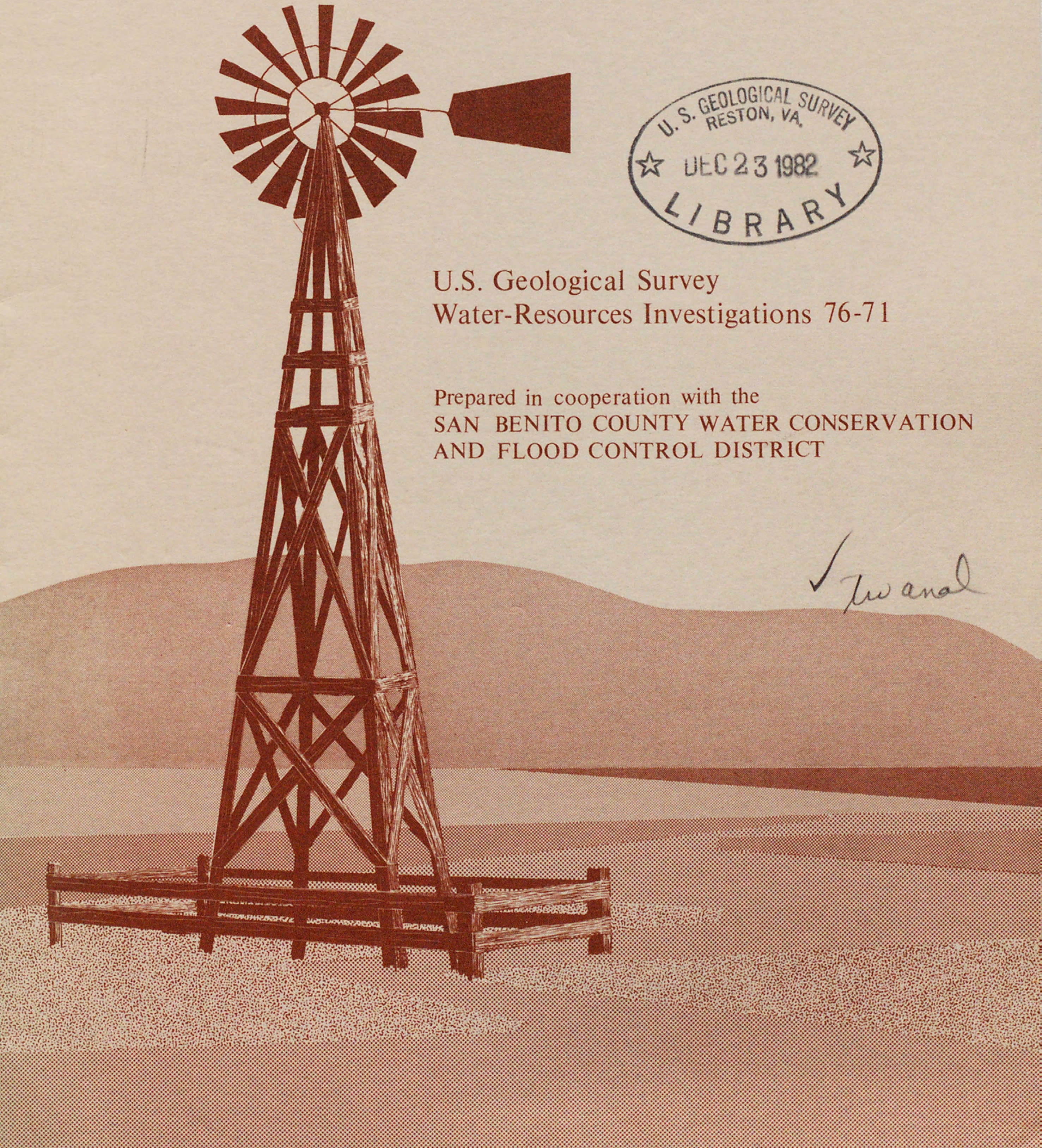
Mathematical Model of the West Bolsa Ground-Water Basin, San Benito County, California



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16. Abstracts

Simulation of the West Bolsa ground-water basin hydrology has provided values of basin recharge and discharge and nodally distributed values of transmissivity and storage coefficient. Average net recharge from April 1945 to March 1969 was 6.2 cubic feet per second (0.18 cubic meter per second) and occurred as subsurface recharge and infiltration of rain and minor streamflow. Discharge from the basin during the same period was 8.1 cubic feet per second (0.23 cubic meter per second) and occurred as pumping and leakage from confined parts of the basin.

Values of transmissivity used in the model generally range from 3,300 to 20,000 feet squared per day (310 to 1,900 meters squared per day). Values of storage coefficient used in the model range from 0.0005 to 0.10.

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By Robert E. Faye

U.S. GEOLOGICAL SURVEY

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San Benito County Water Conservation

and Flood Control District

December 1976

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CONVERSION FACTORS

Factors for converting English units to metric units are shown to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	*Multiply by*	*Metric*
acres	4.047×10^{-3}	km^2 (square kilometers)
acre-ft (acre-feet)	1.233×10^{-3}	hm^3 (cubic hectometers)
(acre-ft/yr)/mi (acre-feet per year per mile)	7.663×10^{-4}	(hm^3/yr)/km (cubic hectometers per year per kilometer)
ft (feet)	3.048×10^{-1}	m (meters)
ft/mi (feet per mile)	1.894×10^{-1}	m/km (meters per kilometer)
ft^2/d (feet squared per day)	9.29×10^{-2}	m^2/d (meters squared per day)
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic meters per second)
in (inches)	2.54×10^{1}	mm (millimeters)
mi (miles)	1.609	km (kilometers)

MATHEMATICAL MODEL OF THE WEST BOLSA GROUND-WATER BASIN,

SAN BENITO COUNTY, CALIFORNIA

By Robert E. Faye

ABSTRACT

A mathematical model has satisfactorily simulated historical hydrologic conditions in the West Bolsa ground-water basin, San Benito County, Calif. Model simulation of predevelopment and transient conditions provided values of basin recharge and discharge as well as nodally distributed values of transmissivity and storage coefficient. Predevelopment recharge to the basin was 11.6 cubic feet per second (0.33 cubic meter per second) and occurred as subsurface recharge, infiltration of rain, and infiltration of minor streamflow. The predevelopment discharge was also 11.6 cubic feet per second (0.33 cubic meter per second) and is considered to have occurred entirely as leakage from confined parts of the basin.

Transient conditions in the basin from 1945 to 1969 reduced aquifer storage and significantly reduced water levels. During this period, net recharge to the basin averaged 6.2 cubic feet per second (0.18 cubic meter per second) and occurred as subsurface recharge, infiltration of rain, and infiltration of minor streamflow; net discharge averaged 8.1 cubic feet per second (0.23 cubic meter per second) and occurred as pumpage and leakage from confined parts of the basin.

Values of transmissivity used in the model ranged from 3,300 to 20,000 feet squared per day (310 to 1,900 meters squared per day). Values of storage coefficient used in the model ranged from 0.0005 to 0.10.

An analysis of the sensitivity of potentiometric heads to simulated subsurface recharge from Santa Clara Valley indicates that heads in the basin vary about 15 feet (4.6 meters) according to the quantity of the simulated recharge. The predictions made with the model for the periods 1969-74 and 1974-79 indicate that water levels would decline about 10 to 15 feet (3.0 to 4.6 meters) in the northern and southern parts of the basin until 1974. After 1974, the northern levels would remain static. Water levels in the southern part of the basin would decline another 10 feet (3.0 meters) by 1979.

INTRODUCTION

Purpose and Scope

This study by the U.S. Geological Survey was done in cooperation with the San Benito County Water Conservation and Flood Control District. The purpose of this study was to assess, qualitatively and quantitatively, the ground-water hydrology of the West Bolsa ground-water basin and to use this assessment to develop a working hydrologic model of the basin. The scope of this study was to:

1. Organize and evaluate hydrologic data for the West Bolsa ground-water basin.

2. Develop a transient-state, digital computer model of the West Bolsa basin.

3. Use the computer model to predict future ground-water levels in the West Bolsa basin.

Location and General Features of the Basin

The West Bolsa ground-water basin is in the northwestern part of San Benito County about 40 mi (64 km) southeast of San Jose (fig. 1). The area consists of a flat alluvial valley bordered on the north by the Pajaro River, on the west and south by low foothills (the Lomerias Muertas and Flint Hills), and on the east by the Hollister Valley (fig. 2). The land surface slopes generally to the north and west with gradients ranging from about 25 ft/mi (4.7 m/km) northwest of Hollister to about 2 ft/mi (0.4 m/km) near the Pajaro River. Land surface altitudes range from about 260 ft (79.2 m) above mean sea level northwest of Hollister to about 135 ft (41.1 m) in the vicinity of the Pajaro River.

Precipitation is generally uniform and consists almost entirely of rain. For the period 1891-1968, annual rainfall at Hollister ranged from 10 to 22 in (254 to 559 mm). The mean annual rainfall for this period was 13.1 in (333 mm).

External drainage from the West Bolsa area occurs mostly during periods of heavy rain when tributary streams and drainage canals discharge into the Pajaro River. Other discharge from the area occurs when confined ground water leaks into the upper alluvial deposits of the basin and eventually flows to drainage canals and the Pajaro River.

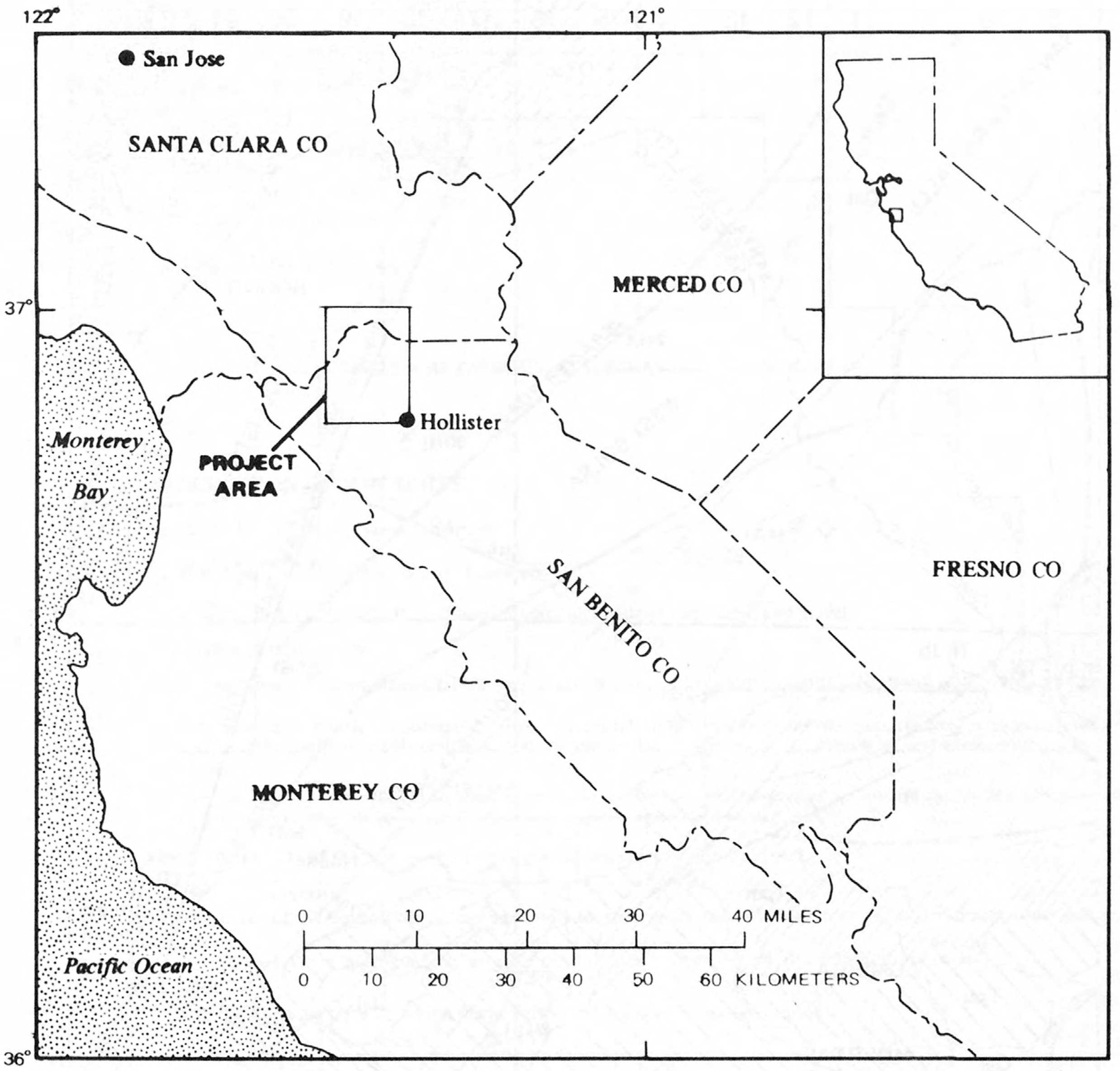

FIGURE 1.--Location of the study area.

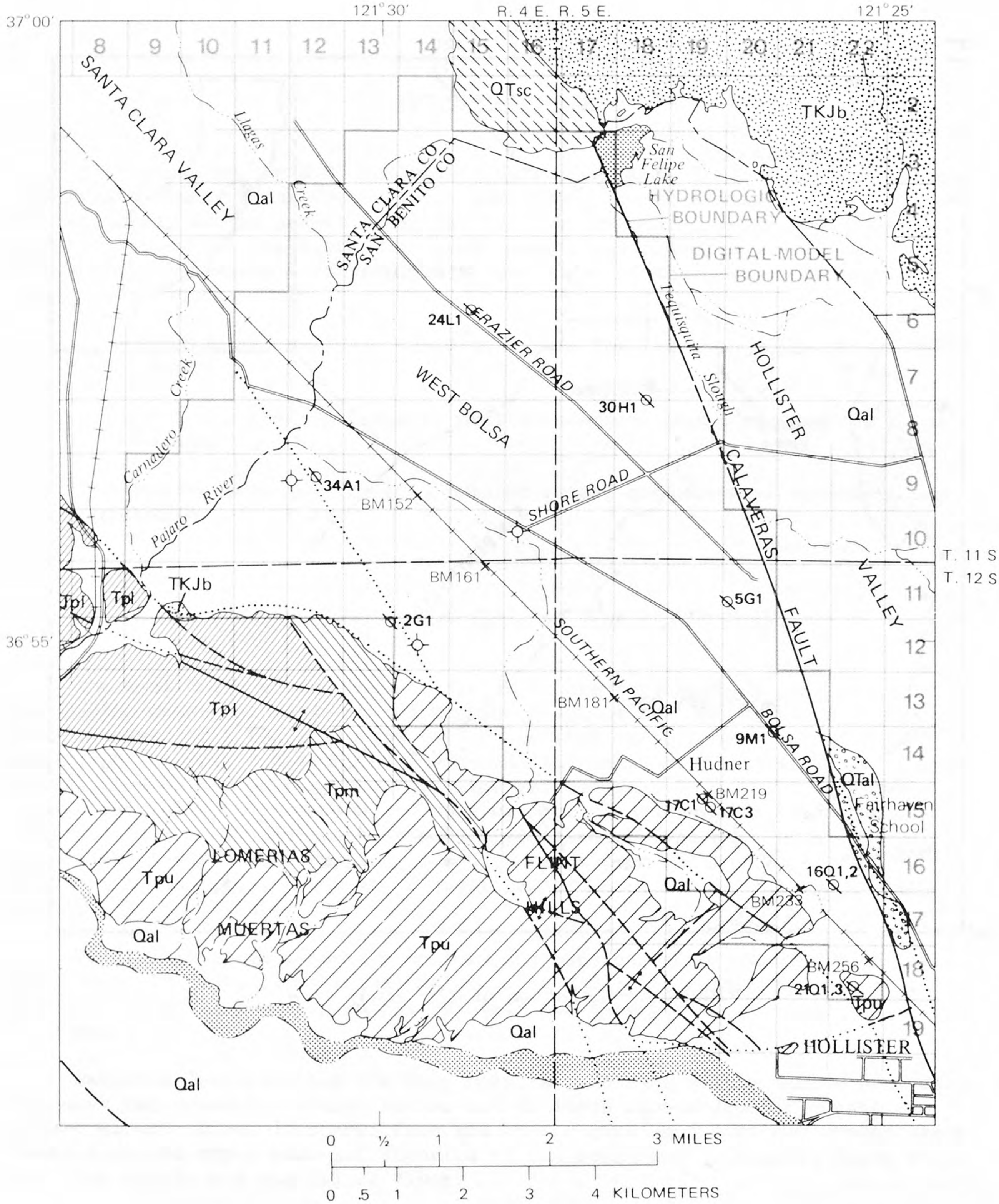

FIGURE 2.--Generalized geologic map showing location of selected observation wells, digital model grid network, and model boundary.

CORRELATION OF MAP UNITS

Qal	Holocene	QUATERNARY
Qtal, QTsc	Pleistocene and Pliocene	QUATERNARY AND TERTIARY
Tpu, Tpm, Tpl	Pliocene	TERTIARY
TKJb		TERTIARY, CRETACEOUS, AND JURASSIC

DESCRIPTION OF MAP UNITS

Qal — ALLUVIUM – Clay, silt, sand, and gravel

Qtal — OLDER ALLUVIUM – Clay, silt, sand, and gravel

QTsc — SANTA CLARA FORMATION – Compact lenticular beds of clay, sand, and gravel

PURISIMA FORMATION

Tpu — Upper member – Predominantly friable pebble gravel and sand. Locally contains siltstone all of terrestrial origin

Tpm — Middle member – Poorly consolidated, mostly terrestrial, friable, massive sandstone interbedded with gypsiferous clay. Locally contains friable pebbly sandstone and pebble conglomerate. Contact with underlying unit gradational

Tpl — Lower member – Mainly friable to semifriable, bedded, fine- to medium-grained arkosic sandstone and interbedded micaceous siltstone, fossiliferous, of shallow marine to brackish marine origin

TKJb — CONSOLIDATED BEDROCK – Sedimentary, igneous, and metamorphic rocks

Lithologic contact – Dashed where approximately located, short dashed where inferred, dotted where concealed

Fault – Dashed where approximately located; short dashed where inferred, dotted where concealed

Anticline – Showing trace of crestal plane. Dashed where approximately located

17C1 Water well – Number and letter indicates well referred to in text

Oil or gas well

FIGURE 2.--Generalized geologic map showing location of selected observation wells, digital model grid network, and model boundary--Continued.

Well-Numbering System

The well-numbering system used by the Geological Survey in California shows the locations of wells and springs according to the rectangular system for the subdivision of public land. For example, in the number 12S/5E-5G1, which was assigned to a well in the West Bolsa ground-water basin, the part of the number preceding the slash indicates the township (T. 12 S.); the number between the slash and the hyphen indicates the range (R. 5 E.); the digits between the hyphen and the letter indicate the section (sec. 5); and the letter following the section number indicates the 40-acre (0.16-km^2) subdivision of the section, as shown in the following diagram. Within each 40-acre (0.16-km^2) tract the wells are numbered serially, as indicated by the final digit of the number. Thus, well 12S/5E-5G1 is the first well to be listed in the SW½NE¼ sec. 5.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Discussion of the Mathematical Model

The mathematical model used in this study is a finite difference approximation of the linear, two-dimensional, partial differential equation that describes the nonsteady-state flow of water through porous media. Pinder and Bredehoeft (1968) and Pinder (1970), following the lead of Hantush and Jacob (1955) and Douglas and Peacemen (1956), used this equation in a digital-computer model that simulates the flow of ground water from node to node (data point to data point) in a model basin. The specific model used in this study is known as Pinder's version V which provides a mechanism to simulate vertical leakage from a confined aquifer through a confining bed.

Hydrologic relations are seldom simple and generally cannot be exactly described by a practical model. Model development thus requires the use of assumptions and approximations that simplify the so-called real world and permit the application of valid and well-known analytical techniques to the simulation of a hydrologic system. A model is only as accurate as the assumptions and data used in its development, and the limitations that are imposed on a model by certain assumptions and approximations must be kept in mind when evaluating model output. The assumptions and approximations used in developing the model for this study are listed on the following pages.

