calibrate the model. For example, if actual pumping was double that used in the model, actual specific yields would have to be double those used in the model to produce the same change in water levels from 1945 to 1965, the transient calibration period.

Similarly, no direct information was available for groundwater recharge rates. Groundwater recharge was calculated using measured precipitation, potential evaportranspiration, and estimates for soil moisture capacity and runoff potential. The rates of groundwater recharge calculated compares well with rates calculated for similar areas of San Diego County, but could still be in error. Errors in recharge rate would result in corresponding errors in specific yield of he alluvium and potentially in aquifer hydraulic conductivity.

We recommend that values of hydraulic conductivity and specific yield be determined for areas that are particularly sensitive to these parameters in groundwater management simulations. This work would proceed in the following manner:

1. Develop reasonable management scenarios.

2. Model the management scenarios using the calibrated model as the "base case" for a projected period of 10 to 15 years.

3. Perform a sensitivity analysis on the management scenarios by performing model runs as above, except using high and low estimates (possibly one-half and two times calibrated values) of hydraulic conductivity and specific yield.

4. Evaluate results of the base case and sensitivity runs in terms of water level and water quality differences in areas of critical interest, which may include: areas of recharge basins, injection barriers, injection and/or extraction wells, the estuary, and existing wells.

5. If sensitivity analyses indicate large uncertainties with respect to water level and water quality impacts in any of the critical areas, then perform pumping tests in these areas designed to refine the appropriate parameter. Note that if results are sensitive to specific yield, observation wells and long-term pumping tests may be required.

It is recommended that work described above, including pumping tests, be performed as part of Phase II work.

## TABLE 3-1
## LAKE HODGES MONTHLY DISCHARGE (Acre-Feet)

| Year | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1921-22 | 0 | 0 | 9,517 | 13,484 | 27,651 | 24,140 | 10,328 | 4,162 | 621 | 0 | 0 | 0 | 89,903 |
| 1922-23 | 0 | 0 | 0 | 40 | 4,602 | 2,689 | 1,736 | 97 | 0 | 0 | 0 | 0 | 9,164 |
| 1925-26 | 0 | 0 | 0 | 0 | 0 | 0 | 13,331 | 500 | 0 | 0 | 0 | 0 | 13,831 |
| 1926-27 | 0 | 0 | 0 | 0 | 123,538 | 15,031 | 6,659 | 2,593 | 0 | 0 | 0 | 0 | 147,821 |
| 1931-32 | 0 | 0 | 0 | 0 | 36,987 | 9,589 | 1,381 | 1,196 | 0 | 0 | 0 | 0 | 49,153 |
| 1932-33 | 0 | 0 | 0 | 0 | 2,888 | 7 | 0 | 2,061 | 0 | 0 | 0 | 0 | 4,956 |
| 1936-37 | 0 | 0 | 0 | 0 | 61,291 | 46,507 | 17,308 | 3,909 | 892 | 0 | 0 | 0 | 129,907 |
| 1937-38 | 0 | 0 | 0 | 0 | 0 | 69,452 | 4,905 | 2,627 | 0 | 0 | 0 | 0 | 76,984 |
| 1938-39 | 0 | 0 | 0 | 996 | 15,185 | 8,321 | 3,169 | 0 | 0 | 0 | 0 | 0 | 27,671 |
| 1939-40 | 0 | 0 | 0 | 0 | 0 | 0 | 4,605 | 0 | 0 | 0 | 0 | 0 | 4,605 |
| 1940-41 | 0 | 0 | 0 | 2,182 | 16,038 | 55,940 | 55,154 | 19,200 | 8,329 | 0 | 0 | 0 | 156,843 |
| 1941-42 | 0 | 0 | 2,766 | 9,095 | 4,163 | 6,329 | 1,195 | 0 | 0 | 0 | 0 | 0 | 23,548 |
| 1942-43 | 0 | 0 | 0 | 566 | 3,926 | 18,976 | 9,013 | 0 | 0 | 0 | 0 | 0 | 32,481 |
| 1943-44 | 0 | 0 | 0 | 0 | 613 | 4,968 | 1,120 | 407 | 0 | 0 | 0 | 0 | 7,108 |
| 1944-45 | 0 | 0 | 0 | 0 | 0 | 3,157 | 1,215 | 0 | 0 | 0 | 0 | 0 | 4,372 |
| 1945-46 | 0 | 0 | 0 | 31 | 603 | 268 | 1,376 | 0 | 0 | 0 | 0 | 0 | 2,278 |
| 1951-52 | 0 | 0 | 0 | 0 | 0 | 0 | 3,550 | 1,161 | 6 | 0 | 0 | 0 | 4,717 |
| 1977-78 | 0 | 0 | 0 | 0 | 0 | 35,899 | 10,298 | 508 | 4 | 0 | 0 | 0 | 46,709 |
| 1978-79 | 0 | 0 | 0 | 11,451 | 18,663 | 24,912 | 14,101 | 4,758 | 1,133 | 0 | 0 | 0 | 75,018 |
| 1979-80 | 0 | 0 | 0 | 473 | 119,456 | 69,207 | 30,531 | 21,288 | 6,796 | 873 | 0 | 0 | 248,624 |
| 1980-81 | 0 | 0 | 0 | 3,506 | 8,130 | 12,119 | 5,207 | 1,759 | 0 | 0 | 0 | 0 | 30,721 |
| 1981-82 | 0 | 0 | 0 | 0 | 0 | 17,160 | 11,671 | 7,027 | 2,023 | 0 | 0 | 0 | 37,881 |
| 1982-83 | 0 | 0 | 0 | 869 | 22,088 | 86,892 | 33,979 | 20,723 | 9,983 | 1,014 | 0 | 0 | 175,548 |
| **TOTAL DISCHARGE (AF)** | | | | | | | | | | | | | **1,399,843** |
| **AVERAGE PER YEAR OVER 23 YEARS DISCHARGE** | | | | | | | | | | | | | **60,862.73** |
| **AVERAGE DISCHARGE PER YEAR OVER 61 YEARS TIME PERIOD (1921-1983)** | | | | | | | | | | | | | **22,948.24** |

**TABLE 3-2**
**Calibrated Hydraulic Conductivity Values**

| | Hydraulic Conductivity (feet/day) | | | |
|---|---|---|---|---|
| | Sand & Gravel | Sand | Silt | Clay |
| Layer-1 | 150 | 50 | 1 | 0.01 |
| Layer-2 | 150 | 50 | 0.1 | 0.01 |
| Layer-3 | 400 | 150 | 1 | 0.01 |
| Layer-4 | 100 | 50 | 1 | 0.01 |
| "Layer-5" is bedrock beneath alluvium, K = 0.1 ft/d | | | | |
| Watershed bedrock K = 0.1 ft/d | | | | |

## Table 3-3
### Water Budget Summary

| | | | | Recharge and Discharge (AF/timestep; (1)) | | | | | | Average Recharge and Discharge (AF/day) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time Step | Ending Date | Ending Time (d) | Time Step Length (d) | Precipitation Recharge | Ocean & Estuary | Pumping Discharge | River | Net | Cumulative | Precipitation Recharge | Ocean & Estuary | Pumping Discharge | River | Net |
| 0 | 1-Sep-44 | 0 | 0 | - | - | - | - | - | - | - | - | - | - | - |
| 1 | Sep-46 | 730 | 730 | 0 | -455 | -2,672 | -13 | -3,140 | -3,140 | 0.00 | -0.62 | -3.66 | -0.02 | -4 |
| 2 | 31-Aug-48 | 1,460 | 730 | 0 | -352 | -2,672 | 0 | -3,024 | -6,165 | 0.00 | -0.48 | -3.66 | 0.00 | -4 |
| 3 | 31-Aug-49 | 1,825 | 365 | 0 | -119 | -1,336 | 0 | -1,455 | -7,619 | 0.00 | -0.33 | -3.66 | 0.00 | -4 |
| 4 | 31-Aug-51 | 2,555 | 730 | 0 | -108 | -2,672 | 0 | -2,780 | -10,399 | 0.00 | -0.15 | -3.66 | 0.00 | -4 |
| 5 | 1-Mar-52 | 2,738 | 183 | 5,579 | -278 | -670 | 0 | 4,631 | -5,769 | 30.48 | -1.52 | -3.66 | 0.00 | 25 |
| 6 | 4-Mar-52 | 2,741 | 3 | 91 | -6 | -11 | 1,163 | 1,237 | -4,532 | 30.48 | -2.07 | -3.66 | 387.53 | 412 |
| 7 | 30-Aug-53 | 3,285 | 544 | 0 | -313 | -1,991 | 0 | -2,304 | -6,836 | 0.00 | -0.58 | -3.66 | 0.00 | -4 |
| 8 | 30-Aug-54 | 3,650 | 365 | 0 | -96 | -1,336 | 0 | -1,432 | -8,268 | 0.00 | -0.26 | -3.66 | 0.00 | -4 |
| 9 | 29-Aug-56 | 4,380 | 730 | 0 | -73 | -2,672 | 0 | -2,744 | -11,012 | 0.00 | -0.10 | -3.66 | 0.00 | -4 |
| 10 | 29-Aug-58 | 5,110 | 730 | 4,575 | -274 | -2,672 | 0 | 1,629 | -9,383 | 6.27 | -0.38 | -3.66 | 0.00 | 2 |
| 11 | 28-Aug-60 | 5,840 | 730 | 0 | 76 | -2,672 | 0 | -2,596 | -11,979 | 0.00 | 0.10 | -3.66 | 0.00 | -4 |
| 12 | 28-Aug-62 | 6,570 | 730 | 0 | 257 | -2,672 | 0 | -2,415 | -14,394 | 0.00 | 0.35 | -3.66 | 0.00 | -3 |
| 13 | 27-Aug-65 | 7,665 | 1,095 | 0 | 618 | -4,008 | 0 | -3,389 | -17,784 | 0.00 | 0.56 | -3.66 | 0.00 | -3 |
| 14 | 27-Aug-66 | 8,030 | 365 | 5,979 | -123 | -1,336 | 0 | 4,521 | -13,263 | 16.38 | -0.34 | -3.66 | 0.00 | 12 |
| 15 | 26-Aug-68 | 8,760 | 730 | 0 | 363 | -2,672 | 0 | -2,309 | -15,572 | 0.00 | 0.50 | -3.66 | 0.00 | -3 |
| 16 | 26-Aug-69 | 9,125 | 365 | 2,912 | 81 | -1,336 | 0 | 1,657 | -13,915 | 7.98 | 0.22 | -3.66 | 0.00 | 5 |
| 17 | 26-Aug-71 | 9,855 | 730 | 0 | 507 | -2,672 | 0 | -2,165 | -16,080 | 0.00 | 0.69 | -3.66 | 0.00 | -3 |
| 18 | 25-Aug-74 | 10,950 | 1,095 | 0 | 1,019 | -4,008 | 0 | -2,988 | -19,068 | 0.00 | 0.93 | -3.66 | 0.00 | -3 |
| 19 | 24-Aug-77 | 12,045 | 1,095 | 0 | 1,209 | -4,008 | 0 | -2,799 | -21,867 | 0.00 | 1.10 | -3.66 | 0.00 | -3 |
| 20 | 23-Feb-78 | 12,228 | 183 | 0 | 217 | -670 | 0 | -453 | -22,319 | 0.00 | 1.19 | -3.66 | 0.00 | -2 |
| 21 | 25-Apr-78 | 12,289 | 61 | 19,951 | -753 | -223 | 12,101 | 31,075 | 8,755 | 327.06 | -12.35 | -3.66 | 198.37 | 509 |
| 22 | 25-Dec-78 | 12,533 | 244 | 0 | -858 | -893 | -34 | -1,785 | 6,970 | 0.00 | -3.52 | -3.66 | -0.14 | -7 |
| 23 | 26-Apr-79 | 12,655 | 122 | 2,190 | -883 | -447 | 8,531 | 9,391 | 16,361 | 17.95 | -7.24 | -3.66 | 69.92 | 77 |
| 24 | 26-Jan-80 | 12,930 | 275 | 0 | -461 | -1,007 | -376 | -1,843 | 14,518 | 0.00 | -1.67 | -3.66 | -1.37 | -7 |
| 25 | 26-Apr-80 | 13,021 | 91 | 5,237 | -299 | -333 | 2,865 | 7,470 | 21,988 | 57.55 | -3.29 | -3.66 | 31.48 | 82 |
| 26 | 26-Dec-80 | 13,265 | 244 | 0 | -429 | -893 | -719 | -2,041 | 19,947 | 0.00 | -1.76 | -3.66 | -2.95 | -8 |
| 27 | 28-Mar-81 | 13,357 | 92 | 0 | -112 | -337 | 2,374 | 1,925 | 21,872 | 0.00 | -1.22 | -3.66 | 25.80 | 21 |
| 28 | 27-Jan-82 | 13,662 | 305 | 0 | -324 | -1,116 | -568 | -2,008 | 19,864 | 0.00 | -1.06 | -3.66 | -1.86 | -7 |
| 29 | 28-Apr-82 | 13,753 | 91 | 0 | -97 | -333 | 2,550 | 2,120 | 21,984 | 0.00 | -1.07 | -3.66 | 28.03 | 23 |
| **Totals** | | | **13,753** | **46,514** | **-2,066** | **-50,336** | **27,873** | **21,984** | | | | | | |

Note: (1) Positive values indicate recharge, negative values indicate discharge

WBUD83.XLS, 1/31/95

| TABLE 3-4 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| OBSERVED AND SIMULATED WATER LEVEL DATA | | | | | | | | | | |
| State Well Number | | Node | Obs WL | Obs WL | TS13 | TS28 | TS29 | Absolute Error | | |
| | | | Spring 1965 | Spring 1982 | 27-Aug-65 | 27-Jan-82 | 28-Apr-82 | 27-Aug-65 | 27-Jan-82 | 28-Apr-82 |
| T13S/R3W | 28N02 | 30896 | -31 | | -28 | 26 | 34 | 3 | | |
| T13S/R3W | 32R01 | 30711 | -49 | | -29 | 17 | 27 | 20 | | |
| T13S/R3W | 33B01 | 31149 | -27 | | -27 | 28 | 35 | 0 | | |
| T13S/R3W | 33B03 | 31142 | | 30 | -27 | 28 | 35 | | 3 | 4 |
| T13S/R3W | 33C01 | 31085 | -30 | | -28 | 27 | 34 | 3 | | |
| T13S/R3W | 33C02 | 30934 | | 23 | -28 | 26 | 33 | | 3 | 10 |
| T13S/R3W | 33C06 | 30902 | | 22 | -28 | 26 | 32 | | 4 | 10 |
| T13S/R3W | 33D01 | 30823 | -30 | | -29 | 25 | 32 | 2 | | |
| T13S/R3W | 33E01 | 30863 | -40 | 21 | -30 | 23 | 30 | 10 | 1 | 9 |
| T13S/R3W | 33F02 | 31025 | -28 | 26 | -28 | 27 | 34 | 0 | 1 | 7 |
| T13S/R3W | 33K06 | 31068 | | 23 | -32 | 18 | 29 | | 6 | 5 |
| T13S/R3W | 33K08 | 31033 | | 24 | -33 | 17 | 28 | | 6 | 5 |
| T13S/R3W | 33L06 | 30946 | -45 | | -31 | 18 | 29 | 14 | | |
| T13S/R3W | 33L09 | 30945 | | 20 | -32 | 18 | 29 | | 2 | 9 |
| T13S/R3W | 33M01 | 30831 | -44 | | -30 | 22 | 30 | 14 | | |
| T13S/R3W | 33N02 | 30868 | | 21 | -30 | 18 | 30 | | 3 | 9 |
| T13S/R3W | 33Q03 | 31071 | -42 | | -32 | 18 | 29 | 10 | | |
| T14S/R3W | 04D01 | 30838 | | 25 | -28 | 18 | 29 | | 7 | 4 |
| T14S/R3W | 05F01 | 30537 | -12 | 18 | -23 | 17 | 26 | 11 | 1 | 9 |
| T14S/R3W | 05H04 | 30775 | | 19 | -26 | 16 | 26 | | 3 | 7 |
| T14S/R3W | 05K01 | 30632 | -29 | 15 | -27 | 17 | 27 | 2 | 2 | 12 |
| T14S/R3W | 05K02 | 30634 | -27 | 15 | -20 | 16 | 24 | 6 | 1 | 9 |
| T14S/R3W | 05N01 | 30492 | -18 | | -11 | 11 | 15 | 7 | | |
| T14S/R3W | 06P03 | 30382 | -7 | 14 | -5 | 8 | 9 | 2 | 6 | 5 |
| T14S/R3W | 06Q02 | 30397 | -11 | 15 | -5 | 8 | 10 | 6 | 7 | 5 |
| T14S/R3W | 07C04 | 30390 | | 13 | -3 | 7 | 9 | | 6 | 4 |
| T14S/R3W | 07C05 | 30369 | -21 | | -3 | 7 | 8 | 18 | | |
| T14S/R3W | 07C06 | 30392 | -1 | 14 | -3 | 7 | 9 | 2 | 7 | 5 |
| T14S/R4W | 01Q01 | 30215 | -2 | | 2 | 3 | 3 | 4 | | |
| T14S/R4W | 01R01 | 30292 | -10 | | 1 | 4 | 4 | 11 | | |
| T14S/R4W | 11J02 | 30113 | -1 | | 4 | 4 | 4 | 4 | | |
| T14S/R4W | 12H01 | 30271 | -2 | 6 | 1 | 5 | 5 | 3 | 1 | 1 |
| | | | | | | | | | | |
| | | | | **Mean Absolute Error:** | | | | 7 | 4 | 7 |
| Obs WL - Observed Water Level | | | | | | | | | | |
| TS - Time Step | | | | | | | | | | |


