UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

USE OF A THREE-DIMENSIONAL MODEL FOR THE ANALYSIS OF THE GROUND-WATER FLOW SYSTEM IN PARKER VALLEY, ARIZONA AND CALIFORNIA

By Patrick Tucci

Open-File Report 82-1006

Tucson, Arizona
December 1982

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
Box FB-44
Federal Building
301 West Congress Street
Tucson, Arizona 85701

CONTENTS

ILLUSTRATIONS

TABLE

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)
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
acre-foot per acre per year [(acre-ft/acre)/yr]	0.00305	cubic hectometer per hectare per year [(hm^3/ha)/yr]
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)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]

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."

USE OF A THREE-DIMENSIONAL MODEL FOR THE ANALYSIS OF THE GROUND-WATER FLOW SYSTEM IN PARKER VALLEY, ARIZONA AND CALIFORNIA

By

Patrick Tucci

ABSTRACT

A three-dimensional, finite-difference model was used to simulate ground-water flow conditions in Parker Valley. The purpose of the study was to evaluate present knowledge and concepts of the ground-water system and the ability of the model to represent the system. Modeling assumptions and generalized physical parameters that were used may have transfer value in the construction and calibration of models of other basins along the lower Colorado River.

The aquifer was simulated in two layers to represent the three-dimensional system. Ground-water conditions were simulated for 1940-41, the mid-1960's, and 1980. Overall model results generally compared favorably with available field information. The model results showed that for 1940-41 the Colorado River was a losing stream throughout Parker Valley. Infiltration of surface water from the river was the major source of recharge. The dominant mechanism of discharge was evapotranspiration by phreatophytes. Agricultural development between 1941 and the mid-1960's resulted in significant changes to the ground-water system. Model results for conditions in the mid-1960's showed that the Colorado River had become a gaining stream in the northern part of the valley as a result of higher water levels. The rise in water levels was caused by infiltration of applied irrigation water. Diminished water-level gradients from the river in the rest of the valley reduced the amount of infiltration of surface water from the river. Model results for conditions in 1980 showed that ground-water level rises of several feet caused further reduction in the amount of surface-water infiltration from the river.

Model results indicated that previous estimates of riverbed hydraulic conductivity may be too low and estimates of inflow from tributary areas may be too high. Model results were most sensitive to changes in the simulated average evapotranspiration rate and less sensitive to changes in hydraulic conductivity, drain leakance, and river leakance.

INTRODUCTION

This report is one of a series that provides documentation of ground-water models developed as part of the Southwest Alluvial Basins, Regional Aquifer-System Analysis (Swab/RASA) Project. The purpose of the Swab/RASA Project is to develop a better general understanding of the extent and workings of the hydrologic systems in the alluvial basins in the study area (Anderson, 1980). A basic assumption of the project is that certain characteristics and relations are common to many of the basins or subsets of basins. The strategy is to look in detail at selected basins that have an extensive data base and that typify a subset of basins that have similar characteristics. The study approach uses ground-water modeling as the principal tool in evaluating the ground-water flow systems. Generalizations of hydrologic parameters for use in the numerical models of these "first-priority" basins are formulated through the use of available geohydrologic data (Anderson, 1980, p. 5). The study will identify the parameters that have the greatest control over model response and the acceptable range in values of those parameters. The generalizations that are developed for the first-priority basins will be applied later to models of geohydrologically similar but less well-defined "second-priority" basins. The transfer value of the generalized parameters and the range of acceptable parameter values will be evaluated further as part of this later stage of modeling.

The Parker basin (fig. 1), of which Parker Valley is a part, is representative of the basins along the lower Colorado River because of similarities in hydrologic, geologic, and climatic conditions and was selected as a first-priority basin. The ground-water systems of these basins are dominated by surface flow in the Colorado River, application of surface water for irrigation, and evapotranspiration by phreatophytes and crops. The geologic units that constitute the main aquifer in Parker Valley also are present in other lower Colorado River basins, and climatic conditions in Parker Valley are typical of those basins. Agricultural development and the resultant changes in the ground-water system in Parker Valley also have occurred in the other basins.

Purpose and Scope

The main objective of the Parker Valley study, which coincides with that of the Swab/RASA Project, is to evaluate present knowledge and existing concepts of the hydrologic system and the ability of a mathematical model to reasonably represent the system. Secondary objectives are to identify the parameters that exert the greatest influence on the operation of the system and to identify the reasonably acceptable range in values of those parameters. These general parameter values will be used later in exploring the transferability of information from Parker Valley to other basins along the Colorado River.

The primary source of information used for model development was a report by Metzger and others (1973), which provides a detailed analysis of the geohydrology of the Parker area. The only additional data acquired was a small number of drillers' logs. Information concerning the system of drains in the area was obtained from the Colorado River Indian Agency (C. L. Jenson, Supervisory Hydraulic Engineer, oral commun., 1980).

