UNITED STATES
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GEOLOGICAL SURVEY

HYDROLOGIC ANALYSIS OF THE UPPER SAN PEDRO BASIN FROM THE MEXICO-UNITED STATES INTERNATIONAL BOUNDARY TO FAIRBANK, ARIZONA

By Geoffrey W. Freethey

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CONVERSION FACTORS

For readers who prefer to use the International System of Units (SI) rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain SI (metric) unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

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ABSTRACT

A definition of the hydrologic system of the upper San Pedro basin was obtained by developing a numerical ground-water model to evaluate a conceptual model of the system. The numerical model uses a three-dimensional, block-centered, finite-difference scheme to simulate ground-water flow, stream-aquifer connection, and evapotranspiration. Information on hydraulic properties of the basin fill, recharge from bordering mountain ranges, discharge by evapotranspiration, and exchange of water between aquifer and stream was available from previous measurements or estimates. The steady-state calibration procedure and subsequent transient simulations demonstrate that the conceptual model of the ground-water flow system can be reasonably simulated.

An analysis of model sensitivity to increases and decreases in certain hydraulic properties indicated a low sensitivity to aquifer anisotropy and a low to moderate sensitivity to stream leakance and evapotranspiration rate. An analysis to investigate the effects of using average values of recharge, hydraulic conductivity, and specific yield indicated that flow components and water-level response to stress could be simulated adequately; however, simulation of steady-state water-level conditions was sensitive to the hydraulic-conductivity distribution.

During equilibrium conditions, the basin received about 16,500 acre-feet per year recharge from runoff, underflow, and stream seepage. The same amount was discharged by evapotranspiration and seepage to streams. By 1978, withdrawal of ground water for irrigation, industrial use, and public supply totaled about 10,500 acre-feet per year. The numerical-model results indicated that about 5,600 acre-feet or 53 percent of the 1977 pumpage represented release of water from aquifer storage; the remainder is derived from adjustments in the evapotranspiration, discharge to and from the river, and underflow in and out of the basin.

INTRODUCTION

This report is one of a series that will describe the development and use of ground-water models as part of the Southwest Alluvial Basins, Regional Aquifer-System Analysis (Swab/RASA) Project (Anderson, 1980).

The purpose of the project is to develop a better general understanding of the extent and workings of the hydrologic systems in the alluvial basins of the study area (fig. 1). The study approach uses ground-water modeling as the principal tool in evaluating the ground-water flow systems. A basic assumption of the project is that certain characteristics and relations are common to many of the basins or subsets of basins. Most aquifer systems within the project area consist of a thick accumulation of alluvial and lacustrine deposits that fill structural troughs between mountain ranges. In the most developed basins only the uppermost part of the basin fill has been penetrated by wells and only a fragmentary definition of the hydrogeologic framework is available. Basins selected for modeling were those with sufficient data to develop a reliable model of the upper part of the basin fill and were thought to be representative in certain geohydrologic aspects of other basins in the study area.

Purpose and Scope

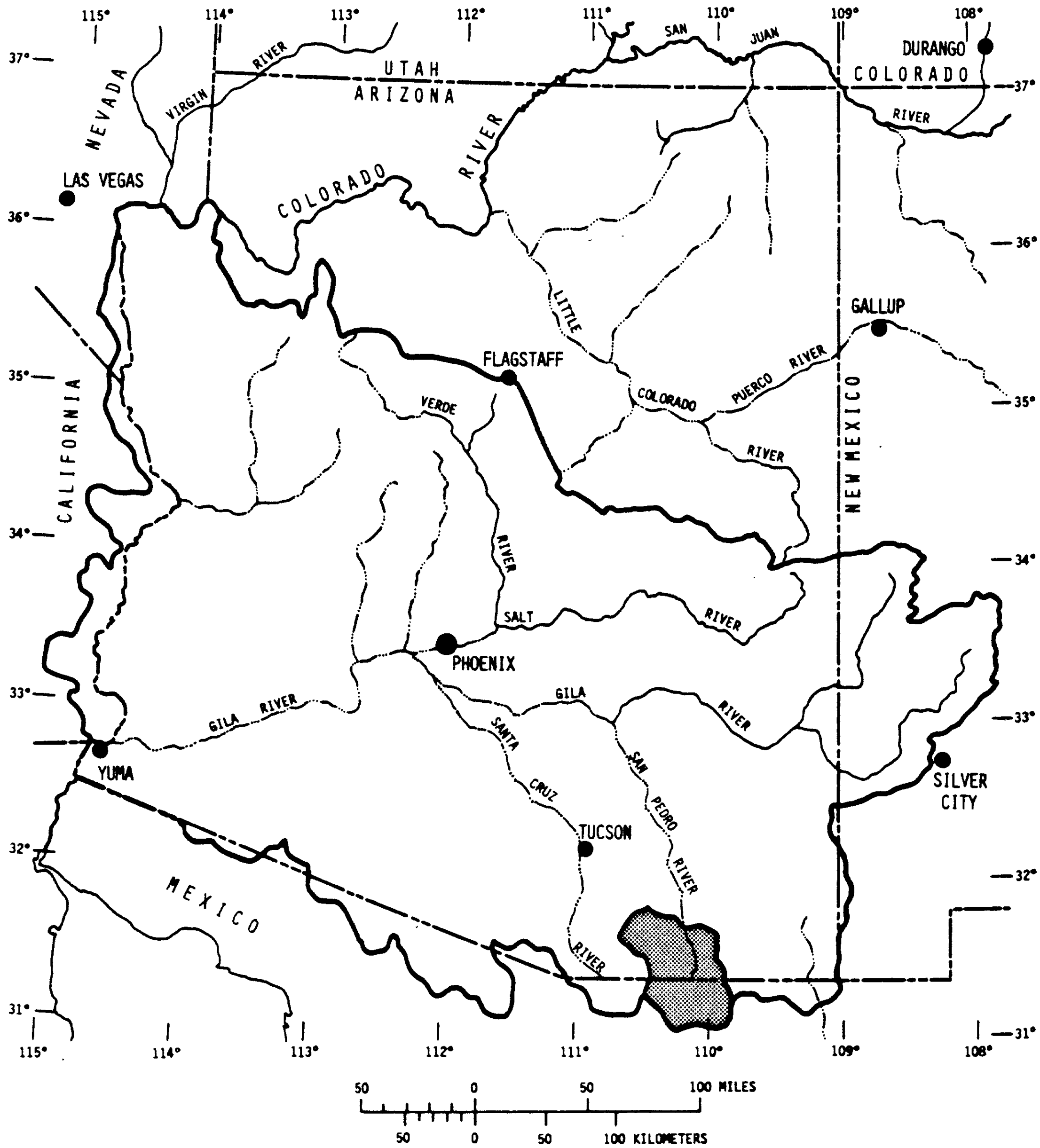
The upper San Pedro basin, although unique in many ways, displays several characteristics that are common to the basins of southeastern Arizona. These characteristics include a common geomorphic, geologic, and meteorologic setting as well as similar patterns of land and water use. The purpose of this investigation was to develop a numerical ground-water model using previous information and interpretations of the workings of the hydrologic system in the upper San Pedro basin. The purpose of the study was also to evaluate the definition of the system and the relative sensitivity of the model to changes in major factors. The model was used to explore hydrologic relations that are thought to be common to many basins in the area, and, where practical, information gained in this study will be transferred and used in models of basins with similar characteristics.

No new hydrologic or geologic data were collected for the development of the ground-water model. Conceptualization of the hydrologic system evolved from available data and interpretations presented in earlier reports. The numerical model was developed to provide a means of evaluating how well this information fits together in a reasonable simulation of the actual ground-water system.

The ground-water model that resulted from this effort was not designed to simulate and analyze site-specific problems or to enable the exact duplication of water-level changes throughout the modeled area. The practical uses of the model are the simulations of general trends in water-level declines and the generalized interbasin and intrabasin responses to basin-wide stress phenomena.

Location, Extent, and Physical Setting

The upper San Pedro basin extends from about 23 mi south of the international boundary with Mexico to about 27 mi north of the



EXPLANATION

BOUNDARY OF SOUTHWEST ALLUVIAL BASINS STUDY

Figure 1.--Swab/RASA study area and the upper San Pedro basin (shaded).

international boundary to Fairbank, Arizona. The basin includes parts of Cochise, Santa Cruz, and Pima Counties in Arizona (fig. 2). The basin trends slightly northwest, averages 50 mi long and 30 mi wide, and is about 1,650 mi^2. The part of the basin studied is north of the international boundary and covers about 950 mi^2.

The study area is bordered on the west by the Huachuca Mountains, the Canelo Hills, the Mustang Mountains, and the southern tip of the Whetstone Mountains. The Mule Mountains and the Tombstone Hills border the area on the east. The Tombstone Hills extend across the axis of the basin at its north end (fig. 2). Altitudes in the mountainous areas range from 4,400 to nearly 9,500 ft, and in the interior of the basin from 3,900 to 4,800 ft. Land-surface gradient from the mountain fronts to the basin axis ranges from 25 to 200 ft/mi.

The basin is drained by the San Pedro River, which flows north along the axis of the basin. The gradient of the San Pedro River flood plain is from 12 to 15 ft/mi. The river contained perennial flow before irrigation diversions began (Bryan and others, 1934, p. 39), but now the river only locally contains perennial flow. The flow in the San Pedro is intermittently supplemented by Greenbush Creek, Government Draw, and other small washes that enter from the east and west. The Babocomari River, which is perennial in places, drains the Mustang Mountains, the Canelo Hills, and the north end of the Huachuca Mountains and enters the San Pedro River just south of Fairbank, Arizona.

Previous Investigations

Previous investigations of this area provided most of the data and estimates of properties used for initial development of a ground-water model. Accounts of predevelopment conditions are given in Bryan and others (1934). The geologic framework of the mountainous areas and the alluvial sediments of the basin are explained by Drewes (1980), Brown and others (1966), and Harshbarger and Associates (1974). Stream-aquifer relations are detailed by Brown and Aldridge (written commun., 1973), and pumpage estimates are provided in the annual summary of ground-water conditions in Arizona (U.S. Geological Survey, 1978). Estimates of recharge to the basin are given by Brown and Aldridge (written commun., 1973) and Heindl (1952). Data for a ground-water model developed by the Arizona Department of Water Resources, formerly the Arizona Water Commission, are given in Harshbarger and Associates (1974).

THE CONCEPTUAL GROUND-WATER MODEL

Before a numerical model of a ground-water system can be developed, a concept of the relation between the physical environment and the movement of ground water must be defined. The physical system in

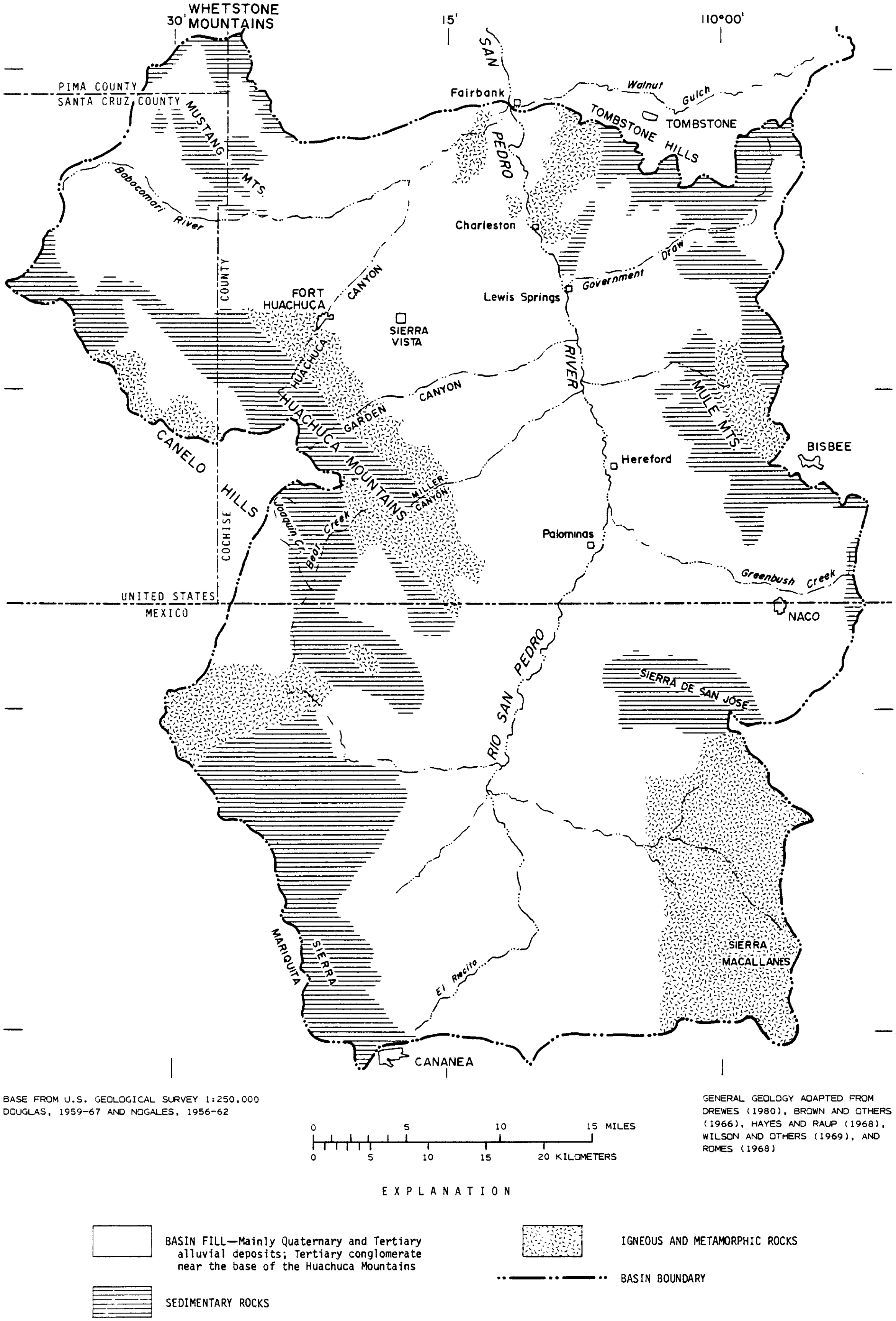


Figure 2.--Physiographic setting and generalized surficial geology of the upper San Pedro basin, Arizona, U.S.A., and Sonora, Mexico.

the upper San Pedro basin is comprised of an elongated north- to south-trending structural trough bounded by mountains and filled with sediments that were eroded from the adjacent mountains. The ground-water resources of the area are the vast amount of water stored in the interstitial voids of the sediments. In comparison to the volume in storage, small amounts of water enter, move through, and leave the system. Water enters the ground-water system as infiltration of surface water along the mountain fronts where minor streams emerge from the hardrock areas and along the major stream channels and as underflow from south of the international boundary.

The main source of ground-water inflow is the infiltration of runoff along the mountain fronts that surround the basin. Recharge probably begins immediately adjacent to the mountain fronts and may occur in an area several miles wide toward the basin axis. Underflow from the Babocomari Valley is derived from infiltration of runoff from the Canelo Hills, the Mustang Mountains, and parts of the Whetstone and Huachuca Mountains. Underflow from Greenbush Valley and Government Draw is derived from infiltration of runoff from the Mule Mountains and part of the Tombstone Hills. Secondary porosity in the consolidated rocks of the mountains may account for a minor amount of ground-water inflow to the basin fill. Owing to the generally impermeable character of the mountains, however, no movement to or from adjacent basins is presumed.

Ground-water underflow entering the basin across the international boundary is a less significant source of recharge. Infiltration of runoff along the mountain fronts south of the international boundary may be similar in magnitude to that north of the boundary. Most of the ground water is discharged as evapotranspiration or as streamflow before it reaches the international boundary. The amount of underflow into the upper San Pedro basin is small.

Ground water moves from the basin margins to the axis where it may be discharged along gaining reaches of the streams or by evapotranspiration. Directions and rates of movement within the aquifer are controlled by the hydraulic properties and boundary conditions of the aquifer.

Aquifer Geometry and Hydraulic Properties

The upper boundary of the aquifer is the water table, and the lower boundary is the consolidated rock that forms the bottom of the structural trough, which may be as deep as 5,000 ft (Oppenheimer and Sumner, 1980). The configuration of this lower boundary is virtually unknown except in areas near the basin margins where drilling has completely penetrated the basin fill. Where no subsurface data are available, the general configuration of buried bedrock surfaces can be extrapolated from the configuration of bedrock outcroppings. The regional direction of ground-water flow, the areas of recharge along the mountain fronts, and the area of discharge along the San Pedro River are indicated by the predevelopment configuration of the water table shown in figure 3. The relative reliability of data used to formulate geologic and hydrologic concepts describing the system is shown on the index map included in figure 3.

The rocks and sediments that make up the upper, definable part of the main aquifer of the upper San Pedro basin consist of a Tertiary conglomerate, a lower basin fill, an upper basin fill, and alluvial material associated with the flood plains of the San Pedro and Babocomari Rivers (Brown and others, 1966). The relative placement of these four units is shown diagrammatically in figure 4. The Tertiary conglomerate is exposed near the mountain fronts and possibly occurs at depth within the basin but is not considered an important part of the aquifer. The hydraulic conductivity is low except where faulting and fracturing may have caused an increase.

Hydrologically, the lower and upper basin fill can be considered as one unit. Vertical and horizontal heterogeneity within each unit overshadow any hydrologic differences between the two units. As in most basins in southeastern Arizona, the units generally grade from fan gravel near the mountain fronts to silt and clay near the valley axis. However, lateral changes in packing, sorting, and degree of consolidation often negate this seemingly simple progression from high to low hydraulic conductivity. The distribution of transmissivity—the product of hydraulic conductivity and saturated thickness—is similarly affected.

The alluvial material of the river flood plains is generally coarser grained, less cemented, and, consequently, higher in hydraulic conductivity than the basin fill. Specific-capacity data for a few shallow wells indicate hydraulic conductivity of flood-plain material may be two to ten times higher than that in the basin fill. The limited distribution and generally small saturated thickness of this alluvial material reduces its influence on the regional transmissivity distribution.

Transmissivity for the basin fill, calculated from 16 aquifer tests performed during 1958-73 (Harshbarger and Associates, 1974), has a wide range in values. Using specific-capacity data to estimate transmissivity (Theis and others, 1963) gives an even greater range of values. Collectively these data indicate transmissivities as low as 100 ft^2/d in some areas near the mountain fronts and as high as 15,000 ft^2/d in areas in the basin.

Confined ground-water conditions occur in several isolated areas in the basin. The confining beds are silt and clay lenses of moderate areal extent. In a few wells in the Palominas-Hereford area the water levels are above the land surface; however, this condition is local and regionally the aquifer is considered unconfined.

The amount of ground water that can be stored in the aquifer is a function of the geologic framework of the aquifer materials. Owing to the heterogeneity of the basin fill, values of the storage coefficient probably cover a wide range. Estimated values of storage coefficient from aquifer tests and from analyses of drillers' logs range from 0.03 to 0.25.