FIGURE 3-1
SAN DIEGUITO BASIN
FINITE ELEMENT GRID

Plot date: 28 Dec 94 10:07:09 Wednesday
/gis4/sandieguito/elemgrid.aml


FIGURE 3-2
SAN DIEGUITO BASIN
LAYER 1 THICKNESS

Plot date: 20 Dec 94 08:53:25 Wednesday
/gis4/sandieguito/r93thick1.aml


FIGURE 3-3
SAN DIEGUITO BASIN
LAYER 2 THICKNESS

Plot date: 28 Dec 94 08:54:10 Wednesday
/gis4/sandieguito/l83thick2.aml


FIGURE 3-4
SAN DIEGUITO BASIN
LAYER 3 THICKNESS

Plot date: 28 Dec 94 08:55:19 Wednesday
/gis4/sandieguito/t83thick3.aml


FIGURE 3-5
SAN DIEGUITO BASIN
LAYER 4 THICKNESS

Plot date: 28 Dec 94 08:56:02 Wednesday
/gis4/sandieguito/r83thick4.aml

**FIGURE 3-6**
**Head and Concentration in Layer-3, Node 30400**

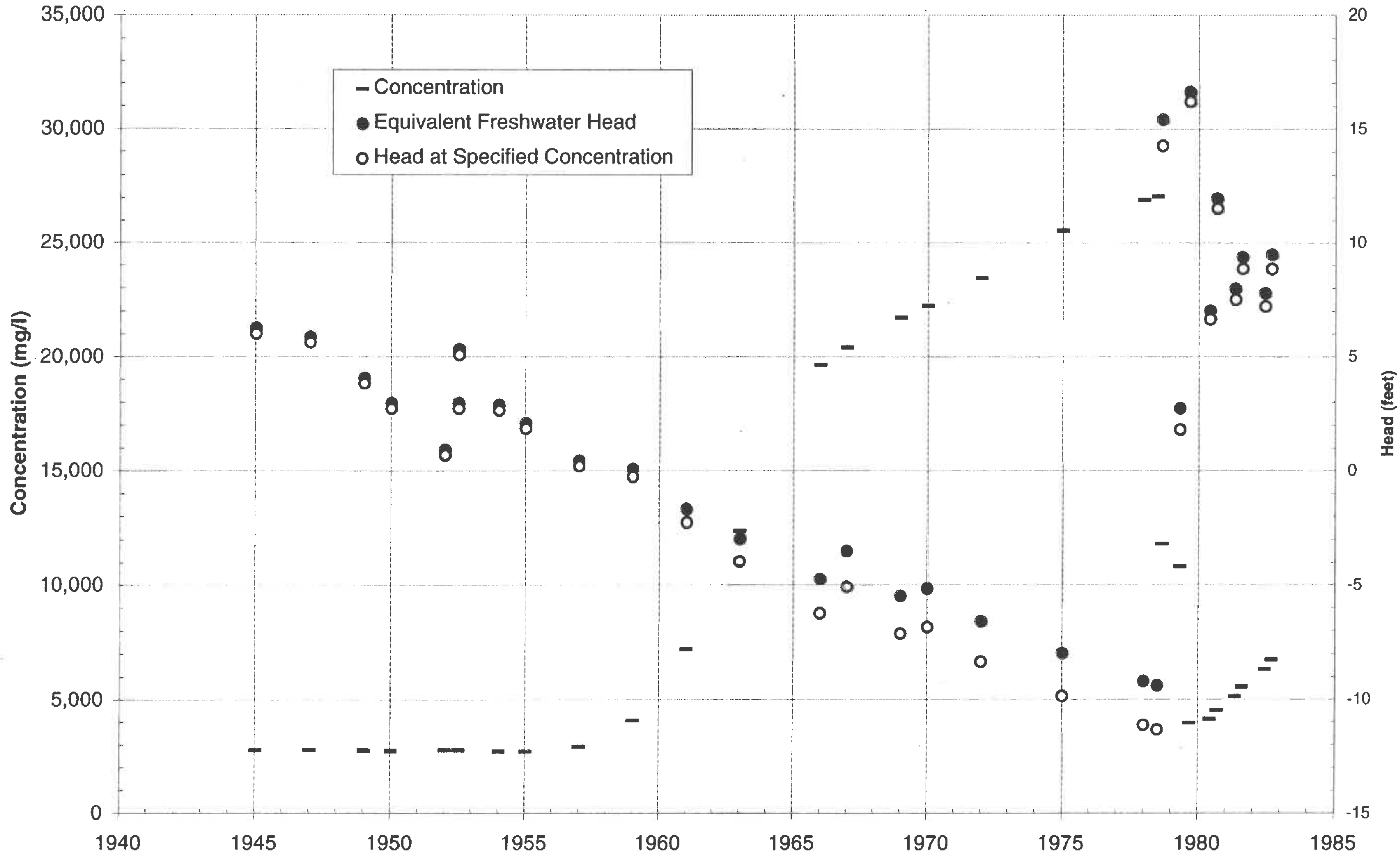



Fig3-6 Chart 1, 3/30/95

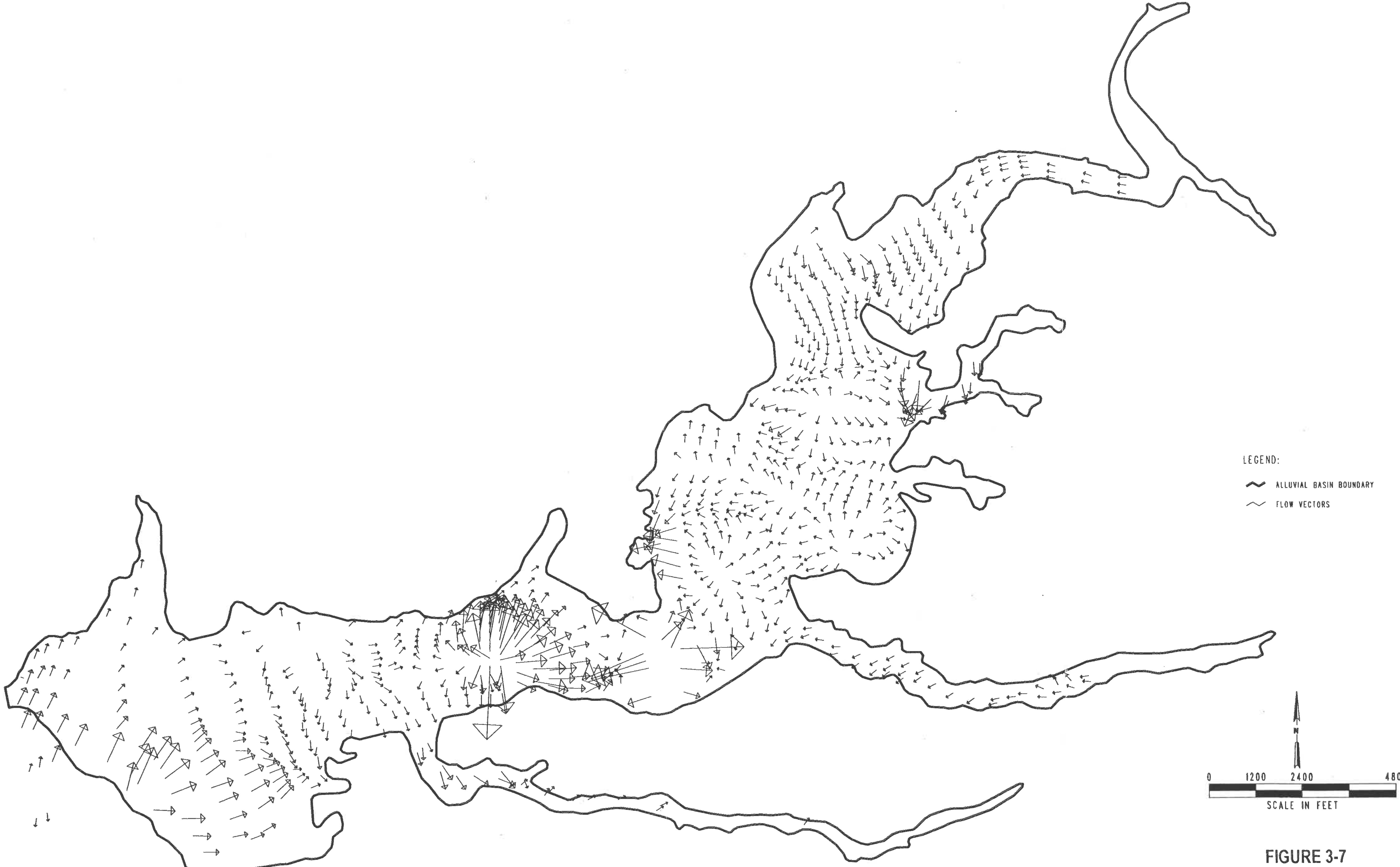



FIGURE 3-7
SAN DIEGUITO BASIN
FLOW VECTORS
**AUGUST 1965**

Plot date: 28 Dec 94 12:10:33 Wednesday
/gis4/sandieguito/arr8383_13.aml


FIGURE 3-8
SAN DIEGUITO BASIN
LAYER 1 TRANSMISSIVITY

Plot date: 20 Dec 94 09:15:40 Wednesday
/gis4/sandieguito/r83trans1.aml


FIGURE 3-9
SAN DIEGUITO BASIN
LAYER 2 TRANSMISSIVITY

Plot date: 28 Dec 94 09:16:37 Wednesday
/gis4/sandieguito/t93trans2.aml

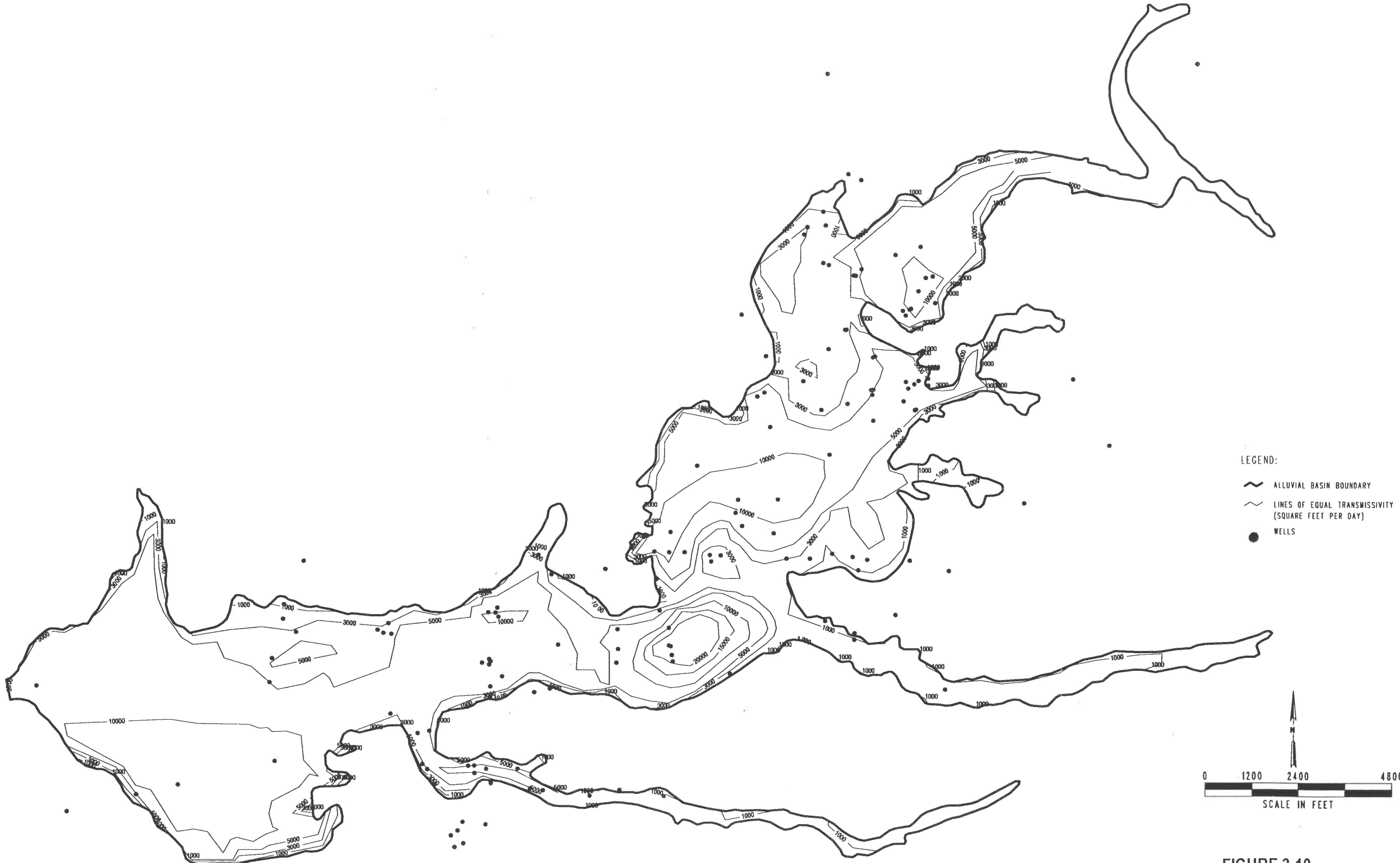


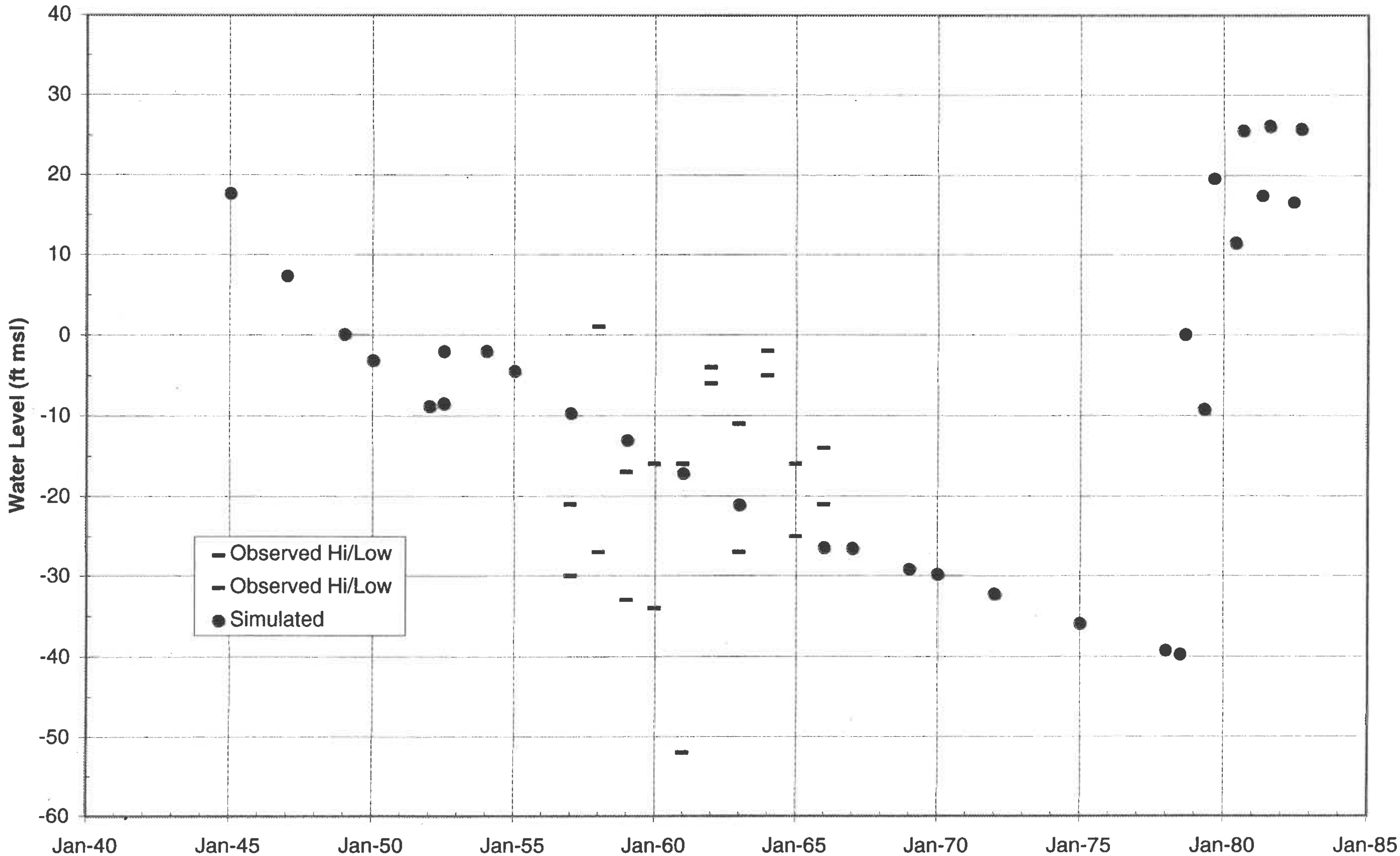

FIGURE 3-10
SAN DIEGUITO BASIN
LAYER 3 TRANSMISSIVITY

Plot date: 28 Dec 94 08:17:45 Wednesday
/gis4/sandieguito/t93trans3.aml


FIGURE 3-11
SAN DIEGUITO BASIN
LAYER 4 TRANSMISSIVITY

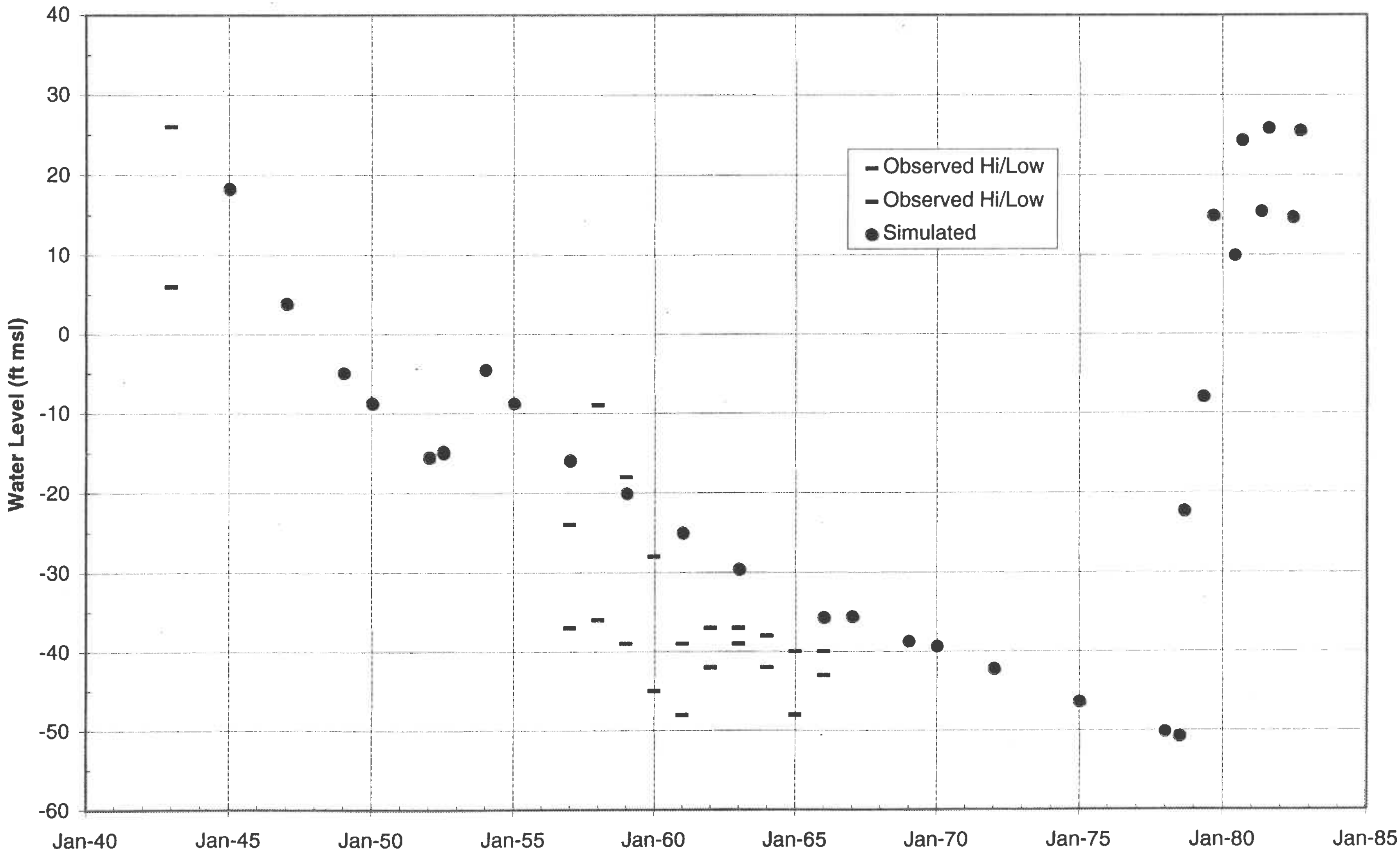
Plot date: 28 Dec 94 09:21:05 Wednesday
/gis4/sandieguito/t63trans4.aml

**FIGURE 3-12**
**Observed and Simulated Water Levels**
**Well 14/03-05N01 and Node 30719**




Calib_1.xls, Fig3-12 Chart 1, 3/30/95

**FIGURE 3-13**
**Observed and Simulated Water Levels**
**Well 13/03-33L03 and Node 30988**




Calib_1.xls, Fig3-13 Chart 1, 3/30/95

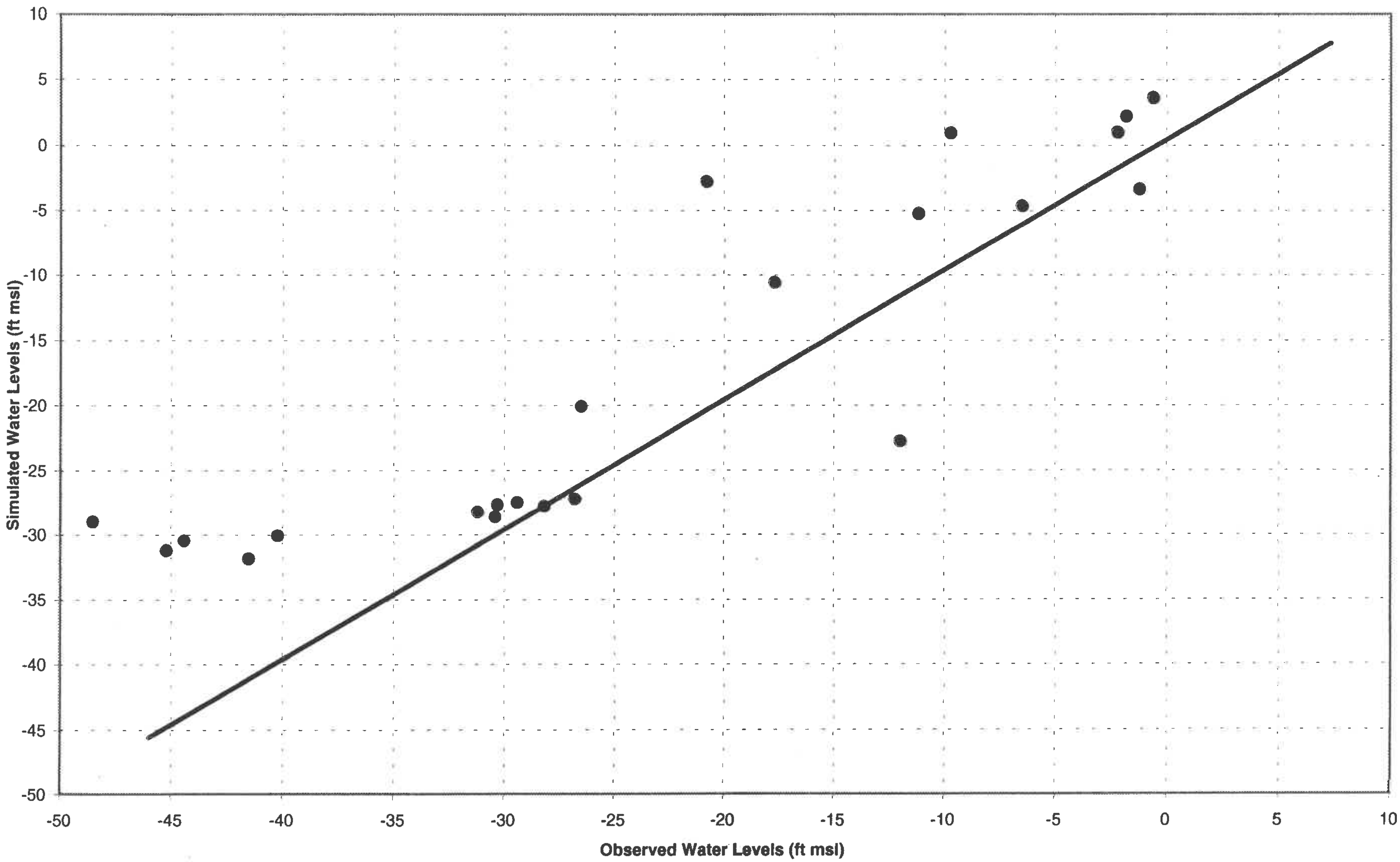

FIGURE 3-14
SAN DIEGUITO BASIN
OBSERVED AND SIMULATED
WATER LEVELS

Plot date: 03 Jan 95 10:38:08 Tuesday


FIGURE 3-15
SAN DIEGUITO BASIN
OBSERVED AND SIMULATED
TDS

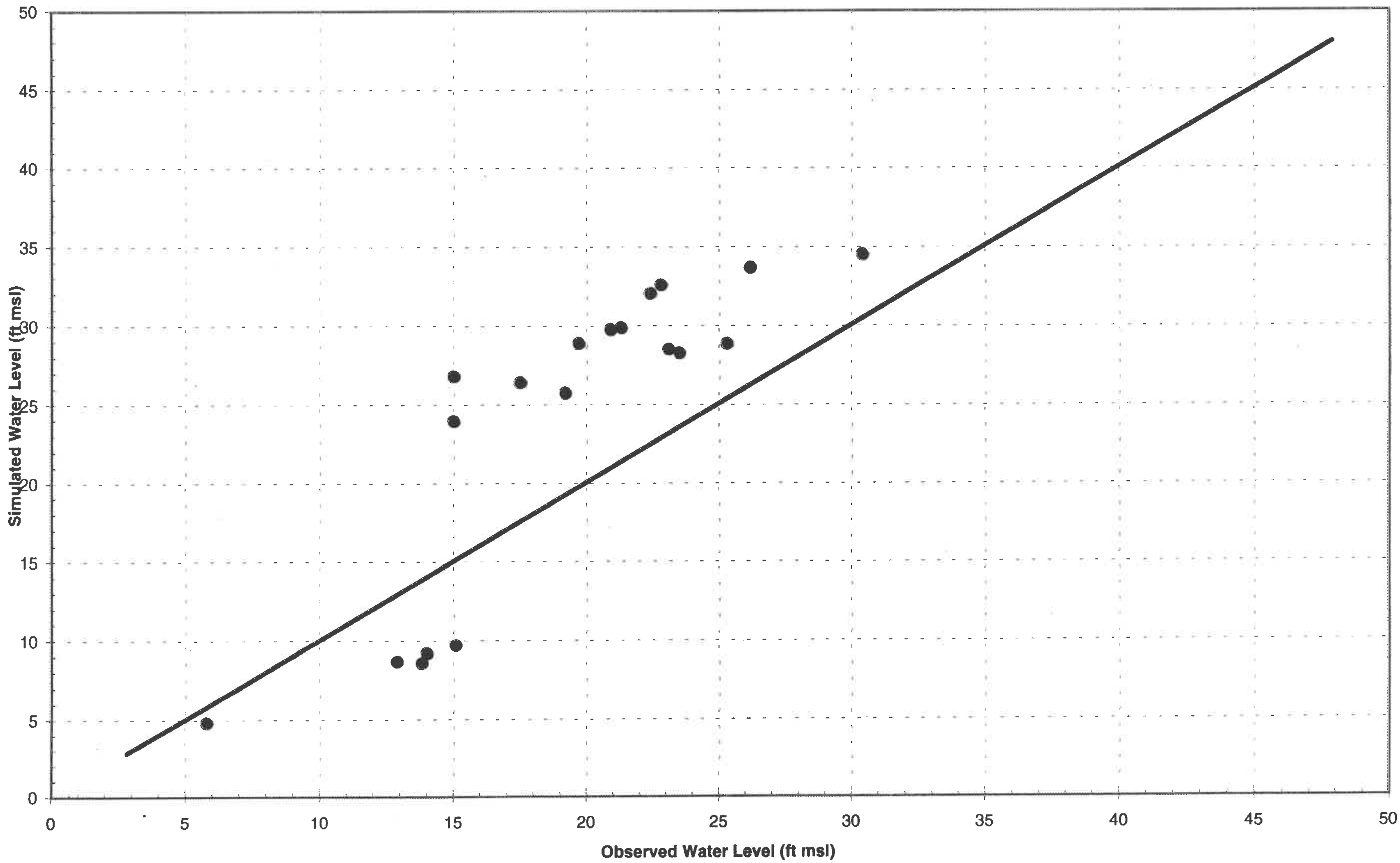
Plot date: 03 Jan 95 10:10:54 Tuesday
/gis4/sandieguito/t93st13cb.aml

