GROUND WATER IN THE FRESNO AREA, CALIFORNIA--
PRELIMINARY REPORT

By Hugh T. Mitten

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4246

Prepared in cooperation with

FRESNO COUNTY

6417-05

Sacramento, California

May 1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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ILLUSTRATIONS

CONVERSION FACTORS

For readers who prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below.

Multiply	By	To Obtain
ft (foot)	0.3048	m (meter)
ft/d (foot per day)	0.3048	m/d (meter per day)
in/yr (inch per year)	25.4	mm/a (millimeter per annum)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

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ABSTRACT

In 1978, the U.S. Geological Survey began a study of the unconfined-aquifer system in the Fresno area. A flow model is used as a tool to better understand that system. The model, after calibration, can be used to evaluate effects of stresses in this rapidly developing area.

The model area includes about 1,840 square miles in parts of Fresno and Madera Counties and is underlain by an impermeable basement complex. Overlying the complex is a sequence of consolidated and poorly permeable marine and continental sedimentary rocks which in turn are overlain by unconsolidated deposits that extend to the land surface. The unconsolidated deposits are divided into lower fine-grained sediments and overlying coarse-grained sediments. Fresh ground water occurs within the saturated section of the coarse-grained sediments.

The alluvial aquifer is assumed to be a single unconfined unit. The top is the water table and the bottom is the base of the coarse-grained deposits. The northeastern boundary is the only natural lateral hydrologic boundary and approximately parallels the foothills of the Sierra Nevada. The other lateral boundaries were placed far enough from the city of Fresno and would not affect computed heads in that area.

In the model study, the top of the system was simulated as a constant-head surface under steady-state conditions and a free surface under transient conditions. The bottom of the coarse-grained sediments was assumed to be a no-flow boundary because field evidence indicated there was very little water moving upward from the fine-grained sediments. All the lateral boundaries were modeled as constant-flux boundaries; in some places the flux may be zero.

Initial heads for the spring of 1943, hydraulic conductivity, and bottom altitudes of the coarse-grained sediments were used in a steady-state finite-difference two-dimensional flow model that generated net flux values to be used later during model calibration.

INTRODUCTION

In October 1978, the U.S. Geological Survey began a cooperative study with Fresno County to model the ground-water system as part of the water-management plans for the Fresno metropolitan area.

The study area contains a large and rapidly growing metropolitan area surrounded by extensively developed agricultural land. The metropolitan area is dependent on ground water for water supply, and agriculture in the vicinity also makes substantial use of ground water. There is evidence of declines in ground-water levels and a deterioration of water quality. Either or both of these trends may eventually converge on usability of the ground-water resource.

The study area overlaps a concurrent modeling effort to the north in Madera County. The area also has been included in a regional model of the entire Central Valley.

Purpose and Scope

The purpose of the study is to improve the understanding of the unconfined aquifer in the coarse-grained sediments in the Fresno area. The scope of the study is to develop a calibrated flow model that may be used to estimate the impact of stresses on the ground water in the coarse-grained sediments. The scope also includes gathering and processing existing data and estimating aquifer and stress parameters which are used for model input and calibration.

This report, the first of two planned reports, describes the geohydrology and concepts of the flow of water in the area, the progress of data collection, analysis, and modeling, and future work.

Acknowledgments

Data collection for this report was made possible by the cooperation of various agencies. Mr. Timothy R. Cockrum of Fresno County was especially helpful in collecting and interpreting data. The California Department of Water Resources furnished water-level and specific yield data. Additional specific yield data were obtained from Fresno County. Municipal utilities furnished municipal pumpage data.

GEOHYDROLOGIC SETTING

Location and Description of Study Area

The study area includes those parts of Fresno County and southern Madera County that lie west of the foothills of the Sierra Nevada and east of the axis of the San Joaquin Valley (figs. 1 and 2). It encompasses about 1,840 square miles and includes the city of Fresno (fig. 2). Two perennial rivers flow through the area, the San Joaquin River near the northern boundary and the Kings River near the southern boundary. Fresno Slough lies near the southwestern boundary, and the foothills of the Sierra Nevada lie along the northeastern boundary. In addition to the river systems, numerous smaller streams, sloughs, and canals carry water throughout the area.

Precipitation in the area averages about 10 inches per year and occurs mostly from October through May (Page and LeBlanc, 1969, p. 7).