Recharge Along Mountain Fronts

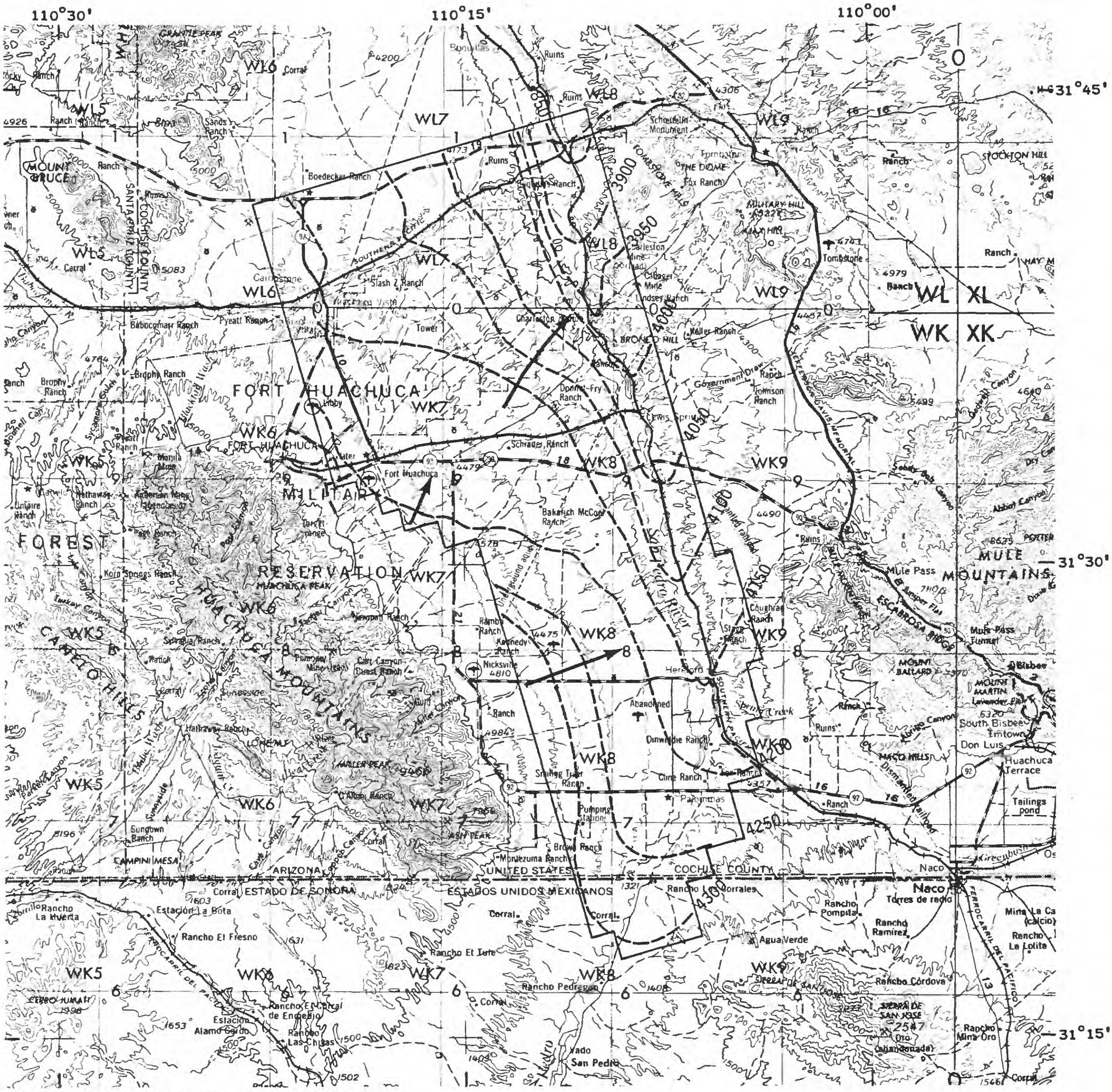
Recharge along the mountain fronts is the amount of surface flow that infiltrates into the basin fill during runoff and eventually reaches the water table. Several factors affect this process, but the most significant is the total amount of precipitation falling on the mountains. The Huachuca Mountains and the Canelo Hills receive more than 25 in./yr of precipitation and contribute a major part of the recharge to the ground-water system of the upper San Pedro basin. The Mule Mountains and the Whetstone Mountains receive between 15 and 25 in./yr (Sellers and Hill, 1974). Recharge along the Huachuca Mountains was previously estimated to be from 5.5 ft^3/s (Harshbarger and Associates, 1974) to 6.9 ft^3/s (Brown and Aldridge, written commun., 1973). Along the Mule Mountains, recharge was estimated to be 2.8 ft^3/s to the basin fill (Brown and Aldridge, written commun., 1973). Along the mountain ranges that surround the headwaters of the Babocomari River, recharge was estimated to be about 5.5 ft^3/s (Brown and Aldridge, written commun., 1973). Recharge to the basin fill bordering the Tombstone Hills is assumed to be minimal because of the relatively small amount of precipitation that falls on the area—about 13 in./yr at Tombstone (Sellers and Hill, 1974, p. 514)—and because most runoff flows directly into the San Pedro River without flowing across the basin fill.

Underflow

The international boundary was selected as the approximate south boundary of the study area. Ground-water underflow moves from the upper reaches of the basin across this boundary into the study area. The quantity of underflow was previously estimated to be between 700 and 3,500 acre-ft/yr or 1.0 and 4.8 ft^3/s (Heindl, 1952; Harshbarger and Associates, 1974). The north boundary of the study area is formed in part by a projection of the Tombstone Hills into the basin. The rocks of the Tombstone Hills form at least a partial barrier to ground-water movement. The north boundary on the west side of the San Pedro River and north of the Babocomari River was selected to be coincident with a ground-water flow line. Thus, no ground water flows out of the basin in this area except in the narrow valley of the San Pedro River where the flow lines are perpendicular to the boundary. The hydrologic conditions that are thought to exist are illustrated in figures 4 and 5.

Stream-Aquifer Connection

Streamflow records, well hydrographs, and the results of seepage investigations indicate that the San Pedro River is in hydraulic



BASE FROM U.S. GEOLOGICAL SURVEY 1:250,000
DOUGLAS, 1959-67 AND NOGALES, 1956-62

0 5 10 MILES

0 5 10 15 KILOMETERS

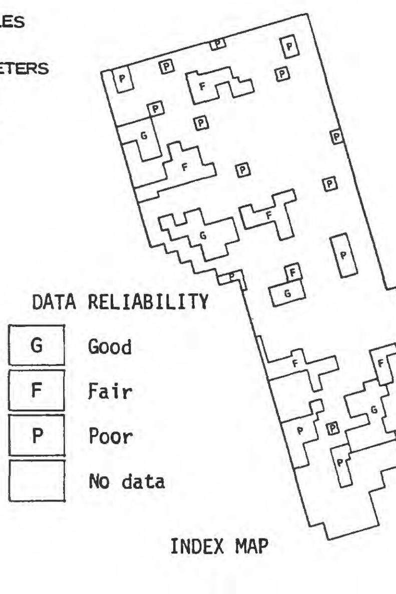
TOPOGRAPHIC CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

---4200--- WATER-LEVEL CONTOUR—Shows altitude of the water level before development. Contour interval 50 feet. National Geodetic Vertical Datum of 1929. Contours modified from Roeske and Werrell (1973) and Konieczki (1980)

→ DIRECTION OF GROUND-WATER FLOW

— BOUNDARY OF MODELED AREA



INDEX MAP

Figure 3.--Predevelopment configuration of the water level within the modeled area and generalized index of data reliability.

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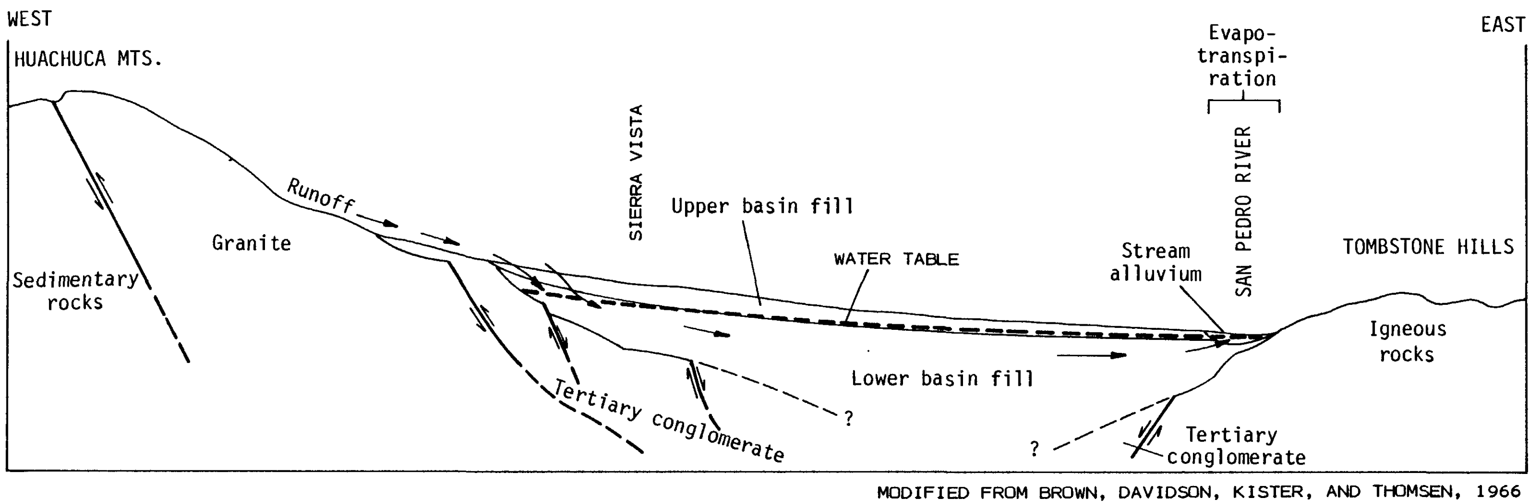
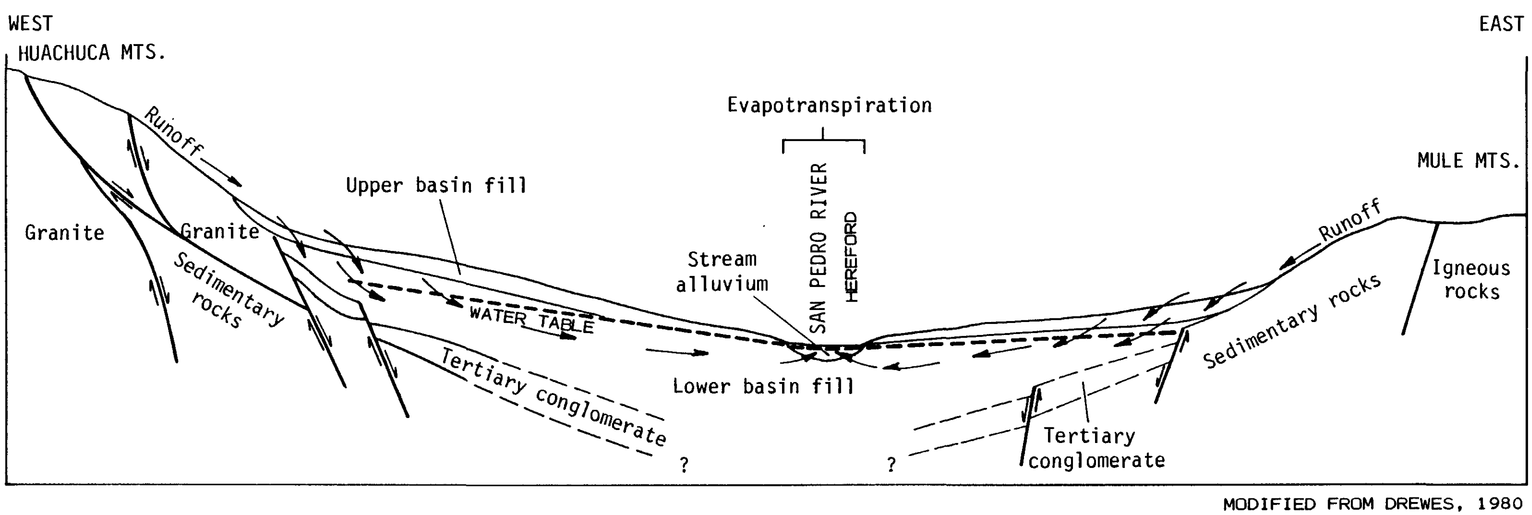
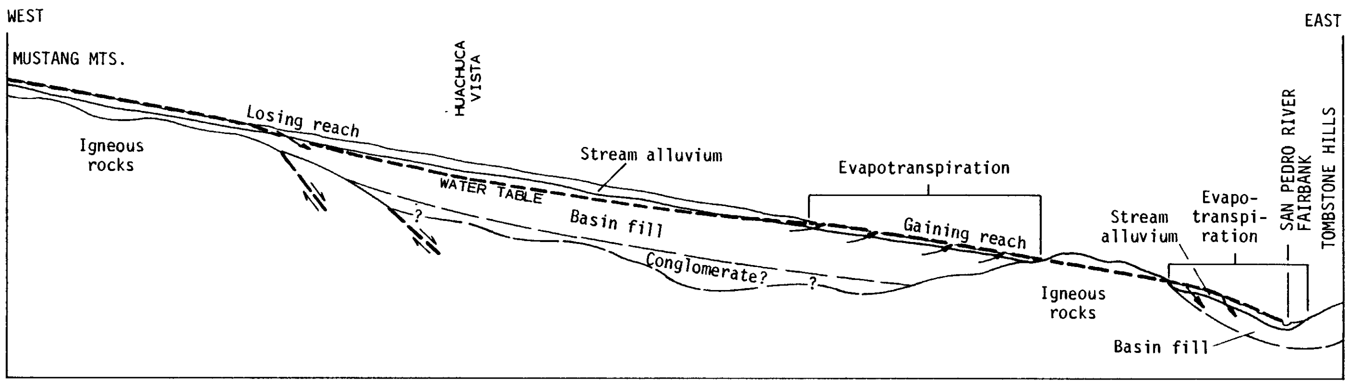


A. Northern part of the basin from the Huachuca Mountains to the Tombstone Hills.

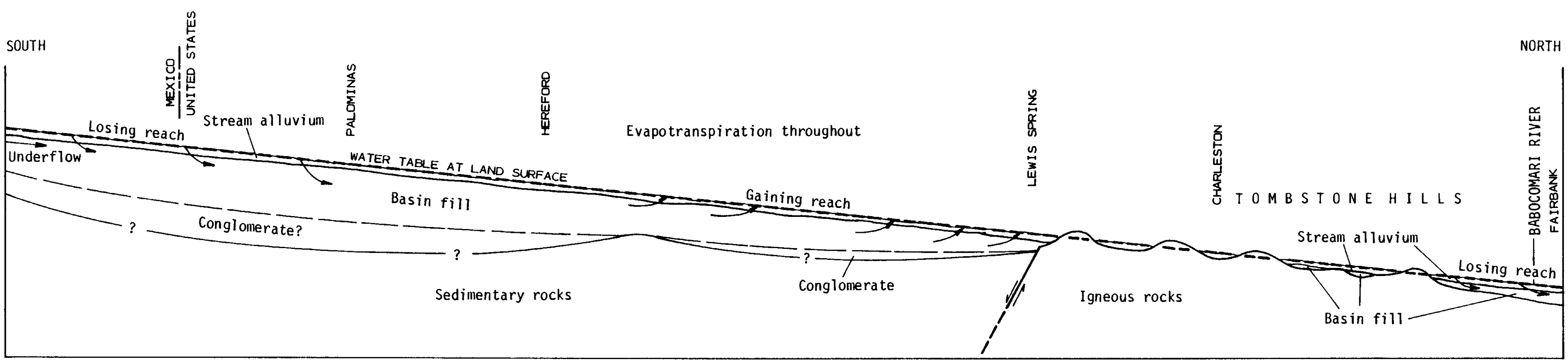


B. Southern part of the basin from the Huachuca Mountains to the Mule Mountains.

Figure 4.--Diagrammatic sections representing hydrogeologic conditions in the San Pedro basin.



A. Beneath the Babocomari River from the Mustang Mountains to Fairbank, Arizona.



B. Beneath the San Pedro River from 2 miles south of the international boundary to Fairbank, Arizona.

Figure 5.--Diagrammatic sections representing hydrogeologic conditions beneath the Babocomari and San Pedro Rivers.

connection with the aquifer. Seepage investigations by the U.S. Geological Survey in 1969 and 1970 show that, on the average, streamflow decreased by 1.7 ft^3/s from the international boundary to Palominas, increased by 8.5 ft^3/s from Palominas to Charleston, and decreased by 0.4 ft^3/s from Charleston to the mouth of the Babocomari River near Fairbank (Brown and Aldridge, written commun., 1973). The Babocomari River gains surface flow in a short reach upstream from its entrance to a small canyon cut in bedrock. The general trend of increasing streamflow from Palominas to Charleston is the result of an increasing downvalley flow and a decreasing saturated thickness of the aquifer. Part of the ground-water flow is discharged to the surface-water system in this reach.

Evapotranspiration

Discharge by evapotranspiration takes place in the river flood plains where ground water at or near land surface evaporates or is transpired by riparian vegetation. Factors that affect the rate at which this discharge takes place include soil type, soil-moisture content, ground-water quality, vegetation type, altitude, and seasons. Aerial photographs taken in 1938 were used to estimate the number of acres covered by the riparian vegetation. Assuming an average areal canopy density of 25 percent and multiplying by evapotranspiration rates characteristic of riparian vegetation in the deserts of the Southwest (3-10 ft/yr), the consumptive use could range from 3,700 to 12,400 acre-ft/yr or about 5 to 17 ft^3/s. By extrapolating the information presented by Heindl (1952) to encompass the area of the model, the evapotranspiration is estimated to be about 5,700 acre-ft/yr or 7.9 ft^3/s. Table 1 summarizes values for recharge and discharge and lists the sources for the estimates.

Changes Due to Development

Development of the ground-water resources of the upper San Pedro basin has altered the original flow system. In places, riparian vegetation along the river flood plains has been replaced by crops. Thus, evapotranspiration rates and the areal distribution may have changed. Ground-water withdrawal for irrigation and public supply has altered the original direction of ground-water movement in the system and has created depressions in the original water table. Consumptive use of ground water has reduced the total amount of discharge to the San Pedro and Babocomari Rivers and thus has altered the original stream-aquifer relations.

THE NUMERICAL GROUND-WATER MODEL

The objective in developing a numerical ground-water model of the upper San Pedro basin was to (1) analyze the reliability of the

Table 1.--Summary of estimated values of recharge and discharge in the upper San Pedro basin

Flow component	Flow, in cubic feet per second		Source of estimate
	Recharge (+)	Discharge (-)	
Mountain-front recharge:			
Huachuca Mountains	+6.9 +5.5		Brown and Aldridge, written commun., 1973 Harshbarger and Associates, 1974
Mule Mountains	+2.8		Brown and Aldridge, written commun., 1973
Babocomari Valley:			
Whetstone Mountains . . .			
Mustang Mountains	+5.5		Brown and Aldridge, written commun., 1973
Canelo Hills.			
Underflow from Mexico	+1.0 to +4.8 +4.7		Heindl, 1952 Harshbarger and Associates, 1974
Streamflow loss:			
San Pedro River	+1.1 to +3.9		Brown and Aldridge, written commun., 1973
Babocomari River	0 to +2		Estimated, 1980
Streamflow gain:			
San Pedro River.		-2.6 to -12.8	Brown and Aldridge, written commun., 1973
Babocomari River		0 to -7	Estimated, 1980
Evapotranspiration		-5 to -17 -7.9	Areal photographs taken in 1938 Heindl, 1952

conceptual model and the adequacy of flow-component definition, (2) evaluate the relative importance of various model conditions pertinent to each hydrologic setting, and (3) determine the sensitivity of model results to the generalization of values for hydraulic properties.