## Figure 3-16
## Observed versus Simulated Water Levels, August 1965



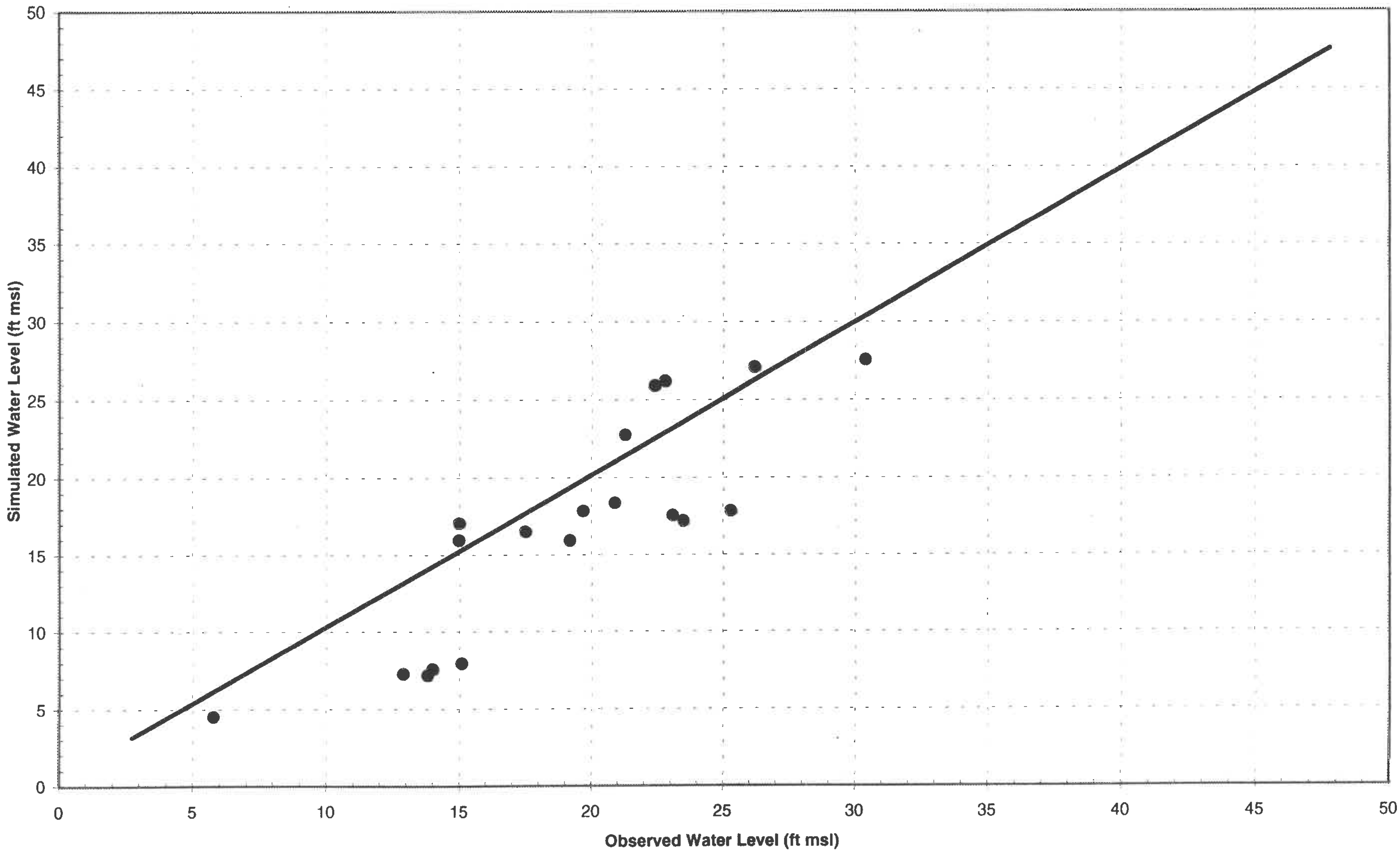

calib2.xls, 1965 Chart 1, 3/30/95

**Figure 3-17**
**Observed versus Simulated Water Levels, April 1982**




calib2.xls, 1978 Chart 1, 3/31/95

## Figure 3-18
## Observed versus Simulated Water Levels, January 1982

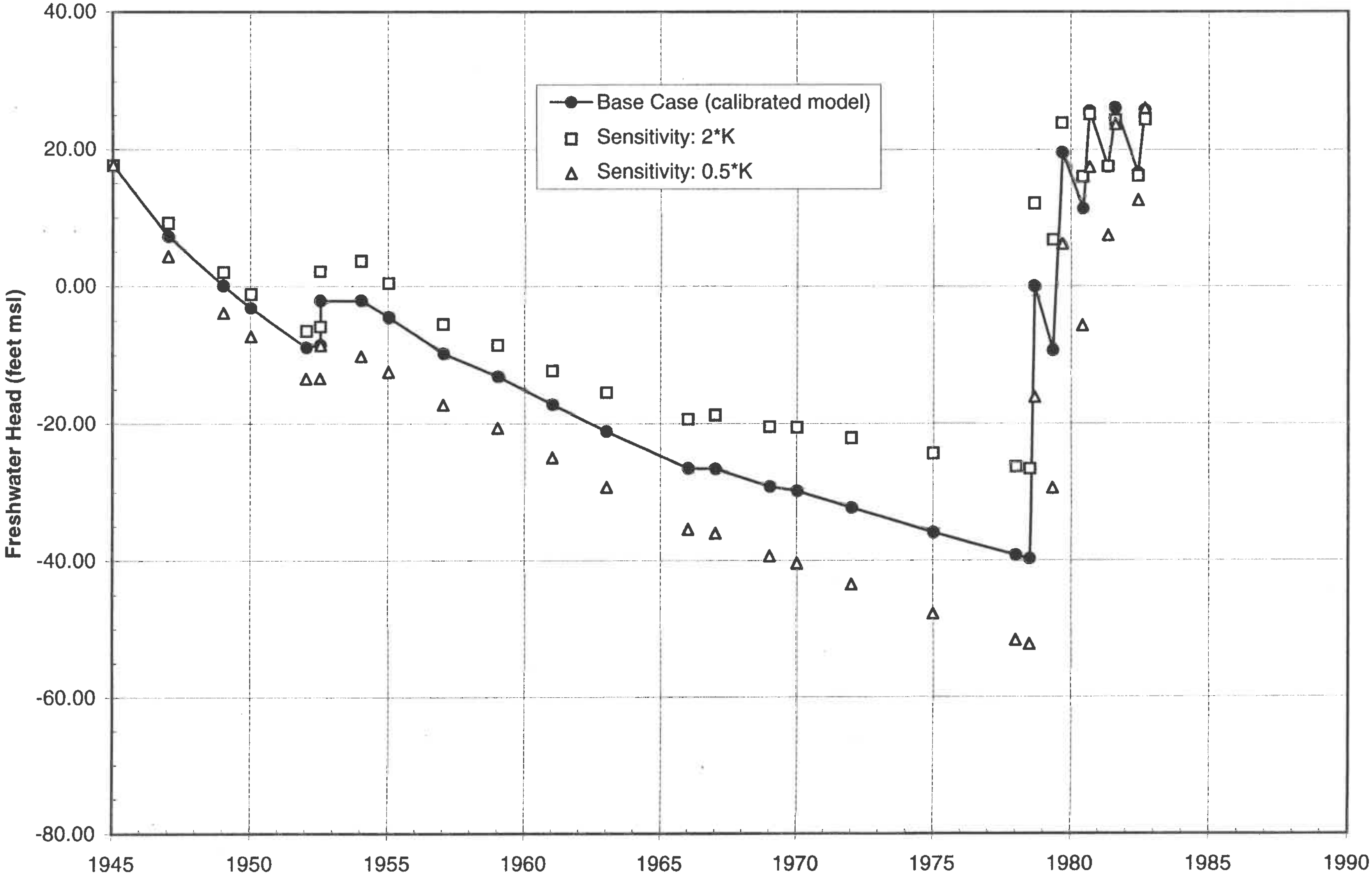



calib2.xls, 1978-b Chart 1, 3/31/95


FIGURE 3-19
SAN DIEGUITO BASIN
WATER LEVEL DIFFERENCE

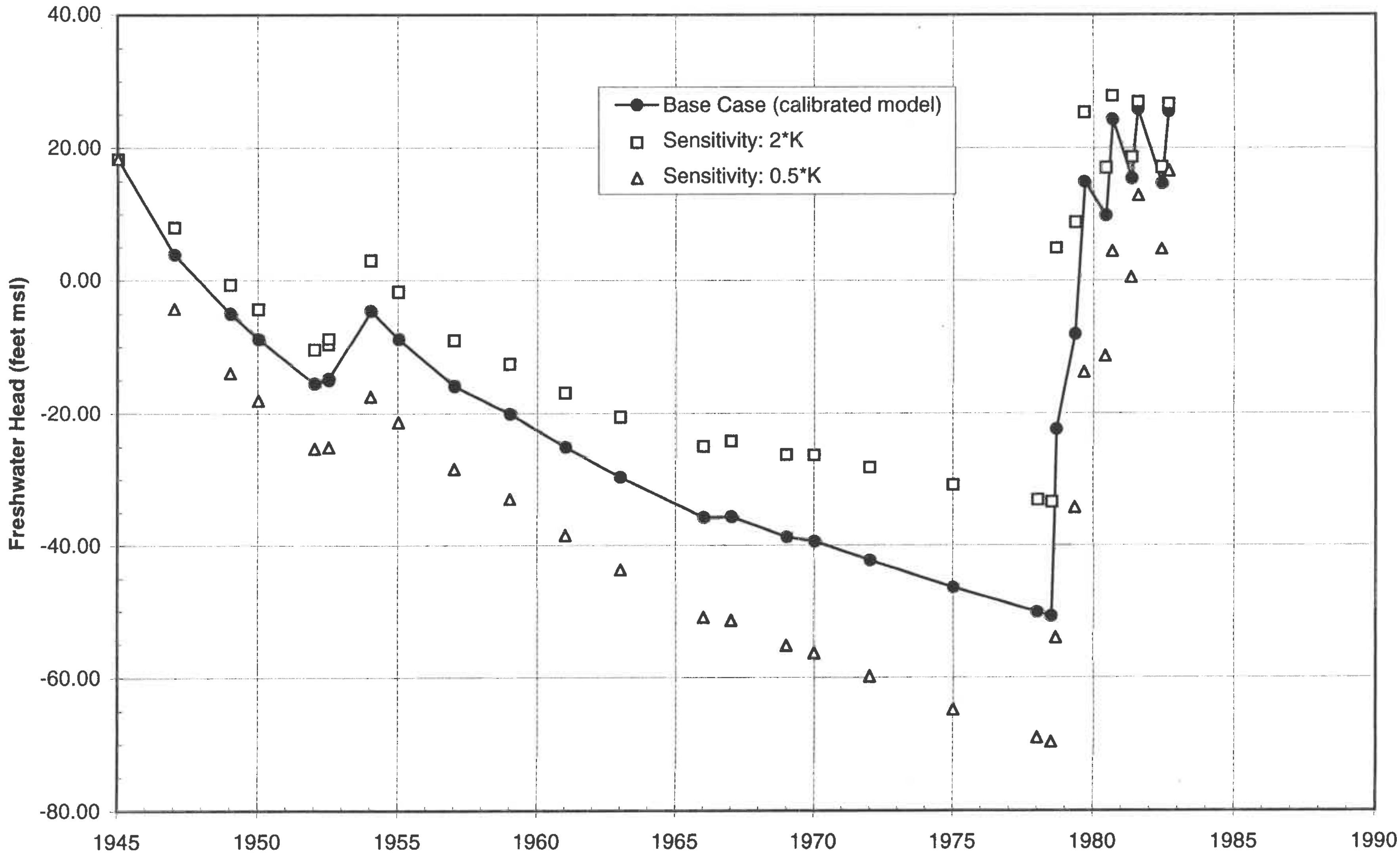
Plot date: 31 Mar 95 14:24:17 Friday
/gis4/sandieguito/r63thick1.aml