1. The West Bolsa basin consists of confined, partly confined, and unconfined aquifers that are to some extent hydraulically connected. Because of the limited quality and quantity of hydrologic data from the basin, it was neither practical nor reasonable to attempt to model each of these aquifers separately. Consequently, the model basin was generalized into two aquifers: one confined and one unconfined. That part of the basin where confining beds and large vertical-flow components exist in the saturated zone was modeled as a confined aquifer. A water-table aquifer was modeled for that part of the basin where ground-water flow is unconfined or partly confined and where vertical-flow components in the total flow regime are considered negligible compared to the horizontal flow components. In those parts of the basin where an unconfined (water-table) aquifer overlies a confined aquifer, the model can simulate ground-water flow only in the confined aquifer. Thus, future reference in this text to components of basin recharge or basin discharge in these areas will always indicate recharge to or discharge from the confined aquifer.

2. In the basin the areal extent of confined and unconfined conditions in the saturated zone is not stationary with time and changes as a function of head in the basin. To a limited degree, this is also true in the model basin. Any change from generally confined to generally unconfined conditions in the actual basin occurs relatively slowly as increased pumping reduces the potentiometric head and causes vertical-flow components in the flow regime to become progressively less significant. In the model basin, however, this change at a particular node takes place immediately when certain predetermined conditions are satisfied. Also, because of the type of formations which compose the ground-water basin, confined ground water occurs to some extent throughout the basin. This local confinement is insignificant, however, in those parts of the basin designated as water table and is not accounted for in the water-table part of the model.

3. The values of transmissivity applied to the model do not vary as a linear function of the saturated thickness of the basin. The model thus requires that the change in saturated thickness of the actual basin be small over the period of interest and that values of hydraulic conductivity along a vertical section be constant with depth. In the actual basin the change in saturated thickness over the period of interest has indeed been small but values of hydraulic conductivity vary considerably along any vertical section of the basin depending generally on the type of materials in the section. Thus, the nodal values of transmissivity used in the model also should be considered effective or average values and cannot be related to specific strata or geologic formations.

4. The values of storage coefficient used for the model remain constant with time except where simulated flow is transformed from confined to partly confined or unconfined conditions as the result of long-term pumping. In the actual basin, storage coefficient values vary considerably in time and space largely as a function of pumping time and the lack of homogeneity of the materials in the aquifers. Significant vertical as well as areal and temporal changes occur in storage coefficient values because of the nonhomogeneity of materials in a vertical section of the basin. The model makes no provision for vertical changes in storage coefficient values and accommodates temporal changes only on the limited basis described above. Areal distribution of storage coefficient values is accomplished in the model by assigning appropriate values at the individual nodes. The model, therefore, is rather limited in its ability to accommodate the various changes in storage coefficient values that occur in the actual basin. For this reason, the nodal values used are more properly termed effective or average storage coefficients and cannot be specifically related to any particular strata or geologic formation.

5. Quantities of basin discharge and recharge applied to or simulated by the model occur at constant rates over a designated period. Quantities of discharge from and recharge to the actual basin, however, are highly variable in space and time. The model cannot accommodate these variations and applies only average flow over a particular simulation period.

6. The hydrologic boundaries of the ground-water basin can be simulated by the model as flow, no-flow, or constant-head boundaries.

Nodal Array and Inputs to the Mathematical Model

Originally, a uniform grid network of 21 rows and 25 columns was superposed on a plan view of the West Bolsa basin area. A model boundary was then placed on the grid by tracing along the individual rectangular areas, or nodes, where they approximate the basin boundary (fig. 2). For modeling purposes, the basin boundary was arbitrarily terminated across the Santa Clara Valley in the vicinity of the Pajaro River (fig. 2). Nodes inside the final boundary in the model are from rows 2 to 18 and columns 9 to 22 of the original grid. The illustrations show information only for the nodes inside the boundary.

The center of each rectangular area, or node, of the model grid is considered a point source of information communicated to, or computed by, the model. Each nodal area represents one quarter of a square mile or 160 acres (0.65 km^2). An individual node is designated by the number of the row (I) and column (J). For example, the node in the tenth row of the fourteenth column is designated node (10, 14).

At each nodal center, the following information is communicated to the model:

1. Nodal dimensions, in feet (ft), designated in the model as DELY (I) and DELX (J).

2. Initial potentiometric head in the basin in feet above mean sea level, designated in the model as PHI (I,J).

3. Storage coefficient of the basin, designated in the model as S (I,J).

4. Transmissivity of the basin in feet squared per second (ft^2/s), designated in the model as T (I,J).

At selected nodal centers, the following information is communicated to the model:

1. Thickness in feet (ft), specific storage in $feet^{-1}$ (ft^{-1}), and hydraulic conductivity in feet per second (ft/s) of a confining bed, designated in the model as RATE (I,J), SS, and HYCOND respectively.

2. Recharge or discharge rates in cubic feet per second (ft^3/s), designated in the model as PUMP (I,J).

3. Head in water-table aquifer in feet above mean sea level (ft), designated in the model as WTABLE (I,J).

Calibration of the Model

In order to use the mathematical model as a predictive tool it must first be calibrated. Model calibration is done by combining, in the model, estimated distributions of transmissivity and storage coefficient values with sets of known or estimated ground-water flow conditions. The "correct" combination of aquifer parameters and flow conditions is said to be determined when model-generated water levels approximate historical water levels within a predetermined limit of accuracy.

Specifically, the first step in calibrating the West Bolsa model was to simulate predevelopment conditions adequately. Basin recharge and transmissivity information developed as a result of the predevelopment simulation was transferred, where appropriate, directly to the simulation of transient conditions. Pumpage and storage coefficients for the designated transient periods were then combined with this information in successive simulations of transient conditions until a satisfactory storage-coefficient matrix was developed for the model.

Quantitative information or parameters generated as a result of model simulations are referred to in this report as model-generated information. The validity and accuracy of this information are contingent on the limitations and assumptions of basin modeling and the information should not be construed as having been determined by actual measurement.

HYDROLOGY OF THE WEST BOLSA GROUND-WATER BASIN

Geology and Aquifer Characteristics

Underlying most of the productive aquifers of the West Bolsa ground-water basin are relatively impermeable bedrock formations of Jurassic, Cretaceous, and Tertiary age. These units consist mostly of sedimentary, igneous, and metamorphic rocks. The major aquifers in the ground-water basin are alluvium of Holocene age and older alluvium of Pleistocene and Pliocene age and the Purisima Formation of Pliocene age (fig. 2). Kilburn (1972) divided the Purisima Formation into upper, middle, and lower members. The lower Purisima overlies the bedrock units and consists mainly of interbedded friable sandstone and poorly consolidated siltstone. The middle member of the Purisima consists of poorly consolidated sandstone and clay. Both the lower and middle members of the Purisima are poorly permeable and generally yield only small quantities of water to wells. Bedrock units and overlying sections of the lower and middle Purisima crop out along the southwestern periphery of the basin near the Pajaro River (fig. 2). The upper member of the Purisima overlies the middle member throughout most of the basin and consists of lenticular deposits of friable pebble gravel and sand. It is exposed in the basin near Hudner. Overlying the upper Purisima in most of the basin are deposits of alluvium and older alluvium which consist of lenticular beds of unconsolidated gravel, sand, silt, and clay.

Saturated deposits of both the alluvium and the upper Purisima are moderately to extremely permeable and are the source of most of the ground water pumped from the West Bolsa basin. Parts of the Santa Clara Formation are exposed in the northeastern part of the basin. This formation contains compact lenticular beds of clay, sand, and gravel and is contemporary with, and often mapped as, the older alluvium.

Cross sections through the West Bolsa ground-water basin drawn by Kilburn (1972) show that the combined thickness of the lower and middle members of the Purisima Formation ranges from about 2,500 ft (762 m) to more than 4,000 ft (1,220 m). According to Kilburn (1972) the upper Purisima exists only in the southern half of the basin where it attains a maximum thickness of about 1,000 ft (305 m) south of Hudner. Kilburn (1972) also shows that the thickness of the Purisima Formation increases from west to east and reaches a maximum at the Calaveras fault. The alluvium, according to Kilburn (1972), forms a relatively thin veneer of sediments overlying the Purisima Formation. Its maximum thickness in the basin is about 150 ft (45.7 m).

The data collected for this study, and the author's interpretation of these data, do not agree with Kilburn's conclusion that the upper member of the Purisima is probably absent in the northern half of the basin. Drillers' logs, electric logs, and pump tests all indicate that thick lenses of permeable materials exist in the upper thousand feet of sediments in this part of the basin. Electric logs from three oil and gas exploration wells (locations given in fig. 2) show that lenses of permeable material occur throughout the upper 750-1,100 ft (229-335 m) of sediments in the north-central and northeastern parts of the basin. These permeable deposits should logically be associated with the upper member of the Purisima rather than the middle or lower member as shown by Kilburn. Thus, the upper member of the Purisima is considered herein to overlie the middle member, in varying thicknesses, throughout the ground-water basin.

Hydrologic and Model Boundaries

The eastern, western, and southern hydrologic boundaries of the basin are no-flow boundaries formed by faults. The entire eastern boundary is formed by the Calaveras fault (fig. 2). The western boundary is formed by an unnamed, northwest-trending fault that borders the northern and eastern perimeter of the Lomerias Muertas and Flint Hills. The narrow southern boundary of the basin is formed by a generally east-west-trending fault that intercepts both the Calaveras fault and the unnamed northwest-trending fault just north of Hollister. Both the western and southern faults are associated with the Purisima Formation and probably have not caused displacement of the alluvium. For modeling purposes, all the fault boundaries are considered to be no-flow boundaries. The aquifers in the southern part of Santa Clara Valley should have been modeled as a northern extension of the West Bolsa ground-water basin. Unfortunately, limited project funds forced the exclusion of the Santa Clara Valley from the model study and required the arbitrary placement of a flow boundary across the Santa Clara Valley near the Pajaro River. The placement of this boundary was done strictly for modeling purposes and does not conform to any natural hydrologic divisions of the basin.

The lower boundary of the basin, considered to be the contact between the bedrock and the Purisima Formation, was modeled as a no-flow boundary.

Ground-Water Movement

The movement of ground water in the basin is controlled, to a large extent, by the lithology of the major aquifers. The alluvium and upper Purisima in the basin contain relatively impermeable beds of clay that occur between permeable lenses of sand and gravel. Where the impermeable clay beds are continuous or nearly continuous over a large area, such as in the basin north and west of Shore Road (fig. 3), the ground water is confined, and significant components of vertical flow are created in the ground-water flow regime. The potentiometric head is above the confining beds in these areas, and ground water is forced through and around the clay beds into overlying strata or onto the land surface. Historically, potentiometric heads well above land surface have existed throughout the northern half of the basin. In predevelopment times, ground-water discharge close to the land surface created the swamps or "bolsa" areas for which the basin was named.

In the southern half of the basin, the thickness and areal extent of clay beds is not sufficient to confine the ground water significantly. Vertical ground-water flow components are negligible with respect to horizontal flow components in this area, and water-table conditions generally prevail.

Clark (1924) provided water-level data and designated an area of flowing wells in the basin during August 1913 (fig. 3). The water-level contours shown in figure 3 were derived, in part, from Clark's data and are indicative of the long-term, generally static conditions that existed in the basin prior to the development of irrigation agriculture in the Santa Clara Valley-West Bolsa area; they are considered representative of predevelopment or steady-state conditions in the basin. No information exists regarding the historical potentiometric heads in confined parts of the basin. However, Chabot Kilburn (written commun., 1972) indicates that, in 1891, the confined head in a well in sec. 3, T. 11 S., R. 4 E. was about 18 ft (5.5 m) above land surface. Noting that this well (not shown in fig. 3) was within Clark's boundary of flowing wells in 1913, L. C. Dutcher and Chabot Kilburn (written commun., 1972) extrapolated this head to the vicinity of the Pajaro River and developed the potentiometric surface shown in figure 3.

When discussing or modeling a basin where ground water occurs under different degrees of confinement, it is often convenient to divide the basin arbitrarily into a water-table aquifer and a confined aquifer. That part of the basin designated as the confined aquifer is characterized by significant upward leakage of ground water and potentiometric heads significantly above the tops of confining beds and often above land surface. In the water-table aquifer, vertical-flow components are considered to be insignificant with respect to horizontal flow components and unconfined or water-table conditions are said to prevail. The areal extent of the so-called confined and water-table aquifers is not static but changes with time according to the degree of confinement and the distribution of potentiometric heads in the basin.

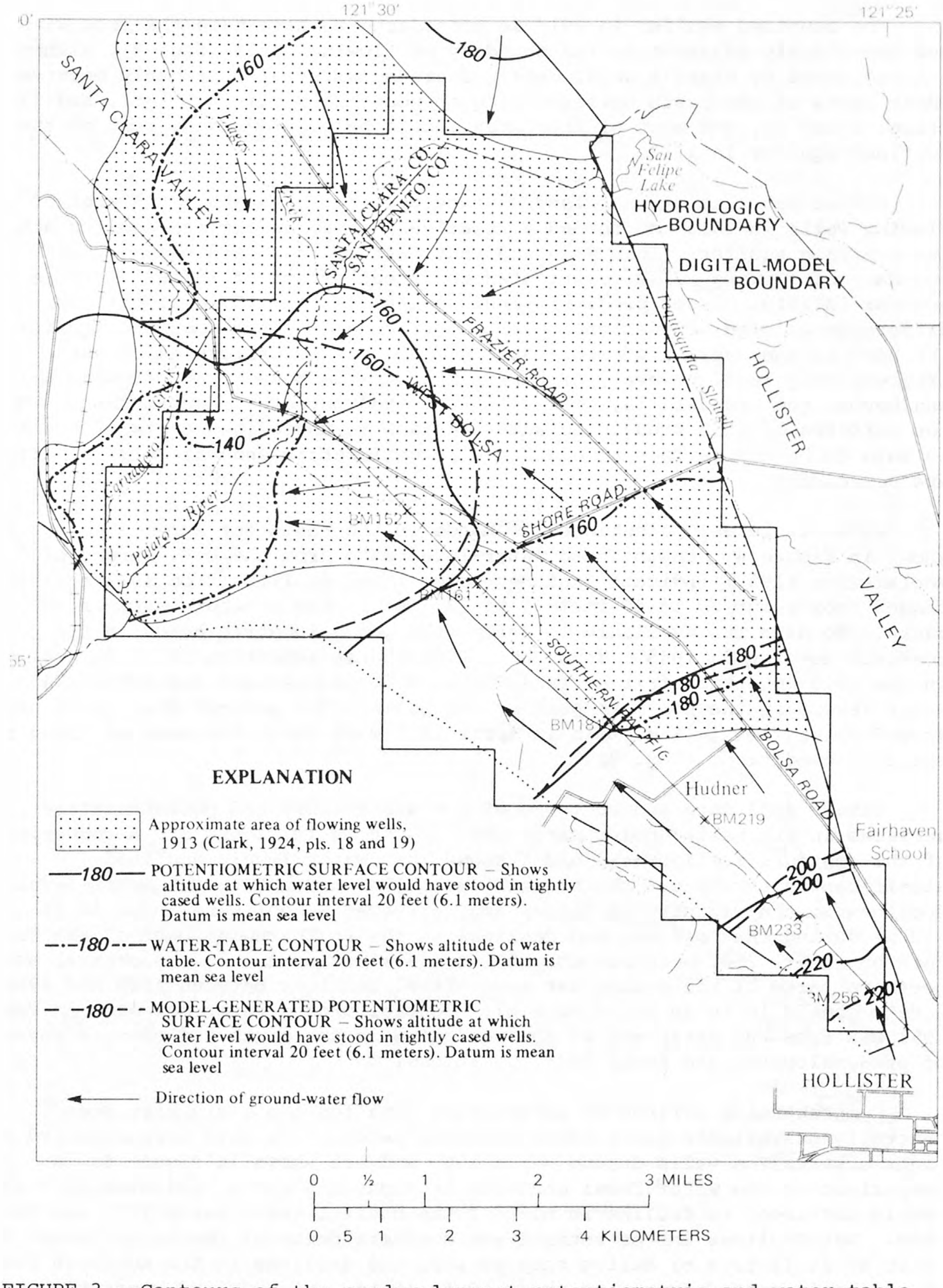

FIGURE 3.--Contours of the predevelopment potentiometric and water-table surfaces and the model-generated predevelopment potentiometric surface.

The confined aquifer in 1913 is considered to have been the area within and immediately adjacent to the boundary of flowing wells (fig. 3). Although not indicated by Clark's data, confined ground water also probably occurred in those parts of the basin corresponding to nodes 11-9, 11-10, 11-11, and 11-12 (figs. 2 and 3), and most of this area should be considered as part of the confined aquifer in 1913.

Ground water at or near land surface occurred throughout the area of flowing wells in 1913 and formed a relatively thin, unconfined aquifer above the confined aquifer. This area and that part of the basin beyond the boundary of flowing wells constituted the areal extent of the water-table aquifer in 1913. Under predevelopment conditions (fig. 3) a significant difference existed between the potentiometric head in the confined aquifer and the head in the overlying water-table aquifer. This difference becomes progressively less, however, with proximity to the boundary of flowing wells and beyond the boundary is, for all intents and purposes, nonexistant. Thus, for purposes of this study, the water surface in unconfined parts of the basin is said to be the surface at which the potentiometric and water-table surfaces are coincident.

Water-table and potentiometric heads in the basin for April 1945 are shown in figure 4. Unpublished water-level data from the U.S. Bureau of Reclamation (1952) indicate that net water-level declines from 1913 to 1945 ranged from about 20 to 40 ft (6.1 to 12.2 m) in the southern part of the basin. No data are available to define the potentiometric heads in the confined aquifer in 1945. Thus, an estimated net reduction of 10 ft (3.0 m) in the 1913 potentiometric surface was used to reconstruct the April 1945 water levels in the northern part of the basin. The general directions of ground-water flow in the basin in April 1945 were about the same as those for the 1913 conditions (fig. 3).

Water-level data and contours of the water-table and potentiometric surfaces in the basin during March 1951 are shown in figure 5. A comparison of the contours in figures 4 and 5 shows that water levels declined significantly throughout the basin between 1945 and 1951. Net water-level declines in the vicinity of Hudner and Fairhaven School were about 40 ft (12 m) during this period, and declines in the southernmost part of the basin, near benchmark 256, were probably 80 ft (24 m) or more. In the central and northern parts of the basin, net water-level declines between 1945 and 1951 were probably 10 to 20 ft (3 to 6 m). General ground-water movement in March 1951 was from the periphery of the basin toward the south and east, a reversal of predevelopment and April 1945 conditions.

Comprehensive springtime water-level data for the basin have been generally unavailable since 1952; however, water-level data were obtained from eight observation wells during March 1969 and are shown in figure 6. A comparison of the water-level contours in figures 5 and 6 indicates that water levels continued to decline in most of the basin between March 1951 and March 1969. Net declines in the central and southern parts of the basin ranged from 10 to 30 ft (3 to 9 m) during this period, and declines in the northern part of the basin ranged from 0 to about 10 ft (0 to 3 m). Ground-water flow during March 1969 continued to be from the northwest to the southeast.