Geology

Alluvial fans are the dominant physiographic features in the area (Page and LeBlanc, 1969, p. 11-14). Large extensive alluvial fans have been formed by the deposits of the Kings and San Joaquin Rivers. Between those rivers, small alluvial fans have been formed near the foothills by deposits from numerous intermittent streams.

The area is underlain at depths from zero to more than 13,000 feet by impermeable basement complex of igneous and metamorphic rocks (Page and LeBlanc, 1969, p. 13; Mitten, LeBlanc, and Bertoldi, 1970, p. 7) (see fig. 3). Overlying the basement complex is a sequence of consolidated marine and continental sedimentary rocks consisting primarily of shale, siltstone, and sandstone. This sequence underlies the area at depths greater than 1,000 feet (Page and LeBlanc, 1969, p. 13).

A sequence of unconsolidated deposits overlies the consolidated rocks and extends to land surface. These deposits consist of intercalated sand, silt, gravel, and clay (Page and LeBlanc, 1969, p. 14). This sequence is divided, on the basis of electric logs, into a lower fine-grained unit and an overlying coarse-grained unit (Page and LeBlanc, 1969, p. 14; Mitten, LeBlanc, and Bertoldi, 1970, p. 9).

Three mappable deposits of mostly silt and clay are interbedded in the upper coarse-grained unit in the western part of the area. These deposits are of low hydraulic conductivity and function as confining beds. From deepest to shallowest, they are designated the E-clay, the C-clay, and the A-clay. Approximate depth below land surface to the top of the E-clay is 460 feet; to the C-clay, 240 feet; and to the A-clay, 60 feet (Page and LeBlanc, 1969, pl. 9).