Technique

The simulation of the hydrologic system of the upper San Pedro basin was accomplished using the finite-difference model described by Trescott (1975). A full explanation of the theoretical development, the solution technique used, and the mathematical treatment of each simulated condition is included in Trescott (1975), Trescott and others (1976), and McDonald and Fleck (1978).

The model described by Trescott (1975) was used in this study because simulative options were available, the documentation was easily understood, and the output format was easily adapted to statistical and plotting programs. The use of the same model on all basins within the project area was desirable in order to maintain compatibility of input and output forms that were subsequently used for plotting and contouring by support programs. The graphic illustrations of arrays from one modeled area could be more easily used when values of hydraulic properties and hydrologic relations are transferred to another area.

Model Characteristics

For simulating the hydrology of the upper San Pedro basin, the following model characteristics were adopted.

——A variable grid size was used to produce better resolution in areas where data density was high or where large variations in aquifer properties or stresses occurred.

——Two layers were used in the simulation. The upper layer represented that part of the basin fill for which data were available and the lower layer represented the basin fill deeper than 1,000 ft below land surface for which no data were available. This arbitrary separation is the approximate limit to which wells have penetrated. The model was to be used to help define the hydrology of the basin. Although the upper 1,000 ft of basin fill is of primary interest, the possibility of some ground-water movement to or from the lower part cannot be ignored. Hydraulic properties for this lower portion are unknown; however, values were chosen to fall in an assumed reasonable range to reflect what little is known about the geology of the lower part and to simulate the structural shape of the basin.

——The upper layer was simulated as an unconfined aquifer.

——Because of the computational characteristics of the numerical model, the lower layer was simulated as a confined aquifer.

——Vertical connection between layers was determined by the model from the assigned hydraulic properties of each layer.

——Most recharge simulated by the model occurred in the upper layer. Specified heads in the lower layer allowed a minor amount of recharge directly into the lower layer.

——Interaction takes place between perennial streams and the upper aquifer, and stream leakance is constant.

——Evapotranspiration discharges water from the upper aquifer and was simulated by a linear relation between a maximum evapotranspiration rate and a depth to water where evapotranspiration ceases.

Properties thought to be influential to model results include boundary recharge, aquifer conductivity, and aquifer storage. In order to evaluate model sensitivity to values and areal distributions of these properties, the following alternative scenarios were explored.

——Boundary recharge was alternately evaluated in two modes: (1) uniformly distributed along mountain fronts to represent a situation of minimum data availability and (2) distributed on the basis of site-specific data and a flow-net analysis.

——Aquifer conductivity was analyzed by comparing model results using (1) uniform values in three geohydrologically similar subareas of the basin and (2) an areal distribution on the basis of meager aquifer-test and specific-capacity data and a flow-net analysis.

——Aquifer storage was examined by comparing three model simulations using (1) a variable distribution of specific yield determined from drillers' logs, (2) a uniformly distributed value for specific yield obtained from scant data in the basin, and (3) the same uniform specific-yield value used in a simulation also using uniform values for boundary recharge and aquifer conductivity.

——Generalized boundary recharge, hydraulic conductivity, and specific yield were used together to represent a crude approximation of the hydrologic system that might be developed from few data. The results were compared to the final calibrated model that used all the available information.

Data Input

Considering the model characteristics adopted, three groups of data were necessary to numerically define the hydrologic system. The first group defined the finite-difference grid. The second group defined the natural recharge and discharge to the aquifer system and the hydraulic properties of the aquifers. The third group defined the stresses that have changed the predevelopment equilibrium conditions. All data for model input to the final calibrated model are included in array format at the end of the report to allow duplication of the model (attachments A-J).

The area to be modeled was divided into 740 rectangular blocks in each of two layers. The finite-difference grid designed to divide the area into discrete blocks was oriented with the axis of the basin to minimize the number of blocks outside the principal aquifer system (fig. 6). Blocks with the smallest dimensions were situated along the river flood plain to minimize area-correction errors in the blocks that represent river leakage and evapotranspiration. Small blocks were also used in the Fort Huachuca area where pumping from the aquifer was high and needed more precise representation in the model than in areas where little or no pumping was taking place. The grid consisted of 740 rectangular blocks in each of two layers. Block dimensions ranged from 0.6 to 1.0 mi². Aquifer properties within each block were assumed to be uniform.

Recharge and discharge in the model were simulated using blocks that represent areal recharge, constant head, the river, and evapotranspiration (fig. 7). The initial uniform recharge rate along mountain fronts was adjusted during the steady-state calibration procedure. Measured streamflow losses and gains were used to check values that simulate the stream-aquifer connection. Estimates of the total evapotranspiration in the basin were used to verify values that simulate evapotranspiration in the model.

The hydraulic properties in each block are defined from six data arrays—starting head, altitude of the bottom of layer 2, hydraulic conductivity of layer 2, transmissivity of layer 1, specific yield of layer 2, and storage coefficient of layer 1. The saturated thickness of the upper layer (fig. 8) is derived from the difference between the altitude of the water table—starting head—and the altitude of the bottom of layer 2. The distribution of the hydraulic conductivity of the upper layer used in the steady-state simulation (fig. 9) approximates the values of hydraulic conductivity derived from the flow-net analysis using specific-capacity and aquifer-test values as check points. The transmissivity distribution shown in figure 10 is a summation of transmissivity for both layers. The storage coefficient in the upper layer is equivalent to the specific yield (fig. 11). Values of specific yield determined from aquifer tests were 0.05 and 0.10. Specific yields from long-term tests in adjacent basins were about 0.12 (Harshbarger and Associates, 1974). Equivalent specific-yield determinations from drillers' descriptions of the units (fig. 11) were also considered and averaged 0.08. The storage coefficient in the lower layer was assigned a uniform value of 10^{-5}. The change in storage with change in head for this layer is the same as that for a confined aquifer. Because no dewatering takes place, any change in storage occurs only as a result of a change in the volume of the skeletal framework of the aquifer material or as a result of expansion of the water.

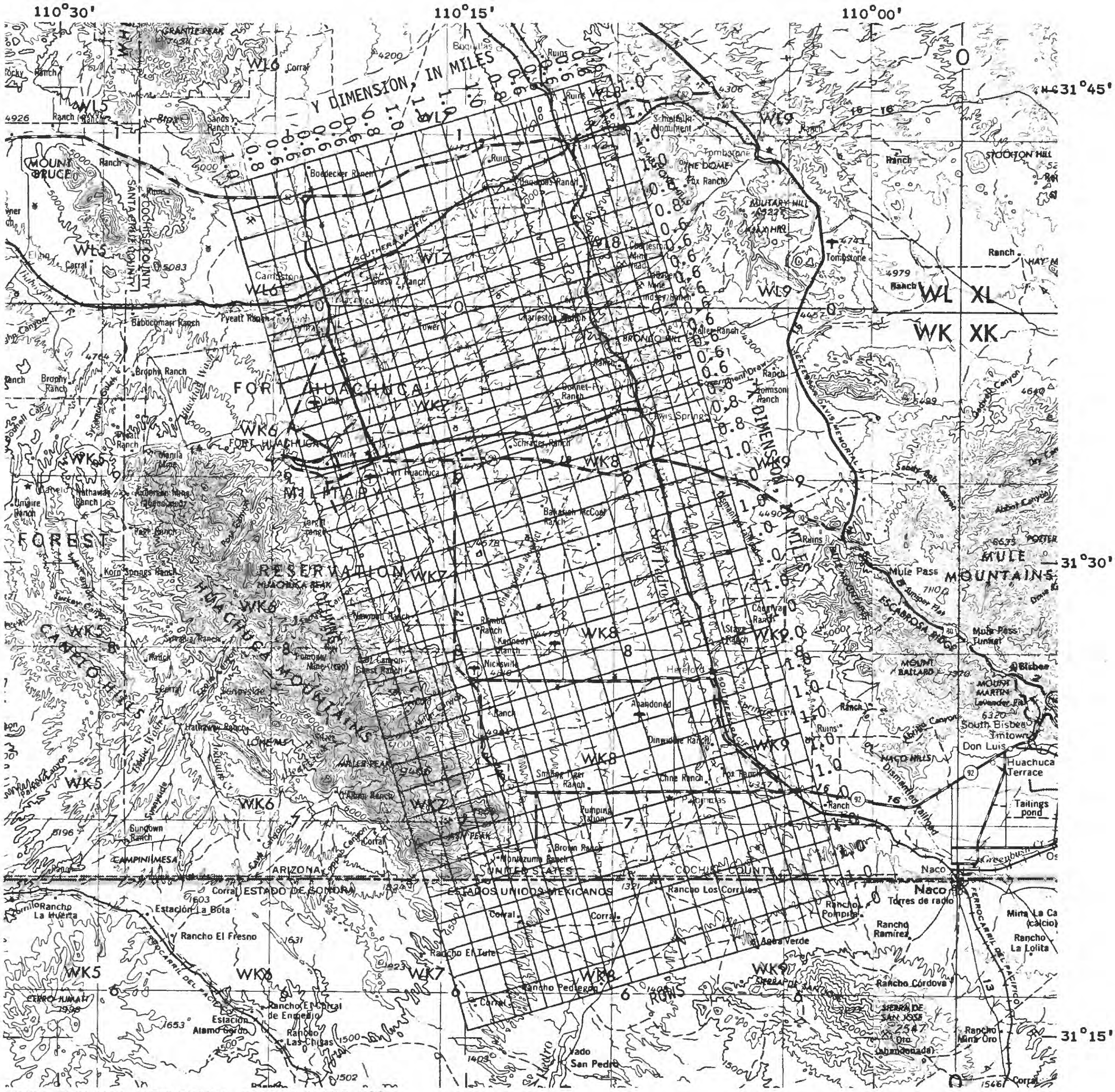
The third group of data defines the pumpage or other stresses that have altered the predevelopment equilibrium conditions. Ground-water withdrawal dates back to the early 1900's but probably had little effect until 1942 when Fort Huachuca was enlarged and water use significantly increased. The estimated historic pumpage (fig. 12) was divided into ten pumping periods for use in the simulation. The divisions were determined by the uniformity of the annual pumpage within a period of time and by the availability of comparative water-level data. Discharge from blocks that represent irrigation pumpage was reduced by 30 percent to account for the return of excess applied irrigation water to the ground-water system.

Steady-State Simulation

The development of the numerical ground-water model of the upper San Pedro basin was begun by simulating hydrologic equilibrium in the basin. Hydrologic equilibrium denotes that ground-water conditions, averaged over a long period of time, are not changing. Inflow to the system equals outflow from the system and storage does not change.

Model calibration consisted of comparing calculated to measured water levels and calculated to estimated water-budget values. Water-level contours for steady-state conditions were determined from sparse data. Trends in water levels shown in hydrographs were used in conjunction with the water levels for 1968 (Roeske and Werrell, 1973) to generate a water-level map for the predevelopment period. Water-level contours produced from the steady-state simulation and those based on field data are shown in figure 13. Model calibration was considered acceptable when differences between model and field water levels were within ±25 ft because the contour interval of the water-level contour map generated from field data was 50 ft. A greater difference was accepted in areas of large water-level fluctuations and where the steady-state data were sparse or of questionable accuracy. Recharge and discharge values for the conceptual model compared to corresponding values for the numerical model are shown in table 2. Recharge in the numerical model is 9 percent higher than the average of the estimates for the conceptual model. Ranges of transmissivity and hydraulic conductivity are slightly lower than those for the conceptual model.

During the steady-state calibration procedure, unreasonably low values for hydraulic conductivity and transmissivity were required to simulate the steep water-level gradients along the mountain fronts. The high vertical component of flow along the mountain fronts could not be



BASE FROM U.S. GEOLOGICAL SURVEY 1:250,000
DOUGLAS, 1959-67 AND NOGALES, 1956-62

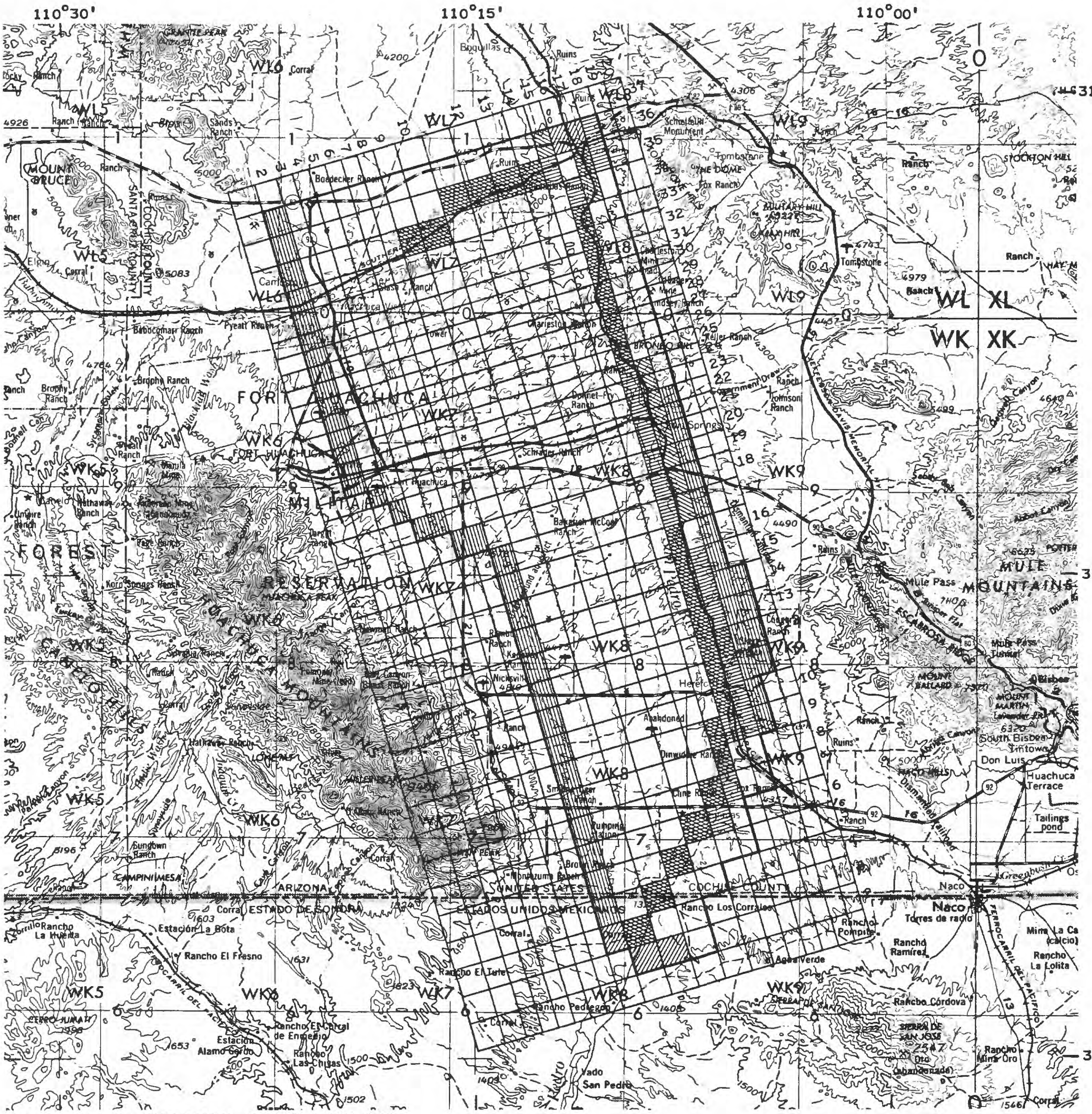
0 5 10 MILES

0 5 10 15 KILOMETERS

TOPOGRAPHIC CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 6.--Finite-difference grid used to model the upper San Pedro basin.

No Page 20



BASE FROM U.S. GEOLOGICAL SURVEY 1:250,000
DOUGLAS, 1959-67 AND NOGALES, 1956-62

0 5 10 MILES
0 5 10 15 KILOMETERS

TOPOGRAPHIC CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

BLOCKS REPRESENTING

Areal recharge

Evapotranspiration

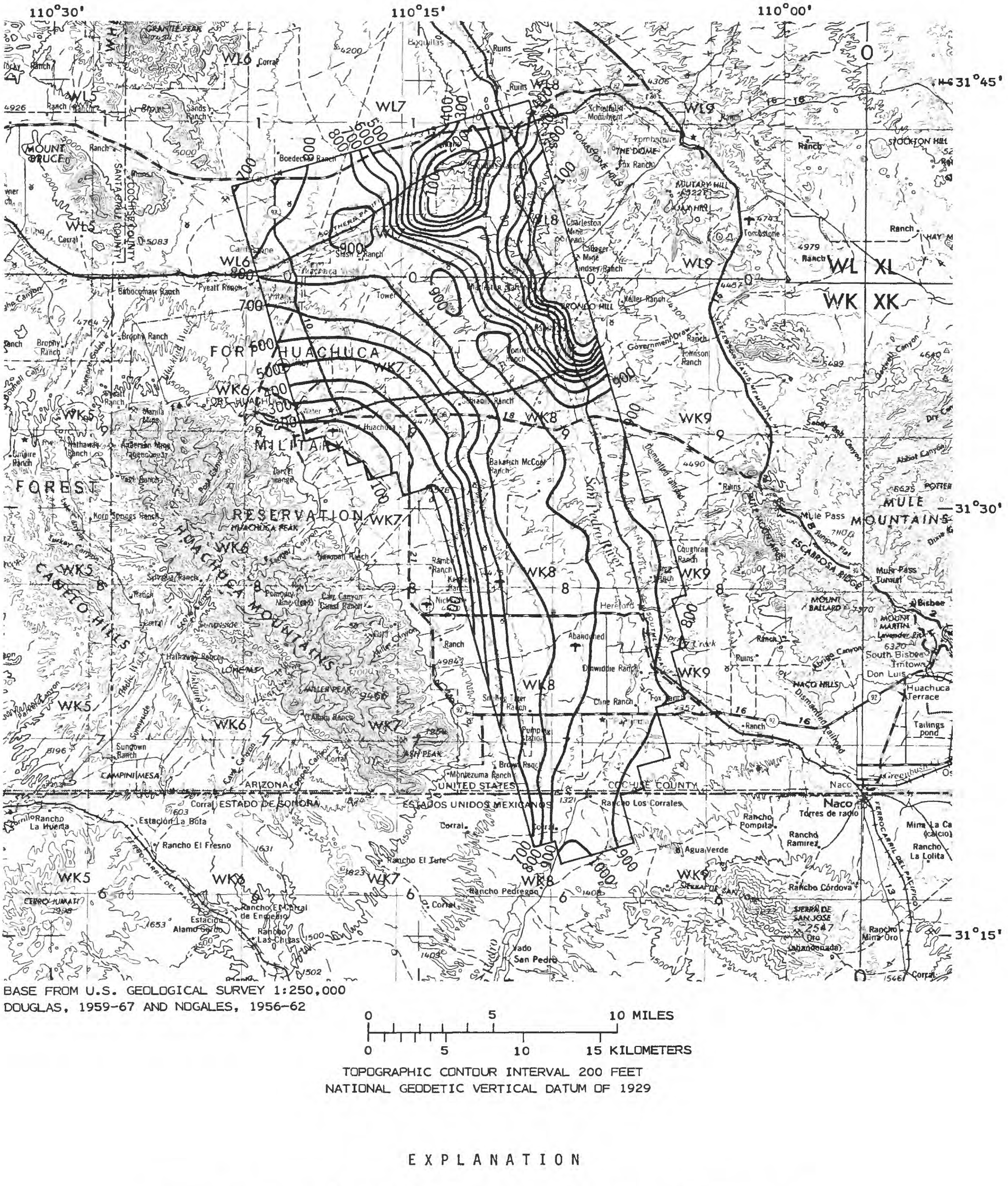
Constant head

BOUNDARY OF MODELED AREA

River

Figure 7.--Model blocks used to simulate recharge and discharge.