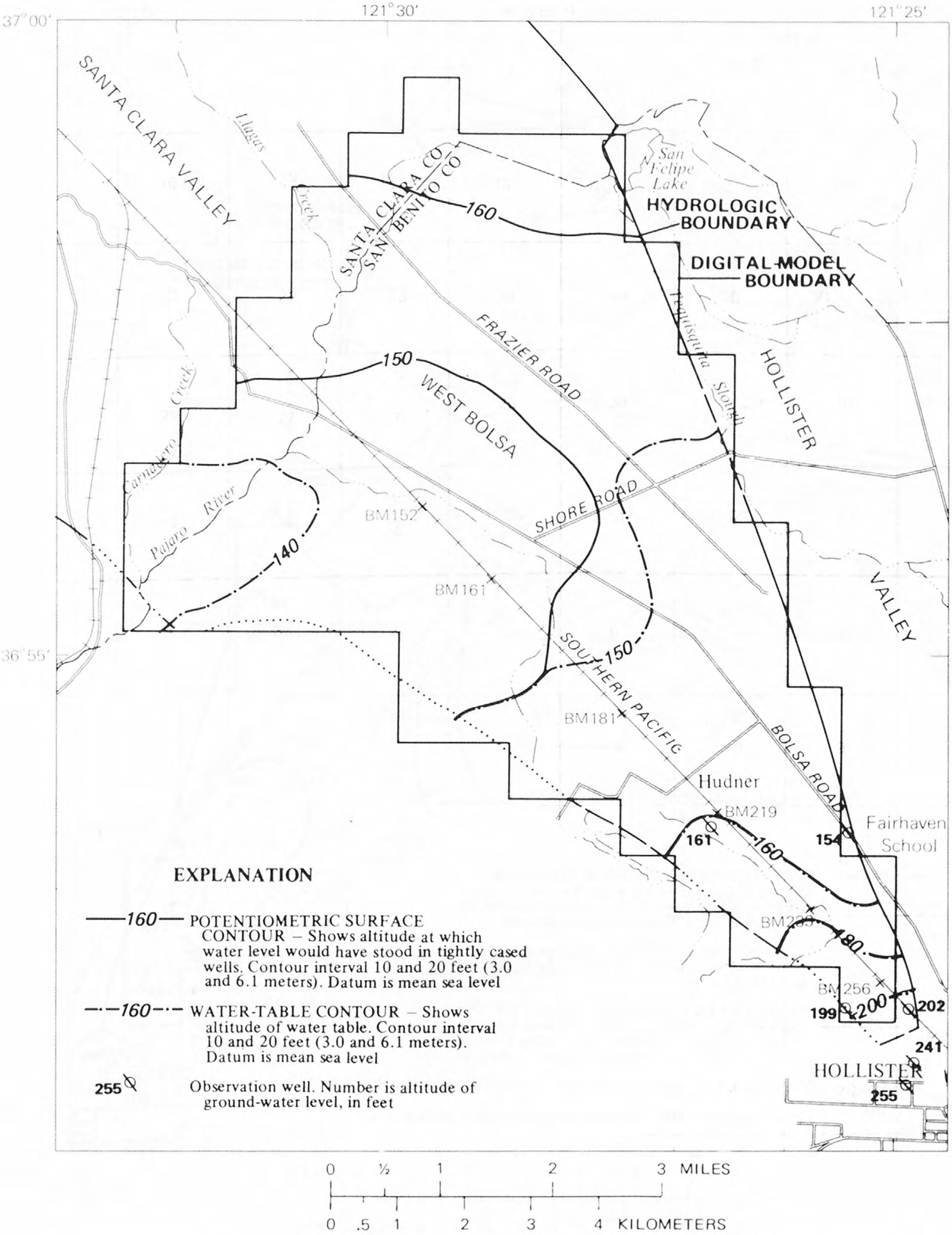

FIGURE 4.--Water-level data and contours of the potentiometric and water-table surfaces, April 1945.

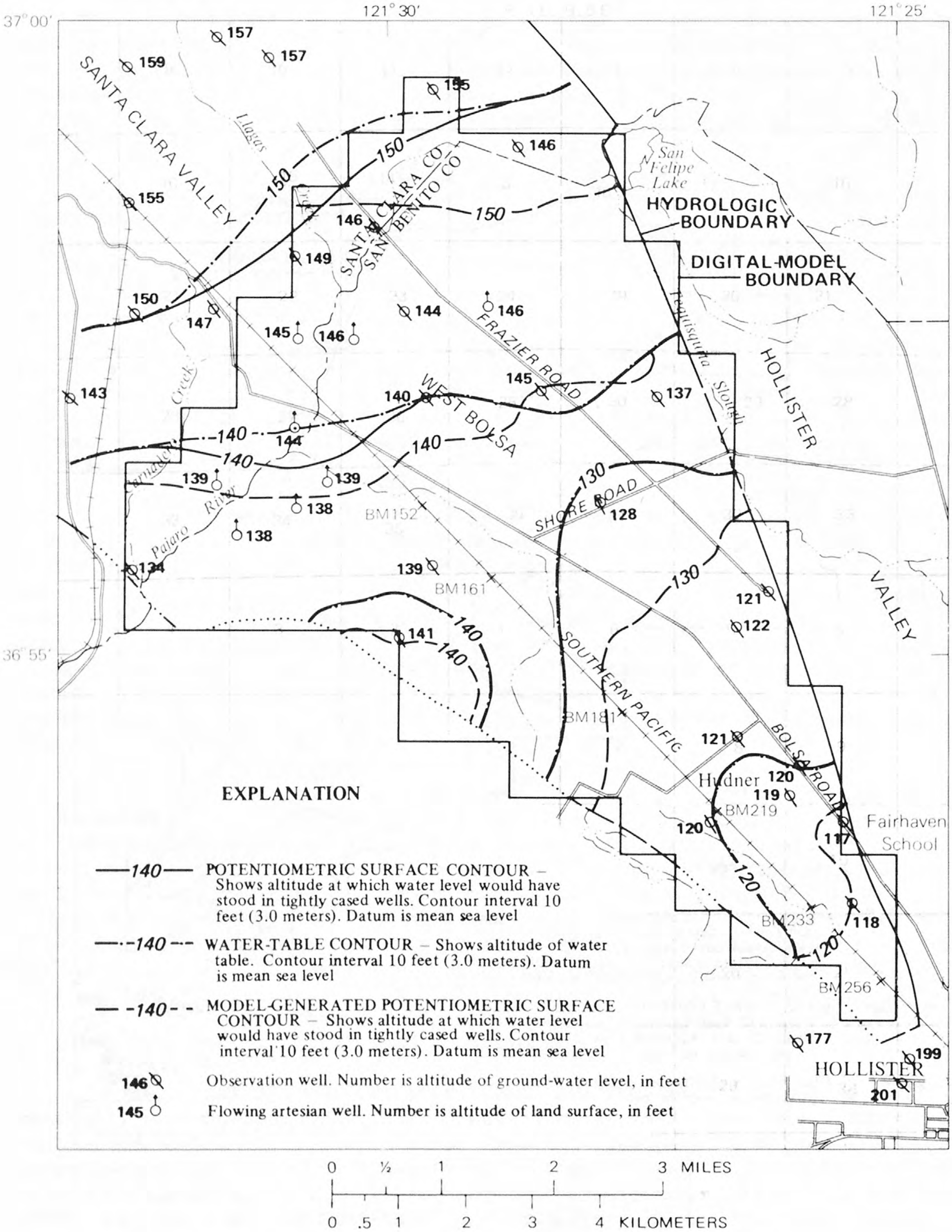

FIGURE 5.--Water-level data, contours of the potentiometric and water-table surfaces, and contours of the model-generated potentiometric surface, March 1951.

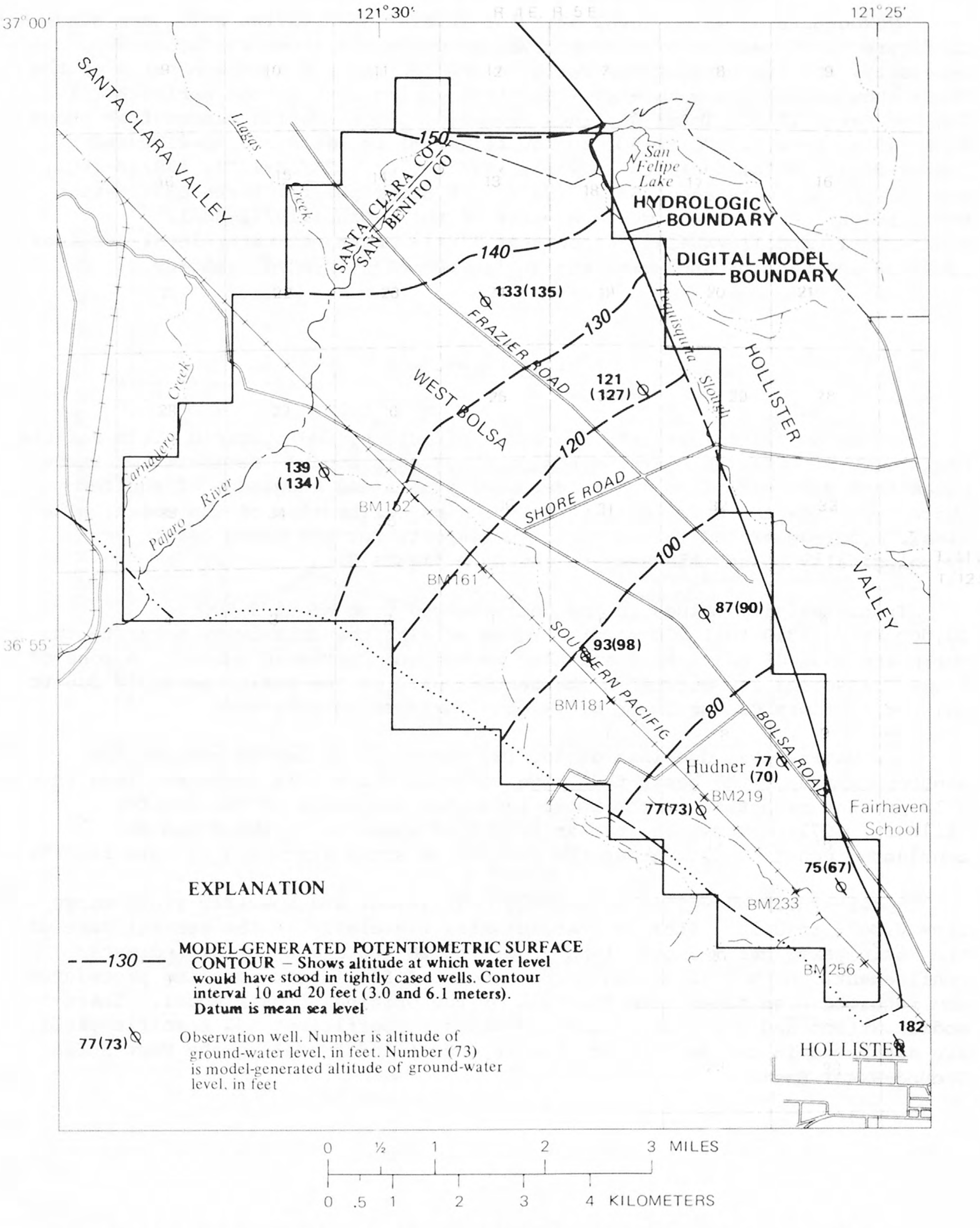

FIGURE 6.--Water-level data and contours of the model-generated potentiometric surface, March 1969.

Hydrographs of water-level data for several observation wells are shown in figure 7. Locations of the observation wells are shown in figure 2. Generally, the hydrographs for wells in the central and southern parts of the basin show continuous water-level declines during most of the period April 1945 to March 1969. Total declines measured in these wells ranged from about 30 ft (9 m) in well 12S/5E-5G1 to 140 ft (43 m) in wells 12S/5E-21Q1 and 12S/5E-21Q3. Total declines in wells 12S/5E-17C1, 12S/5E-17C3, 12S/5E-16Q1, and 12S/5E-16Q3 were about 85 ft (26 m). Hydrographs for three observation wells in the northern and western parts of the basin (11S/4E-34A1, 11S/5E-30H1, and 11S/4E-24L1) show that little or no net water-level declines occurred in these areas during the entire period of record, 1950-69.

Aquifer Parameters

Values of transmissivity, storage coefficient, and specific yield for the basin were not available at the beginning of this study. Estimates of these parameters were made from specific-capacity data and knowledge of aquifer characteristics and were later refined during calibration of the model. The final, model-generated values of transmissivity for the basin are hydrologically reasonable and are shown in figure 8.

Transmissivity values in the basin ranged from about 3,300 to 20,000 ft^2/d (310 to 1,900 m^2/d). Zones of high transmissivity occur to the north and west of Shore Road and near Hudner and Fairhaven School. A zone of lower transmissivity occurs in the central part of the basin, possibly due to thicker sections of the lower and middle Purisima in this area.

The water-level declines of 100-180 ft (31-55 m) in the central and southern parts of the basin that have occurred since 1913 represent less than a 10-percent reduction in the total saturated thickness of the aquifer (Kilburn, 1972). Thus, the transmissivities shown in figure 8 can be considered constant throughout the periods of study discussed in this report.

Model-generated values of storage coefficient and specific yield range from 0.0005 to 0.10. Storage coefficients, especially in the central part of the basin, have changed over time according to the degree of ground-water confinement. Such changes had to be accounted for in the modeling procedures and required significant modification of the original Pinder model. These modifications and the nodal values of storage coefficient and specific yield are discussed in the section of this report titled "Modeling the West Bolsa Ground-Water Basin."

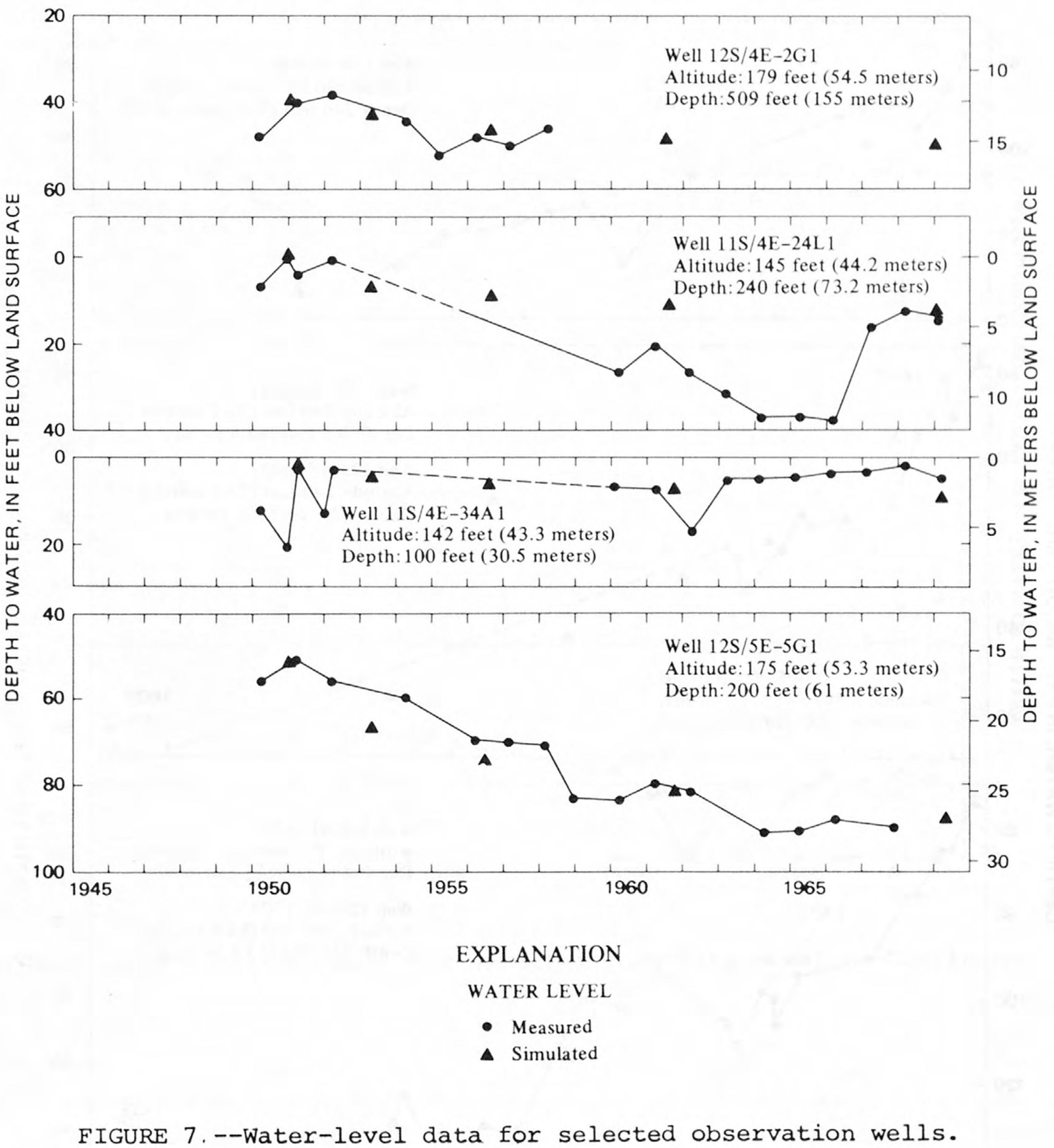

FIGURE 7.--Water-level data for selected observation wells.

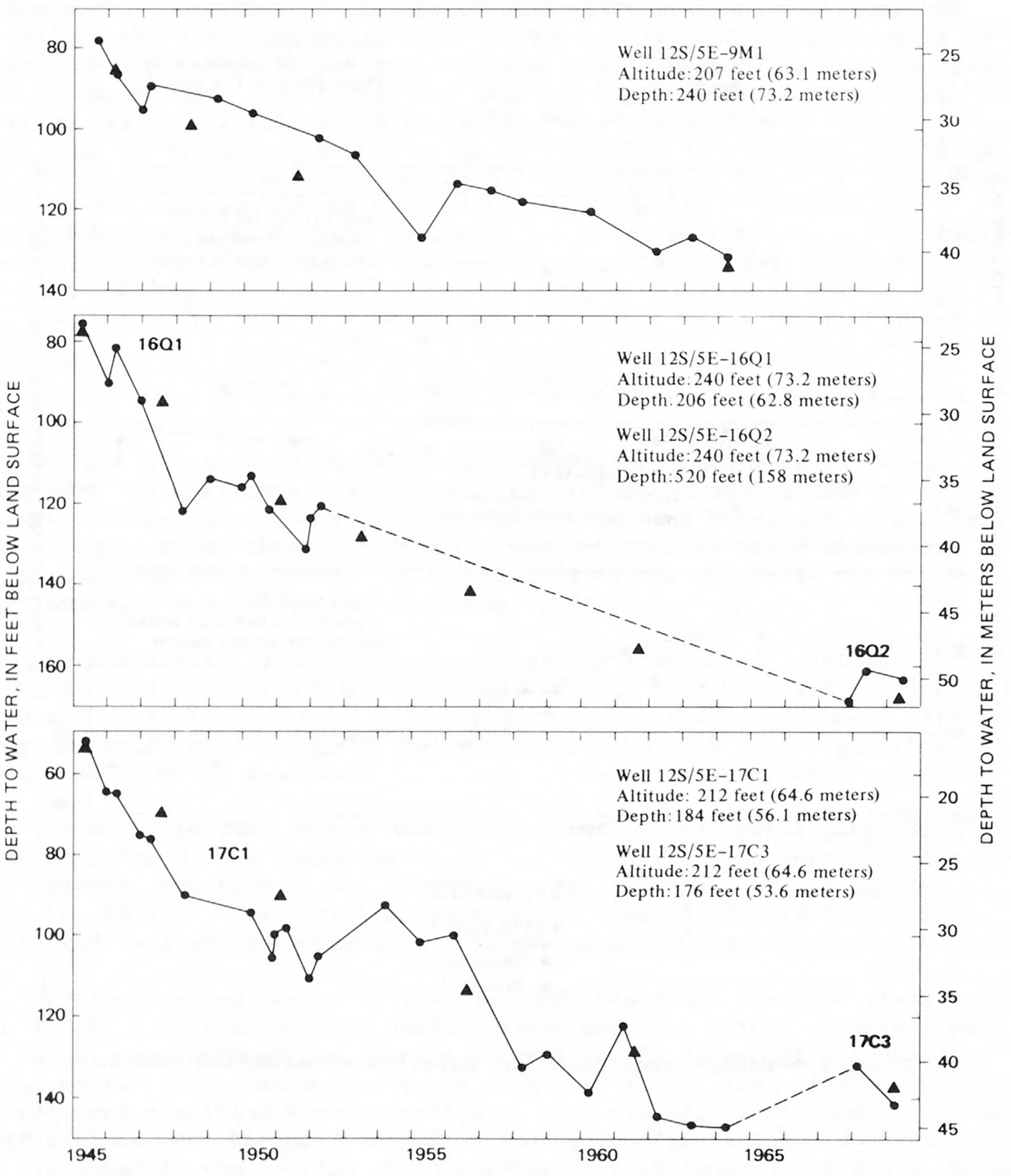

FIGURE 7.--Water-level data for selected observation wells--Continued.