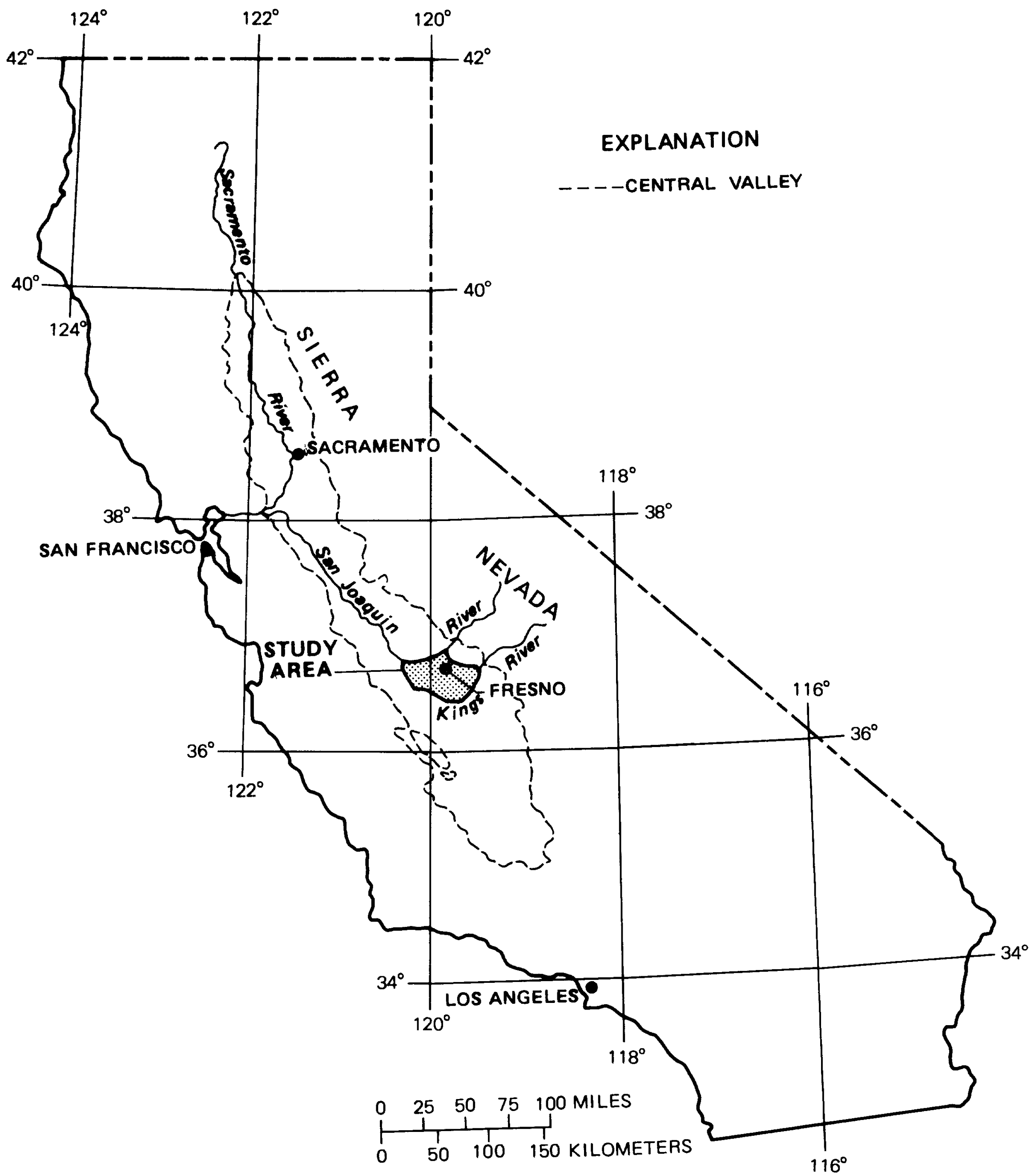


FIGURE 1. – Location of study area.