No Page 22



BASE FROM U.S. GEOLOGICAL SURVEY 1:250,000
DOUGLAS, 1959-67 AND NOGALES, 1956-62

0 5 10 MILES

0 5 10 15 KILOMETERS

TOPOGRAPHIC CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

——— 500 ——— LINE OF EQUAL THICKNESS OF SATURATED MATERIAL—Represents the upper layer (layer 2) in the numerical model for steady-state conditions. Interval 100 feet

——————— BOUNDARY OF MODELED AREA

Figure 8.--Saturated thickness of the upper layer as used in the steady-state simulation.

No Page 24

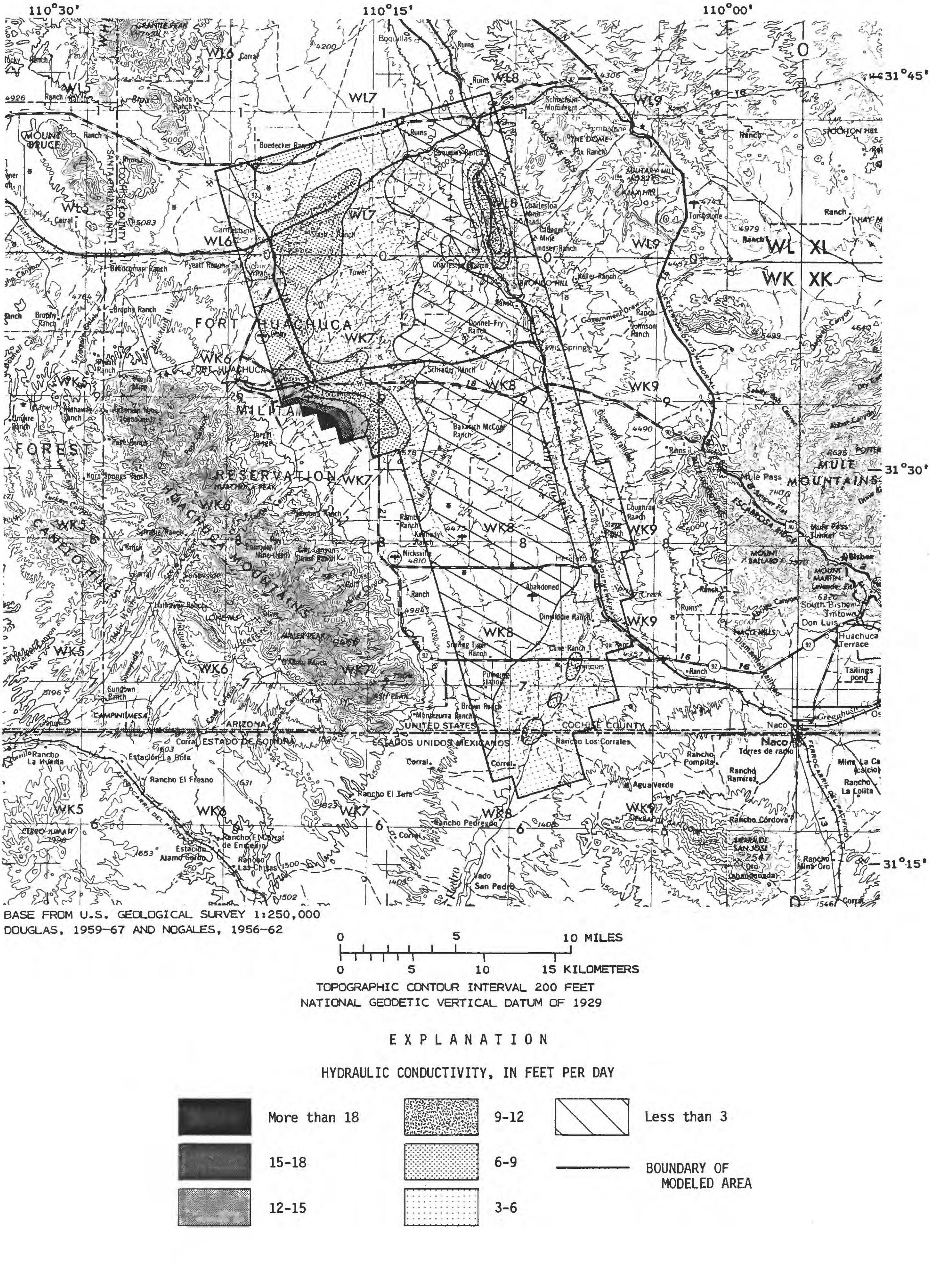
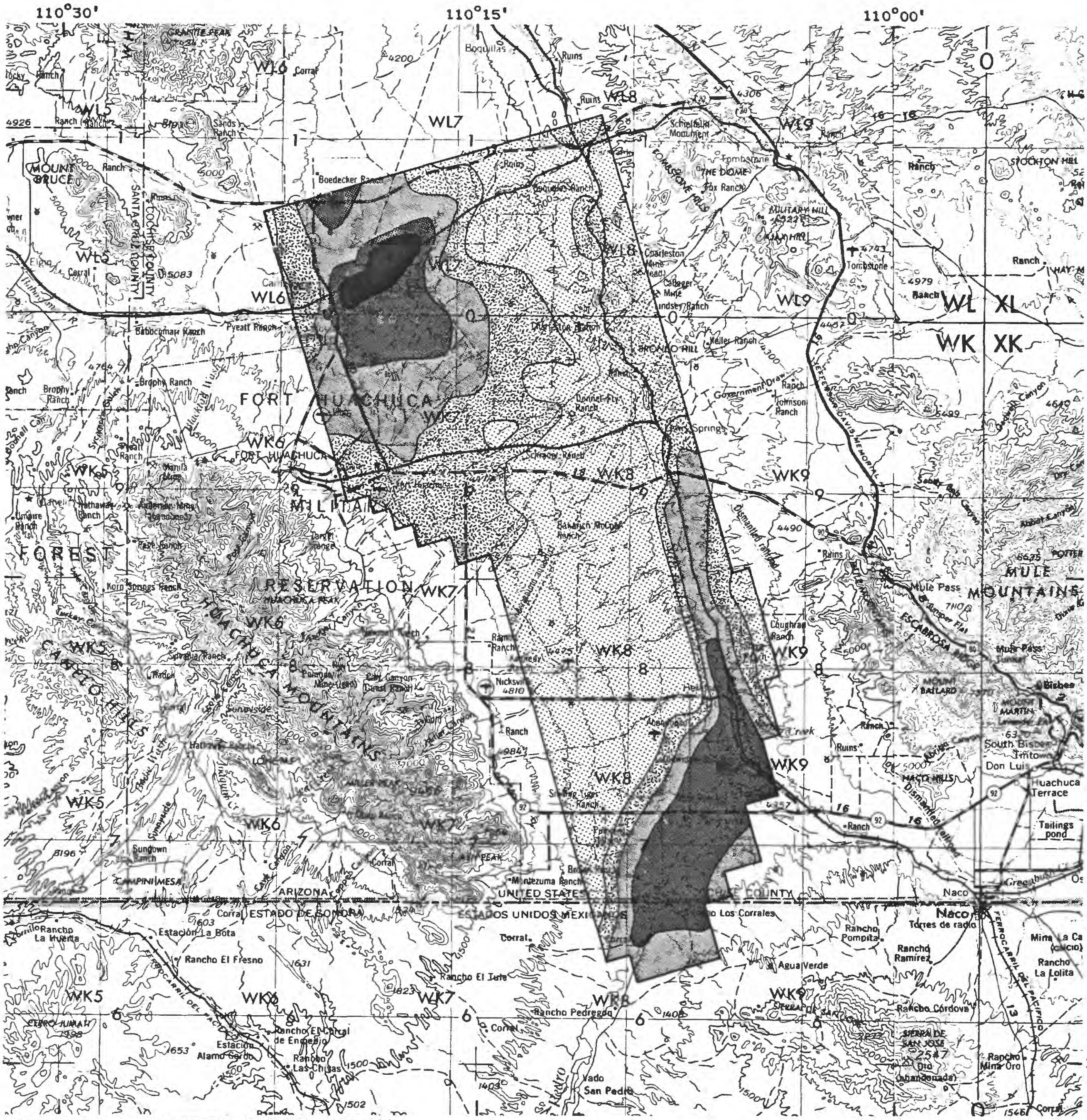


Figure 9.--Distribution of hydraulic conductivity in the upper layer of the model.

No Page 26



BASE FROM U.S. GEOLOGICAL SURVEY 1:250,000
DOUGLAS, 1959-67 AND NOGALES, 1956-62

0 5 10 MILES

0 5 10 15 KILOMETERS

TOPOGRAPHIC CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

TRANSMISSIVITY, IN FEET SQUARED PER DAY

More than 8,000

6,000-8,000

4,000-6,000

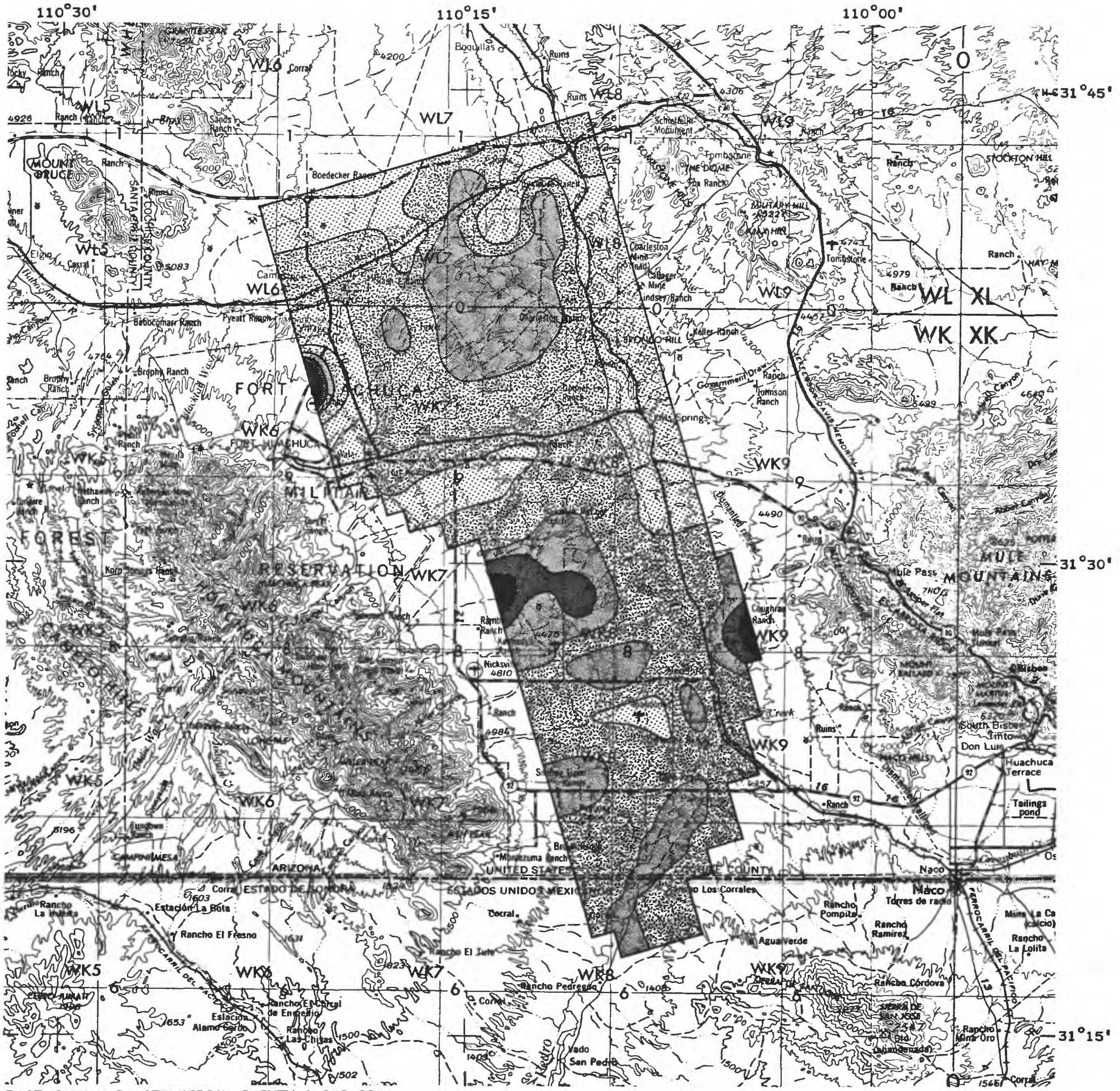
2,000-4,000

Less than 2,000

BOUNDARY OF MODELED AREA

Figure 10.--Distribution of total transmissivity for layers 1 and 2 of the model.

No Page 28



BASE FROM U.S. GEOLOGICAL SURVEY 1:250,000
DOUGLAS, 1959-67 AND NOGALES, 1956-62

0 5 10 MILES
0 5 10 15 KILOMETERS

TOPOGRAPHIC CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

SPECIFIC YIELD

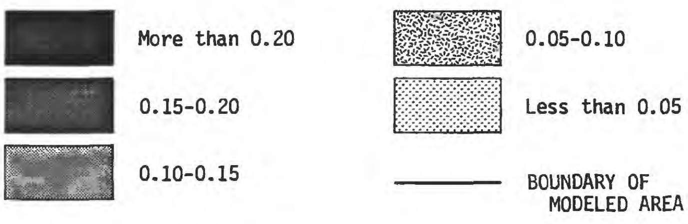


Figure 11.--Distribution of specific yield in the upper layer of the model.

No Page 30

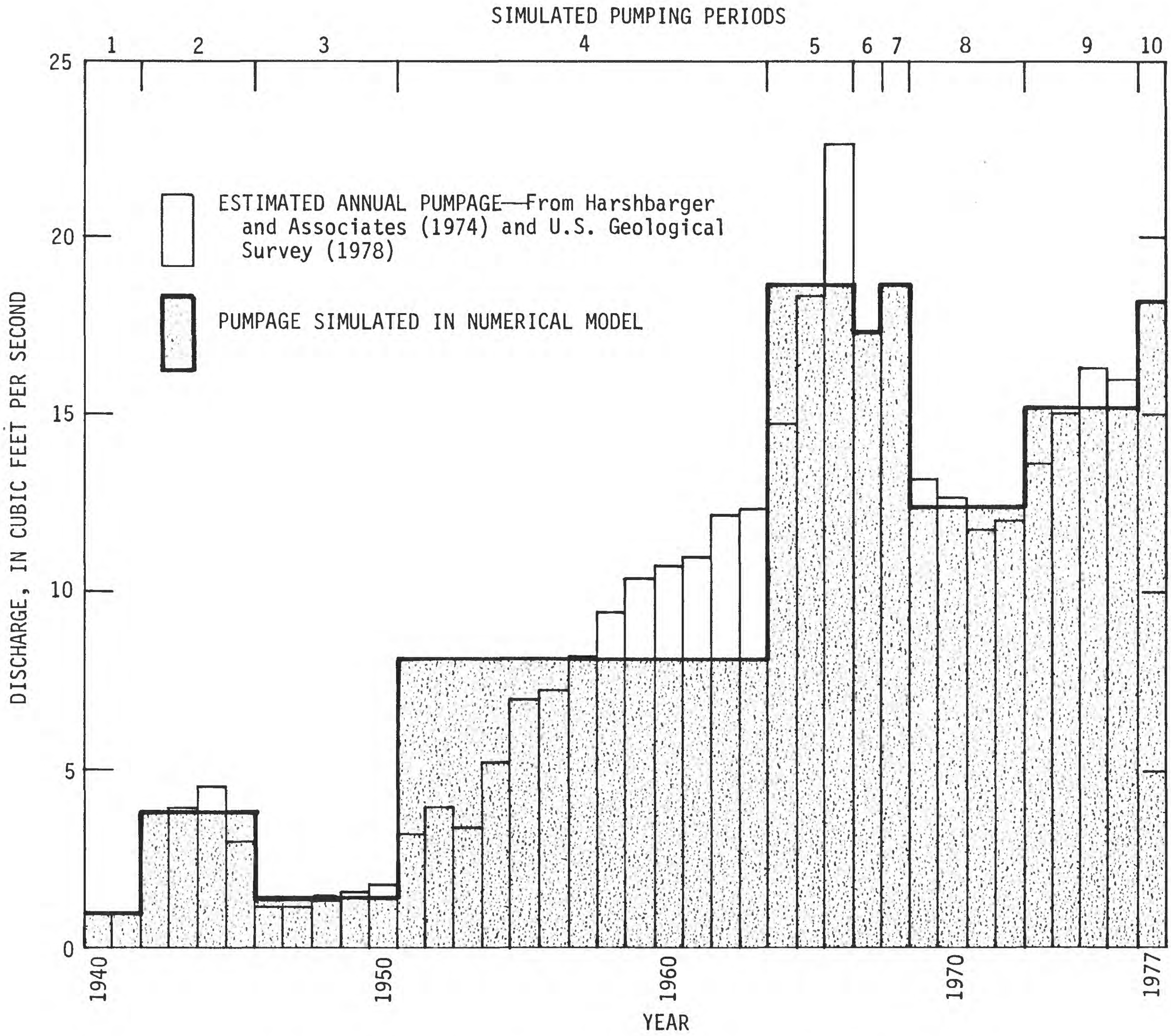
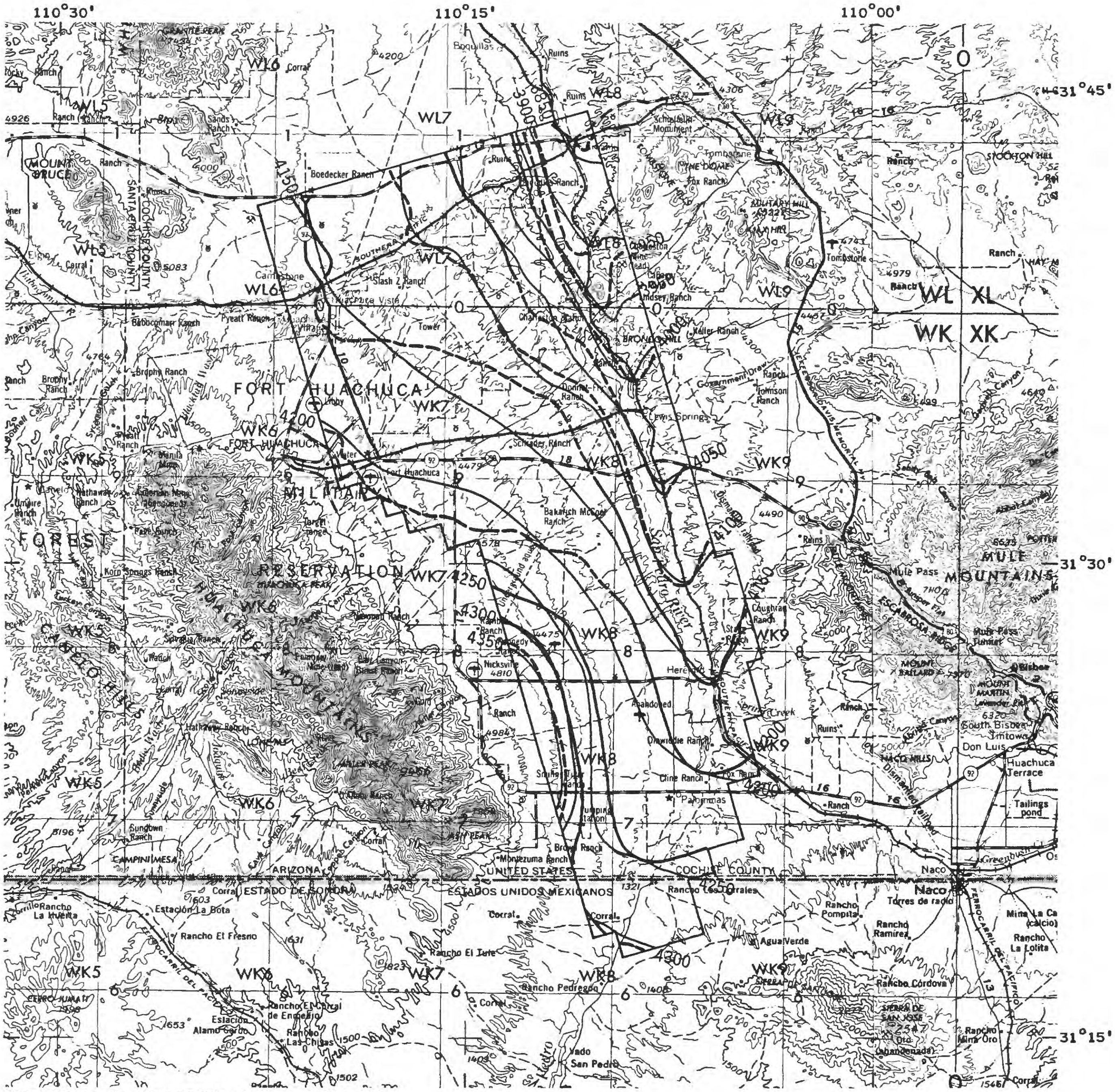