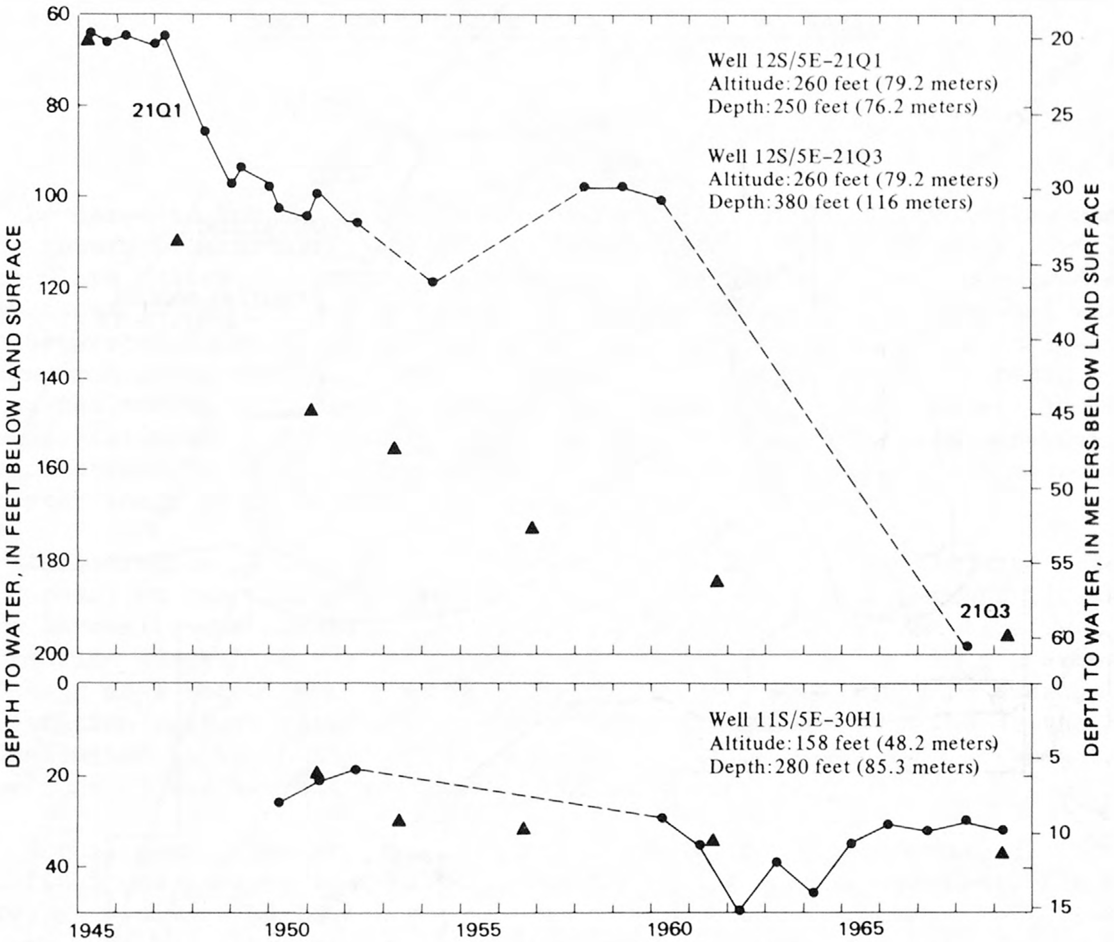

FIGURE 7.--Water-level data for selected observation wells--Continued.

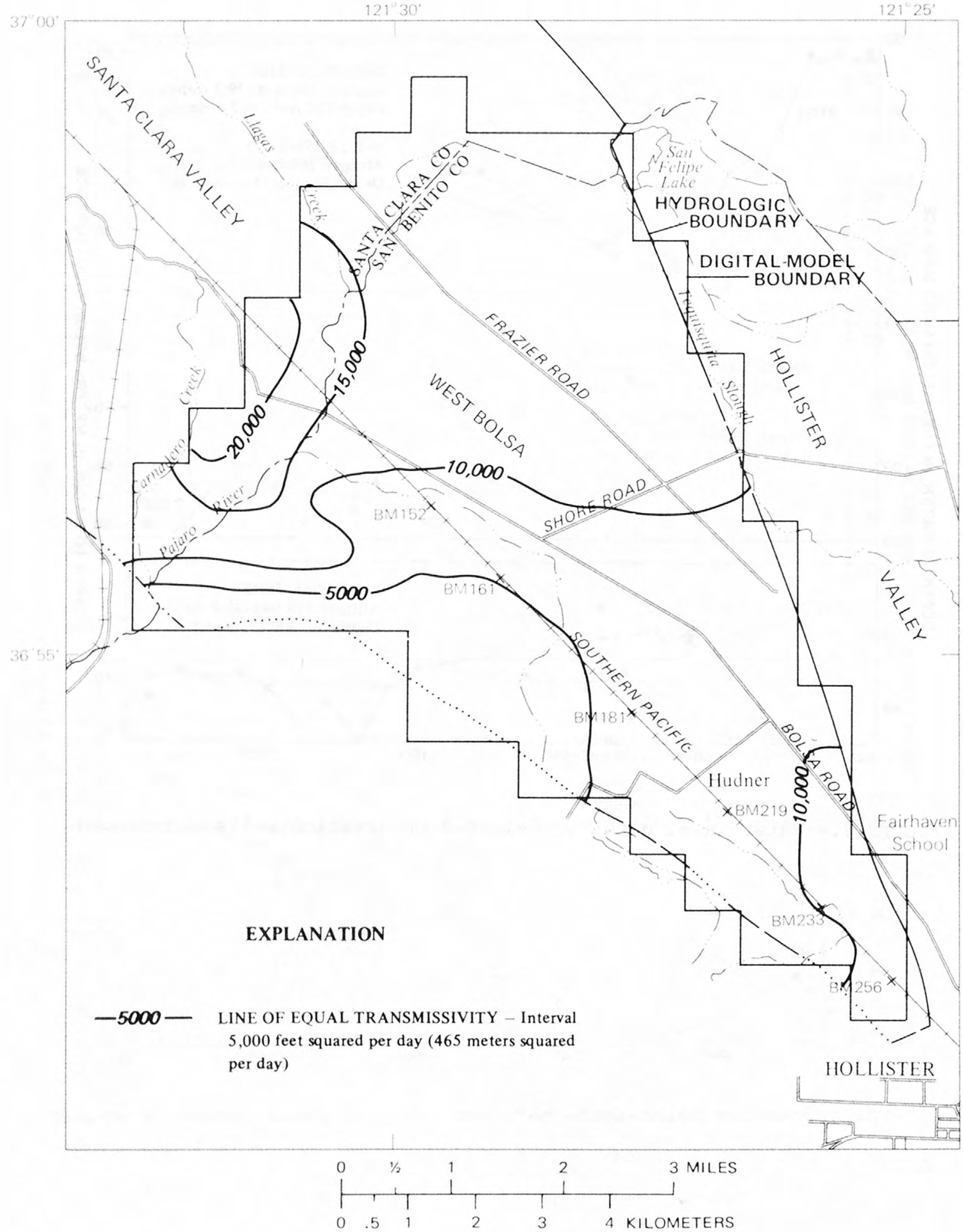

FIGURE 8.--Lines of equal transmissivity in the West Bolsa ground-water basin.

Recharge to and Discharge from the Basin

Recharge

Recharge to the basin occurs mostly as infiltration of streamflow and rain, return flow from irrigation, and subsurface inflow from south Santa Clara Valley. Other recharge during predevelopment times occurred as subsurface flow to the extreme southern part of the basin through what were then saturated deposits of younger alluvium. Infiltration of streamflow occurs from minor streams along the southwestern periphery of the basin. Data giving the annual infiltration losses from these streams are not available; however, estimates used in this study range from 0 to 25 acre-ft per year per mile of stream [0 to 0.019 (hm^3/yr)/km], depending on the rainfall measured at Hollister for a given period.

Infiltration of rain to the basin is highly variable in time and space and depends on many factors including soil saturation, soil permeabilities, storm intensity and duration, and plant cover. Definitive, quantitative information describing the long-term contribution of rain to the recharge of the basin does not exist. However, for this study, the long-term average infiltration rate of rain to the unconfined or semiconfined parts of the basin was estimated to be about 1.6 in (41 mm) per unit area per year or about 12 percent of the average annual rainfall at Hollister.

Actual quantities of irrigation return flow that have recharged unconfined and semiconfined parts of the basin are unknown; however, for this study, an estimate of 10-percent of total withdrawals was used. Infiltration of both rain and irrigation water in parts of the basin where the ground water is or has been extensively confined was considered to be zero.

Prior to development of the ground-water basin, upward leakage from the confined aquifer maintained water levels at land surface throughout most of the northern and central parts of the basin. There was little potential for surface recharge into totally saturated sediments; thus, infiltration of rain and streamflow into the basin during predevelopment times was considered to have occurred only outside the boundary of the area of flowing wells shown in figure 3. Also, drillers' logs, hydrographs, and geophysical logs indicate that extensive confinement or the potential for extensive confinement of the ground water exists generally north of the boundary between T. 11 S. and T. 12 S. and here also the potential for surface recharge was considered to be zero. Data from wells south of this boundary indicate that confinement in most of the southern part of the basin, even within Clark's boundary of flowing wells (fig. 3), was generally not extensive. Thus, infiltration of rain and irrigation water to the water table could occur south of the boundary between townships 11 and 12 whenever sufficient storage space was available in the alluvial sediments.

Subsurface recharge to the West Bolsa ground-water basin occurs mostly as flow through the confined aquifer from the southern part of Santa Clara Valley. During predevelopment times, the distribution and generally static nature of the potentiometric heads in the Santa Clara Valley and West Bolsa ground-water basins was such that subsurface flow to the West Bolsa basin was generally maintained at a steady-state rate. The development of irrigation agriculture north and south of the Pajaro River has reduced and disrupted this flow. Annual, large-scale ground-water withdrawals in the southern part of Santa Clara Valley, especially since 1945, have lowered potentiometric heads, reduced and even reversed gradients, and intercepted ground-water flows that would otherwise have provided recharge to the West Bolsa ground-water basin. Comprehensive water-level data, showing the effect of ground-water withdrawals on the potentiometric surface during the pumping season, are generally not available. However, figure 9 shows water levels in the vicinity of the Pajaro River for the period November 1-8, 1950, about 6 weeks after the end of the pumping season. Potentiometric heads in the area had probably been recovering for several weeks when these measurements were made, but the reduced gradients and lowered heads north and south of the Pajaro River are still evident. These conditions become even more obvious when the data in figure 9 are compared with the water levels shown in figure 5, collected just 5 months later during March 1951.

Data for computing the actual subsurface recharge from Santa Clara Valley to the West Bolsa ground-water basin do not exist; however, model-generated values range from 6,980 acre-ft (8.6 hm^3) per year for steady-state (predevelopment) conditions to 3,490 acre-ft (4.3 hm^3) per year for the period April 1945 to March 1969.

During predevelopment times, subsurface recharge also occurred in the extreme southern part of the basin. Ground water flowing through a relatively thin, unfaulted mantle of saturated alluvium provided an estimated annual recharge of 940 acre-ft (1.16 hm^3) to this area. By 1945, however, ground-water pumpage both within and south of the basin had so dewatered the aquifer that the southern fault boundary became an effective barrier to the northward movement of ground water, and subsurface recharge to the southern part of the basin was effectively terminated.

In parts of the basin where relatively thick sections of sediment have been dewatered by pumping, some recharge to the water table has probably occurred from perched ground water and the consolidation of the confining beds.

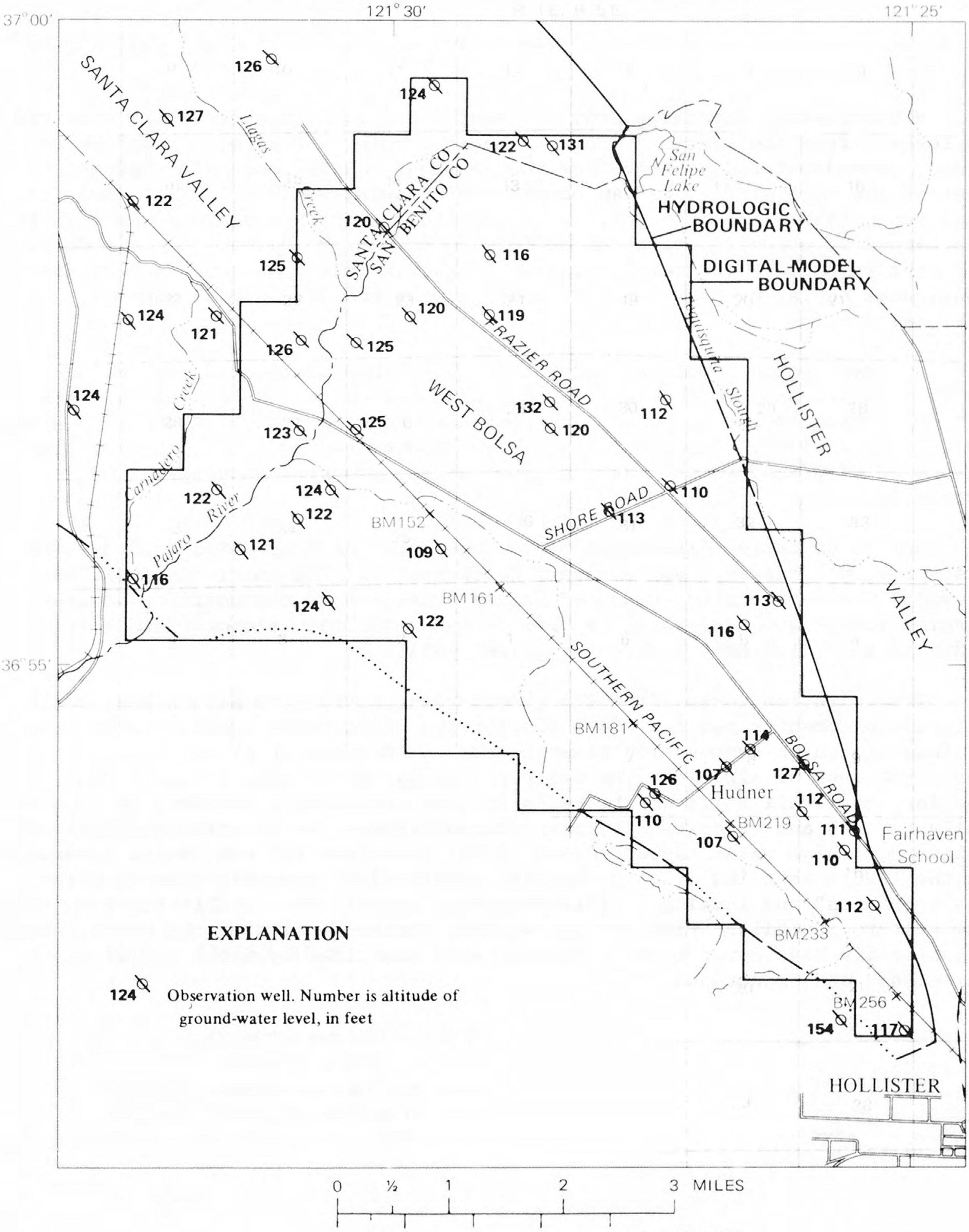

FIGURE 9.--Potentiometric heads in the West Bolsa basin and the southern part of Santa Clara Valley, November 1-8, 1950.

Discharge

Historically, discharge from the West Bolsa basin has generally occurred as leakage from the confined aquifer and as pumping. During predevelopment times, ground-water discharge from the confined aquifer occurred throughout most of the area within Clark's boundary of flowing wells (fig. 3). Most of this water leaked into the shallow, overlying, unconfined aquifer where it was discharged by evapotranspiration or flow to the Pajaro River. Clark's data, gathered in August, indicate that this leakage occurred on an extensive and continuous basis, even during the summer months and during prolonged dry periods.

By 1945, potentiometric heads in the basin had declined an estimated 10 ft (3.0 m), and confined-aquifer discharge close to the land surface was significantly reduced. The decline continued through most of the period April 1945 to March 1969, reducing losses from the confined aquifer until, by 1969, discharge of ground water near the land surface occurred only near the Pajaro River.

Any quantitative discussion of leakage from the West Bolsa ground-water basin is, by necessity, subjective. Calibration of the model, however, has provided model-generated values of steady leakage from the confined aquifer ranging from 8,400 acre-ft (10.4 hm^3) per year in predevelopment times to 1,200 acre-ft (1.5 hm^3) per year in March 1951.

Transpiration losses from the ground-water basin have always been small. In predevelopment times the high, fluctuating water table combined with poor drainage and high evaporation rates caused the deposition of high concentrations of alkali in the soils of the basin. Figure 10 shows the boundary of alkali soils in the basin in 1891 and Clark's boundary of flowing wells in 1913 and suggests a correspondence between the occurrence of alkali soils and a high water table. Broek (1932) described the West Bolsa landscape in the 1920's as being a "vast, barren, alkali flat" sparsely covered with "salt grasses" and lacking "cultivated crops as well as....habitations." Even the western foothills areas and the extreme southern parts of the basin, where alkali soils have never been a problem, were described by Broek (1932) as "treeless" and "monotonous."

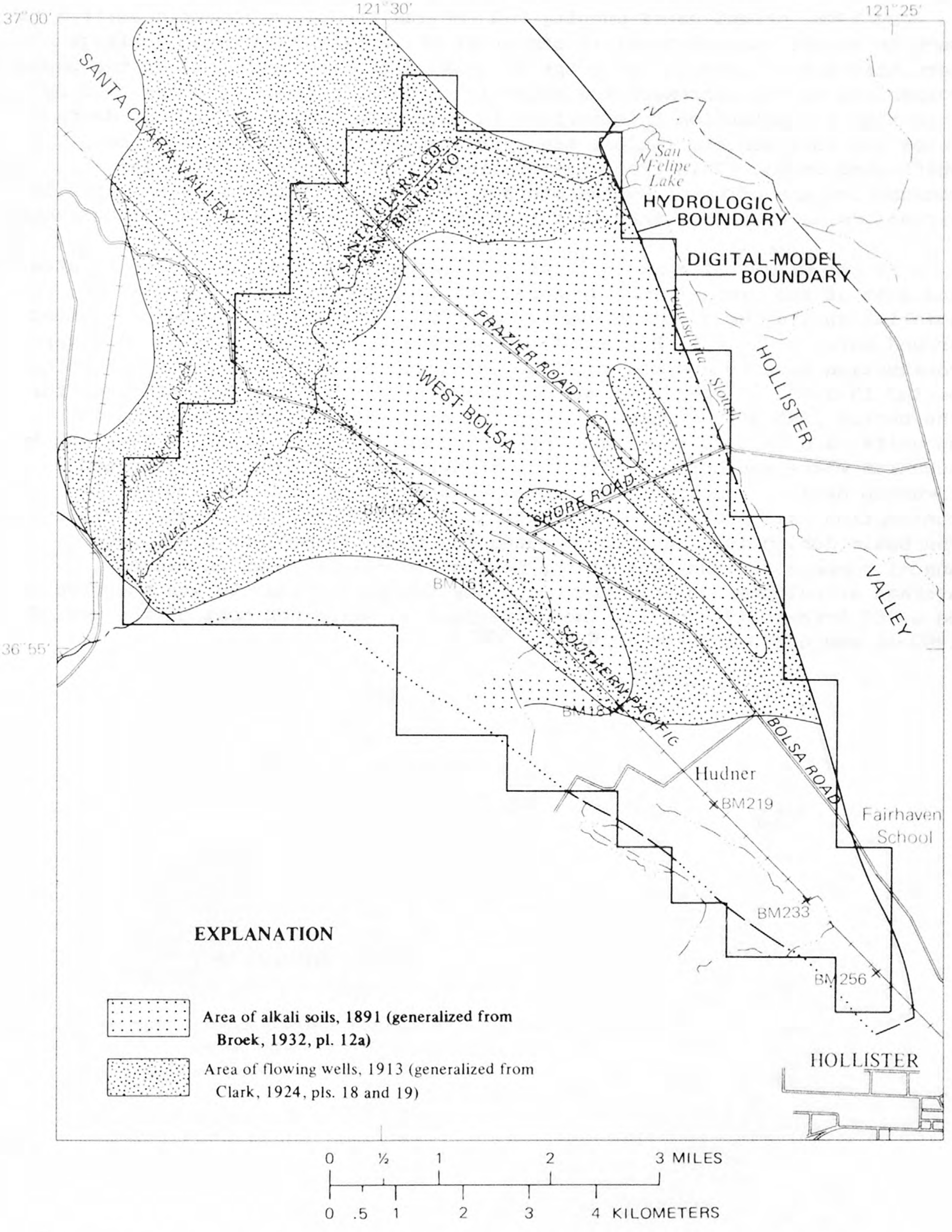

FIGURE 10.--Boundary of flowing wells in 1913 and boundary of alkali soils in 1891.