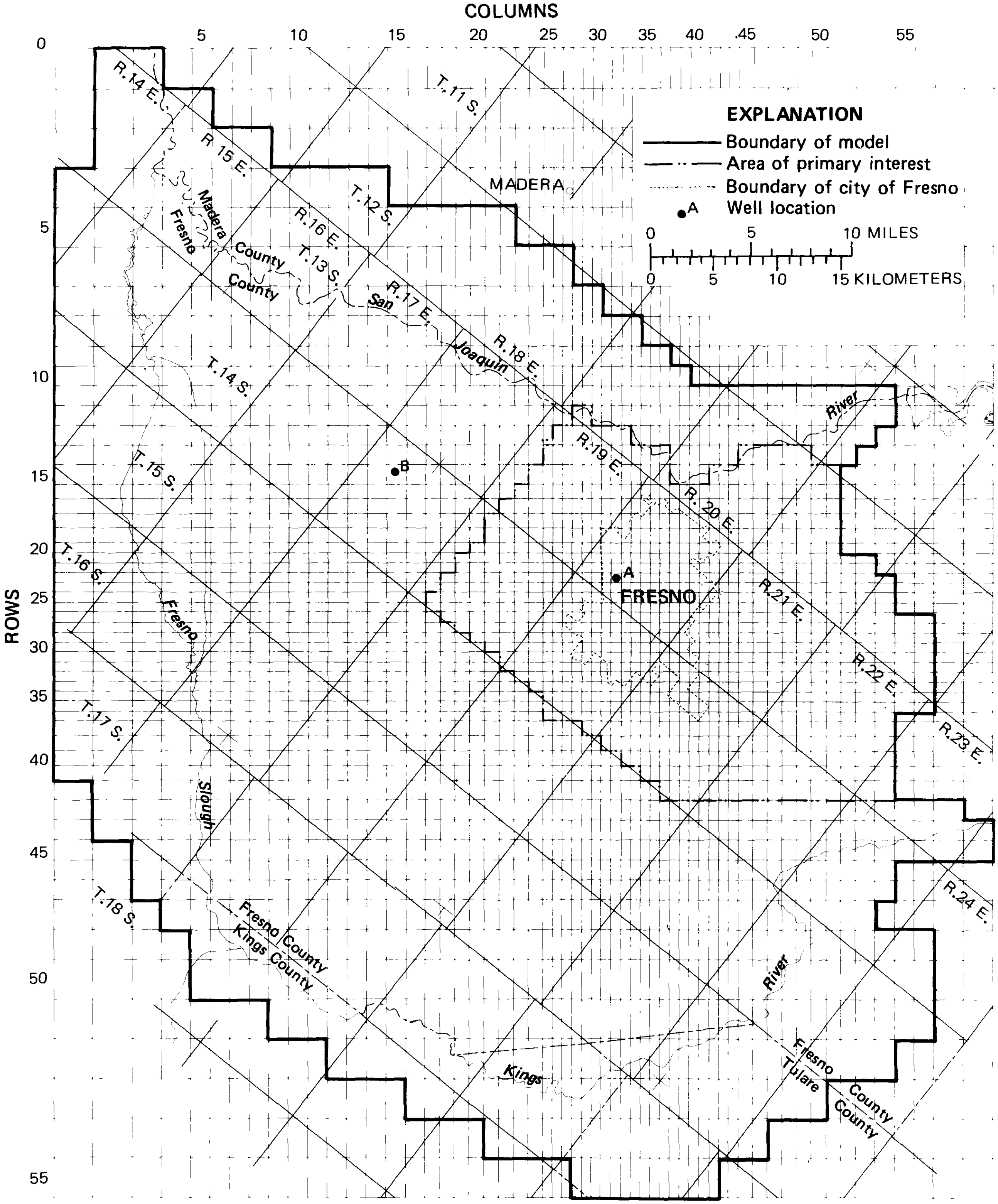


FIGURE 2. – Grid network and boundary of a digital model, Fresno area.

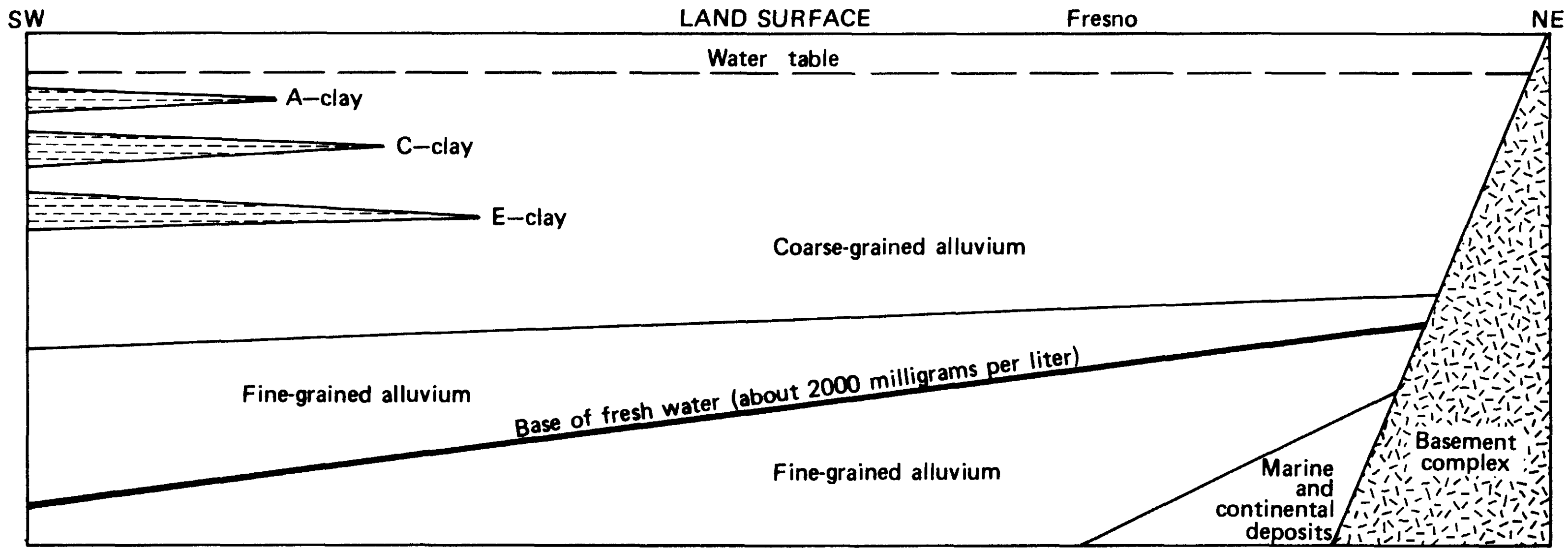


FIGURE 3. — Diagrammatic cross section of the Fresno area viewed from the southeast.

Most of the geologic units dip gently southwestward, approximately paralleling the western slope of the Sierra Nevada. Although some of these geologic units are faulted, especially in the deep subsurface, faulting has not affected the occurrence and movement of fresh ground water (Page and LeBlanc, 1969, p. 25).

Fresh ground water underlies the entire area. However, below depths ranging from about 600 to 3,000 feet in the unconsolidated deposits, the dissolved-solids concentration of the water exceeds 2,000 milligrams per liter (Page, 1973) (see fig. 3).