Figure 12.--Estimated annual pumpage in the upper San Pedro basin and pumpage simulated in the numerical model.



BASE FROM U.S. GEOLOGICAL SURVEY 1:250,000
DOUGLAS, 1959-67 AND NOGALES, 1956-62

0 5 10 MILES
0 5 10 15 KILOMETERS

TOPOGRAPHIC CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

—— 4200 —— CALCULATED WATER-LEVEL CONTOUR—Shows altitude of the water level as calculated by the steady-state numerical model. Interval 50 feet. National Geodetic Vertical Datum of 1929

—— 4200 - - - - WATER-LEVEL CONTOUR—Shows altitude of the water level as conceptualized for the predevelopment period. Dashed where approximately located. Interval 50 feet. National Geodetic Vertical Datum of 1929

—————— BOUNDARY OF MODELED AREA

Figure 13.--Water-level contours for steady-state conditions from the conceptual model and the numerical model.

No Page 34

Table 2.--Comparison of recharge and discharge values and hydraulic properties from the conceptual model and the numerical model

[Recharge (+) and discharge (-) values are in cubic feet per second]

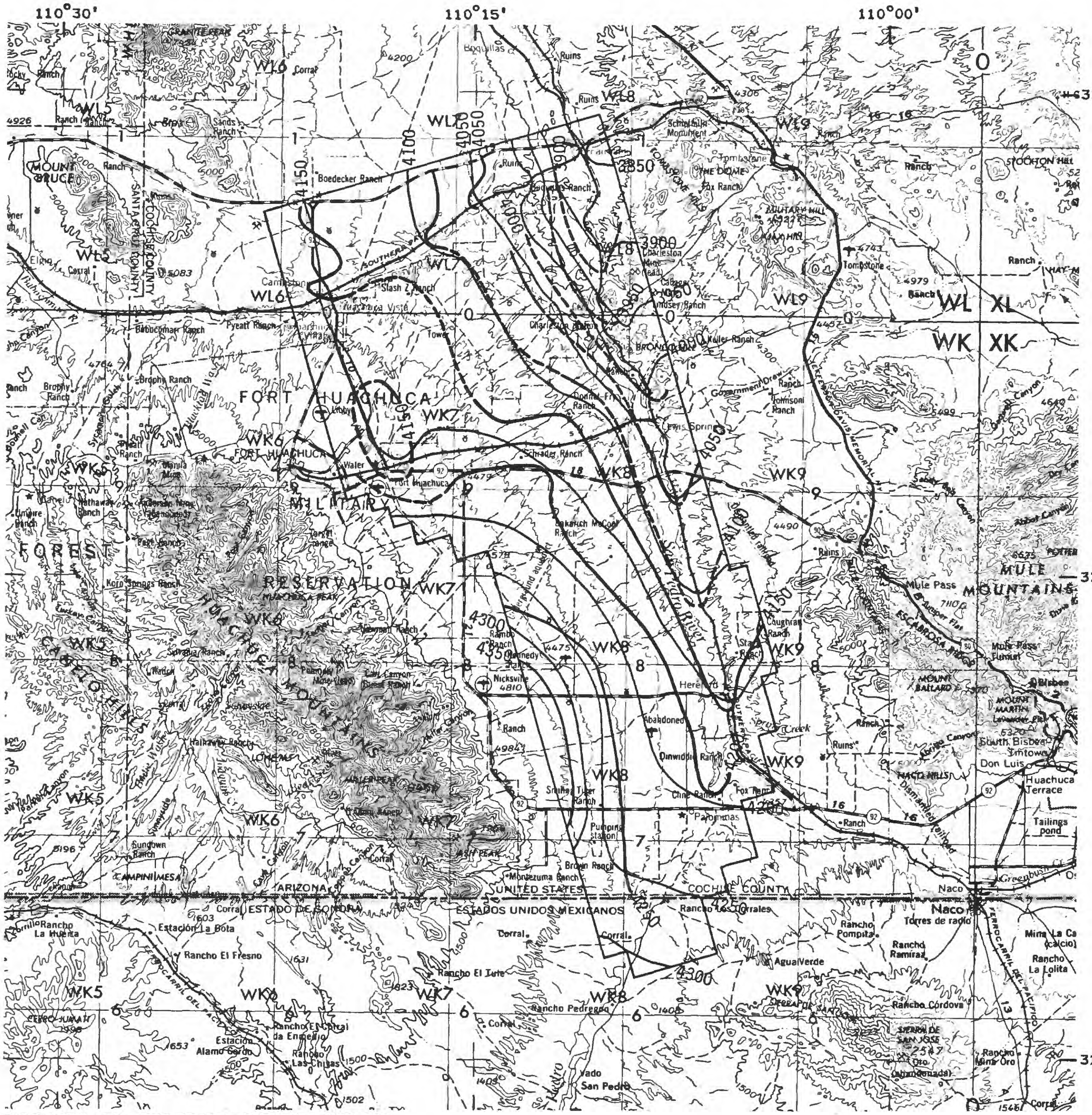
Recharge and discharge values and hydraulic properties	Conceptual-model estimates	Numerical model					
		Steady state		Transient state for 1968 (Pumping period 7)		Transient state for 1977 (Pumping period 10)	
		Input	Output	Input	Output	Input	Output
Recharge and discharge values:							
Huachuca Mountains	+5.5 to +6.9	+7.6		+7.6		+7.6	
Mule Mountains	+2.8	+3.6		+3.6		+3.6	
Babocomari Valley	+5.5	+5.9		+5.9		+5.9	
Tombstone Hills	0	+.2		+.2		+.2	
Underflow from Mexico	+1 to +4.8		+4.4		+4.5		+4.7
Underflow at Fairbank	0		-.5		-.4		-.4
Stream losses	0 to +5.9		+1.1		+1.6		+2.0
Stream gains	-2.6 to -19.8		-11.5		-7.5		-8.2
Evapotranspiration	-5 to -17		-10.8		-8.9		-8.6
Pumping		0		-14.9		-14.6	
Storage		0			+8.3		+7.8
Total recharge (+)	+14.8 to +25.9	+22.8		+31.7		+31.8	
Total discharge (-)	-7.6 to -36.8	-22.8		-31.7		-31.8	
Hydraulic properties:							
Transmissivity for layer 2, in feet squared per day	100 to 15,000	61 to 9,333		61 to 9,333		61 to 9,333	
Hydraulic conductivity, in feet per day	2 to 22	.05 to 18		.05 to 18		.05 to 18	
Coefficient of storage in layer 2	.03 to .25	--------------------		.04 to .21 .02 (bedrock)		.04 to .21 .02 (bedrock)	
Coefficient of storage in layer 2	10^{-5} to 10^{-3}	--------------------		10^{-5}		10^{-5}	

simulated by a single layer in the model. Transient model results will be affected when the effects of pumping reach the bordering areas of the model.

Transient Simulation

The hydrologic system defined with the steady-state model was analyzed using a transient simulation. Stress on the system imposed by man's use of the water resources consists of diversion of the streamflow for irrigation and withdrawal of ground water for industrial, municipal, and agricultural use. The transient simulation did not include the effects of streamflow diversion because they were assumed to be minor compared to the effects of pumpage. Model characteristics for the transient simulation remained unchanged from those of the steady-state simulation. Only aquifer-storage properties were added. Assumptions for transient simulation are that storage properties do not change vertically within a layer and that quantity and distribution of the mountain-front recharge remains constant during the simulation periods. The end of model pumping periods 7 and 10 (attachment K) correspond to the end of 1968 and the end of 1977. Water-level contour maps for the spring of 1968 (Roeske and Werrell, 1973) and for 1977-78 (Konieczki, 1980) were used to compare the transient response of the model and of the actual system. Comparisons of water-level contours constructed from field data and those constructed from model results for the two pumping periods illustrate similar regional patterns of ground-water flow (figs. 14 and 15). Both comparisons for the two pumping periods show a similar amount of water-level decline in the Fort Huachuca-Sierra Vista area. The water-level contour maps for the latest time period illustrate the expansion of the cone of depression in the vicinity of Fort Huachuca, Huachuca City, and Sierra Vista.

The results of the transient analysis for the 1977 simulation period indicate that since the steady-state period the underflow into the area across the international boundary has increased slightly as a result of a slight steepening of the hydraulic gradient. The discharge of ground water to the San Pedro River throughout its length in the modeled area has decreased because of the effects of pumping. In the reaches where streamflow losses were occurring, the quantity of loss has increased by more than 80 percent; in the reaches where streamflow gains were occurring, the amount of discharge from the ground-water system to the stream has decreased by about 30 percent. Loss from the ground-water system by evapotranspiration has decreased by about 20 percent because pumping caused a slight decline in water levels in a small area along the river. The model indicated that 5,600 acre-ft or 53 percent of the 10,500 acre-ft of water pumped from the system in 1977 was withdrawn from storage. The remainder was derived from the other components of discharge, such as evapotranspiration (about 15 percent), streamflow (about 29 percent), or changes in underflow (about 3 percent). The effects of ground-water withdrawals on the flow quantities represented in the steady-state model are summarized in table 2.



BASE FROM U.S. GEOLOGICAL SURVEY 1:250,000
DOUGLAS, 1959-67 AND NOGALES, 1956-62

0 5 10 MILES

0 5 10 15 KILOMETERS

TOPOGRAPHIC CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

——4200—— CALCULATED WATER-LEVEL CONTOUR—Altitude of the water level calculated for pumping period 7 by the model. Interval 50 feet. National Geodetic Vertical Datum of 1929

——4200 - - - - WATER-LEVEL CONTOUR—Altitude of the water level, 1968. Contours from Roeske and Werrell (1973). Dashed where approximately located. Interval 50 feet. National Geodetic Vertical Datum of 1929

———— BOUNDARY OF MODELED AREA

Figure 14.--Comparison of water-level contours from field data and those from model results for the 1968 period.

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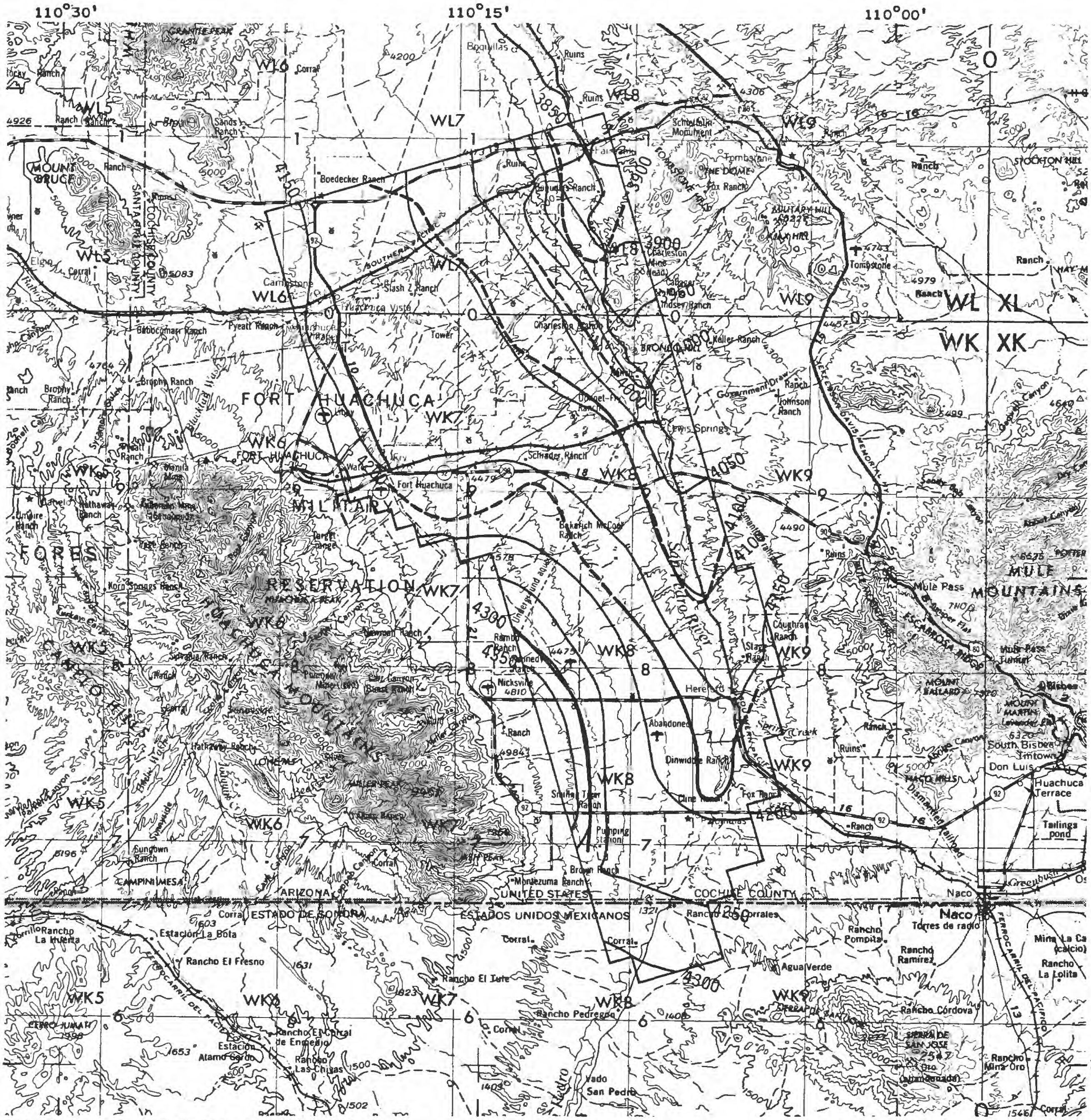

BASE FROM U.S. GEOLOGICAL SURVEY 1:250,000
DOUGLAS, 1959-67 AND NOGALES, 1956-62

0 5 10 MILES
0 5 10 15 KILOMETERS

TOPOGRAPHIC CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

——4200—— CALCULATED WATER-LEVEL CONTOUR—Altitude of the water level calculated for pumping period 10 by the model. Interval 50 feet. National Geodetic Vertical Datum of 1929

——4200 - - - - WATER-LEVEL CONTOUR—Altitude of the water level, 1977-78. Contours from Konieczki (1980). Dashed where approximately located. Interval 100 feet. National Geodetic Vertical Datum of 1929

———— BOUNDARY OF MODELED AREA

Figure 15.--Comparison of water-level contours from field data for 1977-78 and those from model results for the 1977 period.

No Page 40

Effects of Parameter Generalization and Possible Transfer Value

The methods used in this study to obtain values for numerical model input were based on information that, for the most part, is available for every basin within the Swab/RASA study area. Recharge quantity and distribution can be estimated from average annual precipitation. Transmissivities, hydraulic conductivities, and specific yields can be estimated from aquifer tests, specific capacities, or from an examination of drillers' descriptions of the units. A flow net was used in the upper San Pedro basin study to obtain a more detailed distribution of hydraulic conductivity, transmissivity, and mountain-front recharge for the initial input to the model. The success of the flow-net analysis depends on the existence of a steady-state water-level map. If no map exists, the initial input to a model can be developed by using average values of transmissivity and hydraulic conductivity based on stratigraphic, lithologic, and depositional similarities within the basin and by evenly distributing mountain-front recharge.

Results of simulations using selected data arrays developed only from average values were compared to results of the steady-state simulation. Evapotranspiration values, streambed-seepage values, and factors for vertical anisotropy remained unchanged. Generalizing mountain-front recharge resulted in water levels more than 25 ft lower than prototype water levels over about 17 percent of the modeled area. The greatest water-level differences are caused by the greatest difference between nongeneralized and generalized recharge. Water levels higher than that of the calibrated steady-state simulation are caused by generalized recharge greater than nongeneralized recharge, but these water-level increases are typically less than 20 ft. These results indicate that generalizing recharge along a basin boundary may be a transferable technique that does not greatly affect overall modeling results.

Generalizing aquifer conductivity resulted in water levels more than 25 ft lower than prototype water levels over about 53 percent of the modeled area. The model is more sensitive to generalizing aquifer conductivity than recharge because the generalized conductivity values are relatively less accurate than the generalized recharge compared with values obtained from the flow-net analysis. The concept of using generalized conductivity values in a basin model is transferable, but the effectiveness in simulating an actual hydrologic system depends on the variability of the conductivity and the accuracy of the field information on which the generalized values are based.