By 1945, ground-water pumping had lowered the potentiometric surface to such an extent that chemical treatment of the soil and improved drainage permitted the cultivation of crops throughout the southern half of the basin. Comparison of the benchmark and water-level data in figure 4 shows that by this time the potentiometric surface in this area was at sufficient depth below the root zone to inhibit transpiration losses from the basin by cultivated crops. This trend has continued to the present day. The consumptive use of water by the crops is being supplied by rain and applied irrigation water rather than by direct transpiration from the saturated zone.

At the present time, nearly all of the basin is intensively cultivated, and most of the crops in the area require supplemental irrigation water sometime during the growing season. Most of the irrigation water is pumped ground water. The U.S. Bureau of Reclamation (1952) used electrical power consumption data to compute total ground-water pumpage in the basin for the period 1935-50. Pumpage for various subunits in the basin was computed for the period 1945-50. Figure 11 shows the areas and numbers of the basin subunits, and table 1 shows the computed pumpage in the basin by year and by subunits where appropriate. For this study, annual pumpage was computed on a township basis for most of the period 1962-68 using electrical power consumption data provided by the Pacific Gas and Electric Company. Pumpage in the basin during 1966 was not computed due to an incomplete power record. Annual pumpage for the rest of the period 1962-68 is shown in table 2. Average annual pumpage from the basin for the period 1945-50 was computed to be 6,260 acre-ft (7.8 hm^3). The corresponding value for most of the period 1962-68 was 6,100 acre-ft (7.5 hm^3).

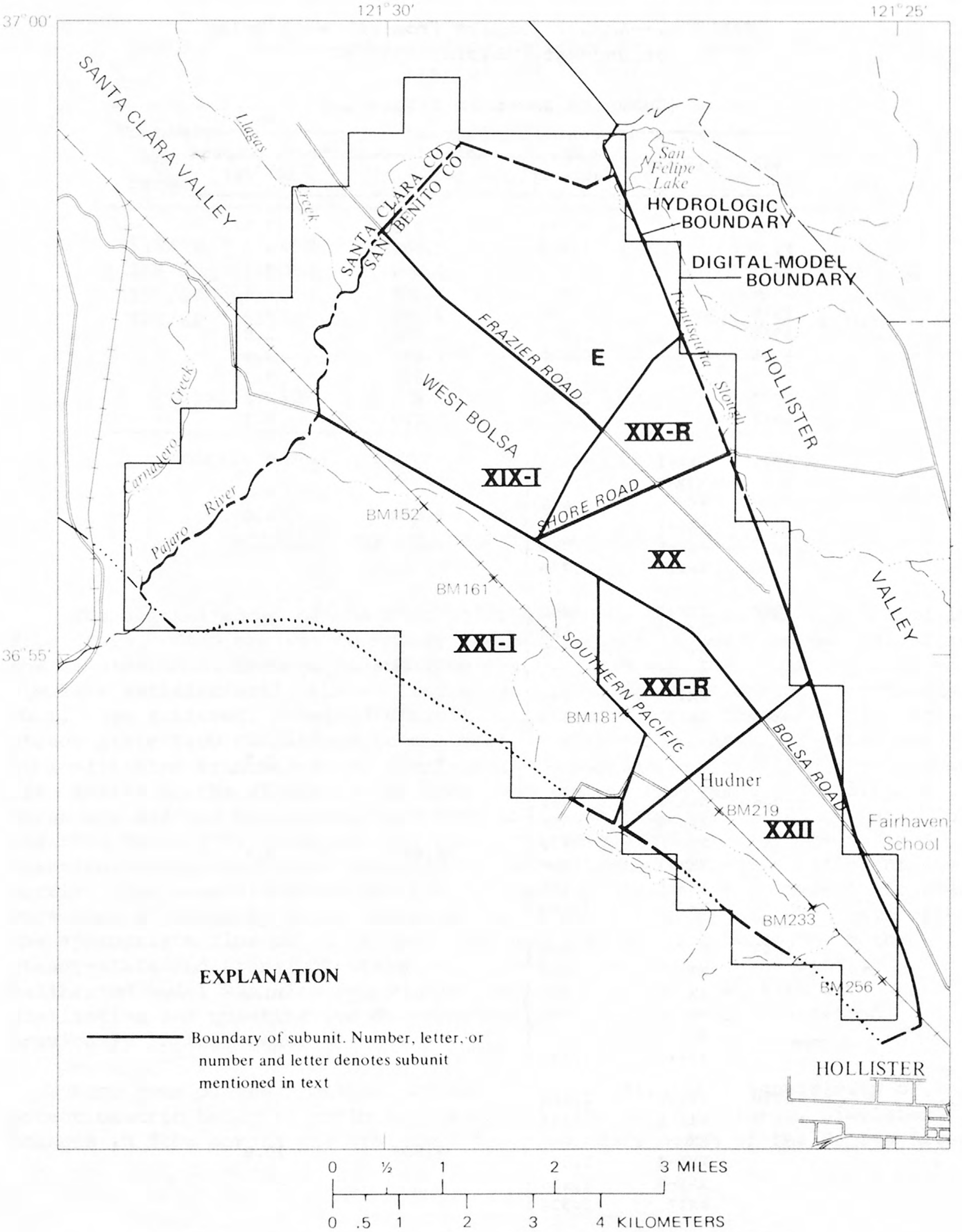

FIGURE 11.--Numbers and areas of subunits used to compute pumpage, 1945-50.

TABLE 1.--*Annual pumpage from the West Bolsa ground-water basin, 1935-50*

[Subunits shown in figure 11]

Year	Subunit	Pumpage (acre-ft)	Total pumpage (acre-ft)	Total pumpage (ft^3/s)
1935		2,270	2,270	3.1
1936		2,880	2,880	4.0
1937		2,680	2,680	3.7
1938		1,860	1,860	2.6
1939		3,260	3,260	4.5
1940		1,880	1,880	2.6
1941		2,370	2,370	3.3
1942		2,400	2,400	3.3
1943		2,970	2,970	4.1
1944		3,870	3,870	5.3
1945	XIX-I	211	4,046	5.6
	XIX-R	532		
	XX	478		
	XXI-I	315		
	XXI-R	740		
	XXII	1,770		
1947	XIX-I	440	5,232	7.2
	XIX-R	668		
	XX	617		
	XXI-I	370		
	XXI-R	924		
	XXII	2,213		
1946			6,140	8.5
1948	XIX-I	362	6,589	9.1
	XIX-R	819		
	XX	732		
	XXI-I	968		
	XXI-R	1,148		
	XXII	2,560		
1949	XIX-I	1,259	7,647	10.6
	XIX-R	751		
	XX	707		
	XXI-I	1,264		
	XXI-R	1,114		
	XXII	2,552		
1950	XIX-I	1,462	7,905	10.9
	XIX-R	744		
	XX	669		
	XXI-I	1,362		
	XXI-R	1,138		
	XXII	2,530		

Average annual pumpage 1945-50 = 6,260 acre-ft

TABLE 2.--*Annual pumpage from the West Bolsa ground-water basin, 1962-65 and 1967-68*

Township and range	Annual pumpage, in acre-ft					
	1962	1963	1964	1965	1967	1968
11S/4E	460	300	350	420	340	670
11S/5E	2,050	1,390	1,150	1,560	1,100	1,550
12S/4E	640	500	390	100	60	360
12S/5E	4,040	3,980	3,670	3,750	3,180	4,480
Total	7,190	6,170	5,560	5,830	4,680	7,060

Average annual pumpage = 6,100 acre-ft

MODELING THE WEST BOLSA GROUND-WATER BASIN

The digital model of the West Bolsa ground-water basin was calibrated in four steps. Step one was to modify the basic Pinder V model to control better the simulation of leakage to and from the confined aquifer. Step two was to simulate satisfactorily the defined steady-state (predevelopment) conditions that, when achieved, provided semicalibrated matrices of transmissivity and steady-state flow conditions in the basin. Step three was to transfer the semicalibrated transmissivity matrix and appropriate parts of the steady-state flow matrix to the simulation of transient-state (time-varying) conditions, which are defined as the conditions in the basin from April 1945 to March 1951 and from March 1951 to March 1969. Satisfactory simulation of the defined transient-state conditions provided a semicalibrated storage coefficient matrix. The semicalibrated matrices of transmissivity and storage coefficient were then adjusted by trial and error until the two matrices, when used with the appropriate flow matrices, provided satisfactory solutions for both steady-state and transient-state conditions in the basin. The final, calibrated model was also required to conform reasonably well to the qualitative and quantitative descriptions of basin hydrology described previously in this text.

Step four of the model calibration was to analyze the sensitivity of potentiometric heads at various locations in the basin to large, simulated changes in flow across the arbitrary basin boundary north of the Pajaro River.

Modification of the Pinder Digital Model

The original version of the Pinder V mathematical model is only partly suited to simulate the West Bolsa ground-water basin. The major incompatibility between the actual basin and the model occurs in the simulation of leakage from confined aquifers. In the actual basin, confinement is the result of interconnected lenses of clay that are highly variable in their hydrologic and spatial characteristics. In the model, however, leakage can occur across only one hypothetical confining bed of defined thickness, hydraulic conductivity, and specific storage. The lowering of potentiometric heads in confined parts of the actual basin is accompanied by a progressive decrease in vertical leakage and may provide small amounts of recharge to the basin from perched water tables and the consolidation of confining beds. In the original Pinder model a lowering of potentiometric heads very often intensifies the quantity of leakage moving across the hypothetical confining bed.

Once leakage is established in the basic Pinder model it occurs continuously throughout a given simulation period. This can be especially troublesome when modeling a basin where leakage terminates or becomes insignificant during a particular simulation period.

As suggested above, the driving force for the simulated leakage results from a head differential between the two aquifers of the model: the water-table and confined aquifers. Therefore, the obvious method of controlling the leakage involves controlling this head differential.

For this study, the head differential between the water-table and confined aquifers was arbitrarily controlled for declining potentiometric heads only. Nodes in the model that required leakage were considered to be those generally corresponding to Clark's area of flowing wells in 1913 and were assembled into four major groups as shown in figure 12. Within each group an arbitrary head differential called ALAG was assigned to each node such that when the potentiometric head at any node declined the distance ALAG below the water-table head, leakage across the confining bed was terminated. With the termination of leakage, the model at that particular node was considered to have made the transition from confined to semiconfined or unconfined conditions, and a change in storage coefficient and possibly an increase in recharge, due to increased infiltration of precipitation and irrigation waters, to the node was required (see discussion of infiltration waters, p. 23). This transition also implied that future water-table and potentiometric heads at the particular node should be coincident. The model modification was such that, once the ALAG value had been exceeded at a node, the combining of water-table and potentiometric heads and any resulting nodal changes in storage coefficient or recharge was entirely automatic and was not dependent on the model operator. It should also be emphasized that a head differential greater than ALAG did not necessarily occur simultaneously at every node within a major group. Rather, each node operated independently according to the value of the nodal poentiometric head computed by the model.

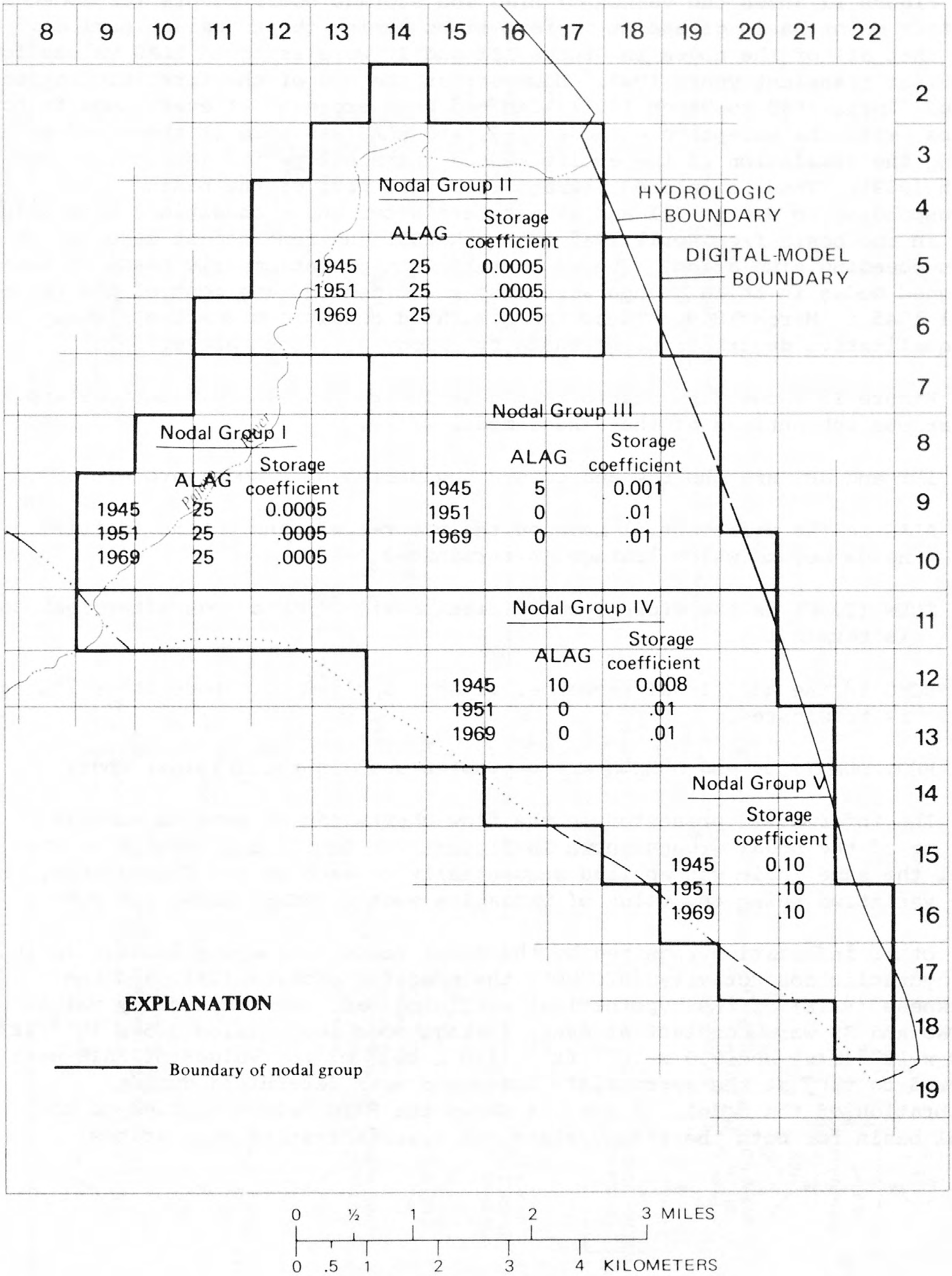

FIGURE 12.--Nodal groups, values of ALAG, and storage coefficients used to simulate leakage in the basin.

Figure 12 shows the values of ALAG and storage coefficients for nodes in the four major basin groups at various times during the transient periods. Note that all of the nodes in Groups III and IV were assigned ALAG values for the first transient year, 1945. However, at the end of the first simulation period (April 1945 to March 1951) ALAG had been exceeded at every node in both groups, with the exception of node 11-9, and ALAG was zero at these nodes during the simulation of the entire second transient period (March 1951 to March 1969). Thus, simulated leakage from that part of the basin corresponding to Groups III and IV was terminated under conditions simulating flow in the basin from April 1945 to March 1951 and remained at zero during the succeeding simulation. The water-table and potentiometric heads at the assigned nodes in these groups were also coincident during most of the period April 1945 to March 1969. Thus, the simulated conditions conform closely to the qualitative descriptions of basin hydrology discussed above.

Figure 13 shows flow charts that describe the model modifications applied to various subroutines of the Pinder model where:

IDI and JDI are the row and column boundaries of a nodal group.

ALAG is the differential between the water-table and potentiometric heads beyond which leakage is terminated.

SNEW (I, J) is the storage coefficient assigned to a node after leakage is terminated.

RCHG is the additional recharge, if any, applied to a node after leakage is terminated.

RHO, DUMMY, D, and DUMDUM are variables used in the original model.

The information presented in the flow charts can be used to analyze any one of the nodal groups shown in figure 12. During calibration of the model the same logic was applied sequentially to each of the four groups, the only variation being the value of variables such as SNEW, ALAG, and RCHG.

Other information required by the model basin to compute leakage includes the hydraulic conductivity (HYCOND), the specific storage (SS), and the thickness (RATE) of the hypothetical confining bed. For this study values of HYCOND and SS were constant at every leakage node and equaled 3.5×10^{-8} ft/s (1.0×10^{-8} m/s) and 6.0×10^{-6} ft^{-1} (1.8×10^{-6} m^{-1}). Values of RATE were allowed to vary at the appropriate nodes and were determined during calibration of the model. Figure 14 shows the RATE values applied to the model basin for both the steady-state and transient-state simulations.

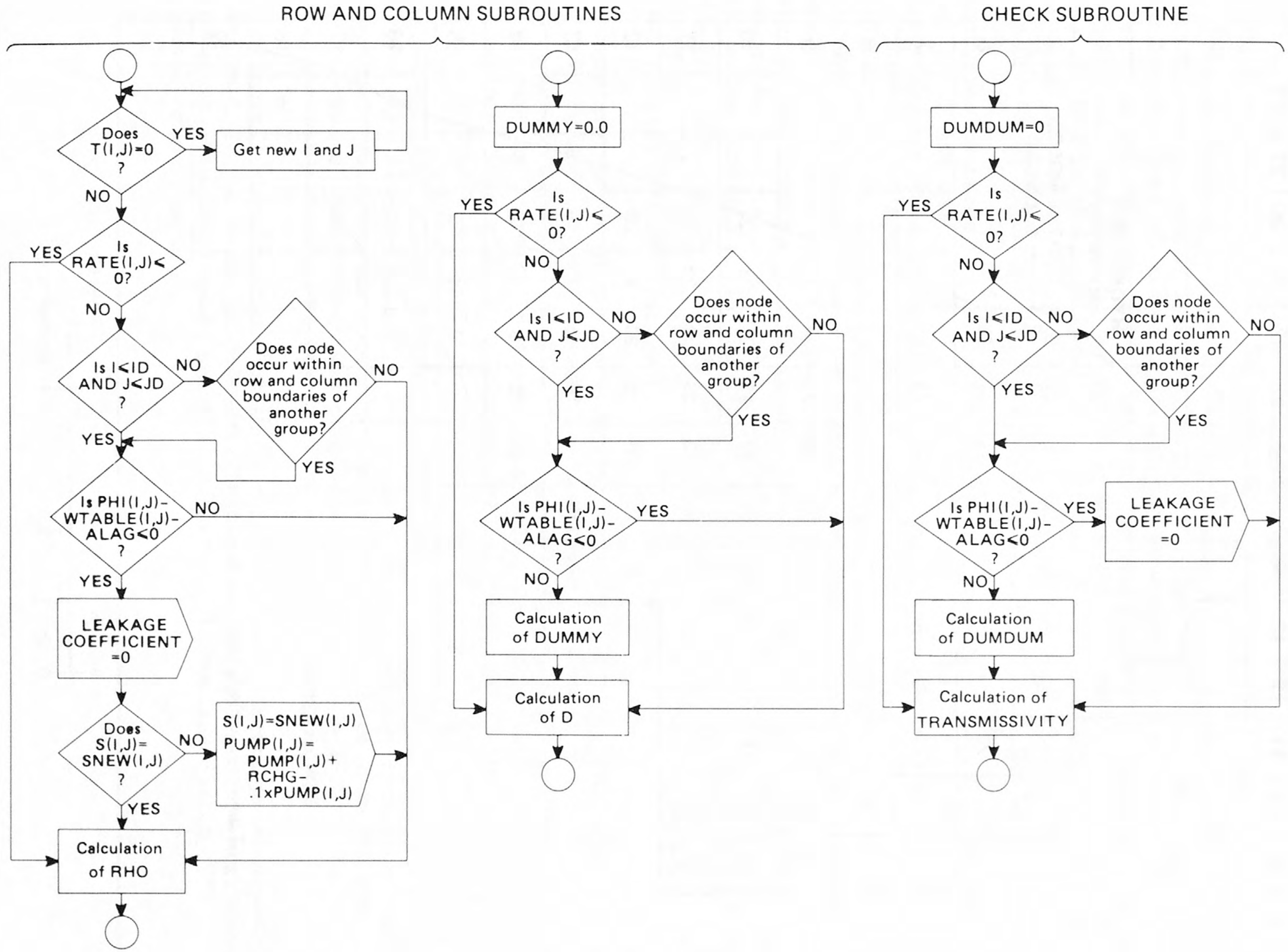

FIGURE 13.--Model modifications applied to various subroutines of the Pinder model.