Hydrology

The principal aquifer system in the area is the coarse-grained sediments. This system generally is unconfined except in the extreme southwestern part of the study area where the three clay layers act as confining beds and in other local areas where intercalated clays cause partial confinement.

The fine-grained sediments yield small amounts of water to wells in the extreme southeastern part of the area (Page and LeBlanc, 1969, p. 14). Elsewhere in the study area, water wells do not penetrate this unit. In fact, most wells in the area penetrate only the upper part of the coarse-grained sediments.

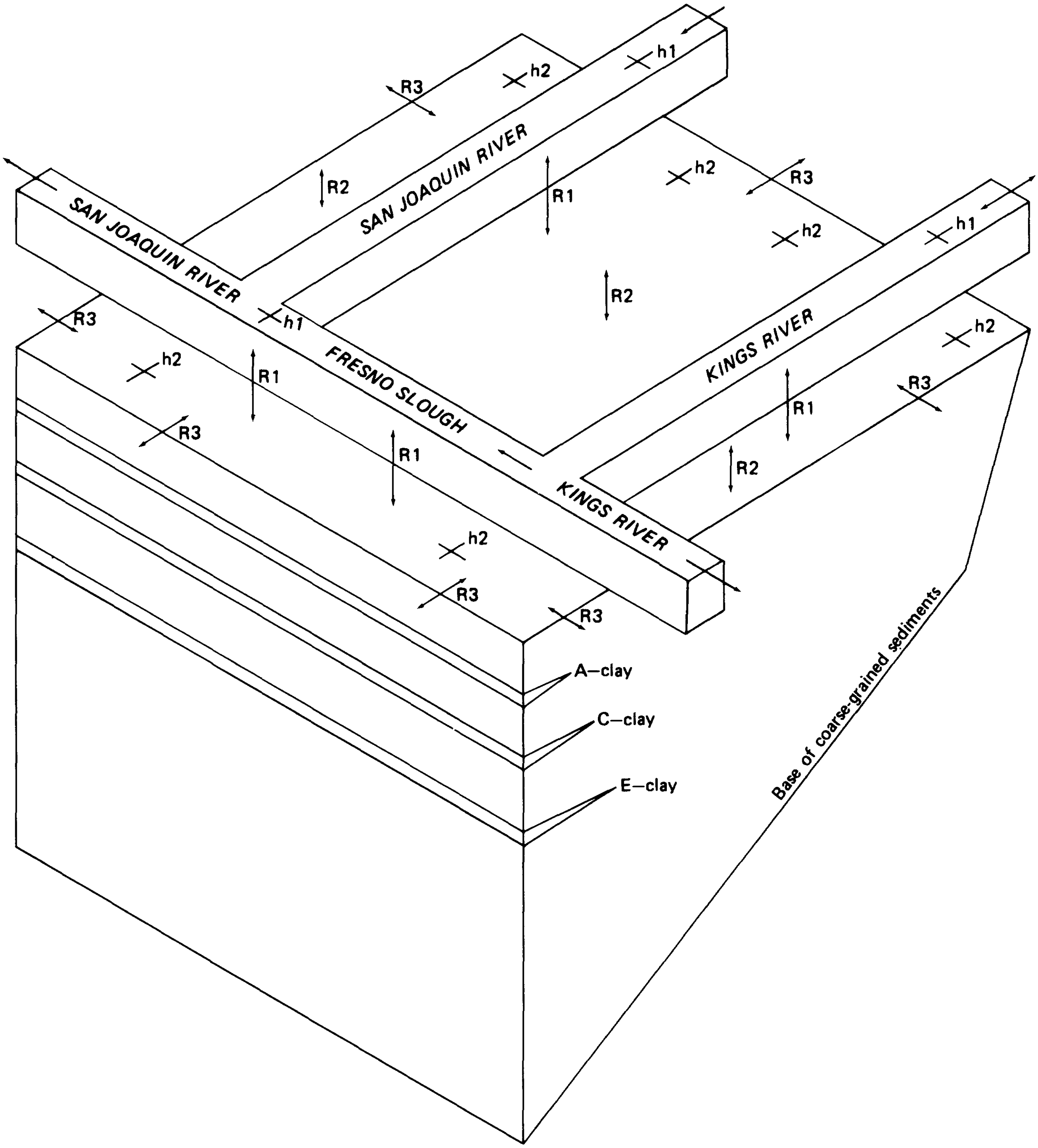
In 1981, the general movement of ground water in the area was toward the southwest, although pumping depressions near Fresno and near the western part of the area caused ground water locally to move toward those depressions (California Department of Water Resources, 1981).