A transient analysis of the model using generalized values served to evaluate model sensitivity to a uniform specific-yield value. The uniform specific-yield value caused 4 ft less to 1 ft more drawdown in the final pumping period of the simulation and resulted in virtually the same depletion of storage in the aquifer. Generalizing recharge, aquifer conductivity, and storage resulted in drawdown in the final pumping period that ranged from 8 ft less to 7 ft more than that in the simulation using nongeneralized values. The pumpage coming from storage increased from 53 to 58 percent. Other flow components remained within previously estimated ranges.

Analysis of Model Reliability

The steady-state conceptual model of the hydrologic system in the upper San Pedro basin was developed on the basis of results of previous studies in the area. Hydraulic properties of the aquifer, mountain-front recharge, configuration of water-level contours, evapotranspiration rates and effective depth, leakage through the riverbed, and the amount and distribution of pumpage were extrapolated, interpolated, and (or) estimated from available previous work. The model represents an accumulation of values and distributions of hydrologic parameters that may not have been previously tested for compatibility. Part of the approach of this study was to use available knowledge to evaluate how well the system is defined and the relative importance of the various components.

The reliability of certain hydraulic properties—riverbed leakance, maximum rate of evapotranspiration, effective depth of evapotranspiration, and vertical leakance between upper and lower layers—was explored by varying their values individually through what was assumed to be reasonable ranges. The ranges were established on the basis of site-specific values within the study area and from basins of similar hydrologic setting. The results of varying the value of each property indicates the relative sensitivity of the model to the value of that property. Each variation was recorded in terms of a relative value to that used in the steady-state model against a relative change in model results. Model results were measured in terms of percent change in the net flux and the standard error of the mean head change.

The riverbed-leakance value controls the net exchange of water between the river and the aquifer. A leakance value derived from the assumption that the ratio of vertical to horizontal hydraulic conductivity in the riverbed is 1:100 was used for steady-state calibration and represents the relative value of 1 (fig. 16). The relative value can be increased beyond the reasonable range with little effect on the head distribution. The net exchange between river and aquifer increases but does not exceed the conceptual-model estimates. Decreasing the relative value below 0.1, however, lowers the net exchange below conceptual-model estimates, and more than 25 ft of head change occurs over much of the modeled area. These results indicate that the riverbed leakance selected for the model could have been higher but not lower. Relative sensitivity of head changes to changes in river leakance is low.

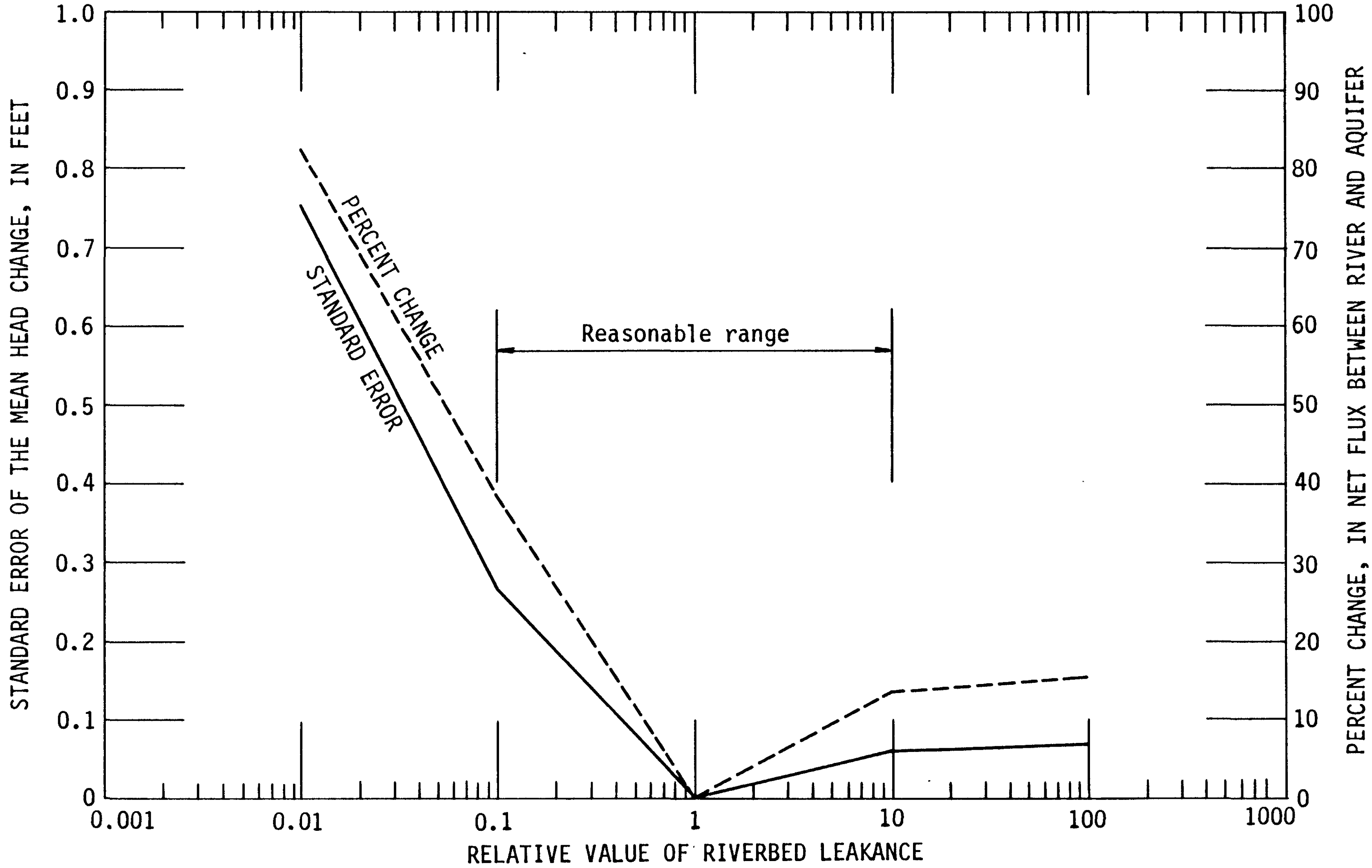

Figure 16.--Sensitivity of model-computed hydraulic heads and model-computed net flux to changes in the rate of leakage to and from the rivers.

Relative sensitivity of the model water budget to an increase in riverbed leakance is low, but if riverbed leakance is decreased by more than 10 times, the sensitivity is high.

The amount of discharge by evapotranspiration is almost half of the total discharge from the steady-state model. Model-simulated evapotranspiration is governed by a linear function between a maximum evapotranspiration rate and the depth below land surface where evapotranspiration ceases. Varying each of these values through reasonable ranges changes the net discharge by evapotranspiration by as much as 45 percent, but the total discharge from the model changes by less than 15 percent. The change in evapotranspiration is compensated for by changes in underflow and discharge to streamflow. Even though a larger than reasonable change in the amount of evapotranspiration is taking place, head changes in the aquifer are insignificant (figs. 17 and 18). Thus, the relative model sensitivity in terms of head change is low, and sensitivity of the model in terms of changes in water-budget components is high.

Modeling the aquifer as two layers served to analyze the ground-water flow relation between the saturated sediments in the upper 1,000 ft of the basin and the underlying sediments. The degree of connection between the two layers is regulated by the vertical hydraulic conductivity in the aquifer and the vertical distance of flow. The steady-state model showed that net vertical movement of ground water is up, but the total amount is less than 2 percent of the total flux. Increasing the relative value of leakance by as much as a factor of 1,000 has little effect on head changes or the model water budget (fig. 19). Decreasing the relative value of leakance by a factor of 1,000 reduces the upward flow by about 10 percent and affects head changes only slightly. Thus, the relative sensitivity of head changes and model water budget to changes in vertical leakance between layers is low. This sensitivity indicates that the hydrologic system, for all practical purposes, can be modeled as a two-dimensional system.

The numerical model developed for the upper San Pedro basin simulates the hydrologic system to an acceptable degree of accuracy on the basis of current knowledge and definition of the system. The numerical model is able to simulate all hydrologic processes presumed to be taking place. The model can produce areal water-level conditions that approximate the field data and ground-water budget values that are within the ranges estimated in previous investigations. The response of the model to manmade stress conditions demonstrate its ability to react to pumpage with moderate accuracy on a regional scale. The predictive capabilities are limited to a general assessment of changes in inflow and outflow values and changes in regional flow directions as a result of pumping. The purpose of the model was not to analyze site-specific ground-water conditions or to predict water-level changes in individual wells. Reliability of the predictive capability of the model also depends on future changes in the hydrologic system and how well the changes can be incorporated into numerical representations.

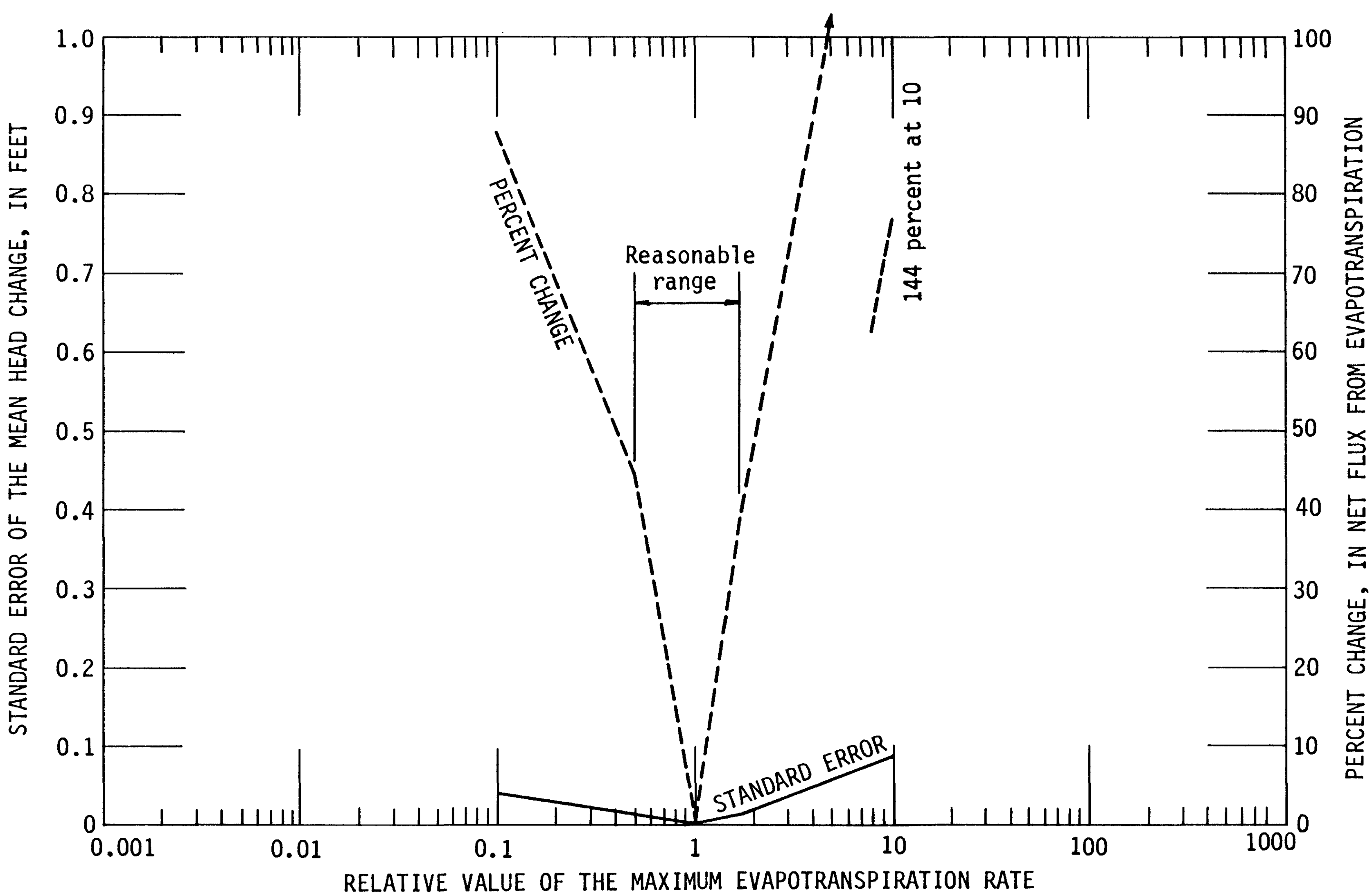

Figure 17.--Sensitivity of model-computed hydraulic heads and model-computed net flux to changes in the maximum evapotranspiration rate.

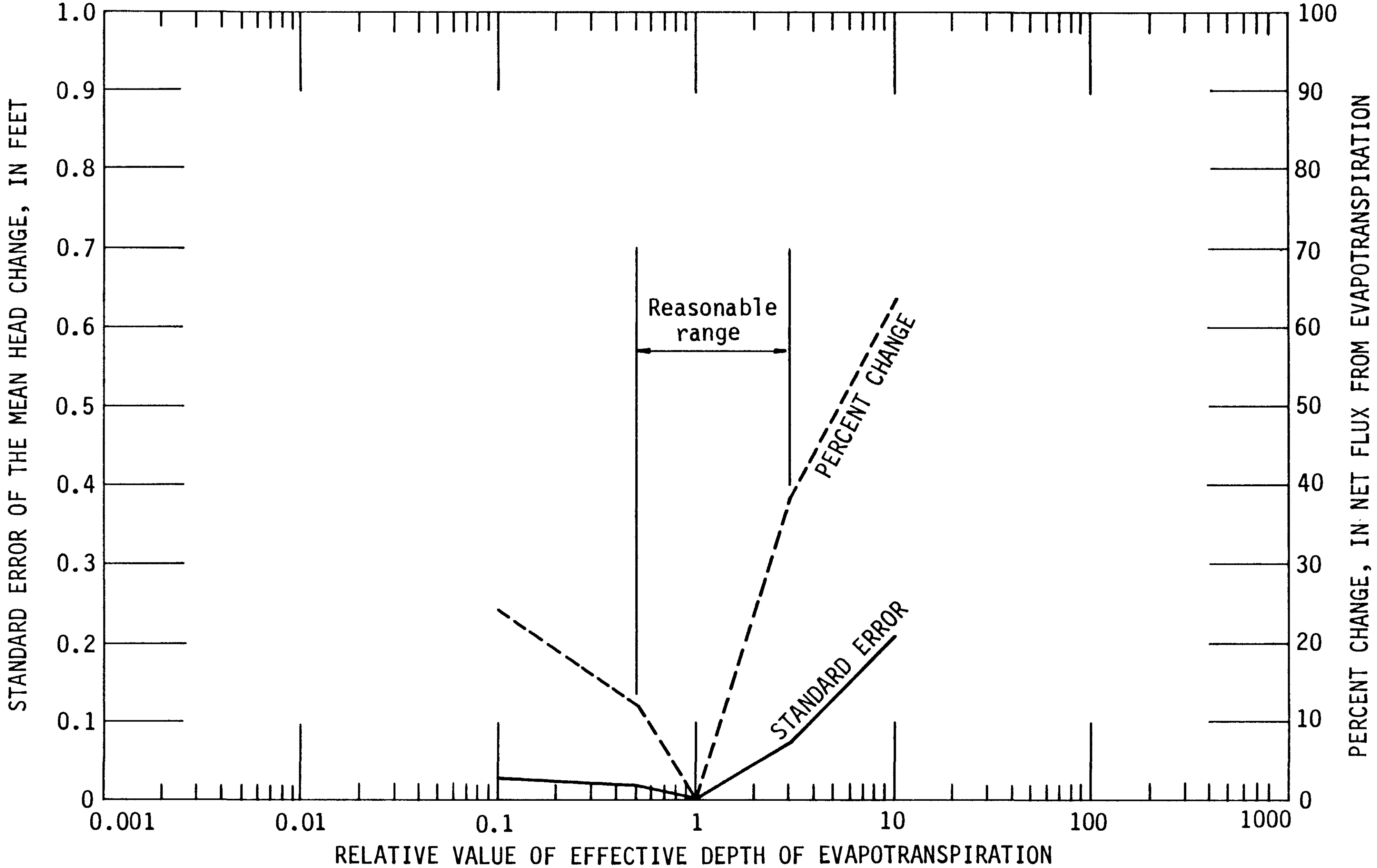

Figure 18.--Sensitivity of model-computed hydraulic heads and model-computed net flux to changes in the cessation depth of evapotranspiration.

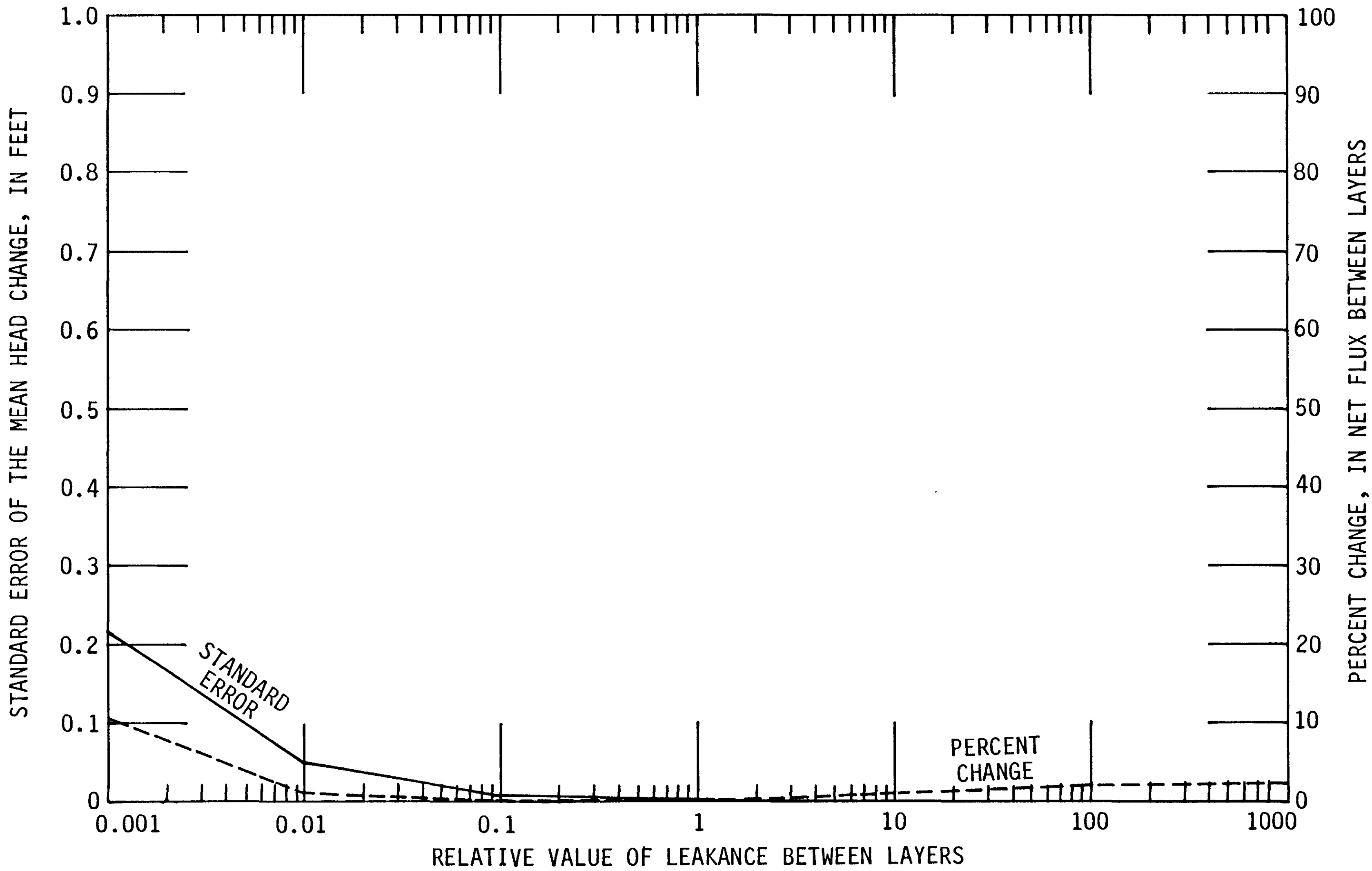

Figure 19.--Sensitivity of model-computed hydraulic heads and model-computed net flux to changes in the rate of vertical flow between layers.