**FIGURE 3-20**
**Simulated Freshwater Head, Layer-3, Node 30719**



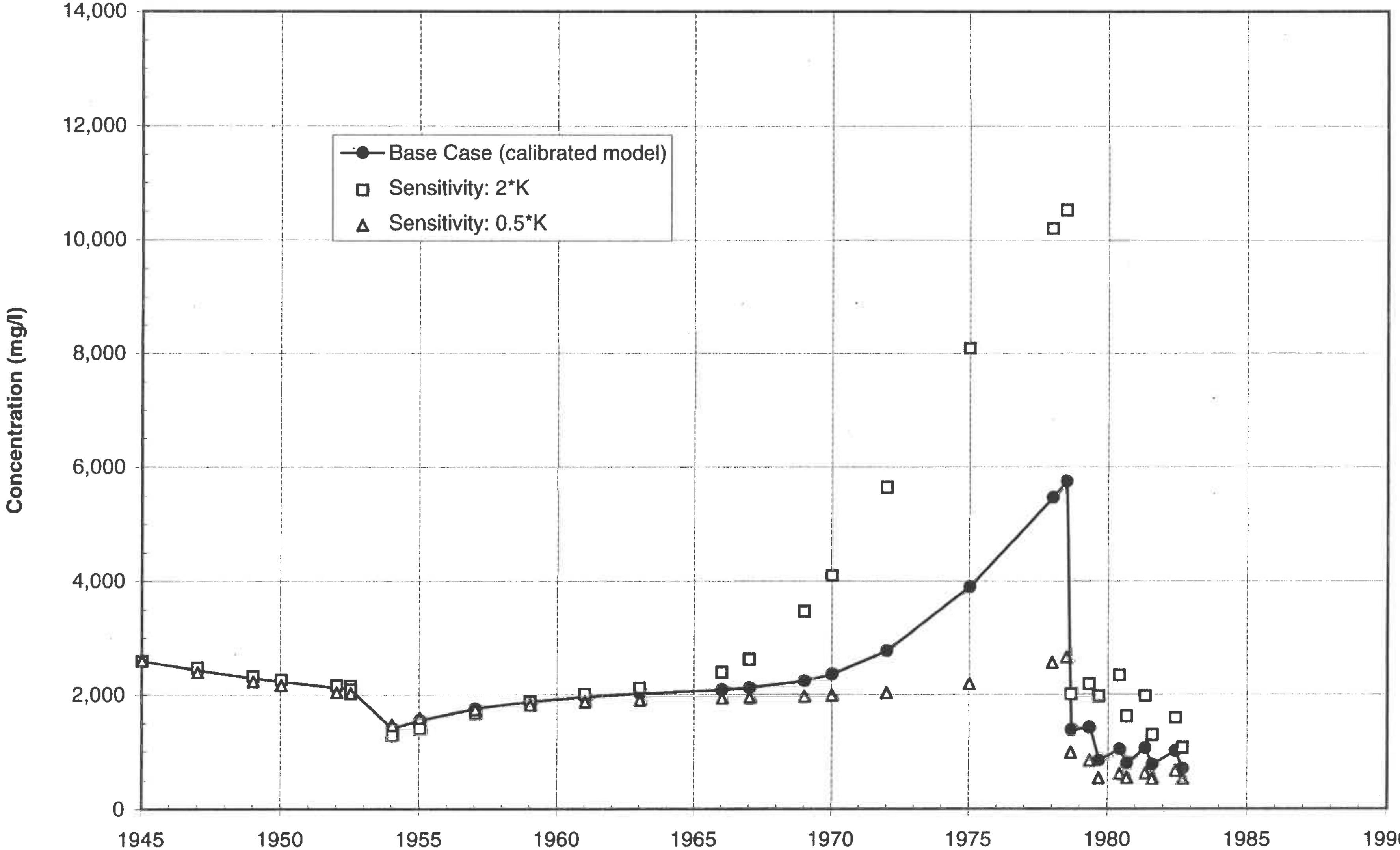

calib_1.xls, Fig3-16 Chart 1, 3/30/95

## FIGURE 3-21
## Simulated Freshwater Head, Layer-3, Node 30988



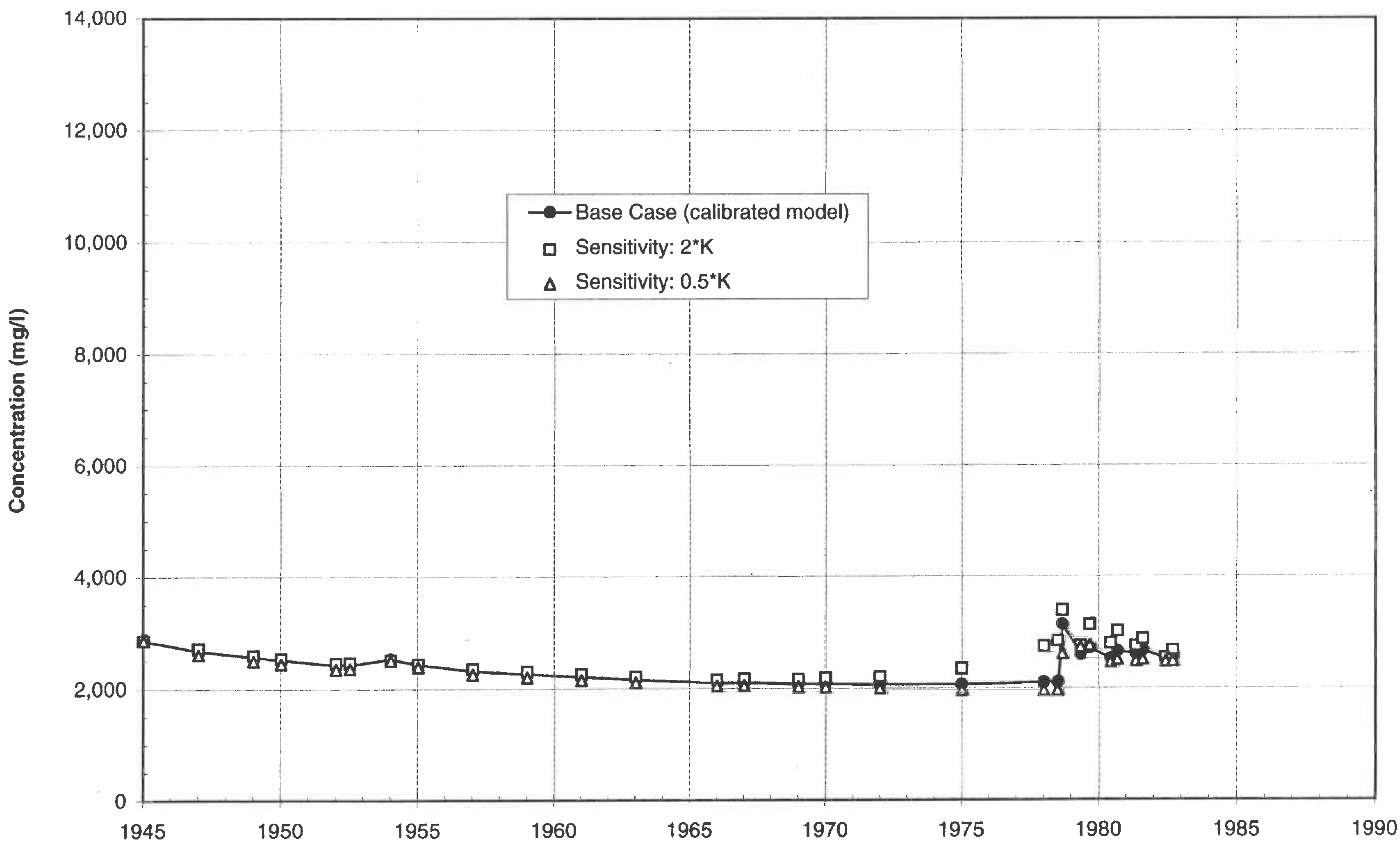

calib_1.xls, Fig3-17 Chart 3, 3/30/95

**FIGURE 3-22**
**Simulated Concentrations, Layer-3, Node 30719**



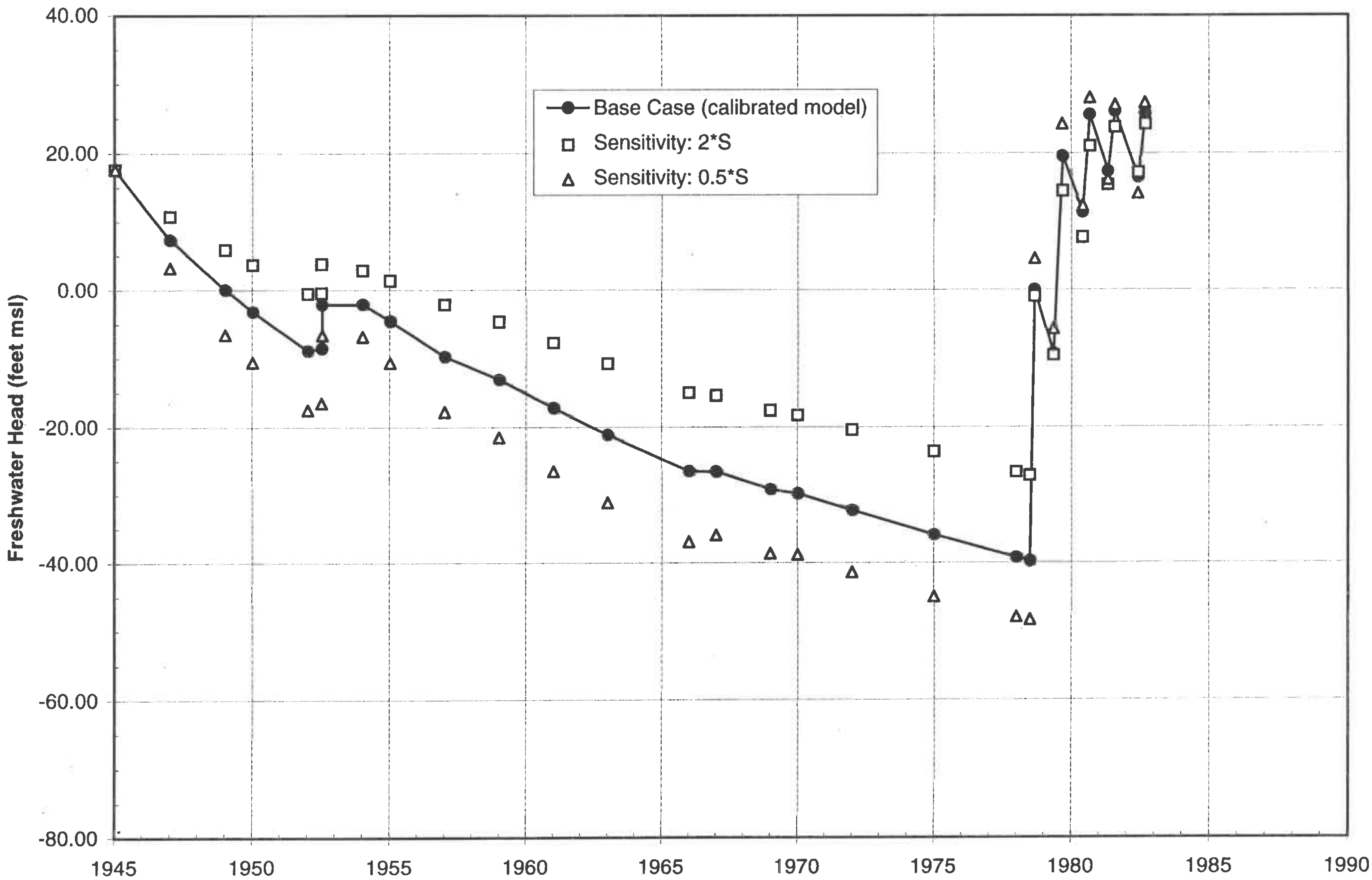

calib_1.xls, Fig3-18 Chart 1, 3/30/95

## FIGURE 3-23
## Simulated Concentrations, Layer-3, Node 30988



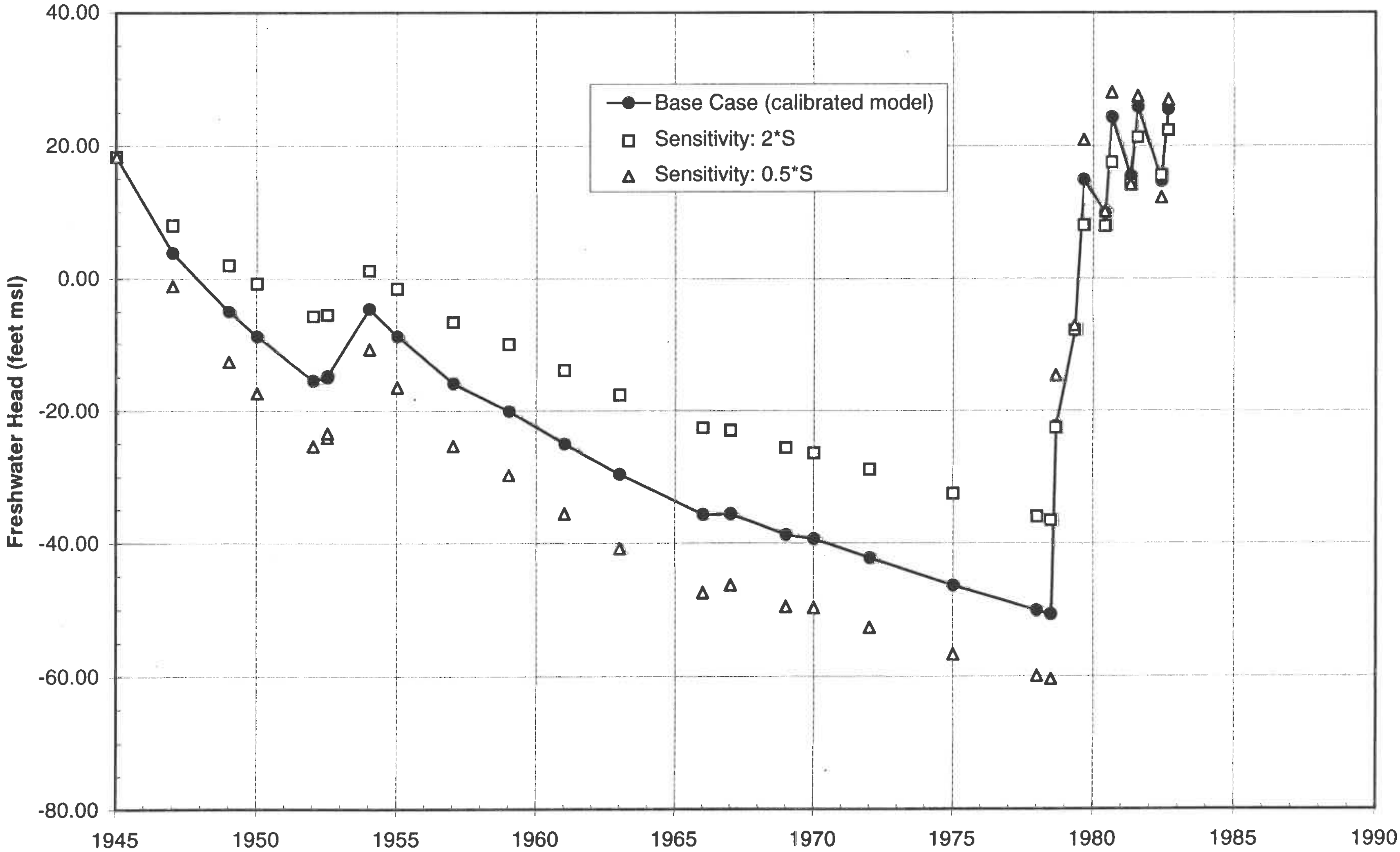

calib_1.xls, Fig3-19 Chart 1, 3/30/95

## FIGURE 3-24
## Simulated Freshwater Head, Layer-3, Node 30719



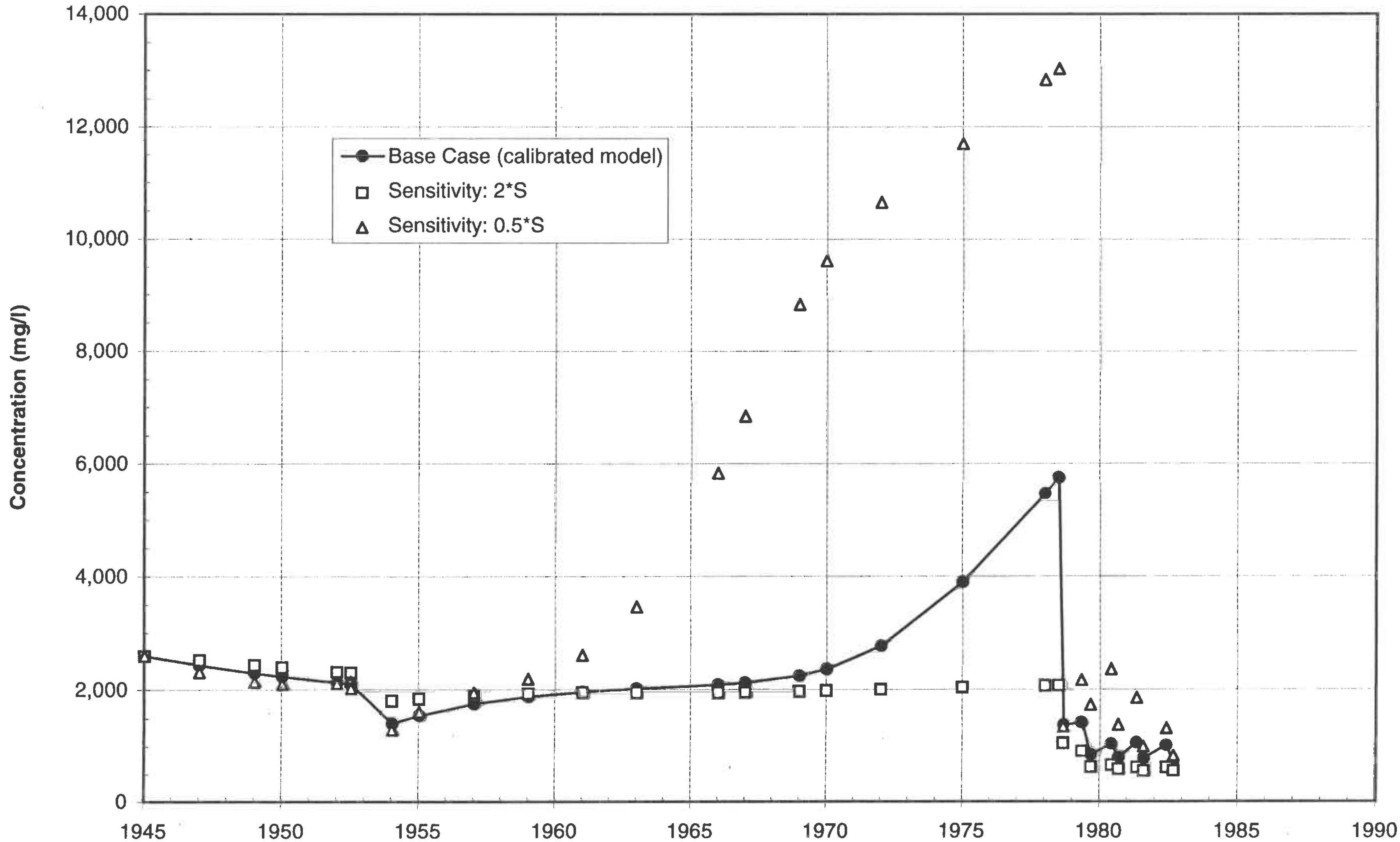

calib_1.xls, Fig3-20 Chart 1, 3/30/95

**FIGURE 3-25**
**Simulated Freshwater Head, Layer-3, Node 30988**




calib_1.xls, Fig3-25 Chart 1, 3/30/95

**FIGURE 3-26**
**Simulated Concentrations, Layer-3, Node 30719**




calib_1.xls, Fig3-26 Chart 1, 3/30/95

**FIGURE 3-27**
**Simulated Concentrations, Layer-3, Node 30988**

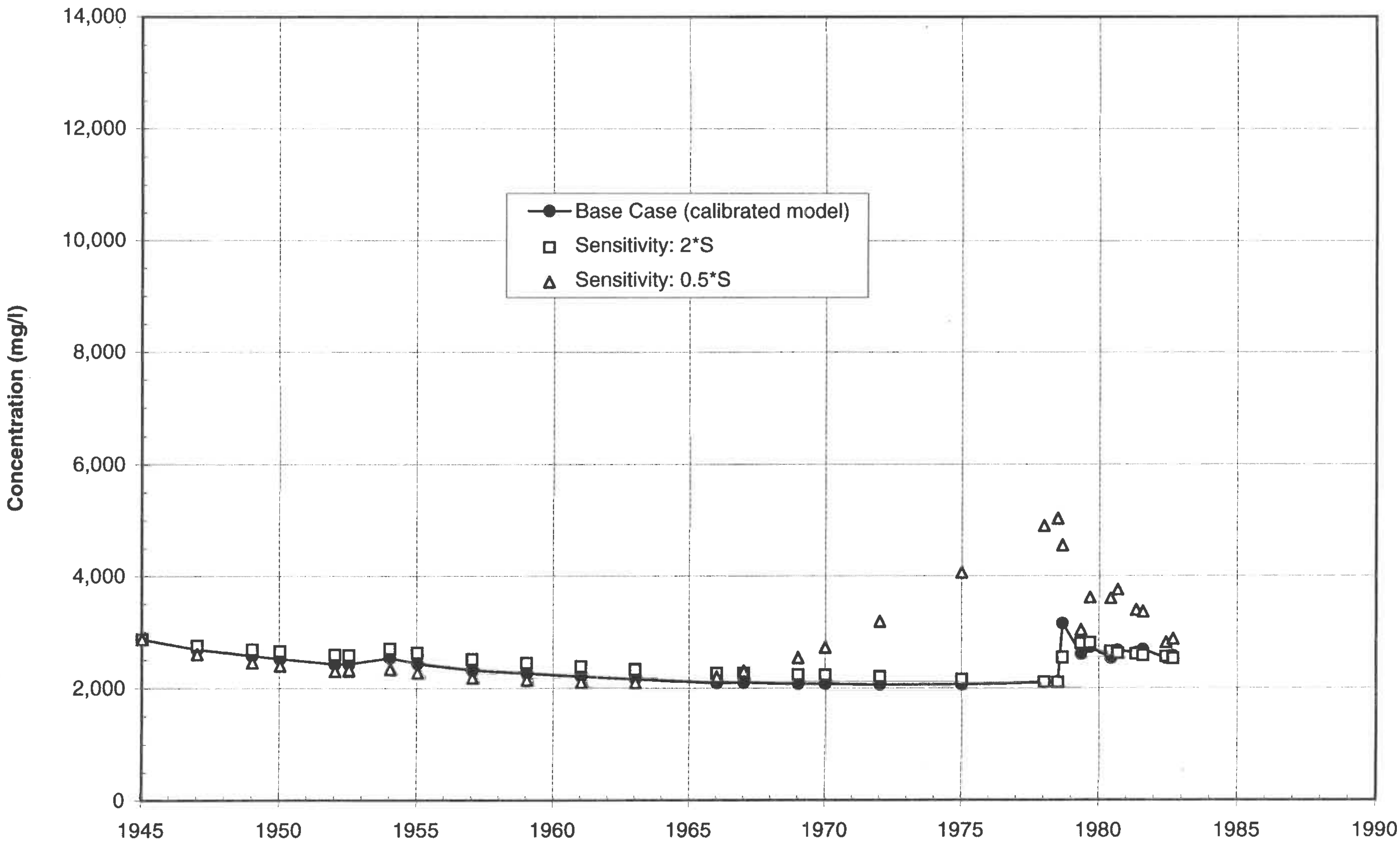
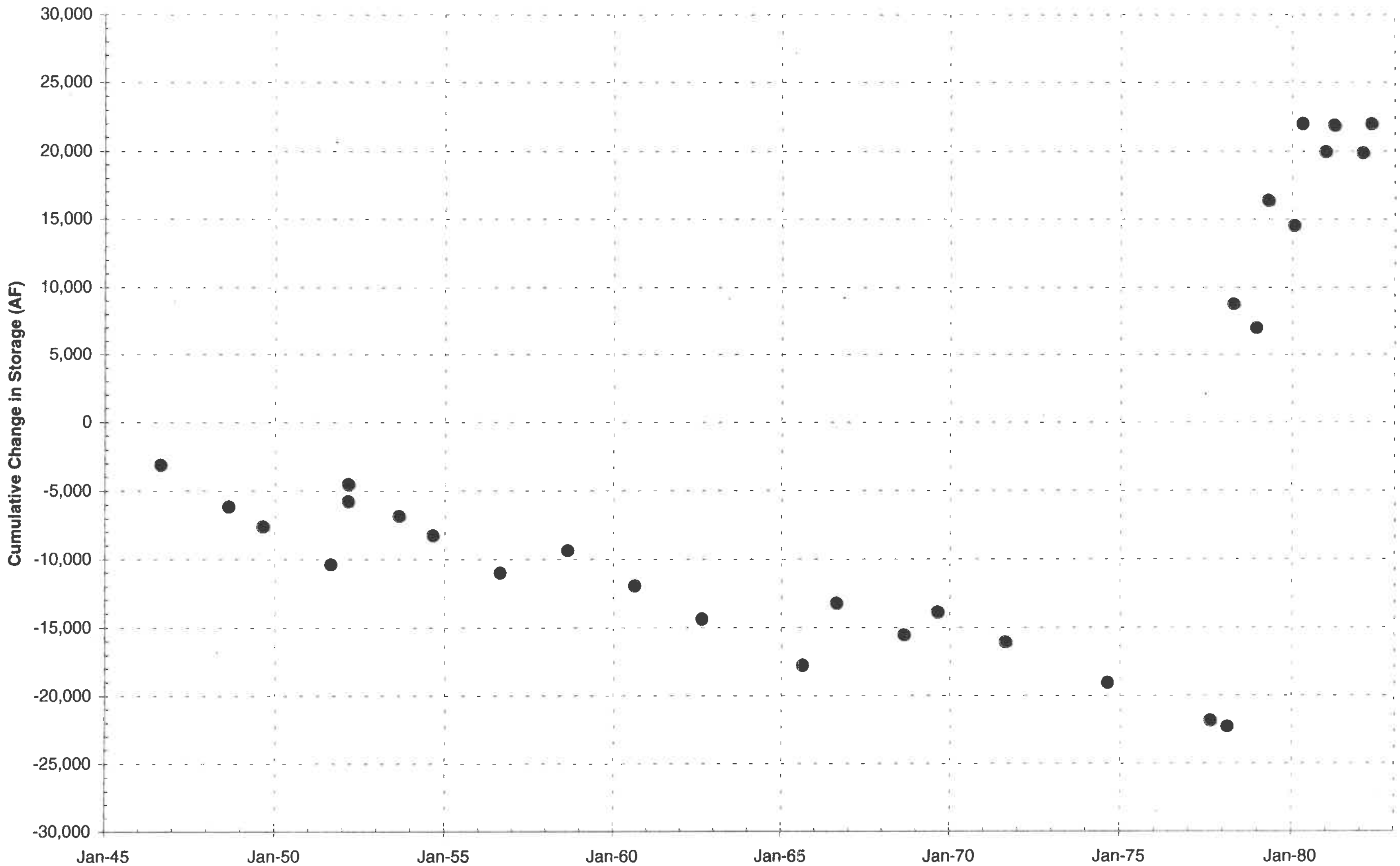


**FIGURE 3-28**
**Cumulative Change in Storage**




Cumulative Chart 1, 3/30/95

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# APPENDIX A

## DWR Well Logs
(see separate volume)

# APPENDIX B

## Layer Bottom Elevations


-100
-50
-50
-50
0
1200
2400
4800
SCALE IN FEET
N
LEGEND:
ALLUVIAL BASIN BOUNDARY
LINES OF EQUAL ELEVATION
(FEET ABOVE MEAN SEA LEVEL)
WELLS
SAN DIEGUITO BASIN
LAYER 1 BOTTOM ELEVATION
Plot date: 23 Jan 95 11:33:35 Monday


SAN DIEGUITO BASIN
LAYER 2
BOTTOM ELEVATIONS

Plot date: 23 Jan 95 11:20:06 Monday
/gis4/sandieguito/r63botelev2.aml


SAN DIEGUITO BASIN
LAYER 3
BOTTOM ELEVATIONS

Plot date: 23 Jan 95 11:27:21 Monday
/gis4/sandieguito/l3botelev3.aml

# APPENDIX C

## Lithologic Percentages by Layer

The attached table lists the percentage of each of the four model lithologic types for each layer and well in the basin. The header for each column defines the layer number and lithology. The number within the table is the calculated percent of the specified lithology within that layer. For each layer, these values must sum to 100 percent. The first two characters define the layer number: Layer-1 (L1), Layer-2 (L2), Layer-3 (3), and Layer-4 (L4). The last two characters identify the lithology as follows:

- S1 - Sand
- S2 - Sand/Gravel and/or Gravel
- S3 - Silt
- S4 - Clay
- -9 - No Data (no well log, layer not present at this location, or beyond bottom of hole)

For example, entries within the L2S3 column indicate the amount of silt in layer two at each of the wells in the basin. If the well has no geologic log then values of -9 are present. Also, if the layer is not present at this location, a value of -9 is present. Contour maps showing the interpolated distribution of each lithology by layer are presented after the table.

# ARC COVERAGE KRIGC

*14-Dec-94*

| STATION-ID | L1S1 | L1S2 | L1S3 | L1S4 | L2S1 | L2S2 | L2S3 | L2S4 | L3S1 | L3S2 | L3S3 | L3S4 | L4S1 | L4S2 | L4S3 | L4S4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13S/3W-28N | 0 | 42.62 | 0 | 57.38 | 0 | 0 | 0 | 100 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-28N1 | 2.73 | 12.73 | 0 | 0 | 0 | 0 | 0 | 92.16 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-28N2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-28N3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-32R1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-32R2 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 46.43 | 0 | 53.57 | -9 | -9 | -9 | -9 |
| 13S/3W-32R3 | 71.43 | 0 | 28.57 | 0 | 0 | 0 | 0 | 100 | 23.53 | 58.82 | 17.65 | 0 | -9 | -9 | -9 | -9 |
| 13S/3W-33B1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33B2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33B3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33C1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33C2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33C3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33C4 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33C5 | 12.5 | 75 | 12.5 | 0 | 0 | 100 | 0 | 0 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33C6 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33C7 | 13.33 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33D1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33D2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33E1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33E2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33E3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33E4 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33E5 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33F2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33F3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33F4 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33F7 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33G2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33G3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33K3 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 100 | 0 | 100 | 0 | 0 | -9 | -9 | -9 | -9 |
| 13S/3W-33K4 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 100 | 0 | 90 | 0 | 10 | -9 | -9 | -9 | -9 |

| STATION-ID | L1S1 | L1S2 | L1S3 | L1S4 | L2S1 | L2S2 | L2S3 | L2S4 | L3S1 | L3S2 | L3S3 | L3S4 | L4S1 | L4S2 | L4S3 | L4S4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13S/3W-33K5 | -9 | -9 | -9 | -9 | 0 | 0 | 0 | 100 | 0 | 58.82 | 0 | 41.18 | -9 | -9 | -9 | -9 |
| 13S/3W-33K8 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33L3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33L4 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33L6 | 3.49 | 0 | 96.51 | 0 | 0 | 17.54 | 82.46 | 0 | 0 | 27.78 | 66.67 | 5.56 | -9 | -9 | -9 | -9 |
| 13S/3W-33L7 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33L9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33M1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33M2 | 0 | 0 | 0 | 3.79 | 7.14 | 0 | 0 | 58.93 | 10 | 0 | 0 | 90 | -9 | -9 | -9 | -9 |
| 13S/3W-33N1 | 0 | 0 | 96.23 | 3.77 | 89.09 | 0 | 10.91 | 0 | 20.83 | 41.67 | 20.83 | 16.67 | -9 | -9 | -9 | -9 |
| 13S/3W-33N2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 13S/3W-33P1 | 78.72 | 0 | 0 | 21.28 | 33.33 | 0 | 0 | 66.67 | 53.49 | 11.63 | 0 | 34.88 | -9 | -9 | -9 | -9 |
| 13S/3W-33Q1 | -9 | -9 | -9 | -9 | 0 | 0 | 0 | 56.25 | 0 | 55.56 | 0 | 44.44 | -9 | -9 | -9 | -9 |
| 13S/3W-33Q2 | 62.5 | 0 | 0 | 37.5 | 24.24 | 0 | 0 | 75.76 | 0 | 73.53 | 0 | 26.47 | -9 | -9 | -9 | -9 |
| 13S/3W-33Q3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-4D1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-4E1 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 50 | 0 | 0 | 50 | -9 | -9 | -9 | -9 |
| 14S/3W-4E2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | 0 | 0 | 97.14 | 2.86 | -9 | -9 | -9 | -9 |
| 14S/3W-4F1 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 50 | 0 | 0 | 50 | -9 | -9 | -9 | -9 |
| 14S/3W-4F2 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 50 | 0 | 0 | 50 | -9 | -9 | -9 | -9 |
| 14S/3W-4L1 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 50 | 0 | 0 | 50 | -9 | -9 | -9 | -9 |
| 14S/3W-4N1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-4P1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-5C1 | 71.43 | 0 | 28.57 | 0 | 0 | 0 | 0 | 100 | 23.53 | 58.82 | 0 | 17.65 | -9 | -9 | -9 | -9 |
| 14S/3W-5E1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-5E2 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 20.24 | 59.52 | 0 | 20.24 | -9 | -9 | -9 | -9 |
| 14S/3W-5F | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-5F1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-5F2 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 3.7 | 92.59 | 0 | 3.7 | -9 | -9 | -9 | -9 |
| 14S/3W-5F3 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 0 | 0 | 97.02 | 2.99 | -9 | -9 | -9 | -9 |
| 14S/3W-5G1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-5H1 | 30.26 | 0 | 67.11 | 2.63 | 0 | 0 | 100 | 0 | 62 | 20 | 10 | 8 | -9 | -9 | -9 | -9 |
| 14S/3W-5H2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-5H3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-5H4 | 100 | 0 | 0 | 0 | 61.67 | 0 | 0 | 38.33 | 58.82 | 0 | 0 | 41.18 | -9 | -9 | -9 | -9 |
| 14S/3W-5H5 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |

| STATION-ID | L1S1 | L1S2 | L1S3 | L1S4 | L2S1 | L2S2 | L2S3 | L2S4 | L3S1 | L3S2 | L3S3 | L3S4 | L4S1 | L4S2 | L4S3 | L4S4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14S/3W-5K1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-5K2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-5K3 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 100 | -9 | -9 | -9 | -9 |
| 14S/3W-5L1 | 45.46 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 50 | 0 | 0 | 50 | -9 | -9 | -9 | -9 |
| 14S/3W-5L2 | 45.46 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 50 | 0 | 0 | 50 | -9 | -9 | -9 | -9 |
| 14S/3W-5N1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-5N2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-5P1 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 50 | -9 | -9 | -9 | -9 |
| 14S/3W-5P2 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 0 | 100 | 0 | 0 | -9 | -9 | -9 | -9 |
| 14S/3W-5P3 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 0 | 100 | 0 | 0 | -9 | -9 | -9 | -9 |
| 14S/3W-5P4 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 0 | 100 | 0 | 0 | -9 | -9 | -9 | -9 |
| 14S/3W-5P5 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-6G1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-6J1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-6P2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-6P3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-6Q1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-6Q2 | -9 | -9 | -9 | -9 | 0 | 0 | 33.33 | 66.67 | 100 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |
| 14S/3W-6R1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7C1 | -9 | -9 | -9 | -9 | 0 | 0 | 0 | 96.59 | 0 | 64.29 | 0 | 35.71 | 61.11 | 33.33 | 0 | 5.56 |
| 14S/3W-7C2 | -9 | -9 | -9 | -9 | 16.98 | 0 | 0 | 79.25 | 0 | 100 | 0 | 0 | 0 | 7.69 | 0 | 92.31 |
| 14S/3W-7C3 | -9 | -9 | -9 | -9 | 0 | 0 | 0 | 96.59 | 0 | 64.29 | 0 | 35.71 | 61.11 | 33.33 | 0 | 5.56 |
| 14S/3W-7C4 | -9 | -9 | -9 | -9 | 0 | 0 | 0 | 86.96 | 84.62 | 0 | 0 | 15.39 | 77.42 | 0 | 0 | 22.58 |
| 14S/3W-7C5 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7C6 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7C7 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7E1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7E2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7J1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7K1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7K2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7K3 | -9 | -9 | -9 | -9 | 47.92 | 0 | 47.92 | 0 | 0 | 100 | 0 | 0 | -9 | -9 | -9 | -9 |
| 14S/3W-7L1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7L2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7L3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7L4 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |

| STATION-ID | L1S1 | L1S2 | L1S3 | L1S4 | L2S1 | L2S2 | L2S3 | L2S4 | L3S1 | L3S2 | L3S3 | L3S4 | L4S1 | L4S2 | L4S3 | L4S4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14S/3W-7M1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7M2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-7M3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-8B3 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 100 | 0 | 0 | 0 | -9 | -9 | -9 | -9 |
| 14S/3W-8C1 | -9 | -9 | -9 | -9 | 0 | 0 | 100 | 0 | 100 | 0 | 0 | 0 | -9 | -9 | -9 | -9 |
| 14S/3W-8D1 | 0 | 100 | 0 | 0 | 0 | 0 | 100 | 0 | 100 | 0 | 0 | 0 | -9 | -9 | -9 | -9 |
| 14S/3W-8M2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/3W-9A1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/4W-11C1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/4W-11J1 | -9 | -9 | -9 | -9 | 50.39 | 0 | 41.86 | 0 | 20 | 80 | 0 | 0 | 8.13 | 6.25 | 48.13 | 18.75 |
| 14S/4W-11J2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/4W-12B1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/4W-12C1 | -9 | -9 | -9 | -9 | 0 | 0 | 0 | 85.71 | 23.08 | 76.92 | 0 | 0 | 0 | 0 | 0 | 100 |
| 14S/4W-12H1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/4W-12L1 | -9 | -9 | -9 | -9 | 0 | 0 | 0 | 85.71 | 23.08 | 76.92 | 0 | 0 | 0 | 0 | 0 | 100 |
| 14S/4W-1P1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/4W-1P2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/4W-1Q1 | -9 | -9 | -9 | -9 | 3.03 | 0 | 0 | 96.97 | 0 | 0 | 0 | 50 | 10.71 | 0 | 0 | 89.29 |
| 14S/4W-1R1 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/4W-1R2 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/4W-1R3 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| 14S/4W-1R4 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 | -9 |
| C1 | 30 | 0 | 0 | 0 | 0 | 0 | 20 | 20 | 40 | 20 | 0 | 0 | 0 | 0 | -9 | -9 |
| C10 | -9 | -9 | 0 | 0 | 0 | 0 | 40 | 10 | 20 | 40 | 0 | 0 | 0 | 0 | 10 | 20 |
| C11 | -9 | -9 | 0 | 0 | 0 | 0 | 40 | 10 | 20 | 40 | 0 | 0 | -9 | -9 | -9 | -9 |
| C2 | 30 | 0 | 0 | 0 | 0 | 0 | 20 | 20 | 40 | 20 | 0 | 0 | 0 | 0 | -9 | -9 |
| C3 | 30 | 0 | 0 | 0 | 0 | 0 | -9 | -9 | 40 | 20 | 0 | 0 | 0 | 0 | -9 | -9 |
| C4 | 30 | 0 | 0 | 0 | 0 | 0 | 20 | 20 | 40 | 10 | 0 | 0 | 0 | 0 | -9 | -9 |
| C5 | 30 | 0 | 0 | 0 | 0 | 0 | 20 | 20 | 40 | 10 | 0 | 0 | 0 | 0 | -9 | -9 |
| C6 | 30 | 0 | 0 | 0 | 0 | 0 | 20 | 20 | 40 | 10 | 0 | 0 | 0 | 0 | -9 | -9 |
| C7 | -9 | -9 | 0 | 0 | 0 | 0 | 30 | 30 | 30 | 40 | 0 | 0 | 0 | 0 | 20 | 20 |
| C8 | -9 | -9 | 0 | 0 | 0 | 0 | 30 | 30 | 20 | 60 | 0 | 0 | 0 | 0 | 20 | 20 |
| C9 | -9 | -9 | 0 | 0 | 0 | 0 | 30 | 30 | 40 | 30 | 0 | 0 | 0 | 0 | 20 | 40 |

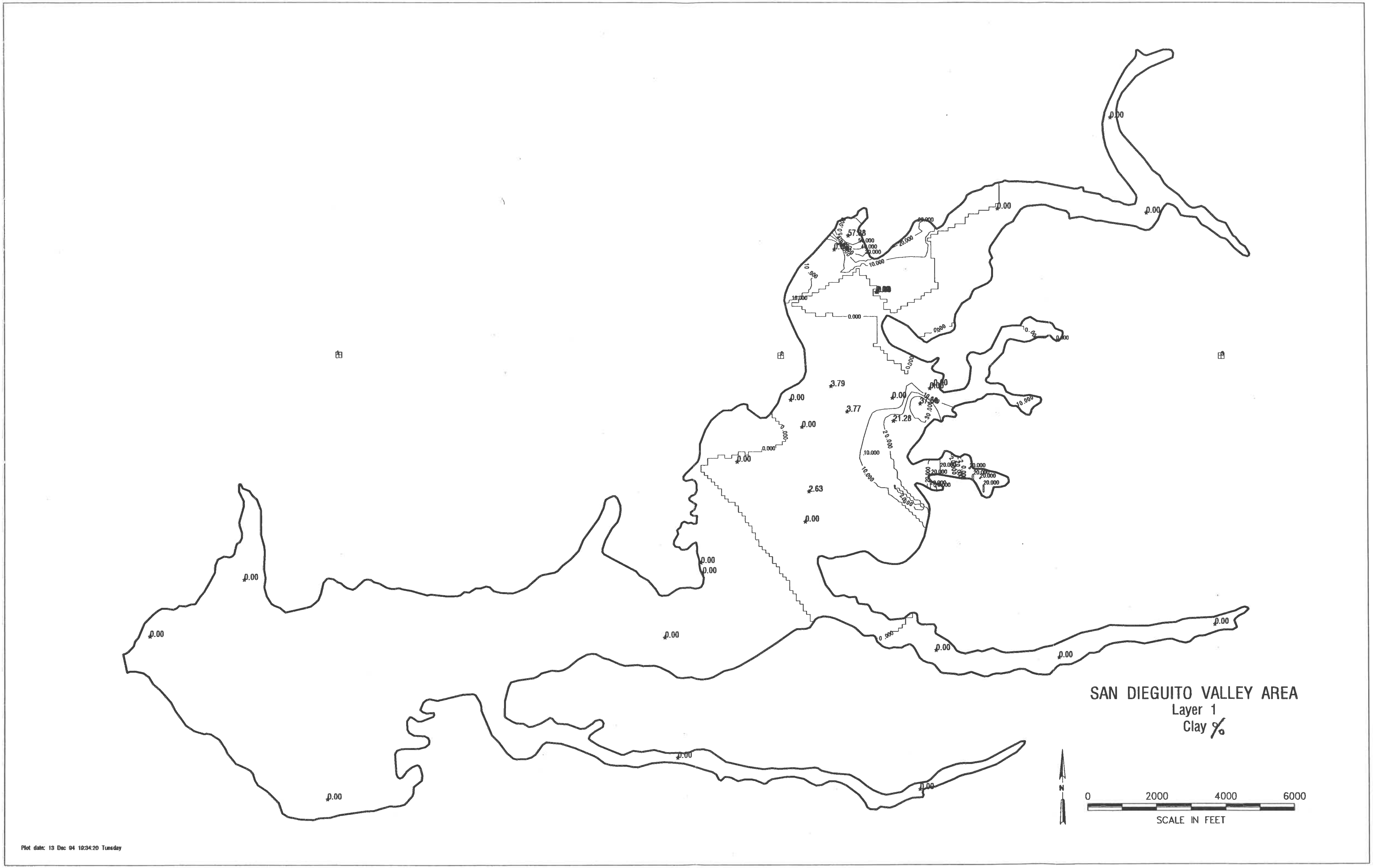

Plot date: 13 Dec 94 10:32:41 Tuesday

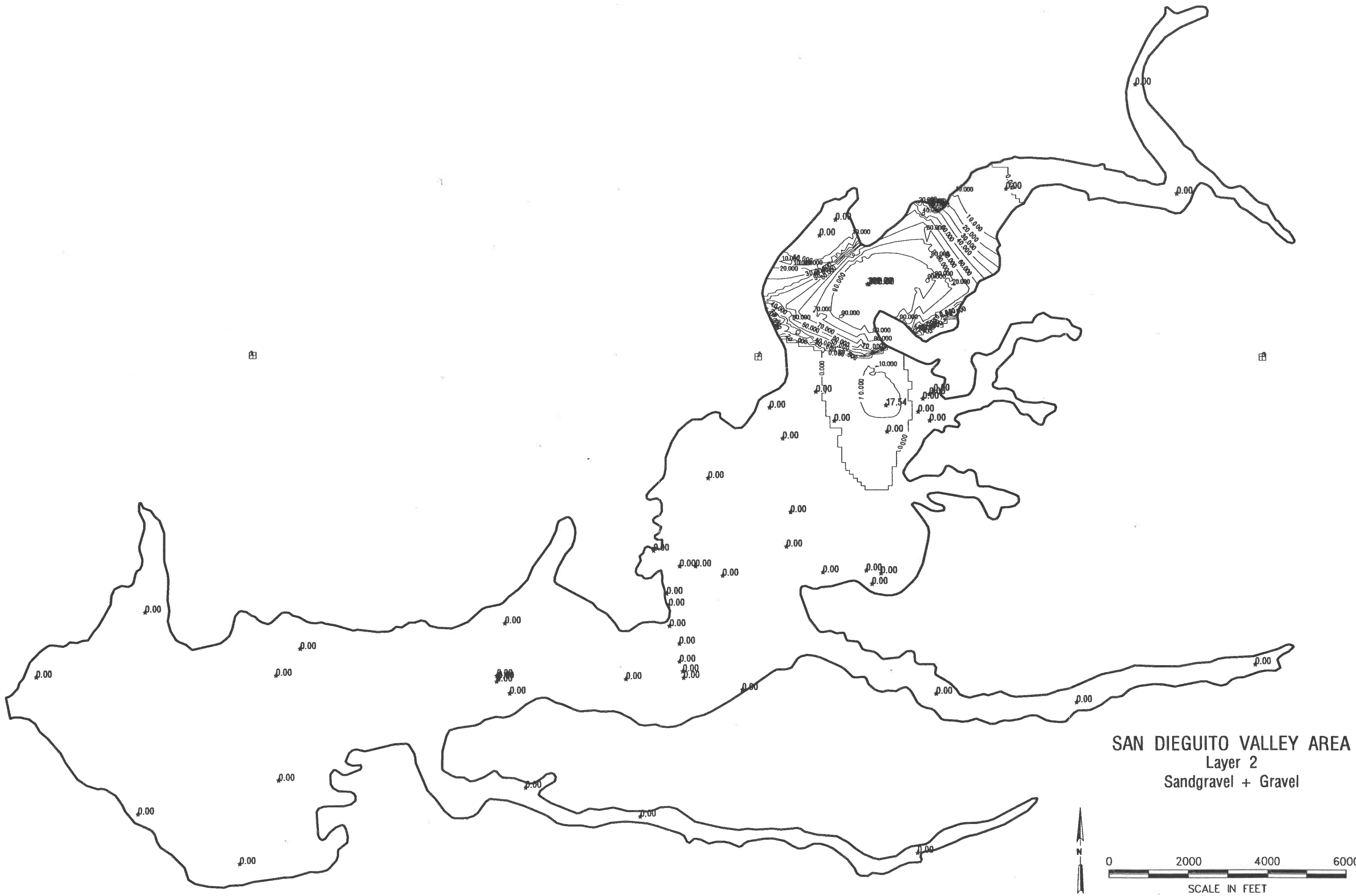

SAN DIEGUITO VALLEY AREA
Layer 1
Sand %

Plot date: 13 Dec 94 19:31:54 Tuesday


SAN DIEGUITO VALLEY AREA
Layer 1
Silt %

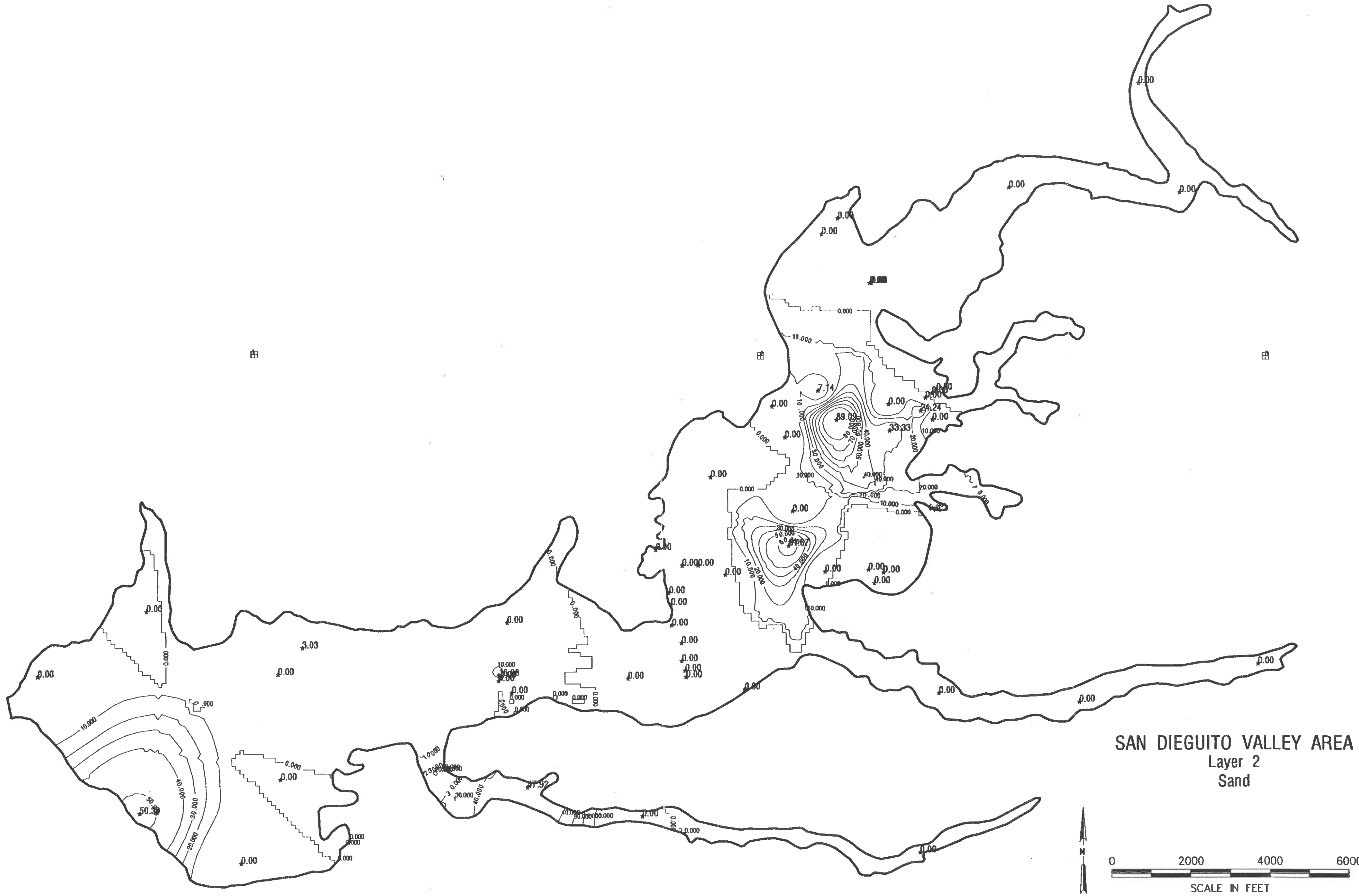
Plot date: 13 Dec 94 19:33:46 Tuesday


SAN DIEGUITO VALLEY AREA
Layer 1
Clay %
N
0
2000
4000
6000
SCALE IN FEET
57.88
3.79
3.77
21.28
2.63
Plot date: 13 Dec 94 19:34:20 Tuesday