CONCEPTUAL MODEL

The conceptual model of the aquifer (fig. 4) is based on existing geohydrologic information for the area. Simplifying assumptions make it possible to describe the aquifer mathematically (Fidler, 1975, p. 7). Sometimes the assumptions must account for unknown characteristics of the aquifer that are impractical to determine. A mathematical model implies at least the following:

1. A three-dimensional body of earth material saturated with ground water
2. The ground water is in motion
3. The three-dimensional saturated porous medium is bounded by a closed surface
4. For an open-flow system to operate continuously through time, input to and output from the system must occur across part of the bounding surface.

Under ideal conditions, model boundaries should correspond to natural physical boundaries. Commonly, however, due to constraints of the area to be modeled, boundaries used in the model are chosen arbitrarily.



EXPLANATION

RECHARGE-DISCHARGE

R1 – Leakage from river to aquifer or aquifer to river

R2 – Recharge from irrigation return, precipitation, leakage from septic tanks and discharge from pumpage and evapotranspiration

R3 – Constant flux boundary, may be either recharge or discharge

HEADS

h1 – Head in river at a given location

h2 – Head generated by model at a given location

FIGURE 4. – Conceptual model of the hydrologic system in the Fresno area. (Modified from Londquist, 1981, fig. 3; and Page, 1977, fig. 6).

The aquifer in the Fresno area is assumed to be a single unconfined unit. The top is the water table. The northeastern boundary is the only natural lateral hydrologic boundary and approximately parallels the foothills of the Sierra Nevada. The aquifer extends beyond the other lateral boundaries, but these boundaries were chosen arbitrarily far enough from the area of interest that the effects of those boundaries would not impact on computed heads (water levels) in the area of interest.

The magnitude and direction of flows below the upper part of the coarse-grained sediments are unknown. However, the magnitude of flows in the fine-grained sediments probably is less than that in the coarse-grained sediments. For modeling purposes, it was assumed that there was no flow moving across the interface between the coarse-grained and the fine-grained sediments; therefore, the bottom of the modeled aquifer was assumed to be a no-flow boundary.

In the model, it was assumed that water enters the aquifer from inflow across lateral boundaries; leakage from streams, canals, and ponds; irrigation return flow from imported surface water; and precipitation. The ground water moves through the aquifer in response to differences in hydraulic heads. Water leaves the aquifer through lateral boundaries, pumping, evapotranspiration, and leakage into streams.

DIGITAL MODEL

Mathematical Description

A digital model can be a useful tool for gaining a better understanding of an aquifer system and for estimating aquifer response to applied stress. However, the model's results should be viewed with caution; the simulated system was simplified through assumptions and it may or may not represent the real system. The model calculates aquifer responses on the basis of: (1) The ability of the aquifer to transmit water (hydraulic conductivity), its ability to store and release water (specific yield), and the saturated thickness; and (2) the rate at which water enters (recharge) and leaves (discharge) the aquifer during a given period of time (Swain, 1978, p. 13; Londquist, 1981, p. 8).

Two basic assumptions were used to develop flow equations: the conservation of mass and the ground-water flow obeyed Darcy's law. The conservation of mass states that if inflow to the system is not equal to outflow, the difference equals change in the volume of water in storage, if the density of the water remains constant. This is a transient state and, under water-table conditions, it implies that water levels are changing to accommodate changes in storage. If inflow equals outflow, there is no change in storage and water levels are constant. This condition is a steady state.

Darcy's law states that the rate of flow through a unit-aquifer area equals the hydraulic conductivity multiplied by the hydraulic head gradient. Hydraulic conductivity will be described in the section on "Specific Yield and Hydraulic Conductivity." A flow model uses numerical techniques in solving the ground-water flow equations.

The theoretical base of the finite-difference model, solution techniques, data requirements, and computer program used in this study are described by Trescott, Pinder, and Larson (1976). The model used in this study can simulate ground-water flow in a water-table (unconfined) aquifer, an artesian (confined aquifer), or a combined artesian and water-table aquifer.

Data Requirements

In order to build a model, the following information needs to be considered.

1. Frame of reference
2. Boundary conditions
3. Specific yield (storage)
4. Hydraulic conductivity
5. Head distribution when the aquifer is in equilibrium
6. Areal recharge or discharge
7. Quantity and distribution of pumpage
8. Leakage to or from rivers.