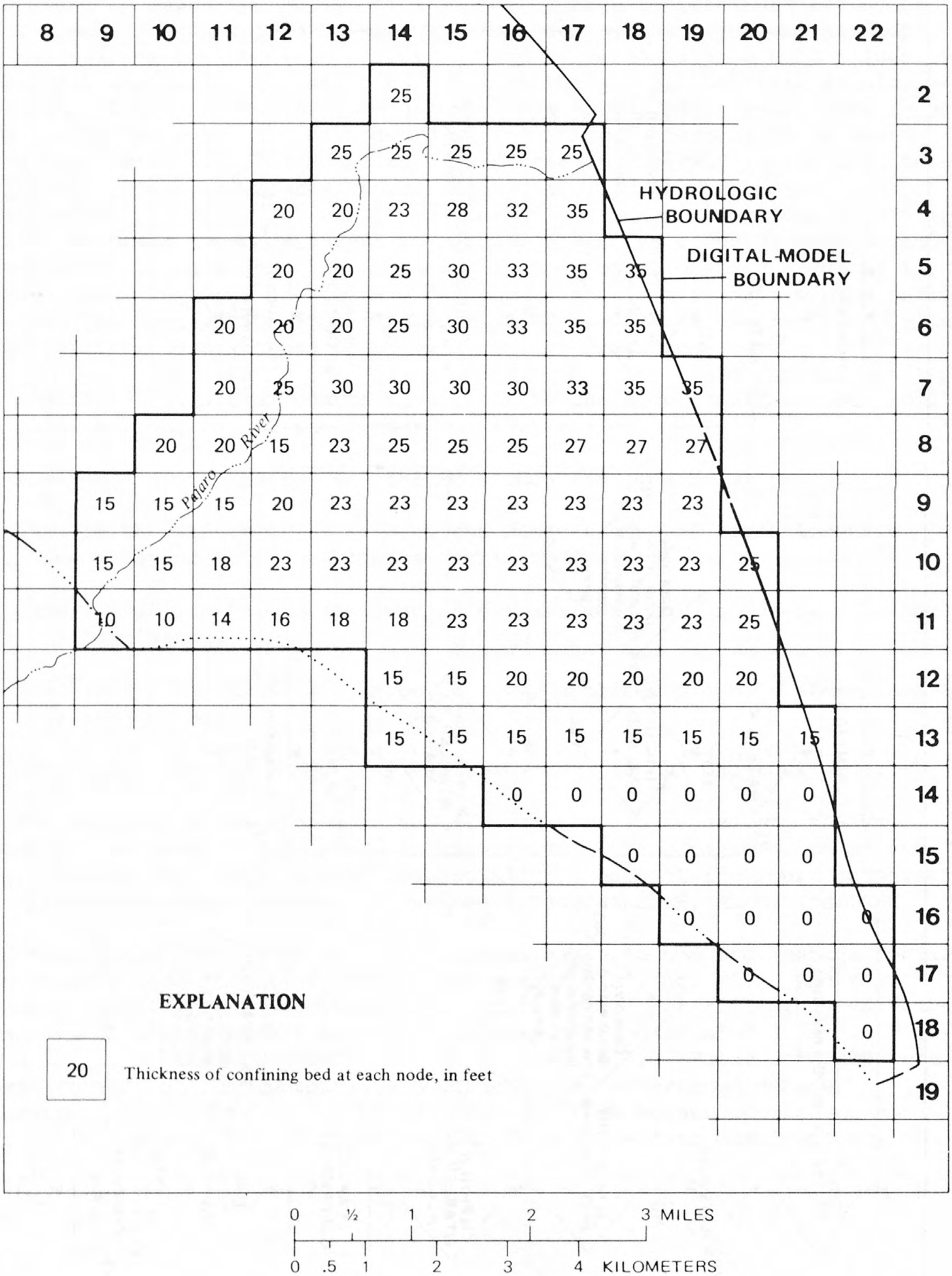

FIGURE 14.--Distribution of RATE values used in the model.

Simulation of Predevelopment Conditions

Predevelopment (steady-state) conditions were simulated using the information in figures 3, 8, 10, and 14 together with other pertinent quantitative data discussed previously. Figure 15 shows the net nodal quantities and distribution of simulated predevelopment recharge to the West Bolsa basin. Recharge to the model from rain was assumed to occur at every node in rows 14 through 18 and was 0.03 ft^3/s (0.0008 m^3/s) or 1.6 in (41 mm) per node per year. Simulation of recharge to the basin from minor streams was provided along the southwestern periphery of the basin at nodes 14-16, 15-18, 16-19, and 17-20 and was 0.02 ft^3/s (0.0006 m^3/s) per node per year. Subsurface recharge to the southern part of the model basin was applied at node 18-22 and was 1.30 ft^3/s (0.04 m^3/s) or 940 acre-ft (1.2 hm^3) per year. Subsurface recharge to the model from the southern part of Santa Clara Valley was simulated by applying constant heads at nodes 2-14, 3-13, 3-15, 3-16, 3-17, 4-12, 5-12, 6-11, 7-11, 8-10, 9-9, 10-9, and 11-9. In the Pinder model, constant-head nodes respond as infinite sources of water or infinite sinks for water: A constant-head node will provide or receive whatever quantity of water is required by adjacent nodes, independent of the model operator. During the satisfactory simulation of predevelopment conditions, the constant-head nodes provided a net recharge of 9.64 ft^3/s (0.28 m^3/s) or 6,980 acre-ft (8.6 hm^3) per year to the model. Total recharge to the basin during predevelopment times was calculated to be 11.6 ft^3/s (0.33 m^3/s) or about 8,400 acre-ft (10 hm^3) per year.

Predevelopment discharge from the basin was simulated as leakage from the confined aquifer. This leakage was computed by the model basin as discharge across the hypothetical confining bed and was not directly determined by the model operator. Figure 16 shows quantities and distribution of leakage from the basin at each node in inches per year as simulated by the model. Note that large quantities of water were discharged in the northern part of the basin where the greatest difference between potentiometric heads and land surface occurred during predevelopment times. Leakage progressively declines to the south as confinement in the basin decreases and the potentiometric and water-table heads become more coincident. Total discharge from the basin during predevelopment times was computed to be 11.6 ft^3/s (0.33 m^3/s) or 8,400 acre-ft (10 hm^3) per year.

Figure 3 shows contours of the simulated predevelopment potentiometric heads in the West Bolsa ground-water basin and indicates a close agreement between the simulated heads and the potentiometric surface during predevelopment times.

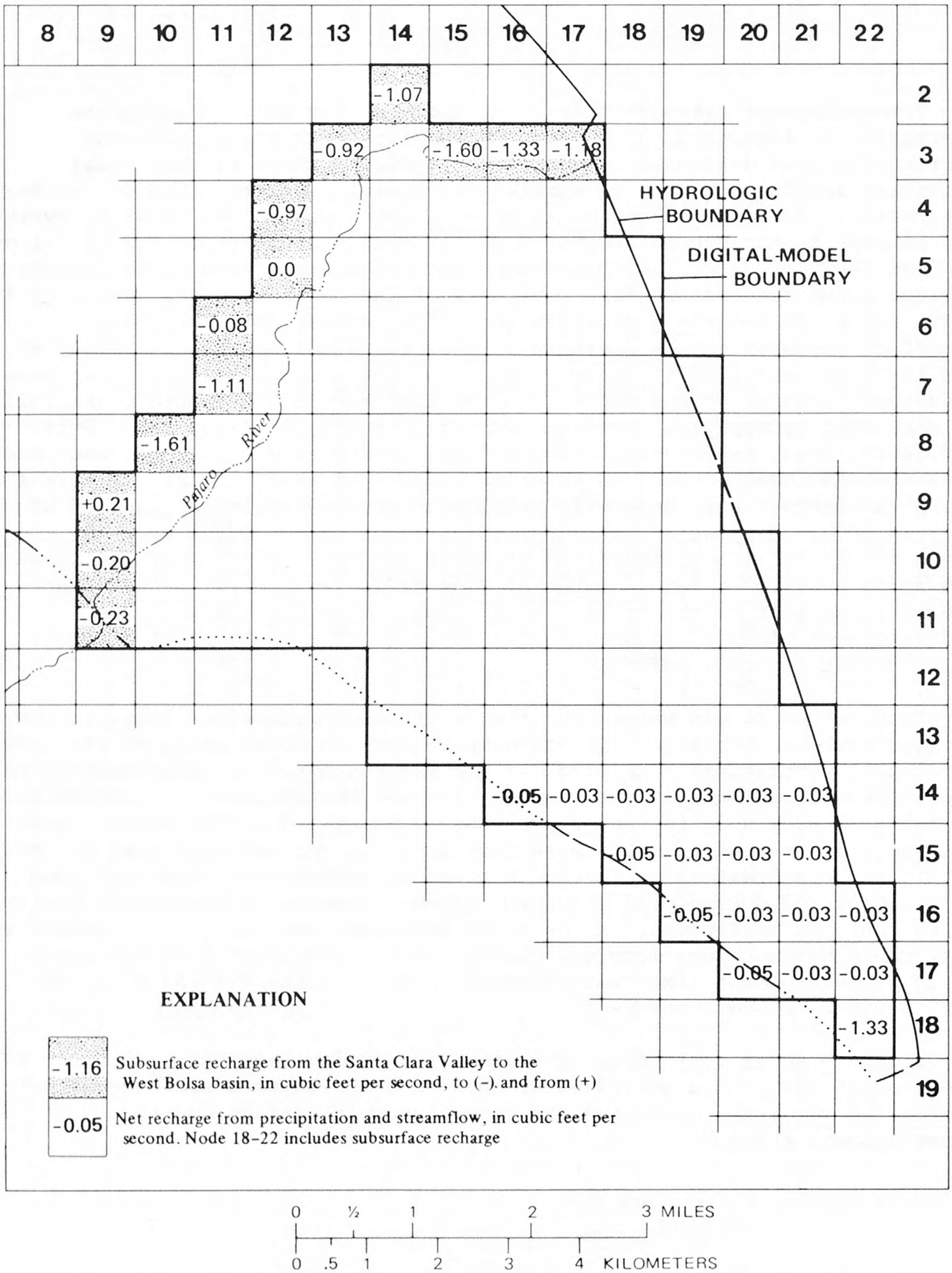

FIGURE 15.--Simulated predevelopment recharge to the basin.

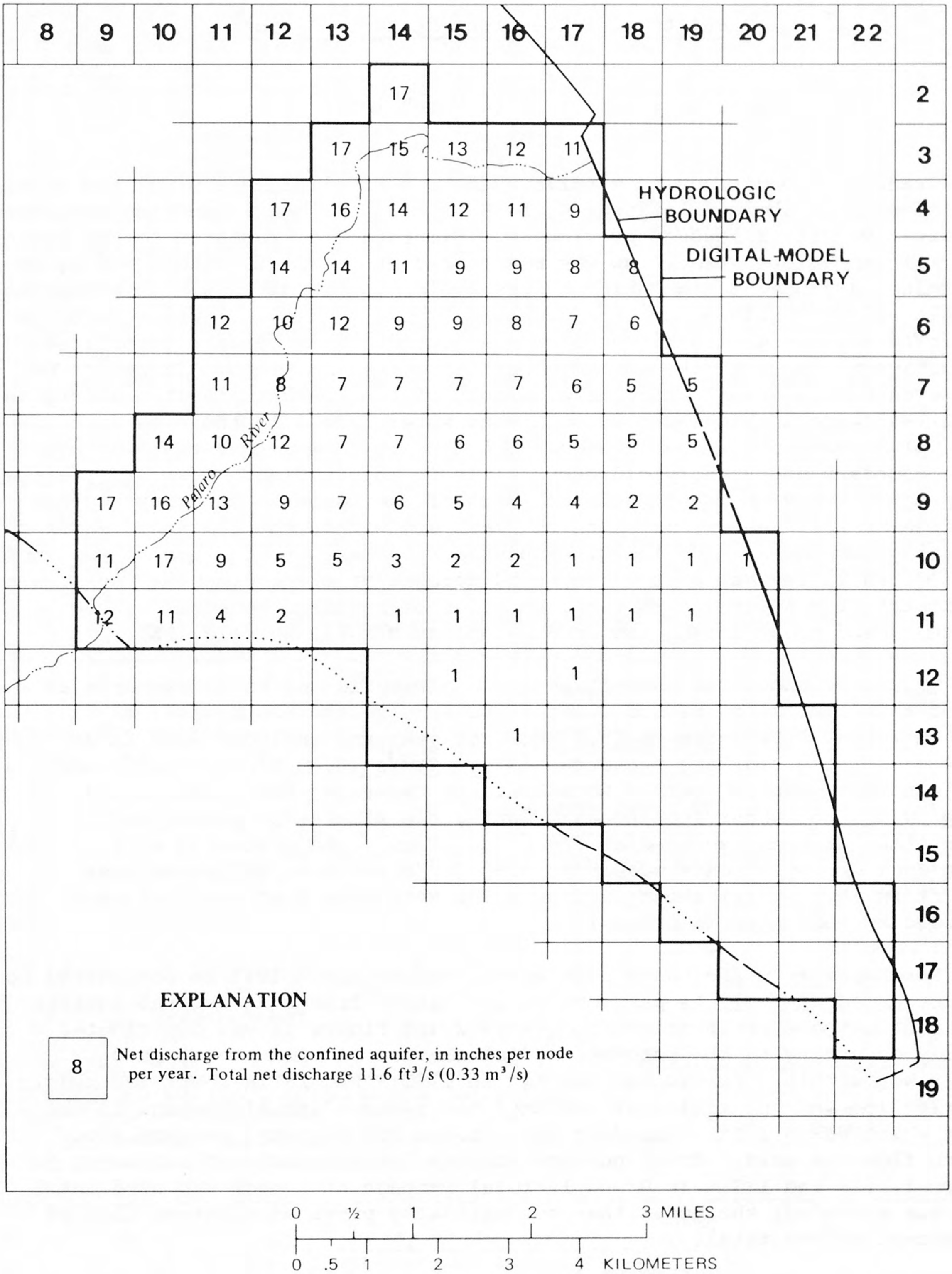

FIGURE 16.--Simulated predevelopment discharge from the basin.

Simulation of Transient-State Conditions

April 1945 to March 1951

Transient conditions from April 1945 to March 1951 were simulated using the information shown in figures 4, 5, 8, 9, 11, 12, and 14 and the pertinent quantitative data discussed previously. Simulation of recharge to the basin from rain and minor streamflow was maintained at the distribution and rates determined during the simulation of predevelopment conditions. An exception to this rule was allowed for the nodes in Group IV (fig. 12) where recharge from rain and irrigation return flow was provided when leakage terminated. Subsurface recharge to the southern part of the basin was considered to be zero even though ground-water levels south of the southern fault boundary in April 1945 were as high as predevelopment water levels in the same area (fig. 4). Some subsurface recharge to the basin from across the southern fault boundary undoubtedly did occur early in this period. However, seasonal and progressively increased pumpage south of the basin so interrupted this recharge that it was estimated to be small and within the limits of error for computing pumpage at node 18-22. Subsurface recharge to the basin from south Santa Clara Valley was assumed to be 50 percent of predevelopment recharge and was distributed according to the quantities of recharge computed at the constant-head nodes during the predevelopment simulation (fig. 15).

Figure 17 shows the quantities and distribution of basin recharge at the end of this simulation period. Total recharge to the basin was 5.82 ft^3/s (0.16 m^3/s) or 4,210 acre-ft (5.2 hm^3) per year and includes 4.82 ft^3/s (0.14 m^3/s) of subsurface recharge and 1.0 ft^3/s (0.03 m^3/s) of infiltration from minor streams and rain. Note that the recharge shown for any node in Group IV did not occur continuously during the simulation period but only after ALAG had been exceeded at the node. Thus, total recharge to the model basin from Group IV nodes was about 0.38 ft^3/s (0.01 m^3/s) rather than the 0.78 ft^3/s (0.02 m^3/s) shown in figure 17. Note also that ALAG was never exceeded at node 11-9 in Group IV.

Discharge from the basin from April 1945 to March 1951 is considered to have occurred entirely as pumping and as leakage from the confined aquifer. Pertinent pumpage information from table 2 and figure 11 was distributed nodally according to the percentage distribution of known total pump horsepower within a particular subunit in 1951. Figure 18 shows the nodal distribution and quantities of computed net average annual pumpage in the basin which was 8.1 ft^3/s (0.23 m^3/s). Below row 13 total pumpage minus return flow was used. Total pumpage was used continuously at all nodes in Groups I, II, and III. In Group IV total pumpage at a node was used until ALAG was exceeded; the model then automatically provided a return flow of 10 percent of the total.