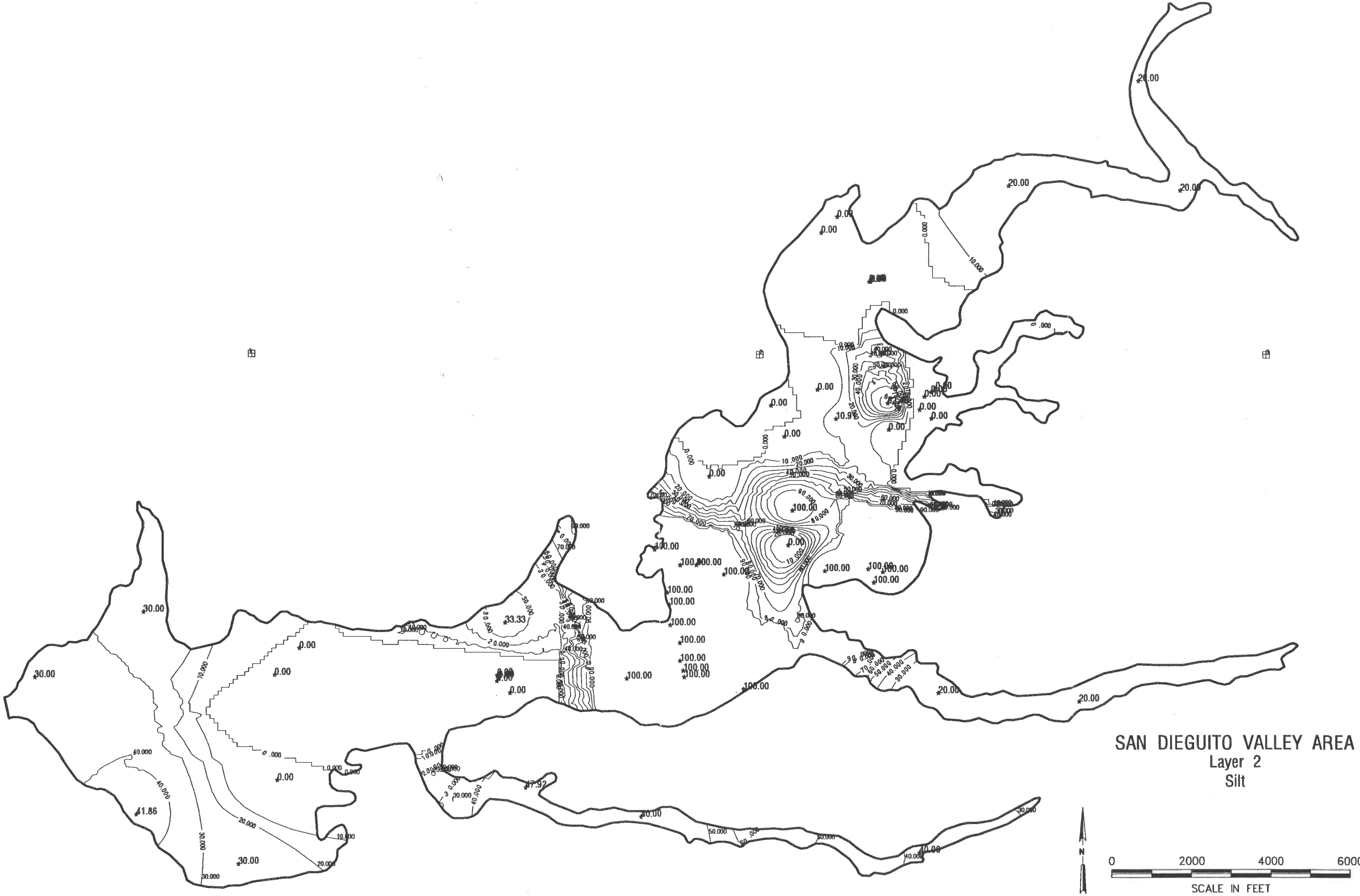



SAN DIEGUITO VALLEY AREA
Layer 2
Sandgravel + Gravel

Plot date: 13 Dec 94 19:35:57 Tuesday




Plot date: 13 Dec 94 10:35:07 Tuesday

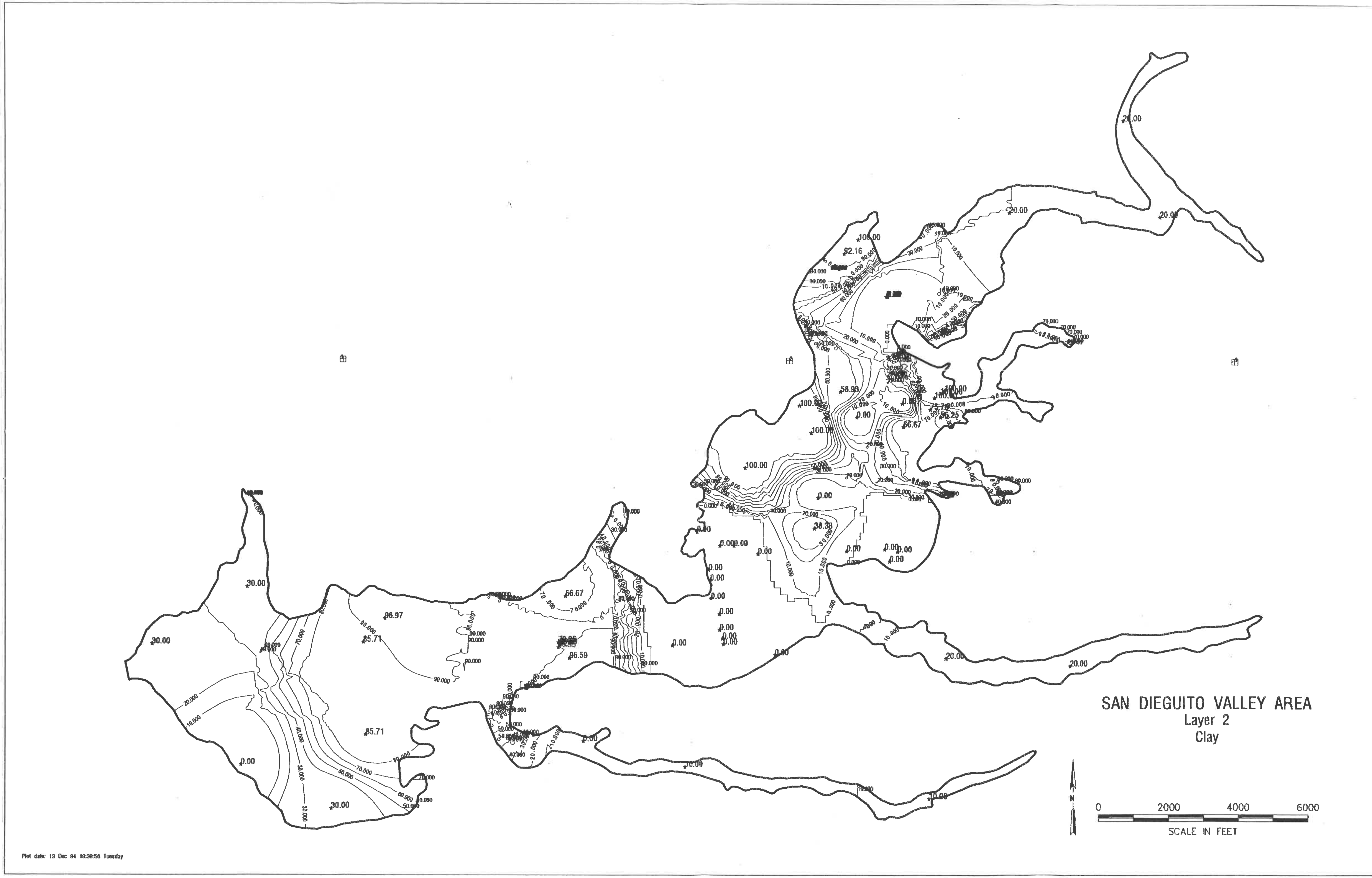



# SAN DIEGUITO VALLEY AREA

Layer 2

Silt

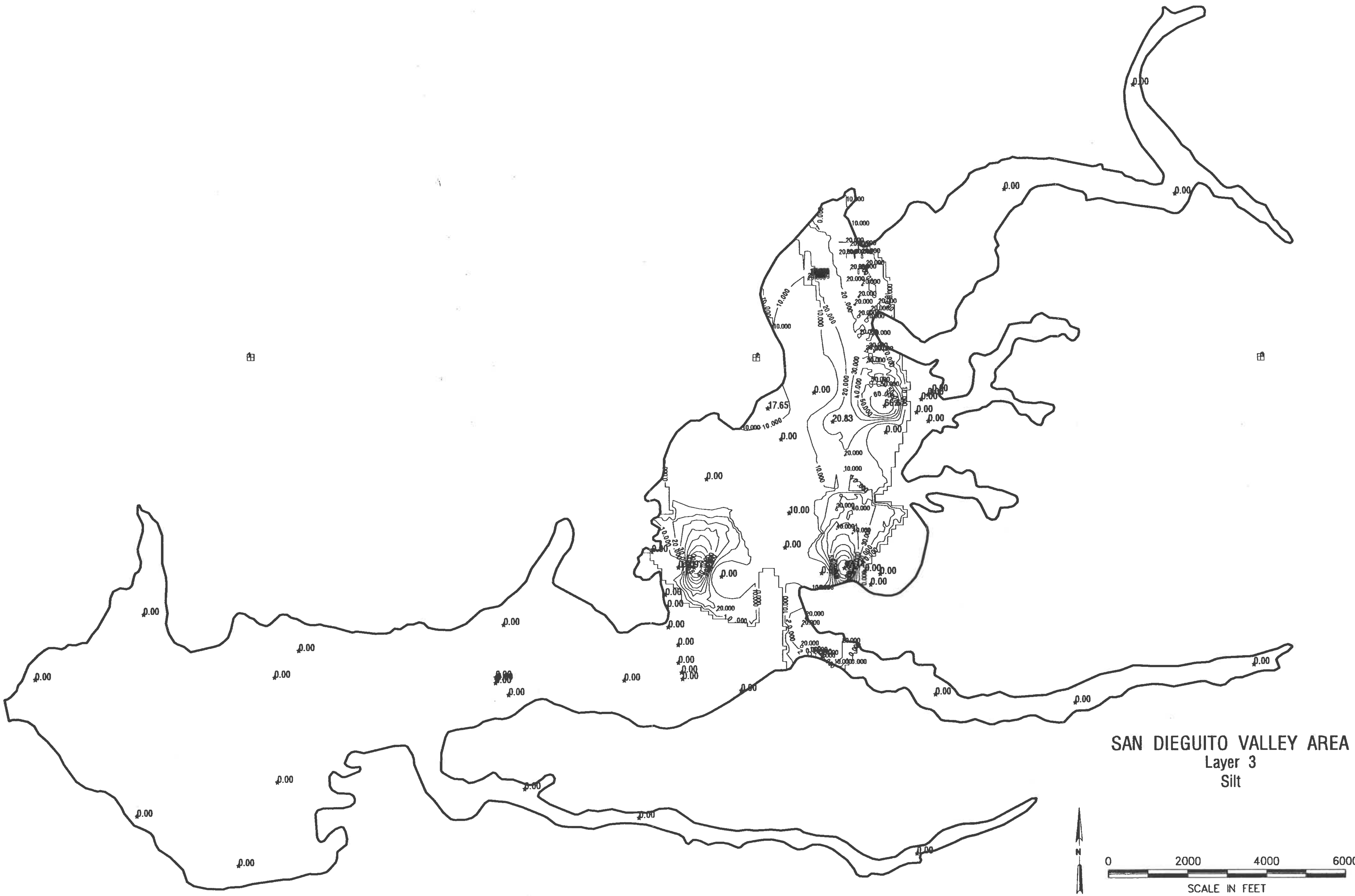
Plot date: 13 Dec 94 10:37:13 Tuesday


SAN DIEGUITO VALLEY AREA
Layer 2
Clay
N
0
2000
4000
6000
SCALE IN FEET
Plot date: 13 Dec 94 10:30:56 Tuesday

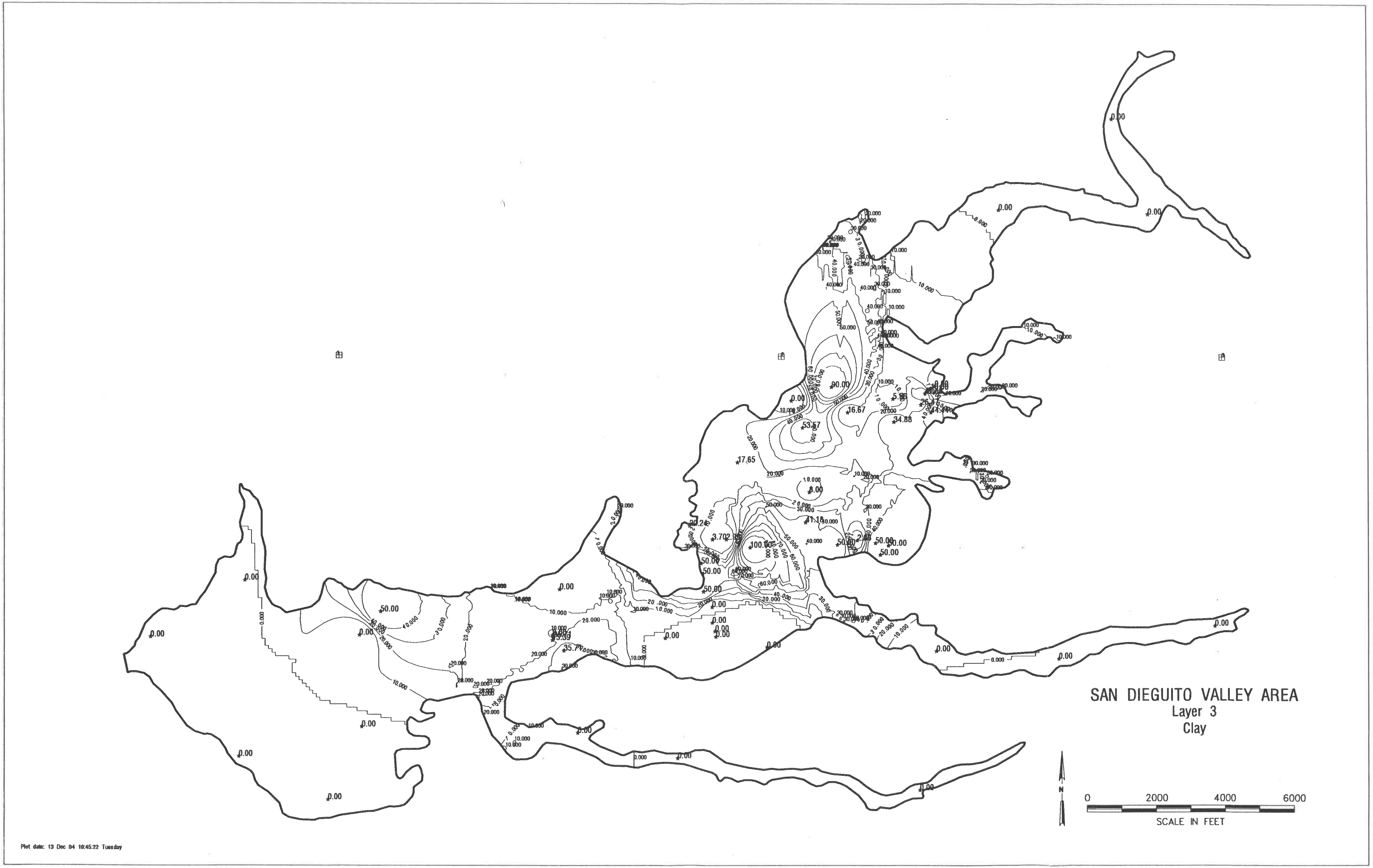

SAN DIEGUITO VALLEY AREA
Layer 3
Sandgravel + Gravel

Plot date: 13 Dec 94 19:42:48 Tuesday


SAN DIEGUITO VALLEY AREA
Layer 3
Sand
0
2000
4000
6000
SCALE IN FEET
Plot date: 13 Dec 94 19:40:43 Tuesday




Plot date: 13 Dec 94 18:43:58 Tuesday

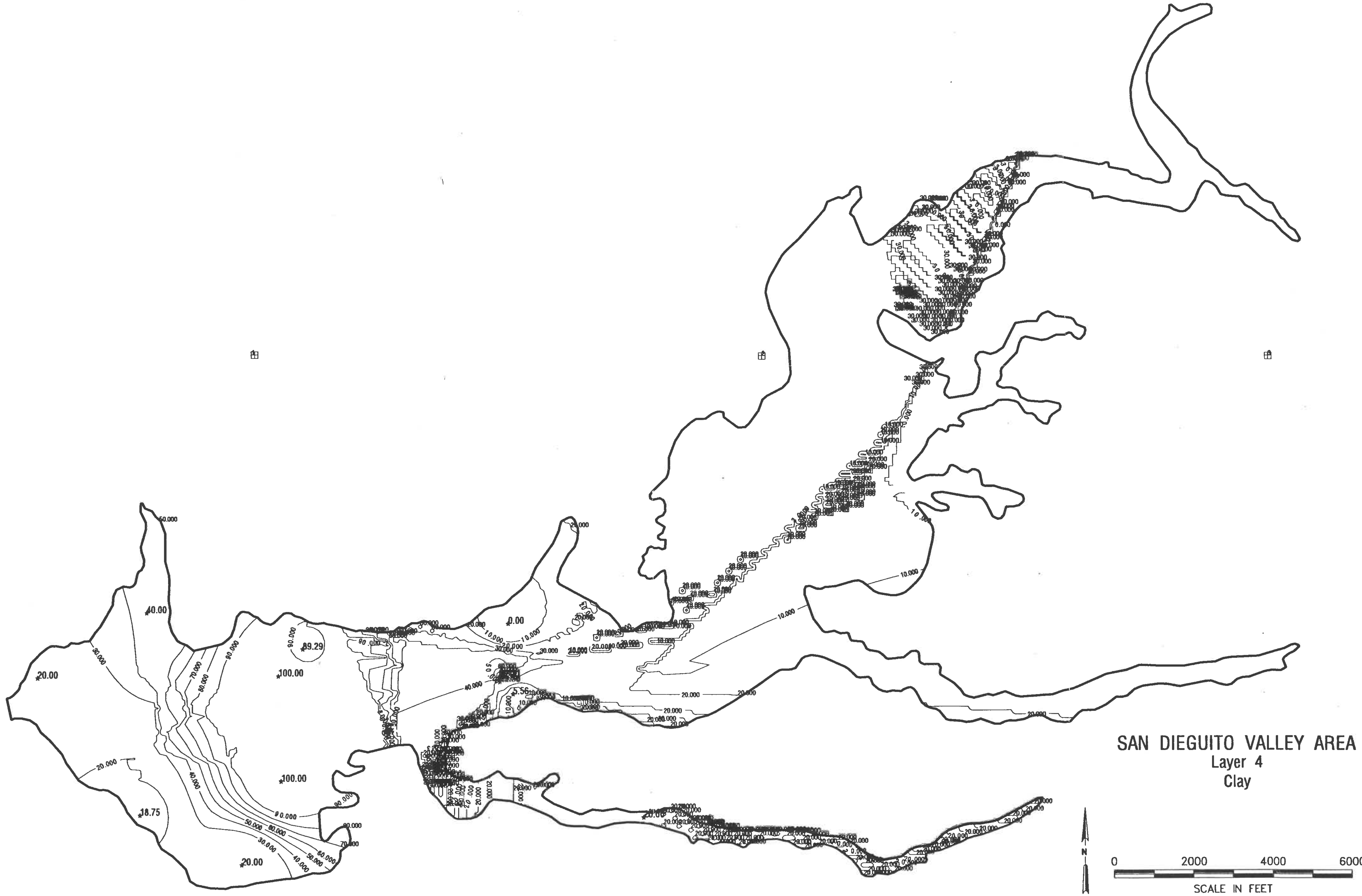

SAN DIEGUITO VALLEY AREA
Layer 3
Clay
N
0 2000 4000 6000
SCALE IN FEET
Plot date: 13 Dec 94 10:45:22 Tuesday

SAN DIEGUITO VALLEY AREA
Layer 4
Sandgravel + Gravel
0 2000 4000 6000
SCALE IN FEET
N
Plot date: 13 Dec 94 19:50:02 Tuesday


SAN DIEGUITO VALLEY AREA
Layer 4
Sand
N
0
2000
4000
6000
SCALE IN FEET
Plot date: 13 Dec 94 10:47:50 Tuesday


SAN DIEGUITO VALLEY AREA
Layer 4
Silt

Plot date: 13 Dec 94 10:50:20 Tuesday




SAN DIEGUITO VALLEY AREA
Layer 4
Clay

Plot date: 13 Dec 94 19:52:52 Tuesday

## APPENDIX D

### Simulated Water Level Contour Maps for Layer-3

Comments on the following water level contour maps:

Groundwater elevations during 1952 represent conditions before significant amounts of seawater intrusion has occurred. Groundwater elevations vary from near sea level in the middle portion of the alluvial basin to about 10 feet below mean sea level (ft below msl) in the eastern portion of the basin. By 1977, groundwater elevations have decreased to about 40 ft below msl in the eastern portion of the basin because of the drought in the early- to middle-1970s. Groundwater elevations in 1982 represent conditions when the basin has been recharged from the river and precipitation. Groundwater elevations in the eastern portion of the basin range from about 20 to 40 feet above mean sea level.


# SAN DIEGUITO BASIN SIMULATED LAYER 3 GROUNDWATER ELEVATIONS (1952)

Plot date: 23 Jan 95 11:43:11 Monday
/gis4/sandieguito/r83st5h.aml


SAN DIEGUITO BASIN
SIMULATED LAYER 3
GROUNDWATER ELEVATIONS
(1966)

Plot date: 23 Jan 95 12:44:20 Monday
/gis4/sandieguito/t93st13h.aml

# APPENDIX E

## Simulated TDS Concentration Contour Maps for Layer-3

Comments on the following TDS contour maps:

The TDS distribution in 1977 represents the furthest eastward advance of seawater intrusion during the 37-year model period. Following 1977, recharge increases and the eastern plume of high TDS water is gradually pushed westward. Estimated TDS in 1979 represents the initial stages of increased recharge following the drought. By 1982, TDS has decreased to about 2,000 to 3,000 mg/L throughout most of the eastern portion of the basin.

The estimated TDS distribution in 1952 indicates that seawater has impacted concentrations a few thousand feet east of the estuary. During succeeding years, seawater intrudes eastward into the basin, as indicated by the successively higher concentrations in 1966 and in 1977. Estimated TDS contours in 1966 approximately correspond to the TDS distribution estimated by Izbecki (1983) for conditions in 1965. Very little data exist to assess the historical distribution of TDS in 1977. Based on the estimated amount of recharge and discharge from 1966 to 1977, groundwater levels continued to remain tens of feet below msl in the eastern portion of the basin. Therefore, seawater intrusion likely extended further eastward from 1966 to 1977.


SAN DIEGUITO BASIN
SIMULATED LAYER 3
GROUNDWATER ELEVATIONS
(1977)

Plot date: 23 Jan 95 13:05:35 Monday
/gis4/sandieguito/t83st20h.aml


SAN DIEGUITO BASIN
SIMULATED
GROUNDWATER ELEVATIONS
(1979)

Plot date: 23 Jan 95 13:09:54 Monday
/gis4/sandieguito/r83st25h.aml


SAN DIEGUITO BASIN
SIMULATED LAYER 3
GROUNDWATER ELEVATIONS
(1982)

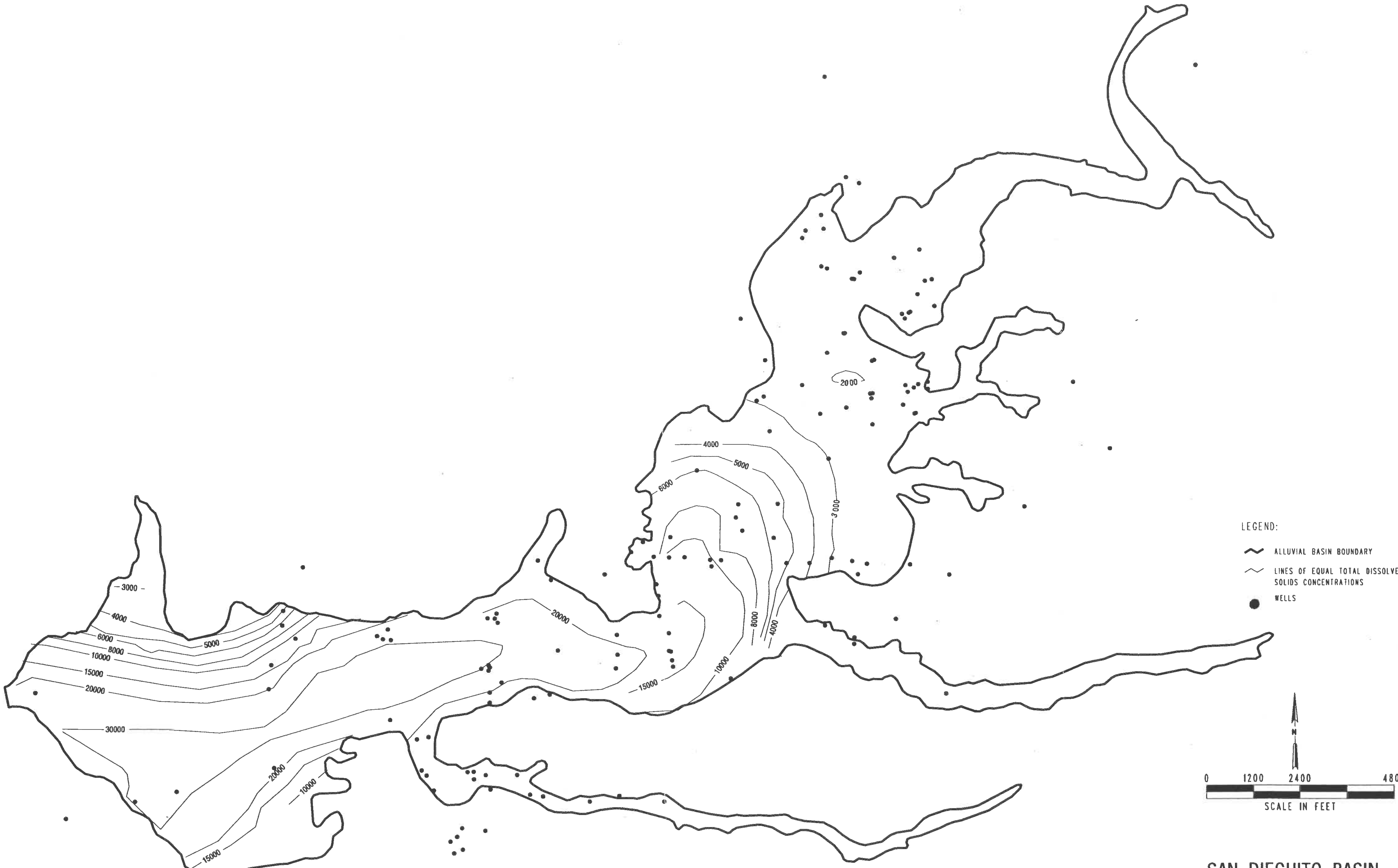
Plot date: 23 Jan 95 13:13:24 Monday
/gis4/sandieguito/r83st29h.aml


SAN DIEGUITO BASIN
SIMULATED
TOTAL DISSOLVED SOLIDS
CONCENTRATIONS (1952)

Plot date: 28 Dec 94 07:55:43 Wednesday
/gis4/sandieguito/r83st5c.aml

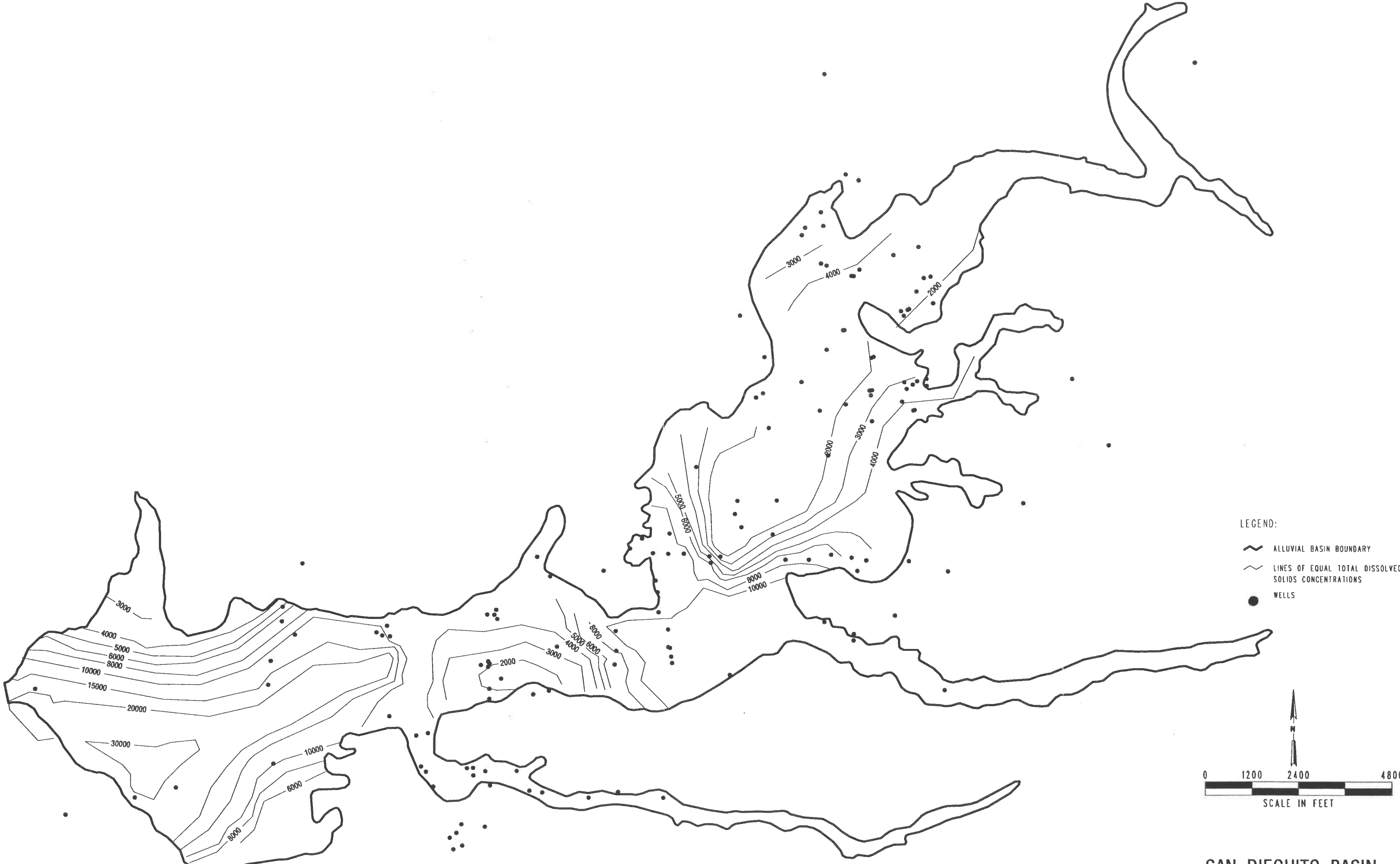

SAN DIEGUITO BASIN
SIMULATED
TOTAL DISSOLVED SOLIDS
CONCENTRATIONS (1966)