Frame of Reference

A rectangular grid over the model area normally is used in a finite-difference approach. Each rectangle is termed a cell. The grid is superimposed on data maps, and average parameter values for each cell within the model boundary are entered as model inputs. Model results are simulated heads at the center of each cell.

The grid for the Fresno area consists of 55 rows and 58 columns (fig. 2). The size of cells increases from one-half mile in the vicinity of Fresno to a maximum of 2 miles near the boundaries. The smaller cells in the area of interest allow a more detailed approximation of the flow system than the larger cells.

Boundary Conditions

Three types of boundaries were assigned in the Fresno flow model:

1. Constant-head boundary: the head in a cell does not change through time, but the flux (amount of water entering or leaving the cell) varies in response to head changes between the constant head cell and adjacent cells.

2. Constant-flux boundary: the flux in or out of a cell does not change through time, but the head varies in response to head changes between the constant flux cell and the adjacent cells (Londquist, 1981, p. 11).

3. Free surface: forms the upper boundary between saturated material below and unsaturated material above. Initial starting heads representing the free surface commonly are obtained from water-level contour maps. During model simulation, under transient conditions, the free surface (water table) position must be calculated by the computer as a solution to the problem.

In the Fresno area, the top of the system is modeled as a constant-head surface under steady-state conditions and a free surface under transient conditions. The bottom is a surface of constant flux equal to zero. All the lateral boundaries are constant flux which in some places may be equal to zero.

Specific Yield and Hydraulic Conductivity

The specific yield of an earth material is defined as the ratio of (1) the volume of water which, after being saturated, will yield by gravity to (2) its own volume (Meinzer, 1923, p. 28). Thus, specific yield is a term indicating potential capacity of a porous medium to store or release water. Hydraulic conductivity of a medium is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Lohman, 1972, p. 6). Thus, hydraulic conductivity of an earth material is a measure of its ability to transmit a specified water under a potential gradient. Except for vertical hydraulic conductivity for river leakage, in this report hydraulic conductivity refers to the horizontal direction because it is assumed that vertical flow components are negligible compared to horizontal components.

It has been demonstrated that an increase in specific yield is related to an increase in hydraulic conductivity (California Department of Water Resources, 1974, p. 135-138), but the relationship is not well understood. Specific yield data were obtained by translating descriptions of materials at various depths on driller's logs to values of specific yield defined by Davis and others (1959, p. 202-206). Values for hydraulic conductivity were estimated for the same depths by correlation of published values of specific yield and hydraulic conductivity (Alex K. Williamson, U.S. Geological Survey, oral communication, 1982). The values for both parameters were processed by a computer program to give average values for specific yield and hydraulic conductivity for the total depth described for each well for which data are available. In the Fresno area, average values for specific yield range from 0.05 to 0.20, and for hydraulic conductivity, from 10 to 70 ft/d.

Head Distribution When the Aquifer is in Equilibrium

Model simulation is best begun when the aquifer system is at equilibrium so inflow equals outflow and water levels are not changing. Figure 5 shows hydrographs for two wells in the study area. Although the seasonal fluctuations probably reflect the effects of pumping, the tendency of the hydrographs indicate that the aquifer probably reached a new equilibrium during the period of 1930-44; thereafter, water levels declined in response to a new stress. From the available hydrographs, water levels observed for the spring of 1943 seem to be the average water level for the equilibrium condition during 1930-44; therefore, the water levels during the spring of 1943 were used for the calibration of steady-state simulations.

Areal Recharge or Discharge

Areal recharge equals discharge ± change in storage ± model errors. Areal recharge includes irrigation return, leakage from canals and ponds, and recharge from precipitation. Discharge includes leakage to small streams, canals, and ponds; evapotranspiration from the water table; and pumpage.

Ground-Water Pumpage

Agricultural pumpage has been estimated for 1962-78 (Mitten, 1972, 1976, 1978; Mitten and Ogilbee, 1971). Municipal pumpage for 1931-79 has been reported (T. R. Cockrum, Fresno County, written communication, 1981-82).