Planning for the Future

The process of developing the numerical model and analyzing its reliability indicates the need for careful planning when considering the use of the ground-water resources in the upper San Pedro basin and similar basins in southeastern Arizona. The properties that quantify the hydrologic processes in the simulation are seldom well known, but more extensive collection of baseline data in undeveloped areas and more detailed investigations of surface-water and ground-water relations, evapotranspiration, and vertical ground-water flow in aquifers can help narrow the range of values that have to be considered. The upper San Pedro basin model could be used as a starting point to develop a detailed site-specific predictive model using new information as it becomes available.

The hydrologic system of the upper San Pedro basin generally can be defined by a unique set of hydraulic properties and hydrologic concepts. The possible transferability of these concepts to geohydrologically similar basins may expedite future model development. The following concepts are thought to be transferable.

—The original concept that little or no flow takes place through mountain ranges is a reasonable assumption because no additional inflow to the system was required to produce a satisfactory steady-state calibration.

—Vertical ground-water flow between the upper and lower parts of the aquifer is insignificant when compared to the total basin inflow and outflow. This vertical flow makes up only 2 percent of the net flux at steady state and only 3 percent of the amount pumped in the most recent pumping period.

—Most of the ground-water flow through the basin probably takes place in the upper part of the saturated basin fill.

—Areas near the mountain fronts where the slope of the water table is high may require the assignment of low transmissivity values to account for a large component of vertical flow, which cannot be simulated within a single layer.

—Use of average values of boundary recharge for model input provided acceptable results and the model was relatively insensitive to changes except where differences between the average value and the final calibrated-model value were large.

——Use of an average hydraulic conductivity for areas of similar geohydrologic setting would be acceptable in a steady-state model analysis only as a first approximation and should be adjusted on the basis of available aquifer-test data or a flow-net analysis. The model is less sensitive to the use of an average hydraulic conductivity in a transient analysis assuming known geohydrologic differences in the parameter are recognized, such as the difference between basin fill and recent stream alluvium.

——Use of an average specific yield is acceptable in a basin if the degree of development has not resulted in extensive ground-water mining. Model results were insensitive to areal variations in specific yield.

Although the model, as developed, is not designed for use in site-specific studies, generalized planning for the future use of the ground water is possible. The model could be used to investigate the effects that might result if significant changes in the hydrologic system take place. The current use pattern could be significantly altered by increased municipal or agricultural pumping, or the natural system could be changed by an increase or decrease in recharge or alteration of the vegetation near the rivers.

SUMMARY

The hydrologic system of the upper San Pedro basin typifies that of several basins in southeastern Arizona. The basin receives a moderate amount of recharge from surrounding mountain ranges, which is discharged through evapotranspiration and by seepage to a small stream during steady-state conditions. The basin fill and the flood-plain alluvium are stratigraphically complex, and water levels in wells drilled into these materials sometimes exhibit an indication of confinement, but regionally the aquifer is considered unconfined. Only the upper, generally more permeable, part of the aquifer has been explored and is being used for ground-water withdrawal.

The conceptual model was assimilated from available data and interpretations from other studies. The development of the numerical model was based on the conceptual model. No changes to the conceptual model were necessary, and changes made in the values of hydraulic properties in the model were kept within the range assumed reasonable for that property. The numerical model used two layers to simulate a single aquifer. The upper layer represented that part of the aquifer for which field data are available; the lower layer represented that part about which little is known. Quantities of recharge and values of hydraulic properties were adjusted to obtain closer comparisons between field data and model results.

The calibrated steady-state model indicated a total recharge to and discharge from the basin of about 16,500 acre-ft/yr or 22.8 ft^3/s. Seventy-five percent of the recharge is attributed to runoff from the mountains, 19 percent to underflow from Mexico, and the remainder to streamflow losses. Discharge is evenly distributed between evapotranspiration losses and streamflow gains and about 2 percent is discharging as underflow near Fairbank. The model simulating 1977 conditions included 10,500 acre-ft/yr of pumpage, and the model results indicated that about 5,600 acre-ft/yr was derived from depletion of water in storage. In addition, long-term decreases in evapotranspiration losses and in discharge of ground water to streamflow have resulted.

To examine the effect of using uniform rather than variable values for boundary recharge, aquifer conductivity, and specific yield, simulations using generalized values were compared to the final steady-state and transient-state simulations. The comparisons indicated that, for this area, generalizing mountain-front recharge and specific yield changed the simulated water levels less than generalizing aquifer conductivity. All such generalizations, however, caused simulated water levels to change by more than 25 ft over at least part of the modeled area. Flux changes that resulted from the generalizations did not cause any flow-component values to fall outside the estimated ranges. Thus, using generalized values for modeling similar basins may be acceptable for testing estimates of flow components but not for simulating water-level conditions.

The numerical model developed during this study was designed and calibrated only to a degree necessary to attain a reasonable definition of the hydrologic system and to support, if possible, prior conceptions of how these hydrologic mechanisms work and interact. This model is one viable representation of the system. It should not be regarded as an exact, unique duplication of the hydrologic processes taking place. The model can be used to gain a better understanding of the interrelations that may occur when significant natural or manmade phenomena change one or more hydrologic processes. This model provides a starting point for the development of more detailed models when additional data become available. Water-level monitoring and streamflow measurements need to be continued and expanded as development in this area progresses.

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ATTACHMENTS

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	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
4	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
5	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
6	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
7	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	4215
8	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	4200
9	•	•	4299	4290	4290	4295	4325	4365	4390	4395	4390	4378	4360	4310	4260	4240	4220	4195
10	•	4299	4280	4270	4260	4268	4275	4280	4290	4295	4300	4295	4288	4265	4242	4220	4210	4190
11	•	4290	4290	4260	4250	4240	4240	4248	4250	4252	4255	4255	4250	4245	4230	4210	4190	4185
12	•	4300	4280	4260	4240	4230	4230	4230	4230	4230	4230	4230	4230	4220	4210	4200	4180	4175
13	•	•	•	4260	4240	4220	4220	4210	4210	4210	4210	4210	4205	4200	4180	4170	4170	4160
14	•	•	•	•	4240	4220	4210	4190	4185	4180	4180	4180	4170	4160	4155	4150	4140	4130
15	•	•	•	•	4235	4230	4200	4180	4170	4165	4150	4150	4140	4115	4105	4100	4100	4100
16	•	•	•	•	•	•	4190	4180	4170	4150	4140	4135	4120	4100	4080	4070	4060	4050
17	•	•	•	•	•	•	4190	4180	4170	4160	4145	4130	4120	4105	4090	4075	4060	4040
18	•	•	•	•	•	•	•	•	4180	4170	4155	4145	4130	4120	4100	4085	4070	4050
19	•	•	•	•	•	•	•	•	•	•	4160	4150	4140	4130	•	•	•	•
20	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	1
2	•	•	•	4210	4200	4200	4200	4190	4185	4180	4180	4175	4170	4165	4170	4180	4185	4190	•	2
3	•	•	4200	4195	4195	4195	4195	4185	4175	4170	4165	4165	4150	4145	4155	4165	4170	4160	•	3
4	•	4200	4195	4190	4190	4190	4190	4180	4170	4165	4160	4150	4140	4140	4145	4155	4150	4140	•	4
5	4205	4195	4190	4190	4185	4185	4180	4175	4170	4165	4160	4145	4140	4140	4140	4145	4140	4140	•	5
6	4192	4190	4190	4185	4180	4180	4175	4170	4165	4160	4155	4140	4140	4135	4130	4130	4140	4130	•	6
7	4195	4190	4185	4185	4180	4180	4170	4165	4160	4155	4150	4140	4135	4130	4120	4120	4130	4130	•	7
8	4192	4185	4185	4180	4180	4175	4170	4165	4160	4155	4145	4135	4130	4120	4115	4110	4120	4120	•	8
9	4190	4185	4180	4180	4175	4170	4165	4160	4155	4150	4140	4130	4120	4115	4110	4100	4110	4105	•	9
10	4185	4180	4180	4175	4170	4165	4160	4155	4150	4140	4130	4120	4110	4105	4105	4090	4090	4080	•	10
11	4180	4175	4170	4165	4160	4160	4155	4145	4130	4120	4120	4110	4100	4100	4080	4070	4060	4060	•	11
12	4170	4165	4160	4160	4155	4150	4130	4110	4090	4080	4070	4070	4060	4060	4060	4050	4040	4035	•	12
13	4155	4150	4150	4145	4140	4120	4090	4070	4060	4050	4040	4040	4040	4030	4030	4025	4020	4020	•	13
14	4125	4120	4120	4110	4100	4080	4060	4050	4040	4030	4020	4020	4010	4000	4000	4000	4000	4000	•	14
15	4100	4090	4080	4070	4060	4050	4040	4030	4000	3980	3960	3940	3920	3900	3890	3890	3900	3900	•	15
16	4045	4040	4030	4020	4010	4000	3980	3960	3950	3940	3930	3920	3910	3890	3890	3870	3870	3860	•	16
17	4035	4030	4020	4010	4000	3995	3990	3985	3980	3970	3960	3950	3930	3900	3890	3860	3850	3850	•	17
18	4040	4035	4025	4015	4005	4000	3995	3995	3985	3975	3965	3955	3935	3905	3895	3865	3855	3855	•	18
19	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	19
20	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	20

SCALE = 1 : 210000

A. STARTING HEAD FOR THE LOWER AND UPPER LAYERS OF THE AQUIFER IN FT ABOVE NGVD OF 1929.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1																																					
2																						53	53	53	53	2135	2135	2135	2135	2135	747	747	533	533	533	533	
3																					53	53	53	2135	2135	2135	2135	2135	2135	2135	1601	1601	533	533	533	533	
4																				53	53	2135	2135	2135	2135	2135	2135	213	2135	2135	2135	2456	2456	2135	2135	2135	
5																			53	53	533	2135	2135	2135	2135	2135	2135	2135	2135	2135	2135	2135	2669	2135	2135	2135	
6																			533	533	1067	2135	2135	2135	2135	2135	2135	2135	2135	2135	2135	2135	2669	2135	2135	2135	
7																		533	533	533	533	533	533	1067	2135	2135	2135	2135	2135	2135	2135	2135	2456	2135	533	533	
8																		533	533	533	533	533	533	533	533	1067	2135	2135	2135	2135	2135	2135	2135	2135	533	533	
9			533	533	74	42	32	32	42	74	106	106	106	106	106	106	533	533	533	533	533	533	533	533	533	533	1067	1067	2135	2135	2135	533	533	1601	533	533	
10		533	533	533	533	320	213	85	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	533	320	320	533	1067	533	533	533	533	533	1067	1067	533	
11		533	533	2135	2135	1067	1067	533	533	533	106	106	106	106	106	106	106	106	106	106	106	106	320	320	320	320	533	533	533	533	533	533	533	533	1067	533	
12		2135	2135	2135	2135	2135	2135	2135	533	533	533	106	106	106	106	106	106	106	106	106	106	106	106	320	320	533	533	533	533	533	533	533	53	53	961	533	
13				2135	2135	2135	2135	2135	2135	1067	747	533	106	106	106	106	106	106	106	106	106	106	320	320	320	533	533	533	53	53	533	533	53	53	53	320	
14					2135	2135	2135	2135	2135	1067	533	533	533	533	533	106	106	106	106	106	53	53	53	42	32	53	53	53	53	53	53	53	53	53	53	320	
15					2135	2135	2135	2135	2135	2135	320	320	320	320	320	106	106	106	106	106	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	533	
16							2135	2135	2135	2135	2135	2135	533	533	533	533	533	533	533	53	53	53	53	53	53	53	85	85	85	85	85	85	85	53	53	533	
17							2135	2135	2135	2135	533	533	533	533	533	533	533	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	533	
18									2135	533	533	533	533	533	533	533	53	53	53	53	53	53	53	53	53	32	21	10	10	21	32	42	42	53	53	533	
19											533	533	533	533																							
20																																					

SCALE = 1 : 210000

B. TRANSMISSIVITY IN LAYER 1 IN FT2/S X 10-5.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1571	1269	1087	846	785	785	725	725	423	423	423	362	362	362	362	.	2
3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1994	1571	1329	846	725	725	725	725	725	483	604	604	362	362	362	362	.	3
4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2115	1873	967	846	785	664	725	725	725	725	725	725	785	785	543	543	725	.	4
5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1873	2054	1390	846	785	664	664	664	664	664	725	725	725	725	846	543	543	725	.	5
6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1571	1450	1027	785	725	664	664	664	664	664	664	725	725	725	906	604	483	725	.	6
7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	967	1329	1208	846	725	725	664	664	664	664	664	664	725	725	725	846	967	483	664	.	7
8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1148	1269	1148	725	664	664	664	664	664	664	664	664	664	725	725	846	1027	483	664	.	8
9	.	.	543	302	48	24	12	6	24	30	30	60	60	181	483	483	362	906	725	604	543	483	604	604	604	664	664	664	664	664	664	664	664	1027	664	664	.	9
10	.	604	725	604	604	483	60	60	60	60	60	60	60	181	181	181	241	362	362	362	423	362	241	302	423	664	664	664	664	664	664	483	483	664	664	423	.	10
11	.	604	604	725	604	604	483	120	60	60	60	60	60	181	120	120	181	241	241	181	302	362	302	181	483	302	302	423	423	423	483	483	483	483	664	423	.	11
12	.	483	604	604	725	604	483	241	120	60	60	60	60	120	120	120	181	241	241	181	181	181	302	302	12	181	362	362	362	362	362	362	30	30	664	362	.	12
13	.	.	.	483	604	725	604	483	181	120	60	120	120	120	181	181	181	241	241	181	181	181	181	12	302	302	302	302	302	302	302	302	302	60	30	302	.	13
14	.	.	.	.	483	604	725	604	604	241	120	30	30	30	60	60	90	181	181	181	120	120	30	30	302	302	302	483	604	362	362	362	181	181	30	60	.	14
15	.	.	.	.	483	604	604	604	604	60	30	30	30	30	30	30	30	30	30	30	30	30	60	60	241	302	302	725	30	30	423	483	181	30	241	60	.	15
16	.	.	.	.	.	.	604	604	604	604	604	604	604	604	604	604	604	120	120	120	120	120	120	120	483	483	604	1208	1208	1208	1208	1208	1208	543	120	604	.	16
17	.	.	.	.	.	.	604	604	604	604	604	604	604	423	423	423	604	604	604	483	483	483	483	483	302	302	302	302	302	302	302	302	302	302	483	604	.	17
18	.	.	.	.	.	.	.	.	302	120	120	120	120	120	423	423	423	604	362	302	302	302	60	60	60	30	30	30	30	30	30	60	60	60	241	241	.	18
19	.	.	.	.	.	.	.	.	.	.	60	60	60	60	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	19
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	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	

SCALE = 1 : 210000

C. HYDRAULIC CONDUCTIVITY IN LAYER 2 IN FT/S X 10-7.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
4	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
5	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
6	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
7	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	3910
8	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	3900
9	•	•	3550	3550	3550	3550	3625	3715	3790	3835	3880	3908	3930	3930	3920	3940	3900	3850
10	•	3280	3280	3340	3360	3470	3475	3480	3515	3545	3575	3595	3613	3615	3617	3600	3700	3550
11	•	3340	3320	3260	3280	3340	3360	3410	3450	3490	3500	3500	3470	3450	3410	3390	3390	3385
12	•	3400	3360	3320	3240	3280	3300	3340	3360	3370	3380	3380	3365	3350	3320	3300	3320	3320
13	•	•	•	3360	3300	3220	3260	3280	3280	3300	3310	3325	3310	3290	3270	3260	3270	3260
14	•	•	•	•	3340	3280	3210	3240	3240	3260	3260	3260	3240	3240	3220	3220	3240	3220
15	•	•	•	•	3320	3320	3280	3190	3200	3220	3220	3220	3200	3200	3180	3160	3160	3160
16	•	•	•	•	•	•	3280	3300	3190	3160	3140	3180	3160	3090	3080	3070	3080	3080
17	•	•	•	•	•	•	3300	3340	3280	3240	3220	3130	3120	3180	3200	3140	3060	3040
18	•	•	•	•	•	•	•	•	3340	3300	3280	3260	3240	3240	3240	3200	3160	3140
19	•	•	•	•	•	•	•	•	•	•	3340	3300	3280	3280	•	•	•	•
20	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
2	•	•	•	4050	3980	3900	3820	3720	3680	3595	3525	3485	3460	3380	3340	3400	3420	3460	•
3	•	•	4090	4020	3950	3875	3795	3720	3650	3575	3510	3470	3410	3350	3300	3340	3380	3420	•
4	•	4090	4050	3990	3940	3850	3770	3700	3630	3560	3470	3440	3380	3320	3280	3320	3360	3380	•
5	4080	4070	4000	3950	3890	3815	3745	3675	3600	3530	3440	3400	3360	3320	3260	3320	3340	3360	•
6	4040	3990	3940	3895	3840	3780	3715	3640	3570	3500	3420	3380	3340	3300	3240	3280	3300	3340	•
7	3960	3910	3870	3810	3770	3720	3670	3600	3535	3450	3400	3365	3340	3280	3220	3220	3260	3300	•
8	3880	3840	3790	3760	3720	3675	3620	3550	3500	3410	3370	3350	3320	3270	3200	3200	3240	3260	•
9	3780	3750	3710	3680	3640	3590	3550	3490	3400	3360	3340	3340	3320	3260	3200	3200	3320	3240	•
10	3660	3630	3600	3570	3540	3500	3410	3360	3340	3320	3300	3285	3270	3240	3400	3290	3360	3500	•
11	3470	3500	3470	3400	3320	3320	3320	3300	3270	3250	3230	3200	3310	3400	3840	3675	3500	3640	•
12	3340	3350	3300	3280	3260	3250	3240	3220	3200	3180	3200	3260	3450	3600	3980	3960	3850	3580	•
13	3260	3240	3230	3230	3210	3170	3160	3400	3550	3510	3510	3510	3500	3560	3940	3990	3990	3660	•
14	3220	3220	3200	3190	3380	3340	3400	3500	3500	3550	3500	3500	3550	3520	3500	3800	3870	3640	•
15	3160	3170	3350	3440	3520	3500	3550	3800	3600	3750	3930	3910	3720	3550	3550	3450	3750	3800	•
16	3150	3300	3400	3700	3700	3550	3630	3900	3830	3820	3810	3800	3710	3590	3540	3470	3460	3420	•
17	3110	3230	3720	3940	3950	3945	3940	3935	3930	3930	3910	3890	3840	3760	3660	3660	3350	3340	•
18	3120	3300	3300	3750	3955	3950	3945	3945	3935	3925	3915	3905	3885	3855	3695	3665	3555	3500	•
19	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
20	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