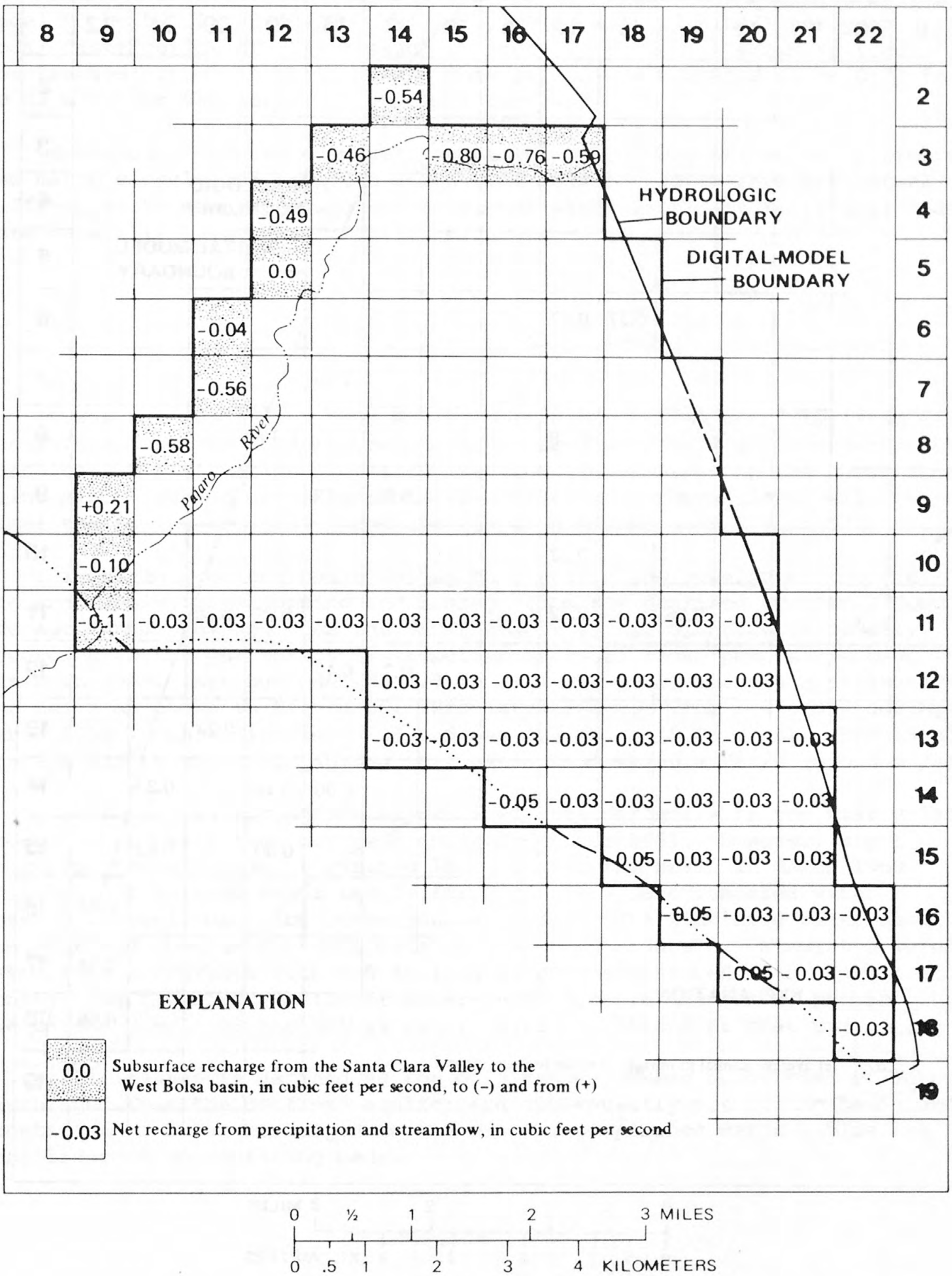

FIGURE 17.--Net average annual recharge to the basin at the end of the period April 1945 to March 1951 and during the period March 1951 to March 1969.

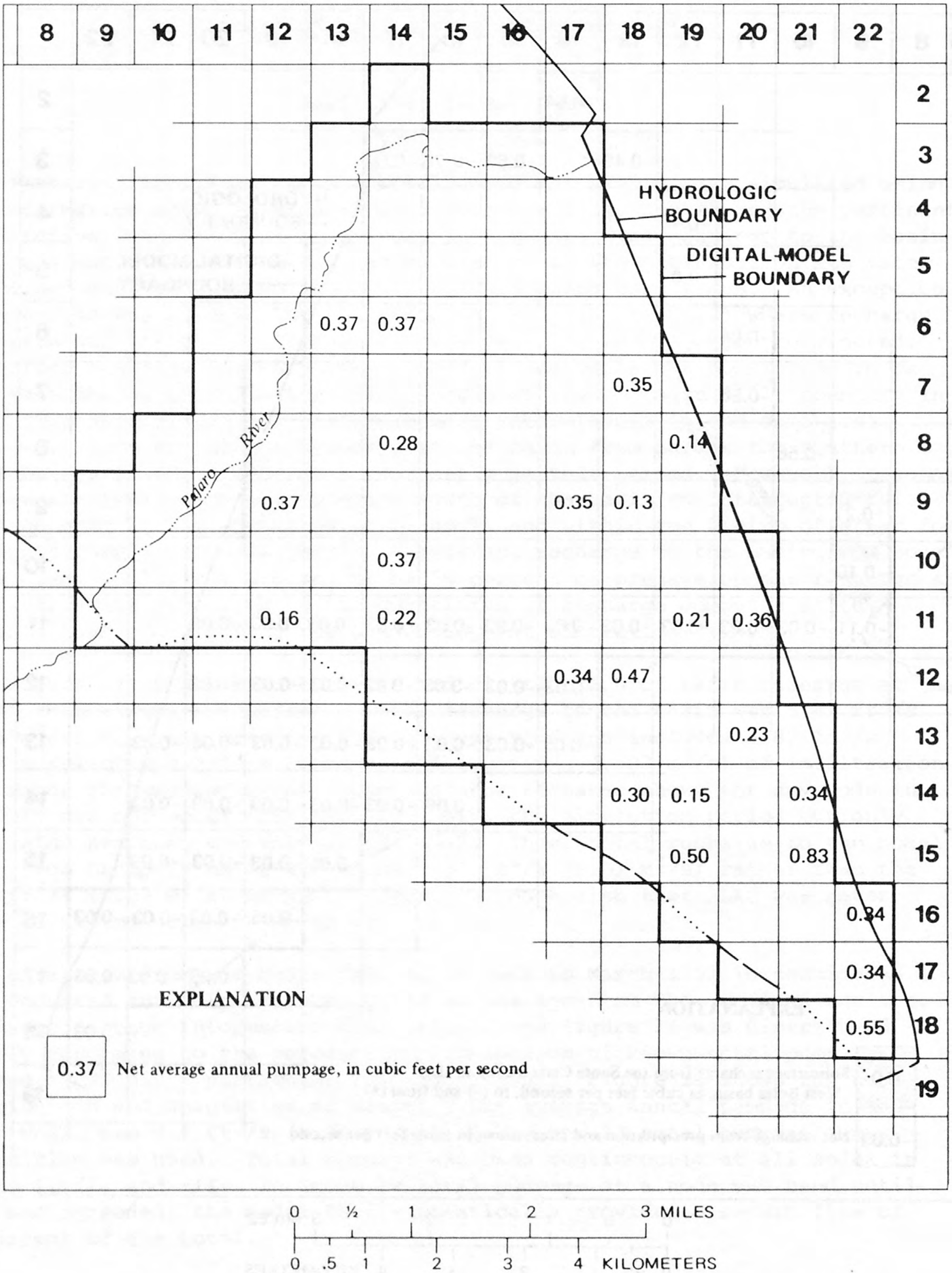

FIGURE 18.--Net average annual pumpage in the basin, April 1945 to March 1951.

Leakage from the confined aquifer for April 1945 was computed by the model to be 5.1 ft^3/s (0.14 m^3/s) or 3,700 acre-ft (4.6 hm^3) per year. The nodal distribution of this leakage in inches per year is shown in figure 19. Net leakage[1] from the basin during this period was computed to be 0.73 ft^3/s (0.02 m^3/s) or 530 acre-ft (0.67 hm^3) per year.

Contours of simulated water levels for March 1951 are shown in figure 5 and match closely the contours drawn from measured water levels. Actual differences between measured and simulated water levels at individual nodes were generally less than 5 ft (1.5 m).

March 1951 to March 1969

Transient conditions from March 1951 to March 1969 were simulated using the information shown in figures 5, 6, 8, 12, 14, and 17 and the pertinent quantitative information discussed previously. Recharge to the basin from rain, minor streamflows, and subsurface flows from Santa Clara Valley was simulated at the same rates and distribution as shown in figure 17.

Discharge from the basin during this period was considered to have occurred entirely as pumping and leakage from the confined aquifer. Computed average annual pumpage from the basin (table 2) was distributed nodally according to the percentage distribution of total known pump horsepower in the basin in 1968. Net pumpage was 7.8 ft^3/s (0.22 m^3/s) and was distributed in the basin as shown in figure 20. Simulated leakage from the basin during March 1951 is shown in figure 21 and was 1.7 ft^3/s (0.05 m^3/s). Simulated net leakage was to the basin during this period and was 0.3 ft^3/s (0.008 m^3/s).

Comprehensive springtime water-level data for wells in the West Bolsa ground-water basin have not been collected since 1951. However, eight measurements were made at various locations in the basin in March 1969 (fig. 6). Simulated water levels for March 1969 were compared with observation-well data for corresponding nodes. The simulated water-level contours and observation-well data are shown in figure 6. Simulated water levels are everywhere within 8 ft (2.4 m) of the measured water levels and, considering the distribution of water-level data in the basin, probably have adequately simulated the actual water-level conditions at that time.

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[1]Net leakage is defined as the difference between quantities of water discharged from the confined aquifer and subsequently out of the basin and quantities of water recharged to the basin from perched water tables and consolidation of confining beds.

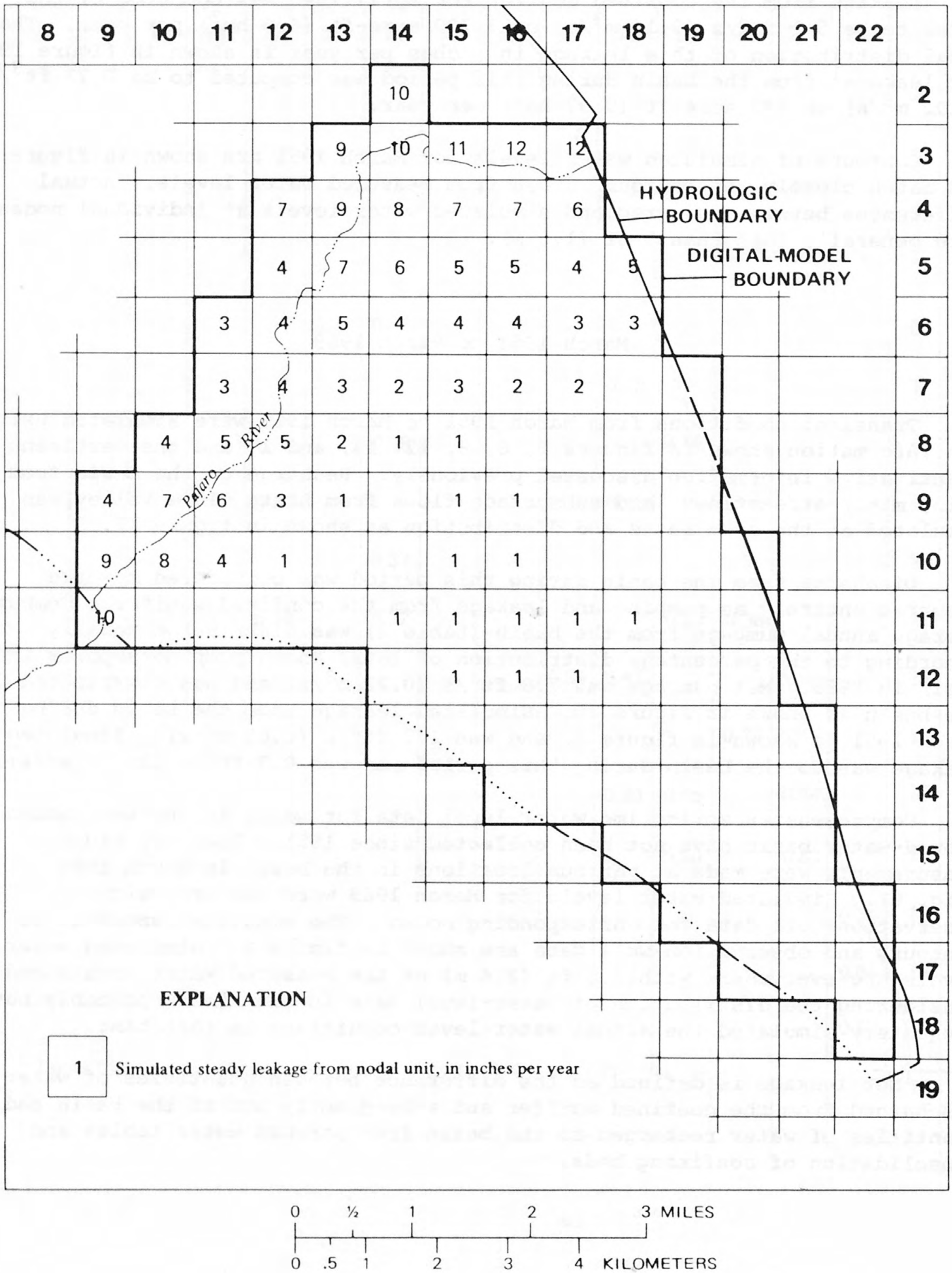

FIGURE 19.--Simulated leakage from the basin, April 1945.

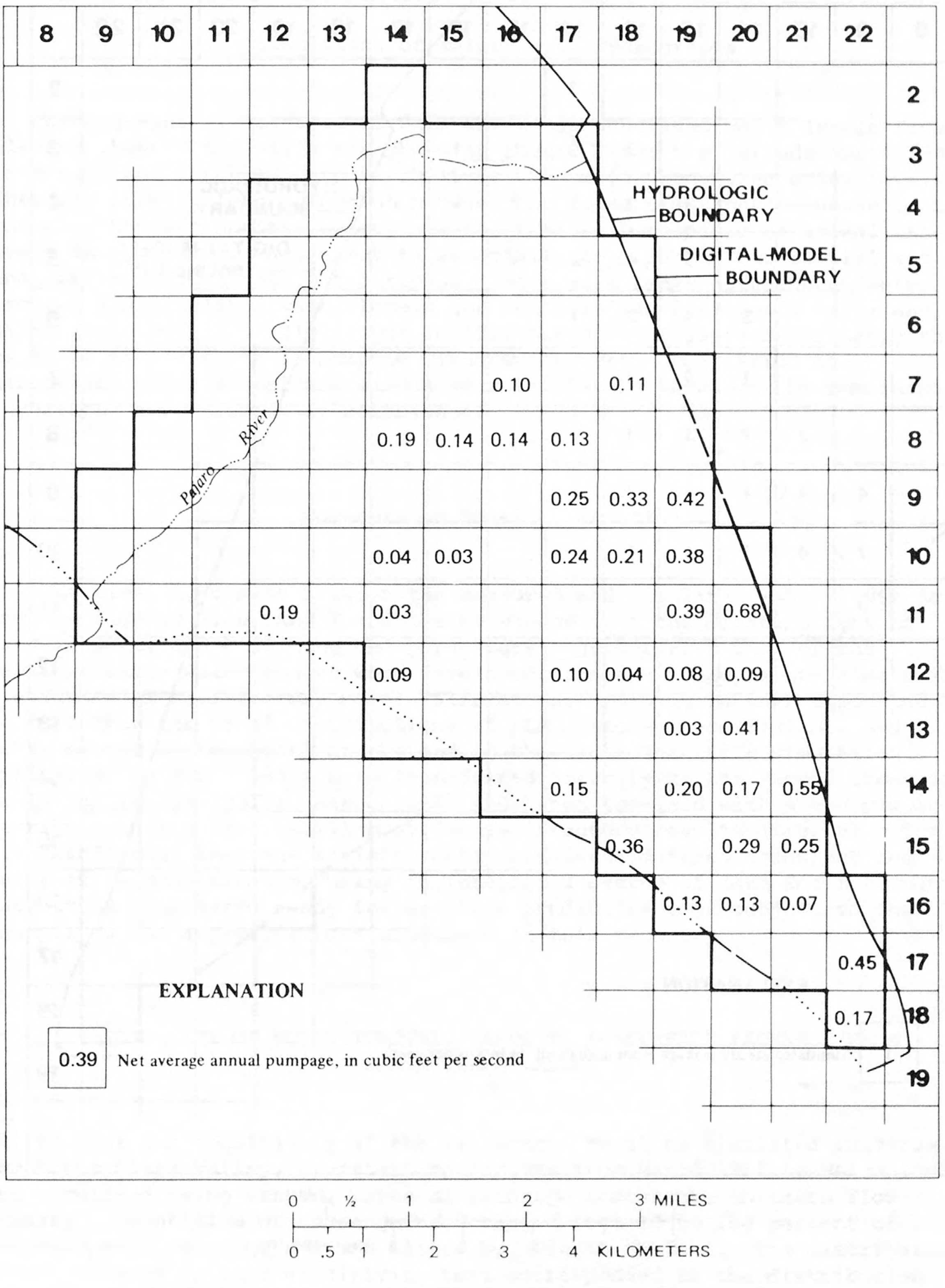

FIGURE 20.--Net average annual pumpage from the basin, March 1951 to March 1969.

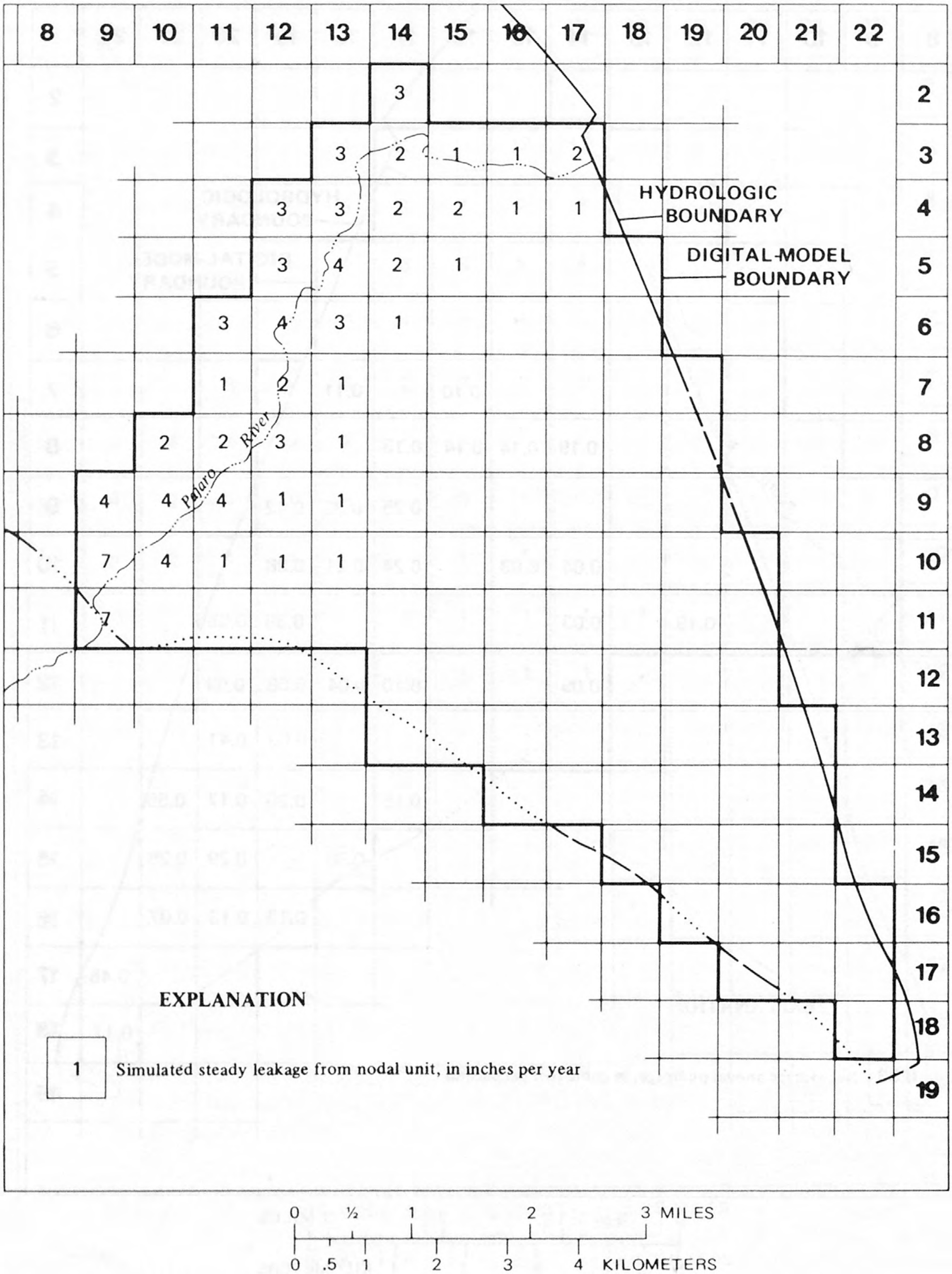

FIGURE 21.--Simulated leakage from the basin, March 1951.

Simulation of Water-Level Hydrographs

Hydrographs of water-level data and model-generated water levels from selected observation wells are shown in figure 7 for the periods April 1945 to March 1969 and March 1950 to March 1969. The model-generated water levels generally show a close agreement between the total transient response of the model, at the appropriate nodes, and the transient response of actual water levels in the basin. Agreement is especially good during the initial and final parts of the transient periods. There were large differences between measured and simulated water levels for wells 11S/4E-24L1 (node 6-15) and 12S/5E-21Q1 and 12S/5E-21Q3 (node 18-22); the differences were probably the result of highly variable pumping withdrawals during the period of measurement. The actual and simulated water levels shown on the remaining hydrographs are practically coincident.