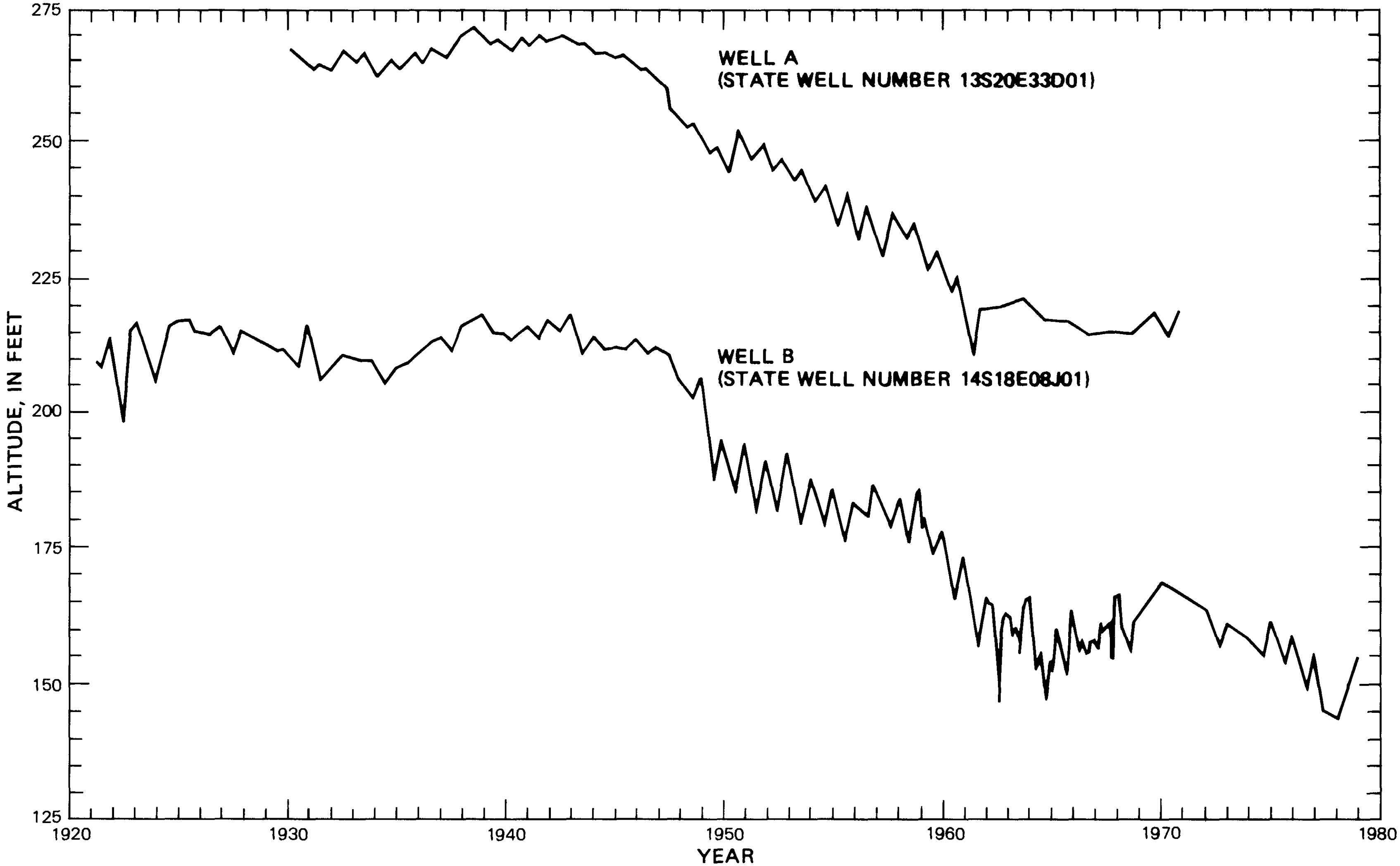


FIGURE 5. – Example of hydrographs of wells in the Fresno area. (See fig. 2 for well locations).

Leakage to or from Rivers

Leakage for the San Joaquin and Kings Rivers is controlled by the altitudes of the water surfaces in the rivers, by the heads in the underlying aquifer, and by the hydraulic conductivities and thicknesses of the river beds. Hydraulic conductivity and thickness of the river beds have not yet been estimated; these values will be analyzed in the future.

FUTURE WORK

Much of the data collection and processing for model development has been done. It is anticipated that most of the remaining effort will center on model calibration. Calibration includes matching water levels simulated by the model with known water-level contour maps and hydrographs of wells.

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