SCALE = 1 : 210000

D. ALTITUDE OF THE BOTTOM OF LAYER 2 IN FT ABOVE NGVD OF 1929.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1																																					
2																						2970	933	2900	4006	2762	2693	2555	1936	864	533	1105	2003	3867	4075	4420	
3																					2141																
4																				3315																	
5																			1381																		
6																			5525																		
7																		1381																			
8																		4144																			
9				34	34	379	518	759	1312	1519	1795	1795	1795	2003	2141	2072	1795																				
10																																					
11																																					
12																																					
13				497																																	
14																																					
15					828	828																															
16																																					
17							621	759																													
18									1450	2072		1174	1243	1174	1657	1243	1105	759	690	621	483	483															
19											2072	1174	1243	1243																							
20																																					

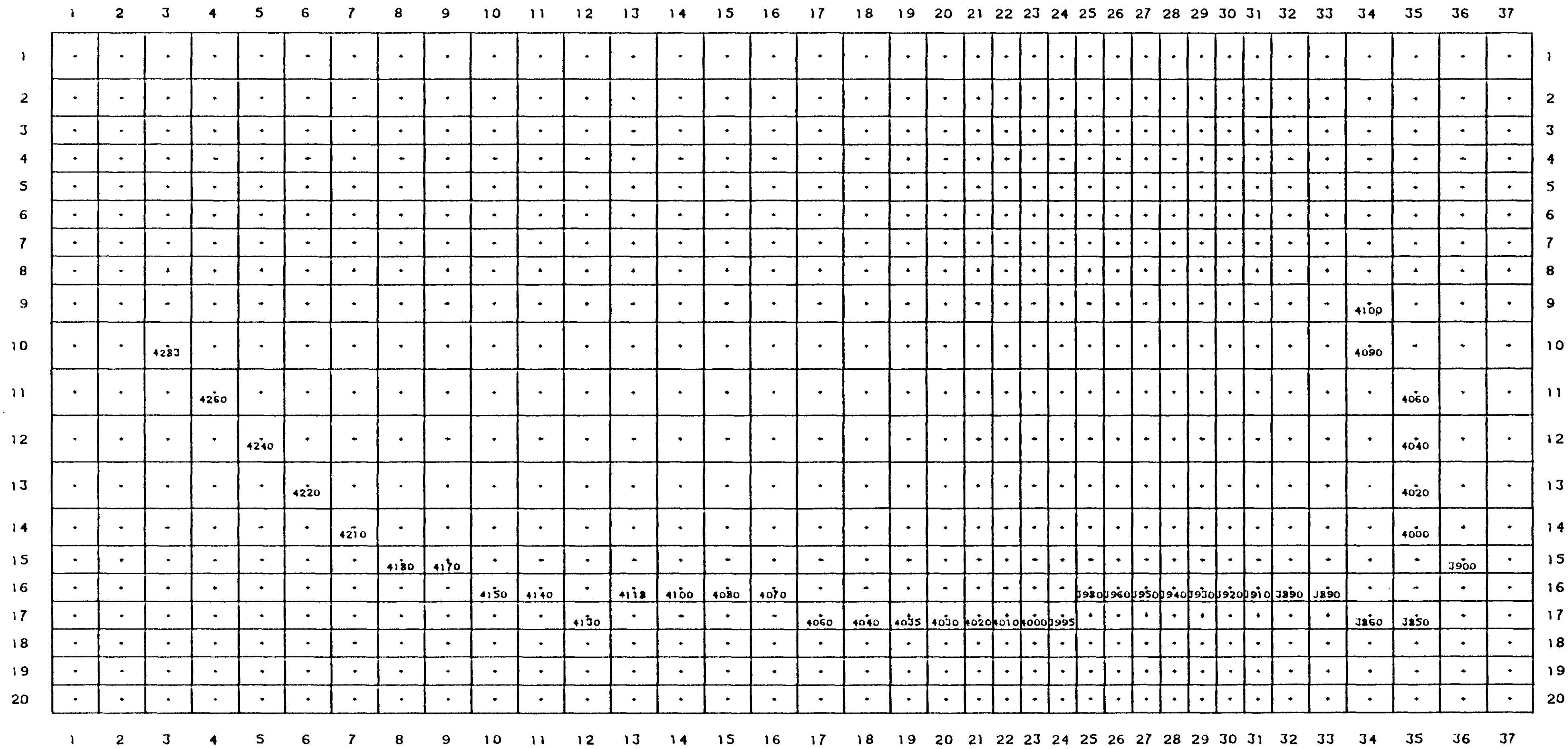
SCALE = 1 : 210000

E. AREAL RECHARGE RATE REPRESENTING RECHARGE FROM THE MOUNTAINS IN FT/S X 10-11.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1																																					
2																																					
3																																					
4																																					
5																																					
6																																					
7																																					
8																																					
9																																		4110			
10			4284																															4093			
11			4260																																4064		
12					4240																														4041		
13						4221																													4030		
14						4230	4210																												4000		
15							4210	4185	4175						4115	4110	4110																		3910		
16									4180	4155	4143	4140	4120	4102	4084	4072	4070	4060	4055	4050	4040	4030	4010	4000	3983	3962	3953	3945	3930	3920	3911	3898	3891	3880			
17									4180	4170	4155	4132	4130	4115	4100			4146	4139	4133	4022	4010	4010	4005	4000	3995	3990	3980	3970	3960	3940	3910	3900	3860	3850		
18																																			3865	3865	
19																																					
20																																					

SCALE = 1 : 210000

F. LAND-SURFACE ALTITUDE IN FT ABOVE NGVD OF 1929 (NODES WHERE ET IS SIMULATED).



SCALE = 1 : 210000

G. ALTITUDE OF THE RIVERS IN FT ABOVE NGVD OF 1929.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	06	06	06	06	269	[illegible]	269	0	268	[illegible]	494	1067	1067	1067	1067	•
3	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	06	06	06	268	268	26[illegible]	269	269	270	269	202	3202	1067	1067	1067	1067	•
4	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	106	06	267	267	268	268	269	269	27	270	270	270	4910	4911	4269	4269	4270	•
5	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	106	106	067	267	268	268	268	269	269	269	270	270	270	4270	5338	4269	4269	4270	•
6	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	1067	1067	2135	267	268	268	.69	269	269	269	270	270	270	4270	5338	4270	4269	4270	•
7	•	•	•	•	•	•	•	•	•	•	-	•	•	•	•	•	•	1067	1067	1067	067	067	067	2135	269	269	269	270	270	270	270	4270	4911	4270	1067	1067	•
8	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	1067	1067	1067	067	067	067	067	067	2135	269	270	270	270	2 0	4270	4270	4271	1067	1067	•
9	•	•	1067	1067	149	85	64	64	85	149	213	213	213	213	213	213	1067	1067	1067	1067	067	067	067	067	067	1067	2135	2135	2 0	270	270	1067	1067	3203	1067	1067	•
10	•	1067	1067	1067	1067	640	427	170	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	067	40	40	067	2135	067	067	067	1067	1067	2135	2135	1067	•
11	•	1067	1067	4270	4270	2135	2135	1067	1066	1066	213	213	213	213	213	213	213	213	213	213	213	213	40	40	40	40	067	067	067	067	067	1067	1067	1067	2135	1067	•
12	•	4269	4270	4270	42 0	4270	4269	4267	1067	1066	1066	213	213	213	213	213	213	213	213	213	213	213	213	40	40	067	067	067	067	067	067	1067	106	106	1920	1067	•
13	•	•	•	4269	4270	4270	4270	4269	4266	2133	1493	1067	213	213	213	213	213	213	213	213	213	213	40	40	40	067	067	067	06	06	067	1067	106	106	106	640	•
14	•	•	•	•	4269	4270	4270	42 0	4270	2134	1067	1065	1065	1065	1066	213	213	213	213	213	06	06	06	85	54	06	06	06	06	06	06	106	106	106	106	639	•
15	•	•	•	•	4269	4270	4270	4270	4270	4256	640	640	640	640	640	213	213	213	213	213	06	06	06	06	06	06	06	06	06	06	06	106	106	106	106	1058	•
16	•	•	•	•	•	•	4270	4270	4270	4270	4270	4270	1067	1067	1067	1067	1067	1067	1067	106	06	06	06	06	06	06	70	70	70	70	70	170	170	106	106	1067	•
17	•	•	•	•	•	•	4270	4270	4270	4270	1067	1067	1067	1067	1067	1067	1067	106	106	106	06	06	106	06	06	06	06	06	06	06	06	106	106	106	106	1067	•
18	•	•	•	•	•		•	•	4268	1067	1067	1067	1067	1067	1067	1067	106	106	106	106	06	06	06	06	06	53	42	21	21	42	53	85	85	106	106	1067	•
19	•	•	•	•		•	•	•	•	•	1066	106.	1066	1066	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•		•	•	•
20	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

SCALE = 1 : 210000

H. VERTICAL LEAKANCE BETWEEN LAYERS(TK) IN /S X 10-9. VERTICAL K MULTIPLICATION FACTORS ARE .01 FOR LAYER 2 AND .00001 FOR LAYER 1.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4215	4210	4206	4201	4192	4187	4183	4179	4174	4169	4166	4168	4175	4179	4181	.	2
3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4209	4205	4200	4194	4189	4184	4180	4175	4171	4166	4161	4158	4157	4159	4161	4161	.	3
4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4216	4206	4198	4193	4188	4183	4178	4173	4168	4163	4159	4155	4152	4149	4148	4149	4149	.	4
5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4219	4210	4201	4193	4188	4182	4177	4171	4167	4161	4157	4153	4150	4146	4143	4141	4142	4141	.	5
6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4220	4206	4197	4190	4183	4177	4171	4165	4160	4155	4151	4148	4144	4140	4137	4133	4134	4134	.	6
7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4220	4212	4202	4193	4185	4178	4171	4165	4159	4154	4150	4146	4142	4138	4134	4130	4125	4125	4126	.	7
8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4219	4207	4197	4188	4180	4172	4165	4158	4153	4148	4144	4140	4136	4133	4129	4124	4117	4116	4117	.	8
9	.	.	4298	4279	4266	4270	4298	4355	4368	4379	4388	4372	4346	4300	4277	4259	4233	4212	4201	4191	4181	4173	4165	4158	4151	4145	4140	4136	4133	4129	4126	4121	4115	4105	4104	4107	.	9
10	.	4298	4283	4268	4256	4243	4247	4256	4276	4290	4300	4299	4283	4261	4250	4234	4213	4199	4188	4178	4169	4161	4154	4146	4139	4134	4130	4126	4122	4119	4115	4111	4104	4092	4088	4091	.	10
11	.	4289	4274	4259	4248	4239	4232	4230	4235	4241	4248	4248	4239	4230	4219	4205	4190	4179	4170	4161	4152	4146	4140	4133	4127	4121	4115	4110	4107	4104	4101	4098	4093	4081	4063	4067	.	11
12	.	4277	4267	4252	4239	4230	4223	4215	4212	4212	4210	4209	4205	4200	4189	4178	4168	4159	4152	4144	4137	4131	4125	4120	4106	4096	4093	4090	4088	4084	4079	4074	4064	4053	4040	4044	.	12
13	.	.	.	4242	4231	4220	4212	4204	4195	4191	4189	4184	4180	4174	4165	4158	4149	4141	4134	4127	4121	4115	4110	4093	4072	4069	4067	4063	4058	4052	4043	4034	4010	4004	4019	4020	.	13
14	.	.	.	.	4223	4215	4204	4193	4183	4178	4174	4164	4152	4142	4136	4132	4127	4123	4118	4111	4106	4099	4081	4057	4044	4041	4033	4028	4030	4023	4000	3978	3957	3943	3989	3964	.	14
15	.	.	.	.	4221	4213	4198	4184	4174	4165	4155	4143	4131	4117	4105	4095	4089	4085	4080	4077	4068	4058	4036	4019	4012	4008	3997	3990	3975	3961	3943	3929	3917	3902	3890	3900	.	15
16	.	.	.	.	.	.	4193	4183	4171	4155	4142	4132	4118	4101	4083	4071	4064	4053	4047	4041	4032	4022	4005	3993	3982	3961	3952	3944	3929	3918	3910	3897	3890	3874	3864	3860	.	16
17	.	.	.	.	.	.	4191	4183	4171	4158	4144	4131	4120	4105	4087	4073	4061	4045	4038	4032	4021	4009	4000	3994	3983	3967	3955	3943	3929	3916	3906	3895	3885	3859	3849	3850	.	17
18	.	.	.	.	.	.	.	.	4173	4165	4152	4141	4130	4114	4090	4077	4062	4048	4041	4034	4028	4024	4008	3996	3985	3971	3958	3944	3928	3914	3904	3893	3880	3861	3850	3850	.	18
19	.	.	.	.	.	.	.	.	.	.	4165	4151	4140	4128	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	19
20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	

SCALE = 1 : 210000

I. HEADS IN LOWER AND UPPER LAYERS USED IN TRANSIENT SIMULATIONS IN FT ABOVE NGVD OF 1929 (GENERATED BY STEADY-STATE MODEL).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4.	4.	4.	4.	4.	21.	21.	21.	4.	4.	4.	8.	8.	4.	4.	.	2
3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	8.	8.	4.	4.	.	3
4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4.	8.	8.	8.	4.	4.	4.	4.	4.	4.	4.	4.	4.	8.	8.	4.	4.	.	4
5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4.	4.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	4.	4.	.	5
6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4.	4.	4.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	4.	4.	.	6
7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8.	4.	4.	4.	8.	8.	8.	8.	8.	8.	8.	12.	12.	12.	8.	8.	8.	4.	4.	.	7
8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8.	4.	4.	4.	8.	8.	8.	8.	8.	8.	4.	4.	4.	4.	4.	4.	4.	4.	4.	.	8
9	.	.	-8.	8.	8.	8.	8.	16.	8.	8.	8.	8.	12.	12.	21.	21.	8.	8.	4.	4.	4.	8.	8.	8.	8.	8.	12.	12.	12.	12.	12.	12.	4.	4.	4.	4.	.	9
10	.	-12.	12.	8.	8.	8.	8.	16.	8.	8.	8.	8.	12.	12.	12.	21.	8.	8.	4.	4.	4.	8.	8.	8.	8.	12.	12.	12.	12.	12.	12.	12.	12.	4.	8.	4.	.	10
11	.	8.	8.	12.	8.	8.	8.	8.	8.	4.	8.	12.	8.	16.	16.	12.	12.	8.	8.	4.	4.	8.	8.	8.	8.	12.	12.	12.	12.	12.	12.	12.	12.	12.	8.	8.	.	11
12	.	8.	8.	8.	16.	8.	8.	8.	8.	4.	12.	12.	8.	16.	16.	12.	12.	8.	8.	8.	4.	8.	8.	8.	8.	12.	12.	12.	12.	12.	12.	12.	2.	2.	16.	8.	.	12
13	.	.	.	8.	8.	16.	8.	8.	4.	4.	8.	12.	8.	8.	8.	8.	8.	8.	8.	8.	4.	8.	8.	8.	8.	8.	12.	12.	12.	12.	12.	12.	4.	2.	2.	8.	.	13
14	.	.	.	.	8.	8.	12.	4.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.	4.	8.	8.	8.	8.	8.	8.	12.	12.	12.	12.	12.	12.	12.	2.	4.	.	14
15	.	.	.	.	8.	8.	8.	12.	12.	12.	8.	8.	8.	8.	8.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	2.	2.	4.	12.	12.	12.	4.	4.	.	15
16	.	.	.	.	.	.	8.	8.	8.	8.	8.	8.	8.	8.	8.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	-8.	.	16
17	.	.	.	.	.	.	8.	8.	8.	8.	8.	8.	8.	8.	8.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	2.	2.	2.	2.	4.	4.	4.	4.	8.	-8.	.	17
18	.	.	.	.	.	.	.	.	8.	8.	21.	21.	8.	8.	8.	4.	4.	4.	4.	4.	4.	4.	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.	4.	4.	8.	8.	.	18
19	.	.	.	.	.	.	.	.	.	.	21.	21.	12.	12.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	19
20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	

SCALE = 1 . 210000

J. STORAGE COEFFICIENT FOR LAYER 2 X 10-2 (NEGATIVE VALUES IDENTIFY CONSTANT-HEAD CELLS).

LOCATION		PUMPING PERIOD									
Row	Column	1	2	3	4	5	6	7	8	9	10
2	27				0.15	0.65	0.76	0.79	0.70	0.40	0.34
3	33			0.01	.05	.09	.12	.13	.16	.20	.20
4	24				1.07	1.12	1.30	1.36	1.20	.71	.60
4	25	0.15	0.97		.41	.57	.67	.70	.62	.31	.31
4	33			.01	.05	.09	.10	.11	.13	.17	.19
5	23				.21	.84	.99	.92	.84	.98	1.00
5	24	.15	.97		.78	.72	.84	.87	.78	.47	.40
5	28	.15	.97		.22	.57	.67	.70	.62	.37	.31
6	23					.01	.04	.06	.11	.22	.35
6	29								.32	1.04	.88
7	22				.03	.10	.14	.05	.11	.22	.35
7	23					.01	.04	.07	.11	.22	.35
8	22				.04	.16	.15	.46	.32	.50	.50
9	6						.10	.16	.11	.17	.22
9	22				.04	.16	.15	.05	.22	.25	.25
10	13						.43	.26			
11	7				.16						
12	4				.10	.18	.21	.32	.23	.34	.45
12	5			.05	.22	.36	.31	.48	.34	.51	.68
12	6			.03	.12	.18	.10	.16	.11	.17	.22
12	8				.02	.07	.10	.16	.11	.17	.22
12	17						.85	.52			
13	6			.07	.22	.36	.31	.48	.34	.51	.68
13	7		.07	.15	.28	.50	.42	.64	.46	.67	.97
13	8					.13	.21	.32	.23	.34	.45
13	9					.13	.10	.16	.11	.17	.22
14	7		.10	.21	.41	.71	.52	.80	.57	.85	1.13
14	8					.27	.21	.32	.23	.34	.45
14	9	.14	.14	.15	.28	.50	.31	.48	.34	.51	.68
14	10					.13	.10	.16	.11	.17	.22
15	7		.08	.10	.22	.36	.21	.32	.23	.34	.45
15	8	.10	.10	.10	.22	.36	.21	.32	.23	.34	.45
15	9				.20	.36	.21	.32	.23	.34	.45
16	7					.18	.10	.16	.11	.17	.22
16	9	.10	.10	.10	.22	.18	.10	.16	.11	.17	.22
16	10					1.03	.96	.69	.11	.17	.22
16	16					.66	.43	.26			
16	17					.66	.43	.26			
16	18					.66	.43	.26			
17	10				.44	.78	.10				
17	11				.46	.78	.43				

Discharges are in cubic feet per second.

K. WELL DISCHARGES FROM THE UPPER LAYER FOR THE TEN SIMULATED PUMPING PERIODS.