Plot date: 28 Dec 94 07:52:05 Wednesday
/gis4/sandieguito/r83st13c.aml



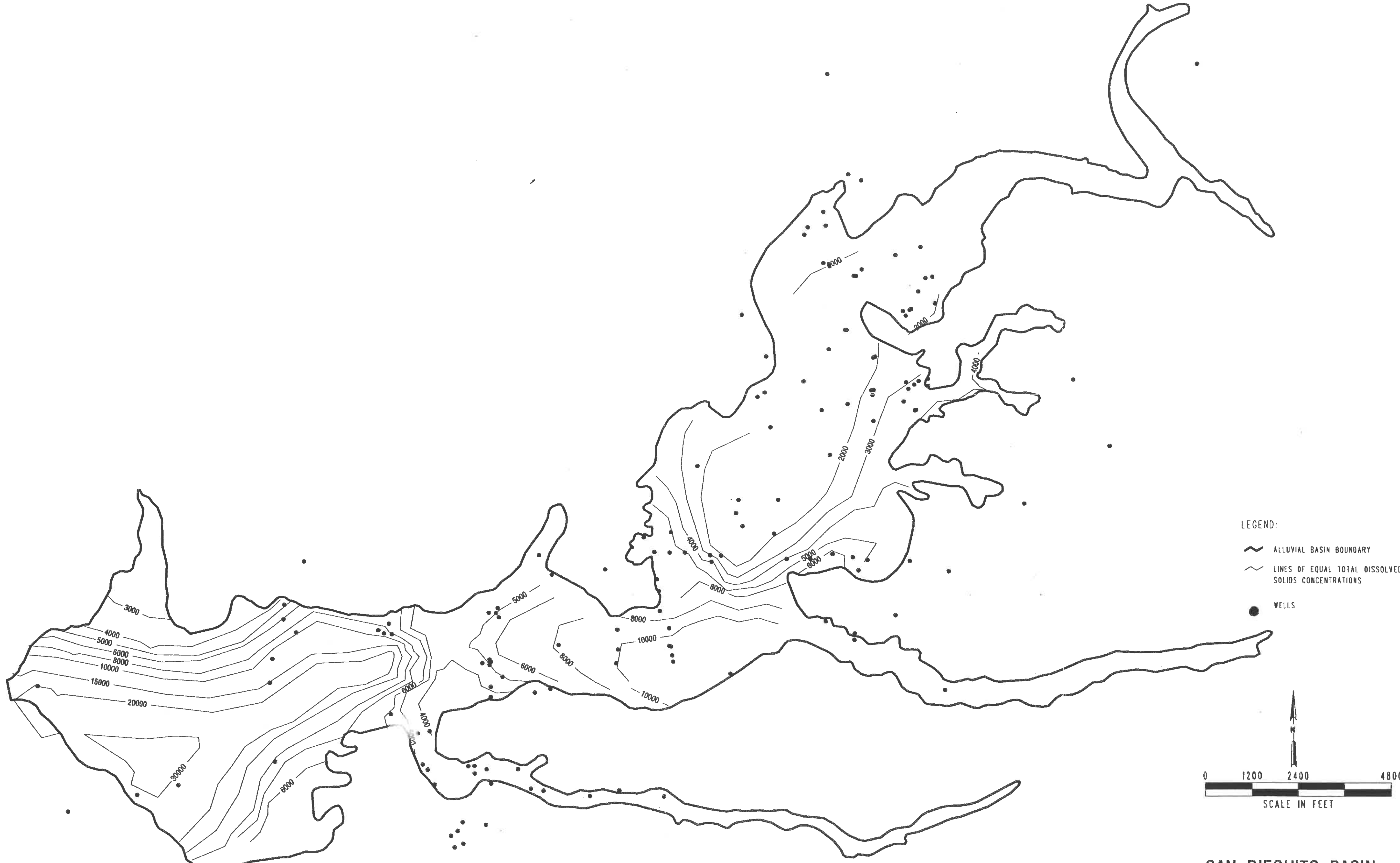

SAN DIEGUITO BASIN
SIMULATED
TOTAL DISSOLVED SOLIDS
CONCENTRATIONS (1977)

Plot date: 20 Dec 94 07:47:58 Wednesday
/gis4/sandieguito/r83st20c.aml




SAN DIEGUITO BASIN
SIMULATED
TOTAL DISSOLVED SOLIDS
CONCENTRATIONS (1979)

Plot date: 28 Dec 94 07:43:48 Wednesday
/gis4/sandieguito/t93st25c.aml




SAN DIEGUITO BASIN
SIMULATED
TOTAL DISSOLVED SOLIDS
CONCENTRATIONS (1982)

Plot date: 28 Dec 94 07:36:50 Wednesday
/gis4/sandieguito/t83st29c.aml

# APPENDIX F

## Precipitation Recharge Calculations

# APPENDIX F

## Precipitation Recharge Calculations

yearly soil moisture budgets were calculated using the Lake Hodges rainfall and evapotranspiration data, a soil moisture capacity of 5 inches (representative of average watershed materials), and with a 20 percent maximum runoff percentages. A micro-computer program, called RECHARGE, was used to calculate the monthly soil moisture budget for the period 1920 through 1982 using the above equations and assumptions (Appendix ?). This program merely replaces the tedious hand calculation of recharge and, at the same time, allows runoff to be iteratively calculated as a function of the average monthly soil moisture. The average recharge calculated in the 1920 to 1982 period using this approach was 0.78 inches/yr (0.065 acre-ft/acre/yr). The 1945 to 1982 period was significantly drier than this average, resulting in a calculated recharge of only 0.53 inches/yr (0.044 acre-ft/acre/yr) with most of the years having no recharge.

Table_-1
Recharge Calculations



| Year | Total Rainfall | Calculated Runoff | Calculated Recharge |
|---|---|---|---|
| 1920 | 10.99 | 0.22 | 0.00 |
| 1921 | 12.45 | 0.16 | 0.00 |
| 1922 | 24.98 | 3.44 | 7.58 |
| 1923 | 11.17 | 0.16 | 0.00 |
| 1924 | 8.84 | 0.24 | 0.00 |
| 1925 | 12.29 | 0.46 | 0.00 |
| 1926 | 20.35 | 1.14 | 0.00 |
| 1927 | 22.54 | 2.77 | 3.28 |
| 1928 | 12.79 | 0.64 | 0.00 |
| 1929 | 12.71 | 0.47 | 0.00 |
| 1930 | 14.39 | 1.20 | 0.00 |
| 1931 | 14.97 | 0.87 | 0.00 |
| 1932 | 19.53 | 2.53 | 2.92 |
| 1933 | 15.53 | 1.45 | 0.86 |
| 1934 | 8.71 | 0.12 | 0.00 |
| 1935 | 19.36 | 1.87 | 0.00 |
| 1936 | 11.48 | 0.84 | 0.00 |
| 1937 | 32.93 | 4.60 | 8.70 |
| 1938 | 17.55 | 1.86 | 1.24 |
| 1939 | 16.72 | 1.54 | 0.00 |
| 1940 | 14.88 | 1.50 | 0.19 |
| 1941 | 26.98 | 4.13 | 3.79 |
| 1942 | 19.03 | 1.24 | 0.00 |
| 1943 | 16.75 | 1.78 | 0.10 |
| 1944 | 16.20 | 1.98 | 1.07 |
| 1945 | 16.77 | 1.26 | 0.00 |
| 1946 | 11.03 | 0.79 | 0.00 |
| 1947 | 10.65 | 0.30 | 0.00 |
| 1948 | 9.09 | 0.06 | 0.00 |
| 1949 | 13.02 | 1.07 | 0.00 |
| 1950 | 10.70 | 0.61 | 0.00 |
| 1951 | 10.02 | 0.18 | 0.00 |
| 1952 | 22.37 | 2.92 | 2.39 |
| 1953 | 10.44 | 0.15 | 0.00 |

**Table_-1**
**Recharge Calculations**



| Year | Total Rainfall | Calculated Runoff | Calculated Recharge |
|---|---|---|---|
| 1954 | 13.41 | 1.37 | 0.00 |
| 1955 | 11.24 | 0.53 | 0.00 |
| 1956 | 8.41 | 0.33 | 0.00 |
| 1957 | 14.29 | 1.01 | 0.22 |
| 1958 | 23.75 | 2.28 | 1.71 |
| 1959 | 6.35 | 0.45 | 0.00 |
| 1960 | 12.93 | 1.02 | 0.00 |
| 1961 | 5.97 | 0.00 | 0.00 |
| 1962 | 13.93 | 0.95 | 0.00 |
| 1963 | 9.03 | 0.11 | 0.00 |
| 1964 | 7.68 | 0.00 | 0.00 |
| 1965 | 11.83 | 0.06 | 0.00 |
| 1966 | 16.46 | 2.30 | 2.52 |
| 1967 | 15.02 | 0.93 | 0.00 |
| 1968 | 11.77 | 0.65 | 0.00 |
| 1969 | 15.98 | 1.80 | 1.23 |
| 1970 | 7.64 | 0.08 | 0.00 |
| 1971 | 11.36 | 0.18 | 0.00 |
| 1972 | 6.65 | 0.21 | 0.00 |
| 1973 | 15.62 | 1.03 | 0.00 |
| 1974 | 8.21 | 0.23 | 0.00 |
| 1975 | 13.29 | 0.30 | 0.00 |
| 1976 | 12.89 | 0.65 | 0.00 |
| 1977 | 10.65 | 0.15 | 0.00 |
| 1978 | 28.23 | 3.85 | 8.40 |
| 1979 | 18.91 | 2.39 | 0.92 |
| 1980 | 18.33 | 1.89 | 2.23 |
| 1981 | 10.58 | 0.34 | 0.00 |
| 1982 | 15.56 | 1.06 | 0.00 |

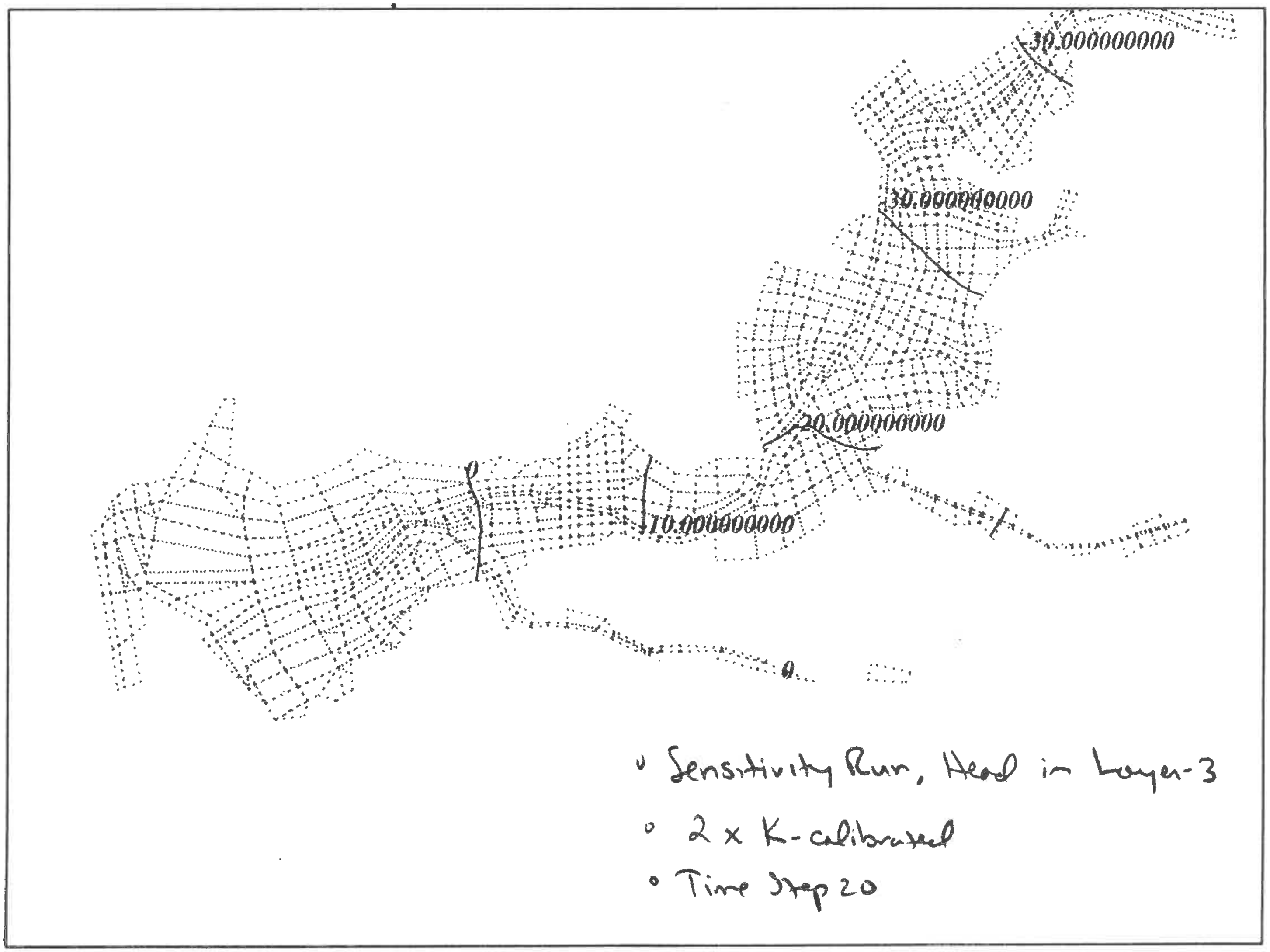
Soil Moisture Capacity = 5.00 inches
Calculated Average Recharge = 0.78 inches
Assumed maximum runoff = 20.00 percent
Calculated average runoff = 6.50 percent

# APPENDIX G

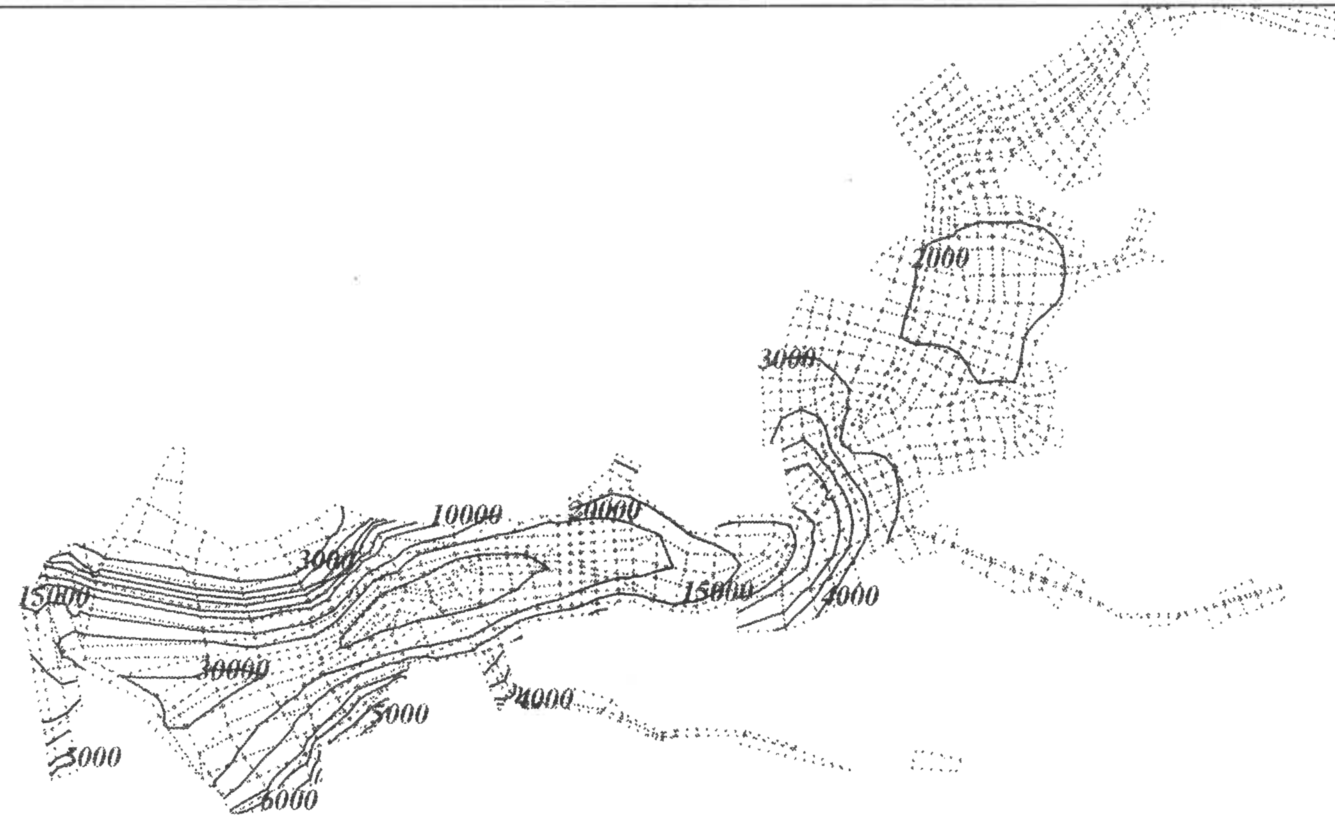
## Results of Hydraulic Conductivity Sensitivity Analysis for Layer-3