Comments on Model Calibration

The close agreement between the measured and simulated water-level data shown in figures 5, 6, and 7 and the knowledge that the distributions of transmissivity and confining bed parameters together with much of the transient-state water budget were developed from the steady-state simulation is evidence of satisfactory model calibration. This is further supported by the fact that the nodal distributions of ALAG, storage coefficient, and recharge used by the model at the end of the first transient simulation (April 1945 to March 1951) were transferred directly to the second transient simulation (March 1951 to March 1969) and, when combined with a new pumpage distribution (fig. 20), still provided satisfactory results (fig. 6). The calibrated model has thus satisfactorily simulated defined transient and steady-state conditions by using an integrated system of data and information. Thus, it is considered ready for use as a predictive tool subject to the assumptions and approximations discussed in this report.

SENSITIVITY OF POTENTIOMETRIC HEADS TO SUBSURFACE RECHARGE FROM SANTA CLARA VALLEY

To test the sensitivity of the calibrated model to simulated recharge from Santa Clara Valley, transient conditions from March 1951 to March 1969 were simulated using varying rates of recharge across the northern flow boundary. Quantities of recharge used ranged from 10 to 100 percent of predevelopment recharge and are listed by node in table 3. The distribution of the recharge in this sensitivity test corresponded to the distribution computed at constant-head nodes during the simulation of predevelopment conditions.

TABLE 3.--*Nodal quantities of recharge used in sensitivity analysis*

Node	Percentage of predevelopment recharge, in cubic feet per second				
	10	25	50	75	100
2-14	-0.10	-0.25	-0.54	-0.80	-1.1
3-13	-.04	-.23	-.46	-.69	-.92
3-15	-.16	-.40	-.80	-1.20	-1.6
3-16	-.13	-.33	-.76	-1.00	-1.3
3-17	-.12	-.30	-.59	-.89	-1.2
4-12	-.10	-.24	-.49	-.73	-.97
5-12	.0	.0	.0	.0	.0
6-11	-.01	-.03	-.04	-.06	-.08
7-11	-.11	-.27	-.56	-.83	-1.1
8-10	-.12	-.30	-.58	-.87	-1.2
9-9	+.02	+.05	+.21	+.16	+.21
10-9	-.02	-.05	-.10	-.16	-.20
11-9	-.02	-.05	-.11	-.17	-.23
Total	-0.90	-2.40	-4.82	-7.24	-9.69

The results of the sensitivity analysis are shown in figure 22. The zero line in the figure represents zero departure from measured March 1969 water levels in observation wells which correspond to particular nodes in the model. The deviation from the zero line, in feet, at a given node is shown for varying quantities of simulated recharge from Santa Clara Valley. The extremes of the deviations, shown by dotted lines, define the sensitivity limits of the model with respect to the various quantities of recharge. A recharge of 50 percent of the steady-state flow from the Santa Clara Valley had been used to calibrate the model during the period March 1951 to March 1969. As would be expected, the deviations of the computed heads from the zero line at 50 percent recharge are less than the deviations for other recharge quantities tested.

Figure 22 shows a relatively large disparity between simulated heads at the same node, depending on the quantity of water recharged to the model from Santa Clara Valley. The difference between heads computed using 10 percent and 100 percent of predevelopment recharge is about 15 ft (4.6 m). Thus, one can conclude that relatively large changes in recharge from Santa Clara Valley to the West Bolsa basin will result in similarly large changes in water levels in the basin.

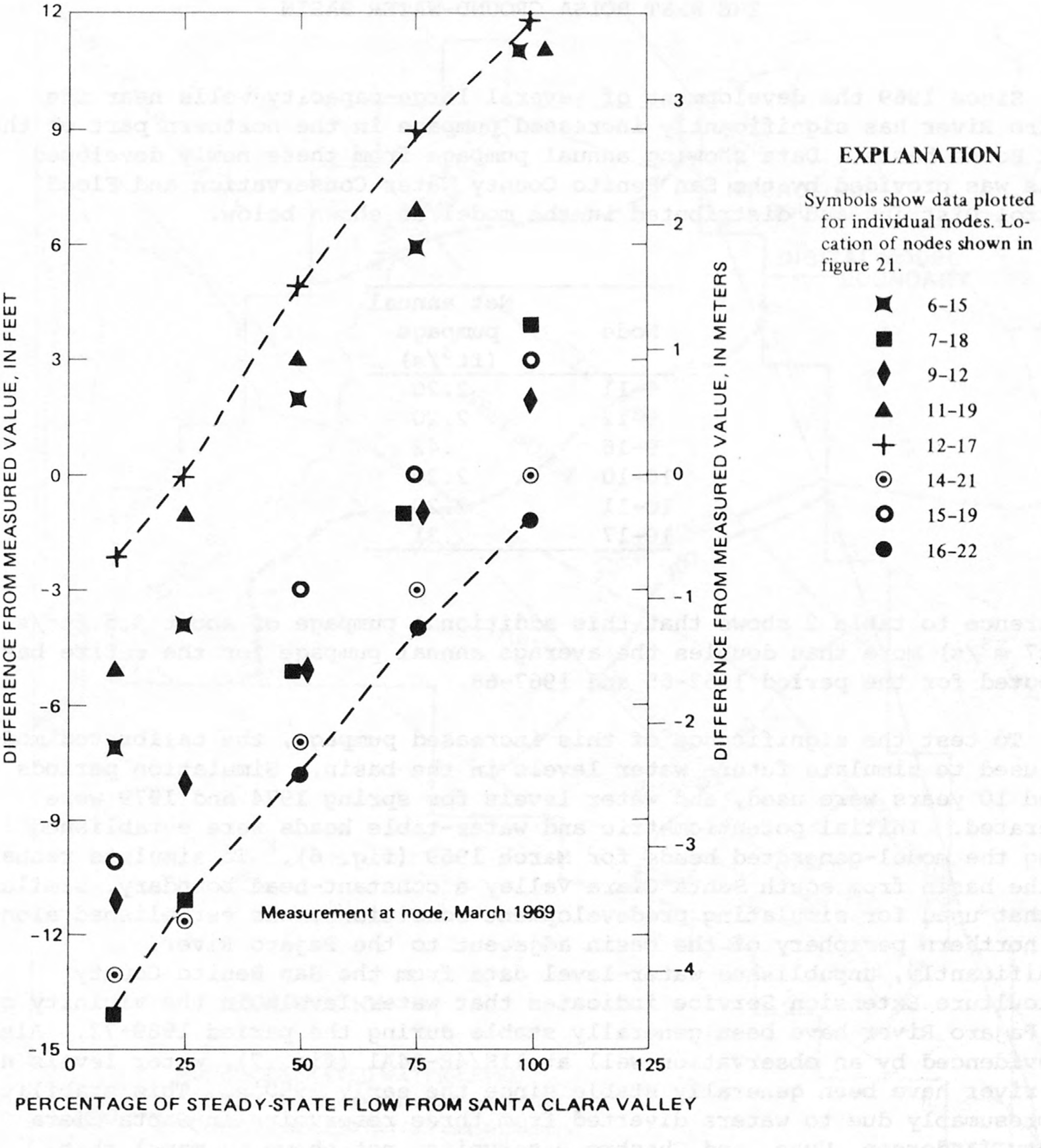

FIGURE 22.--Measured and simulated heads in the basin at given rates of simulated recharge from Santa Clara Valley, March 1969.

SIMULATION OF FUTURE WATER-LEVEL CONDITIONS IN THE WEST BOLSA GROUND-WATER BASIN

Since 1969 the development of several large-capacity wells near the Pajaro River has significantly increased pumpage in the northern part of the West Bolsa basin. Data showing annual pumpage from these newly developed wells was provided by the San Benito County Water Conservation and Flood Control District and distributed in the model as shown below.

Node	Net annual pumpage (ft^3/s)
9-11	2.20
9-12	2.20
9-16	.42
10-10	2.20
10-11	2.20
10-17	.31

Reference to table 2 shows that this additional pumpage of about 9.5 ft^3/s (0.27 m^3/s) more than doubles the average annual pumpage for the entire basin computed for the period 1962-65 and 1967-68.

To test the significance of this increased pumpage, the calibrated model was used to simulate future water levels in the basin. Simulation periods of 5 and 10 years were used, and water levels for spring 1974 and 1979 were generated. Initial potentiometric and water-table heads were established using the model-generated heads for March 1969 (fig. 6). To simulate recharge to the basin from south Santa Clara Valley a constant-head boundary, similar to that used for simulating predevelopment conditions, was established along the northern periphery of the basin adjacent to the Pajaro River. Significantly, unpublished water-level data from the San Benito County Agriculture Extension Service indicates that water levels in the vicinity of the Pajaro River have been generally stable during the period 1969-73. Also, as evidenced by an observation well at 11S/4E-34A1 (fig. 7), water levels near the river have been generally stable since the early 1950's. This stability is presumably due to waters diverted from three reservoirs in Santa Clara County (Anderson, Uvas, and Chesbro Reservoirs, not shown on maps) that recharge the aquifer near the Pajaro River. Other recharge and discharge conditions in the model were maintained at the rates described for the period March 1951 to March 1969. The exception to this rule occurred at the nodes listed above where the more recent pumpage either replaced entirely or was superimposed upon the earlier pumpage values shown in figure 20. Figures 23 and 24 show simulated water-level contours in the basin at the end of the designated simulation periods.

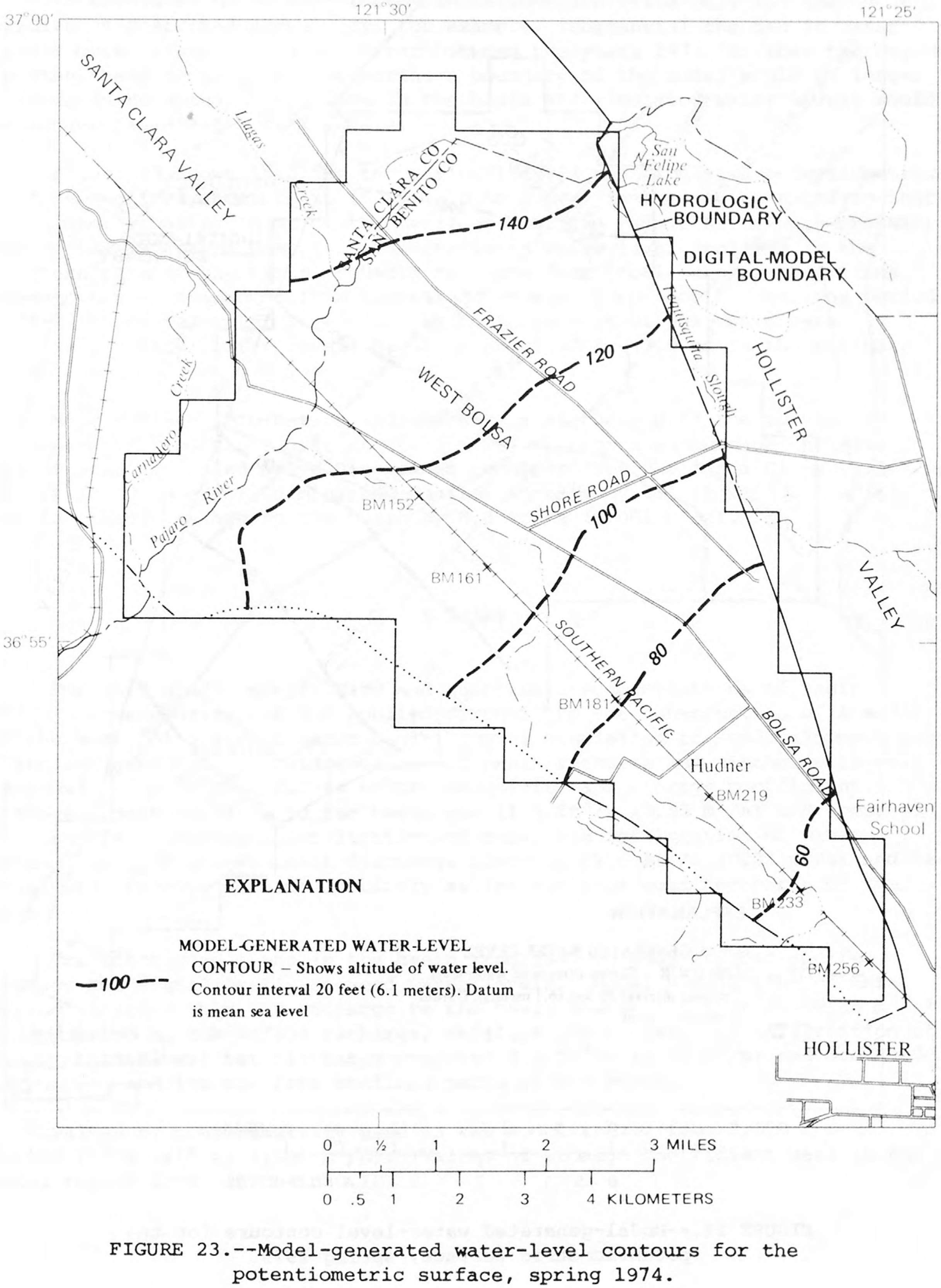

FIGURE 23.--Model-generated water-level contours for the potentiometric surface, spring 1974.

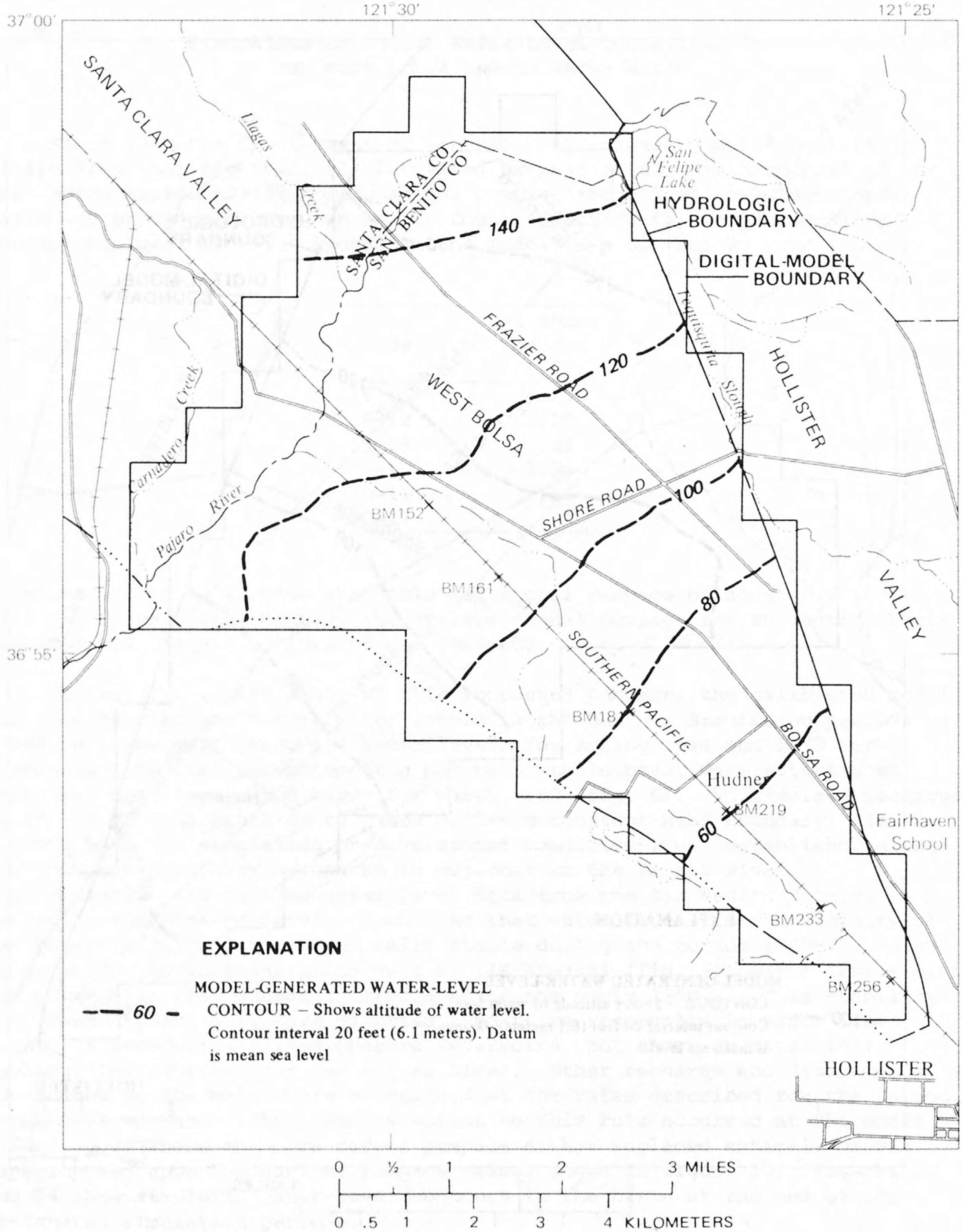

FIGURE 24.--Model-generated water-level contours for the potentiometric surface, spring 1979.

It should be noted that these simulations are valid only for the conditions described above. If, for example, substantial changes in water levels occur along the Pajaro River between the years 1973-79, then the use of constant-head nodes along the northern boundary of the model would no longer correspond to actual conditions in the basin and simulated water levels would no longer represent actual levels.

Figure 23 shows that for the period 1969-74 the simulated potentiometric surface declined about 10 to 15 ft (3.0 to 4.5 m) in the northern and southern parts of the basin. Most of the declines near the Pajaro River were probably due to the increased pumpage. The predicted water-level declines in the southern part of the basin probably resulted from local pumping conditions rather than as drawdowns from increased pumpage to the north. For the period 1974-79 predicted water levels in the northern part of the basin were generally static; water levels declined about 10 ft (3.0 m) in the southern part.

Mass balance information indicates that at the end of the 10-year simulation period the 9.5 ft^3/s (0.27 m^3/s) of increased pumpage, nodally distributed as listed above, increased recharge from the Santa Clara Valley by 8.1 ft^3/s (0.23 m^3/s), diminished aquifer storage by 1.1 ft^3/s (0.03 m^3/s), and increased leakage to the basin by 0.3 ft^3/s (0.001 m^3/s).

SUMMARY

For this study, qualitative and quantitative descriptions of basin hydrology were developed and applied directly to the construction of a model of the West Bolsa ground-water basin. Model simulation of predevelopment and transient conditions provided values of basin recharge and discharge as well as nodally distributed values of transmissivity and storage coefficient. Predevelopment recharge to the basin was 11.6 ft^3/s (0.33 m^3/s) and occurred as subsurface recharge, infiltration of rain, and infiltration of minor streamflows. Predevelopment discharge also was 11.6 ft^3/s (0.33 m^3/s) and is considered to have occurred entirely as leakage from confined parts of the basin.

Transient conditions in the basin from 1945 to 1969 reduced aquifer storage and significantly reduced water levels. Model simulations of this period indicate that net recharge to the basin averaged 6.2 ft^3/s (0.18 m^3/s) and occurred as subsurface recharge, infiltration of rain and infiltration of minor streamflows; net discharge averaged 8.1 ft^3/s (0.23 m^3/s) and occurred as pumping and leakage from confined parts of the basin.

Values of transmissivity used in the model ranged from 3,300 to 20,000 ft^2/d (310 to 1,900 m^2/d). Values of storage coefficient used in the model ranged from 0.0005 to 0.10.

An analysis of the sensitivity of potentiometric heads to simulated subsurface recharge from Santa Clara Valley indicates that heads in the basin vary about 15 ft (4.6 m) according to the quantity of the simulated recharge. The predictions made with the model for the periods 1969-74 and 1974-79 indicate that water levels would decline about 10 to 15 ft (3.0 to 4.6 m) in the northern and southern parts of the basin until 1974. After 1974, the northern levels would remain static. Water levels in the southern part of the basin would continue to decline another 10 ft (3.0 m) by 1979.

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