- Sensitivity Run, Head in Layer-3
- ½ × Kcalibrated
- Time Step 20

File: R85ST20H
1/30/95

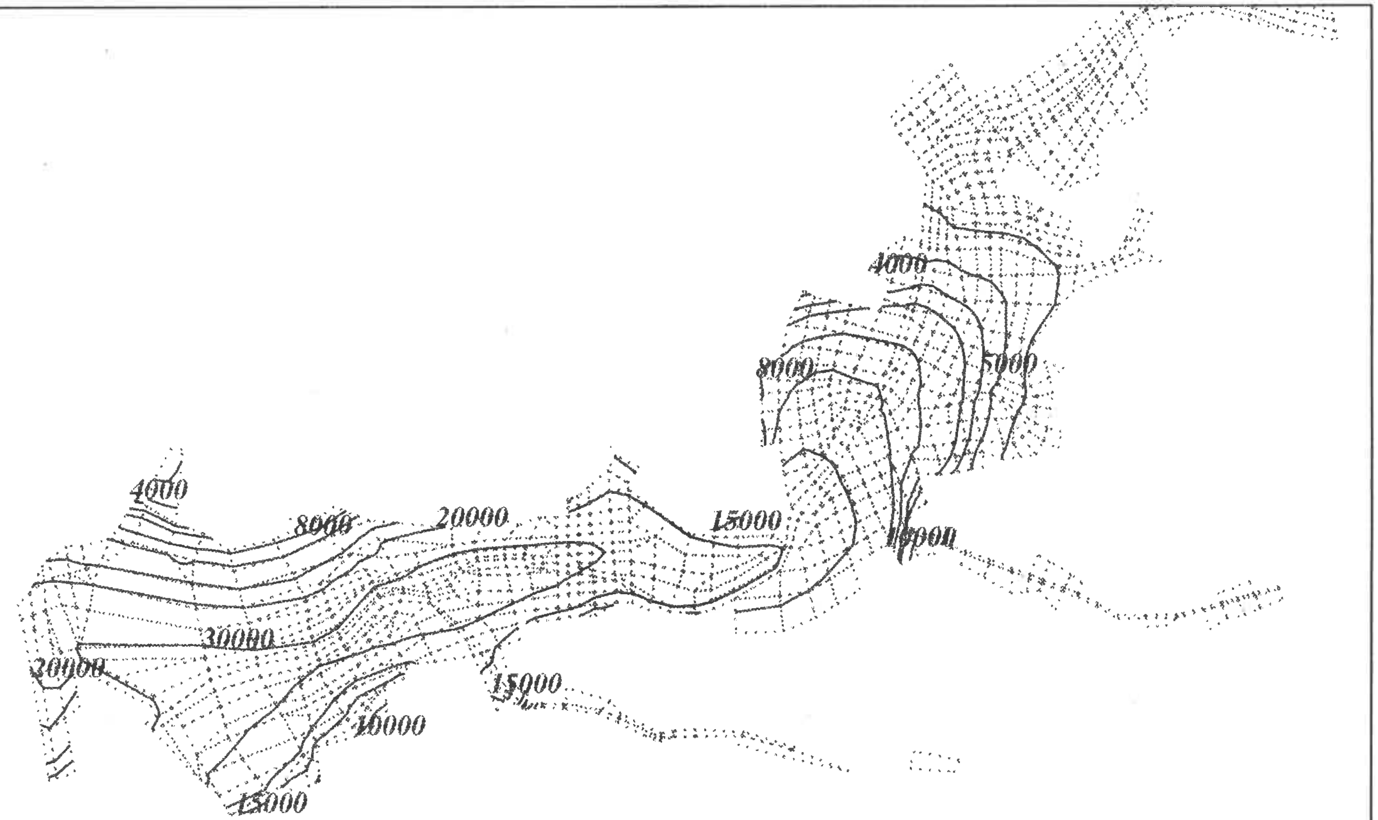



File: R84ST20H
1/30/95




- Sensitivity Run, Concentration in Layer-3
- 1/2 x Kcalibrated
- Time Step 20

File: R85ST20C
4/30/95

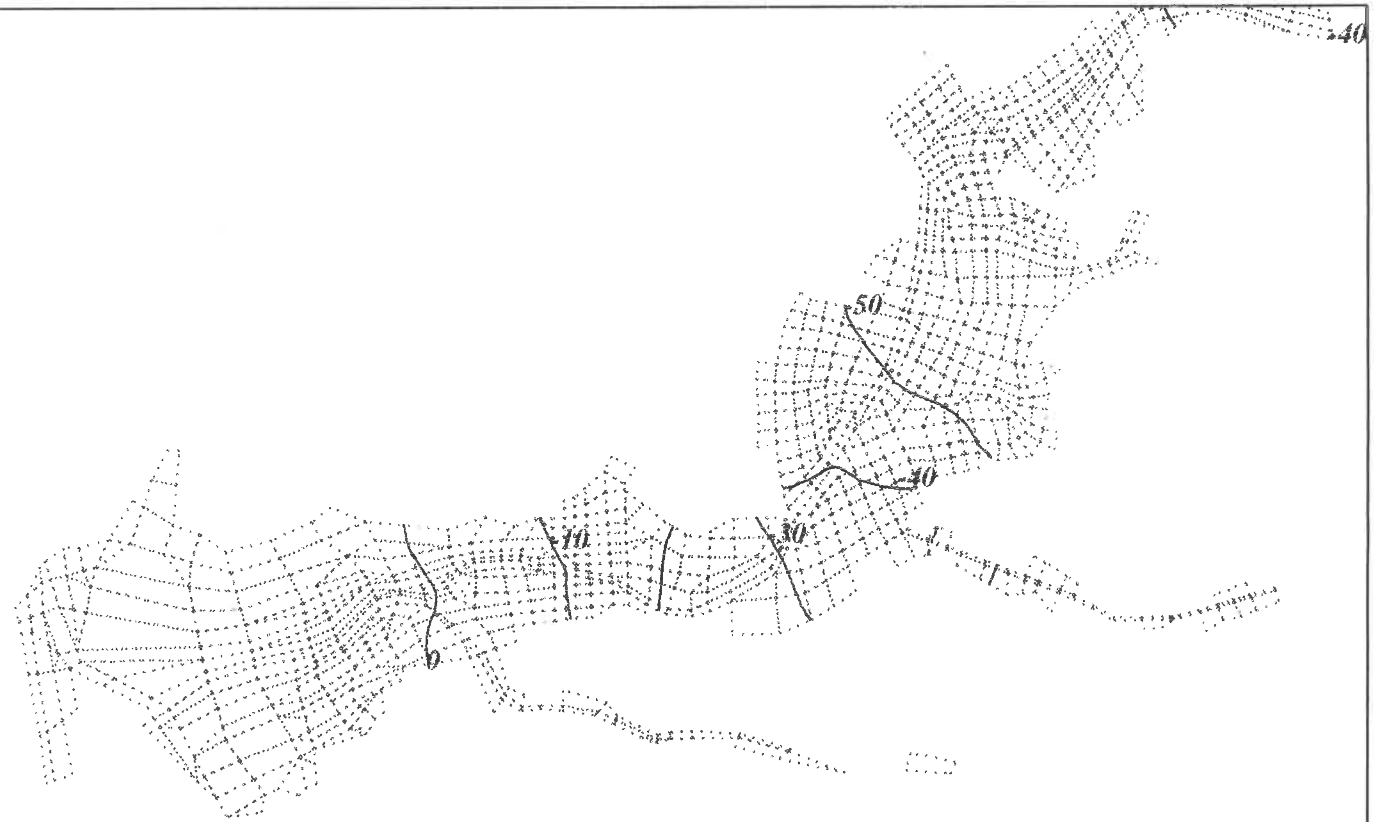



• Sensitivity Run, Concentration in Layer-3
• 2x K-calibrated
• Time Step 20

File: R84ST20C
1/30/95

# APPENDIX H

## Results of Specific Yield Sensitivity Analysis for Layer-3

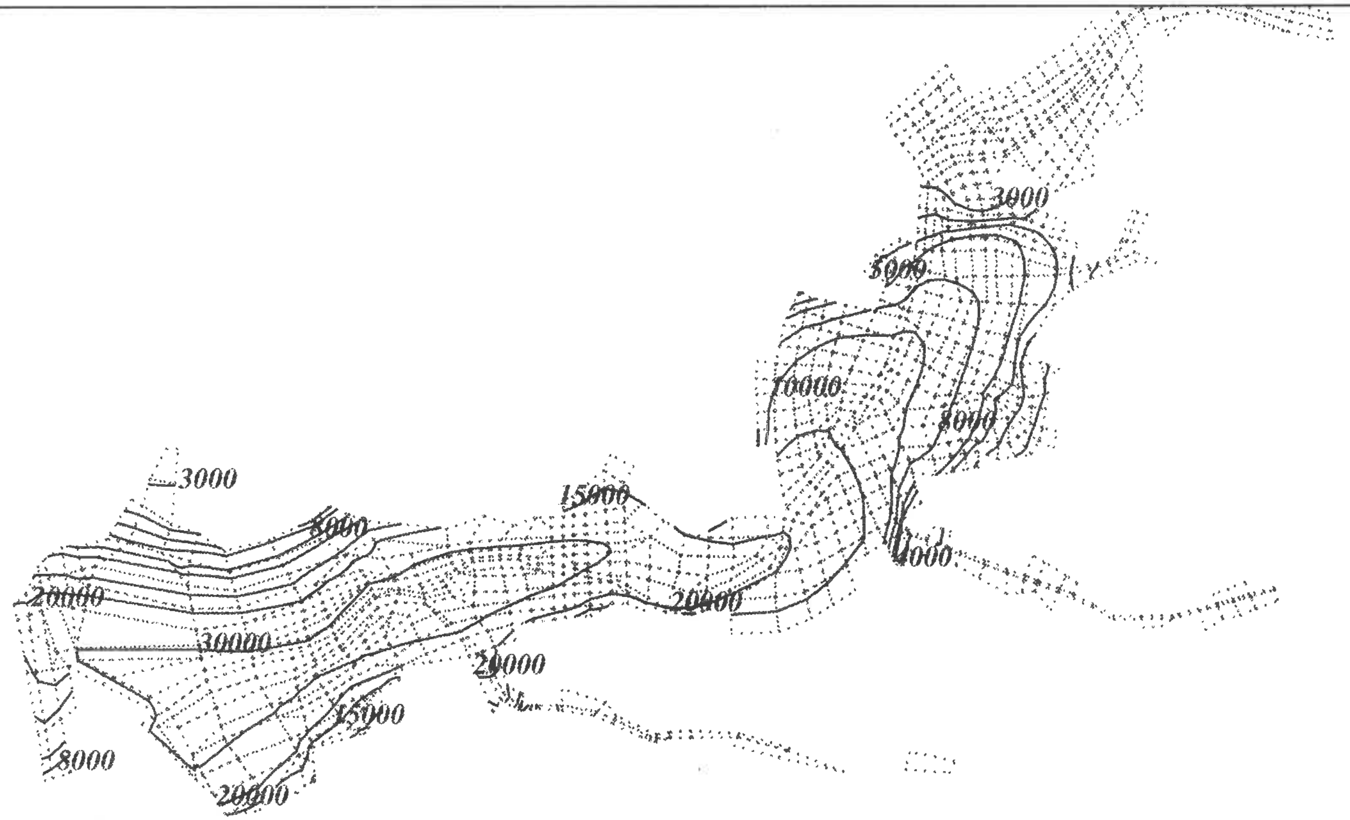



- Sensitivity Run - <u>Head</u>, Layer-3
- 1/2 x Sy - calibrated
- Time Step 20

File · R87ST 2017
7/27/95

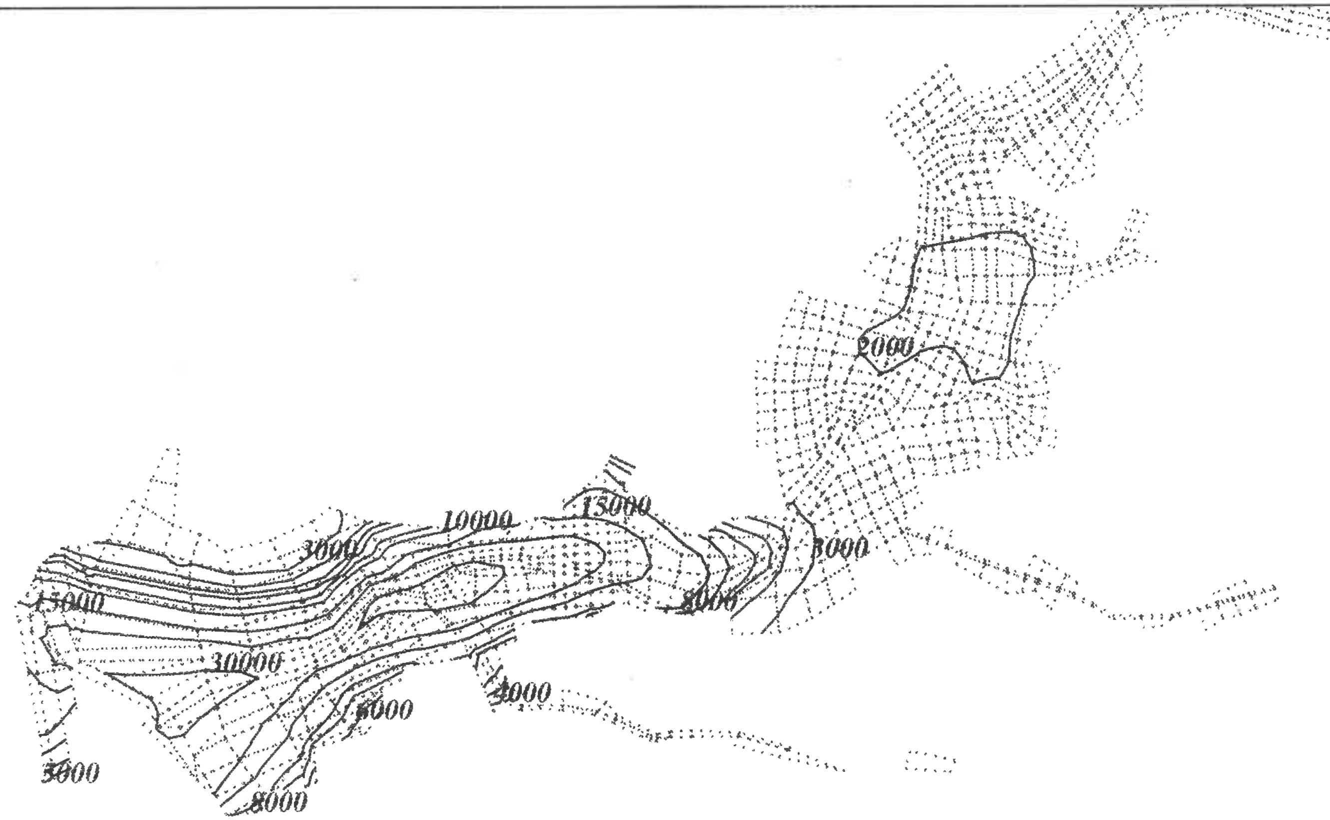

- Sensitivity Run – Head, Layer-3
- 2 * Sy-calibrated
- Time Step 20

File: R86ST20H
4/29/85




- Sensitivity Run - Concentration, Layer-3
- ½ x Sy. calibrated
- Time Step 20

File: R89ST20C
7/29/95

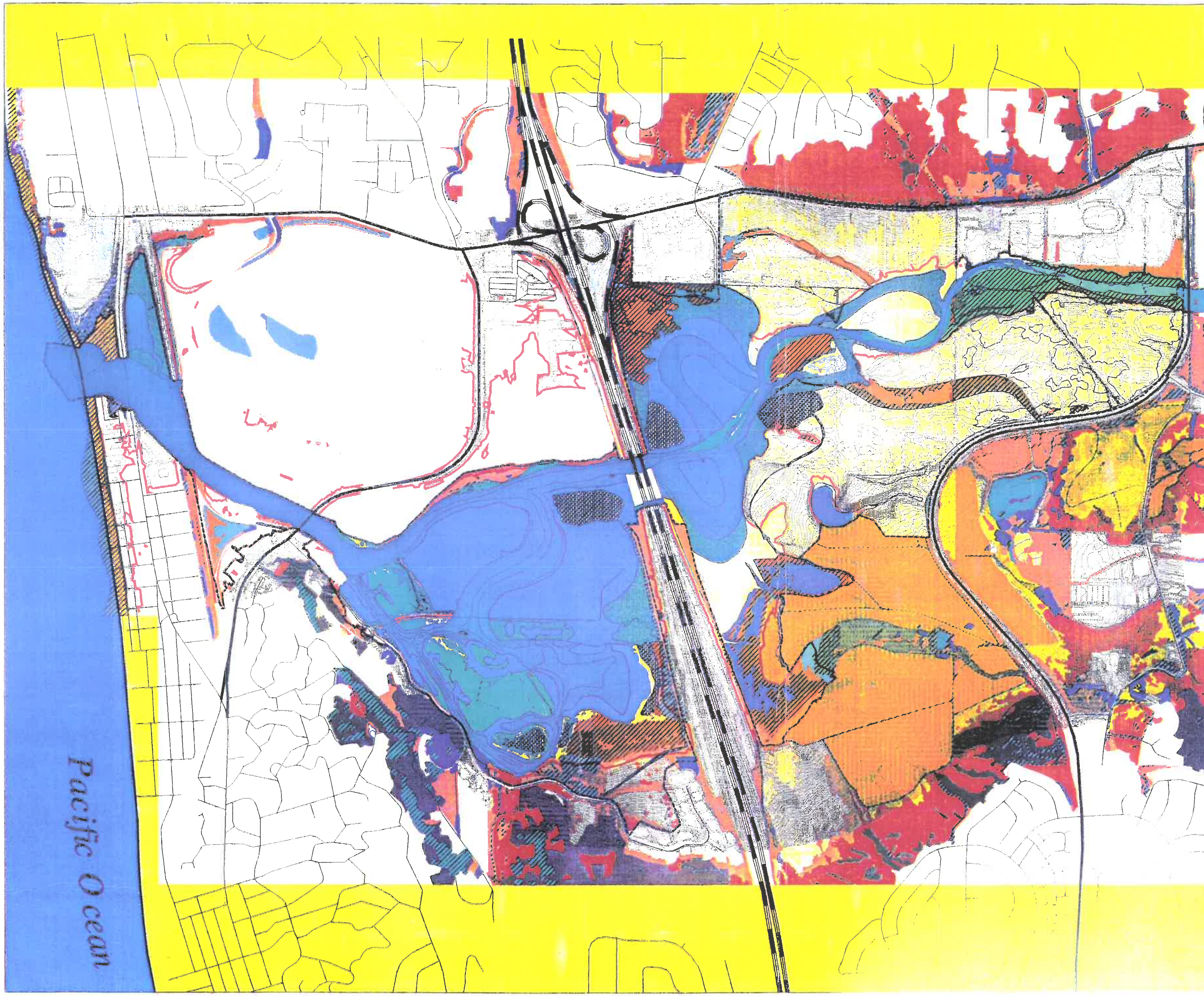



- Sensitivity Run - Concentration, Layer-3
- 2 x Sy-calibrated
- Time Step 20

File: RB6ST20C
1/29/95

# APPENDIX I

## Estuary Boundary Data

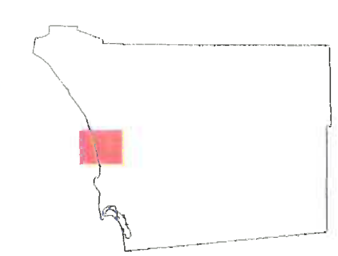



# Alternative B MHHW

## LEGEND

- Agriculture
- Arrowwood Scrub
- Coastal & Valley Freshwater Marsh
- Coastal Brackish Marsh
- Diegan Coastal Sage Scrub
- Estuarine Flats (inter-tidal)
- Estuarine Flats (non-tidal)
- Exotic Trees
- Marine Intertidal
- Mule Fat Scrub
- Non Native Grassland
- Non-Vegetated (least Tern Habitat)
- Non-Vegetated Bluffs
- Non-Vegetated Disturbed
- Open Water
- Palustrine & Riverine Flats
- Palustrine Open Water
- Reservoirs / Man Made Lakes
- Ruderal (Baccharis dominant)
- Ruderal (grassland dominant)
- Ruderal (woody dominant)
- Seasonal Salt Marsh
- Seasonal Salt Marsh (transitional)
- Shallow Water
- Southern Coast Bluff Scrub
- Southern Coastal Foredunes
- Southern Coastal Salt marsh (high)
- Southern Coastal Salt marsh (low)
- Southern Coastal Salt marsh (middle)
- Southern Mixed Chaparral
- Southern Willow Scrub
- Torrey Pine Forest
- Undifferentiated Riparian
- Urban
- Alternative Boundary
- Ten Foot Contour
- One Foot Contours Above Ten Feet

### INDEX MAP OF SAN DIEGO



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**SAN DIEGUITO WETLANDS**

Map Prepared for: MEC

Project Manager: Frank Malone

Map Prepared by: John Meske

Map Projection: State Plane NAD 83

Date: September 22, 1995

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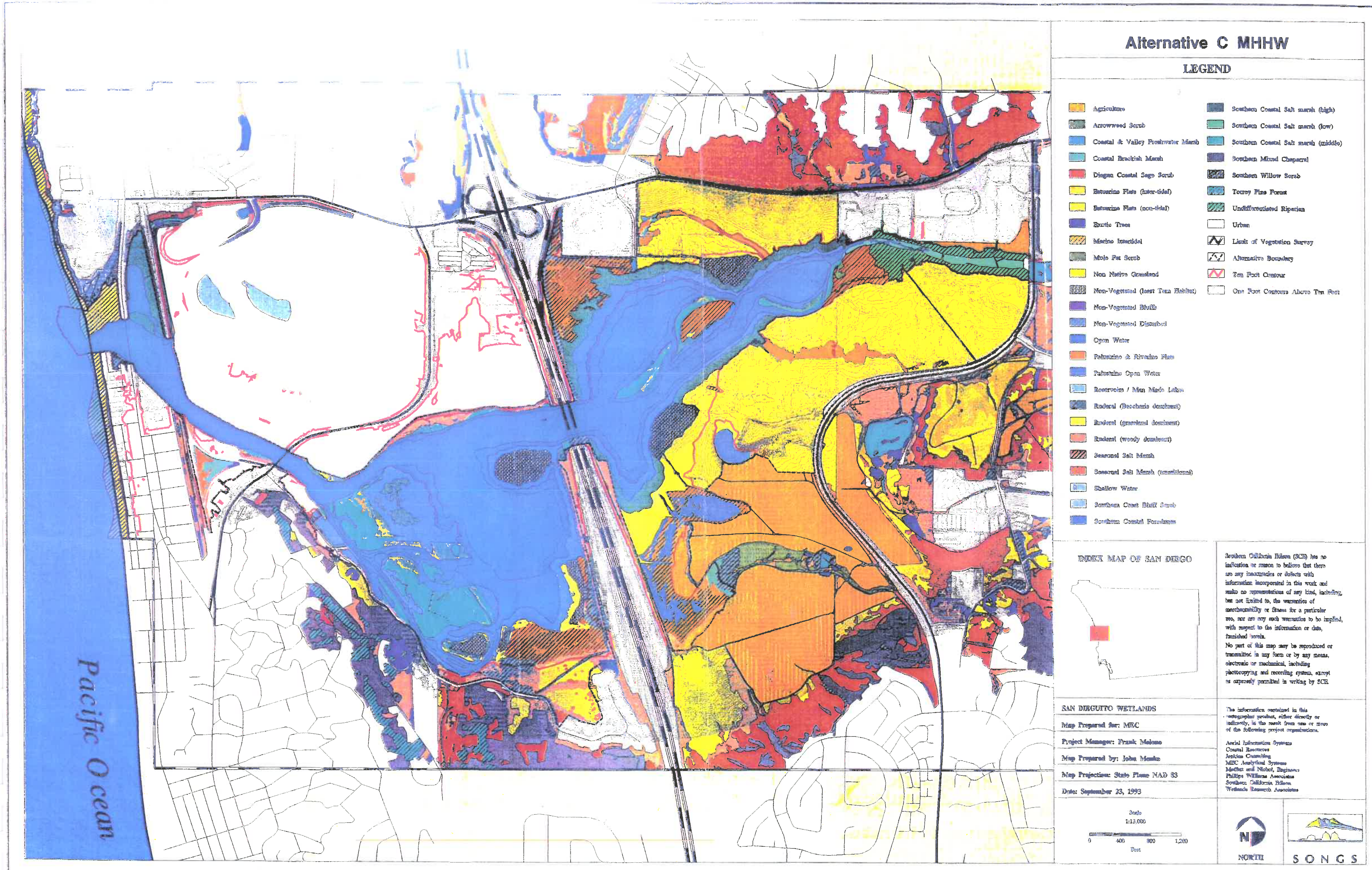
SONGS


Alternative C MHHW
LEGEND
Agriculture
Arrowweed Scrub
Coastal & Valley Freshwater Marsh
Coastal Brackish Marsh
Diegan Coastal Sage Scrub
Estuarine Flats (inter-tidal)
Estuarine Flats (non-tidal)
Exotic Trees
Marine Intertidal
Mule Fat Scrub
Non Native Grassland
Non-Vegetated (least Tern Habitat)
Non-Vegetated Bluffs
Non-Vegetated Disturbed
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Palustrine & Riverine Flats
Palustrine Open Water
Reservoirs / Man Made Lakes
Ruderal (Baccharis dominant)
Ruderal (grassland dominant)
Ruderal (weedy dominant)
Seasonal Salt Marsh
Seasonal Salt Marsh (transitional)
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Southern Coastal Foredunes
Southern Coastal Salt marsh (high)
Southern Coastal Salt marsh (low)
Southern Coastal Salt marsh (middle)
Southern Mixed Chaparral
Southern Willow Scrub
Torrey Pine Forest
Undifferentiated Riparian
Urban
Limit of Vegetation Survey
Alternative Boundary
Ten Foot Contour
One Foot Contours Above Ten Feet
Pacific Ocean
INDEX MAP OF SAN DIEGO
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SAN DIEGUITO WETLANDS
Map Prepared for: MEC
Project Manager: Frank Malone
Map Prepared by: John Menke
Map Projection: State Plane NAD 83
Date: September 23, 1993
Scale
1:13,000
0
400
800
1,200
Feet
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Southern California Edison
Wetlands Research Associates
NORTH
SONGS

# APPENDIX J

## Listing of Estuary, River, and Ocean Boundary Node Numbers

| Node # | Boundary Type | Boundary Types: | |
|---|---|---|---|
| | | | 1 - Estuary |
| | | | 2 - River |
| 11 | 1 | | 3 - Ocean |
| 12 | 1 | | |
| 20 | 1 | | |
| 30 | 1 | | |
| 29 | 1 | | |
| 37 | 1 | | |
| 38 | 1 | | |
| 46 | 1 | | |
| 47 | 1 | | |
| 48 | 1 | | |
| 51 | 1 | | |
| 55 | 1 | | |
| 110 | 1 | | |
| 138 | 1 | | |
| 146 | 1 | | |
| 169 | 1 | | |
| 191 | 1 | | |
| 221 | 1 | | |
| 243 | 1 | | |
| 264 | 1 | | |
| 286 | 1 | | |
| 295 | 1 | | |
| 296 | 1 | | |
| 287 | 1 | | |
| 265 | 1 | | |
| 244 | 1 | | |
| 222 | 1 | | |
| 192 | 1 | | |
| 170 | 1 | | |
| 147 | 1 | | |
| 139 | 1 | | |
| 111 | 1 | | |
| 68 | 1 | | |
| 63 | 1 | | |
| 71 | 1 | | |
| 64 | 1 | | |
| 56 | 1 | | |
| 52 | 1 | | |
| 49 | 1 | | |
| 40 | 1 | | |
| 39 | 1 | | |
| 31 | 1 | | |
| 21 | 1 | | |
| 13 | 1 | | |
| 4 | 3 | | |
| 5 | 3 | | |
| 346 | 2 | | |
| 353 | 2 | | |
| 367 | 2 | | |
| 388 | 2 | | |

| | | | |
|---|---|---|---|
| 404 | 2 | | |
| 435 | 2 | | |
| 450 | 2 | | |
| 462 | 2 | | |
| 478 | 2 | | |
| 487 | 2 | | |
| 495 | 2 | | |
| 517 | 2 | | |
| 546 | 2 | | |
| 586 | 2 | | |
| 585 | 2 | | |
| 584 | 2 | | |
| 600 | 2 | | |
| 633 | 2 | | |
| 661 | 2 | | |
| 722 | 2 | | |
| 721 | 2 | | |
| 720 | 2 | | |
| 719 | 2 | | |
| 718 | 2 | | |
| 717 | 2 | | |
| 715 | 2 | | |
| 714 | 2 | | |
| 713 | 2 | | |
| 712 | 2 | | |
| 711 | 2 | | |
| 710 | 2 | | |
| 709 | 2 | | |
| 708 | 2 | | |
| 707 | 2 | | |
| 706 | 2 | | |
| 705 | 2 | | |
| 813 | 2 | | |
| 826 | 2 | | |
| 859 | 2 | | |
| 904 | 2 | | |
| 936 | 2 | | |
| 980 | 2 | | |
| 1022 | 2 | | |
| 1087 | 2 | | |
| 1139 | 2 | | |
| 1150 | 2 | | |
| 1162 | 2 | | |
| 1180 | 2 | | |
| 1222 | 2 | | |
| 1229 | 2 | | |
| 1238 | 2 | | |
| 1244 | 2 | | |
| 1251 | 2 | | |
| 1259 | 2 | | |
| 1270 | 2 | | |
| 1281 | 2 | | |