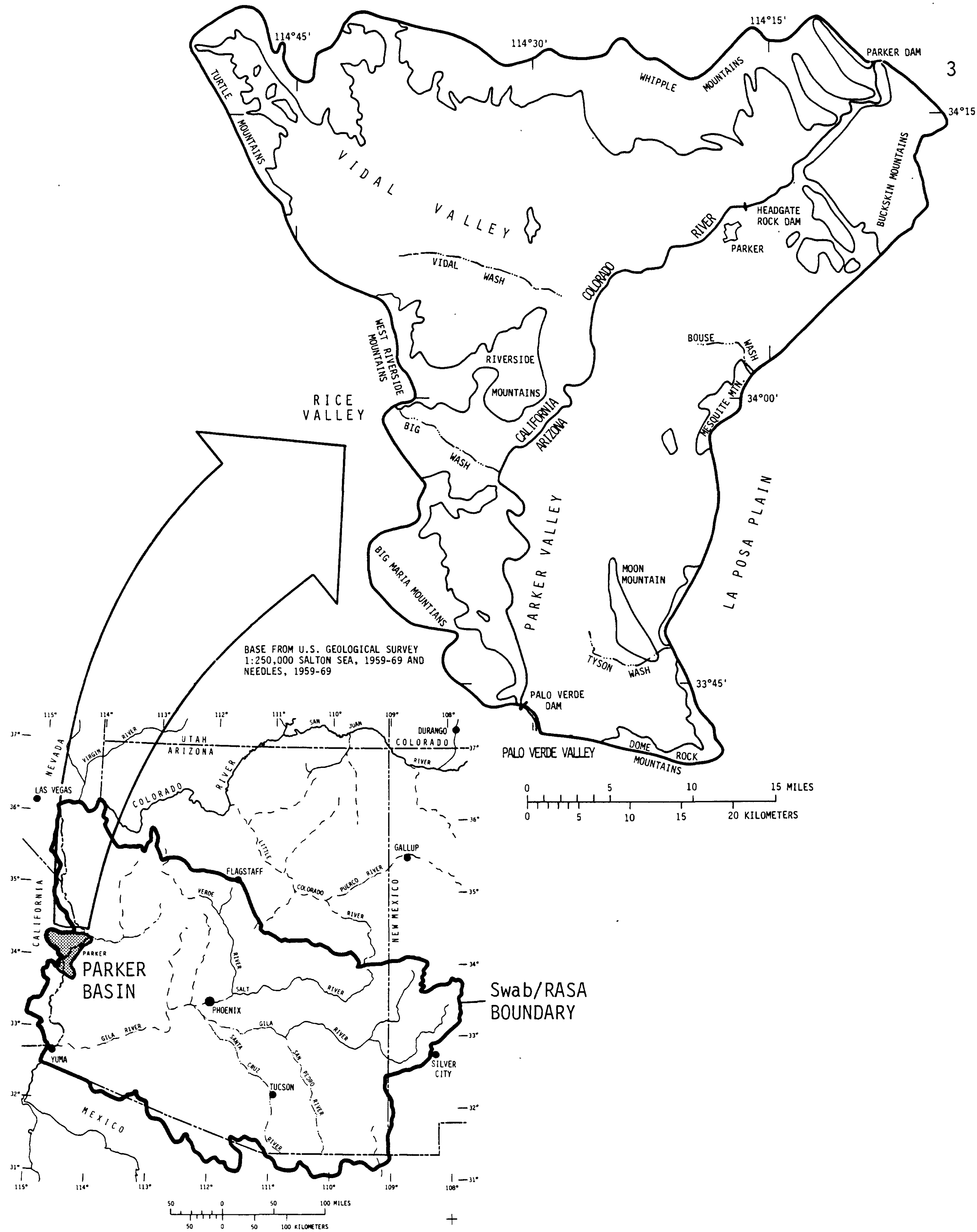


Figure 1.--Swab/RASA and Parker Valley study areas.

The modeling approach was to use the aquifer parameters and hydrogeologic conditions presented by Metzger and others (1973) to simulate ground-water levels and flow quantities for two periods of time during which the hydrologic system appeared to be in a state of equilibrium, although at differing stages of development. The model was used first to simulate hydrologic conditions for the mid-1960's. This period was the most recent period for which areal water-level data and water-budget estimates were available. The second period—1940-41—was similar to predevelopment conditions and was the earliest for which areal water-level information was available. Physical properties of the aquifer and the relation between evapotranspiration and depth to water were held constant between simulation periods. Equilibrium conditions could be assumed for both time periods because of the apparent uniformity in the degree of development and agricultural practices within the area for at least 10 years prior to each period. Water-level conditions and water budgets for the area were assumed to represent a "quasi-steady-state" condition in each of the time periods.

A third time period—1980—was also simulated in order to further evaluate the model as a mathematical representation of the hydrologic system. Equilibrium conditions may not have existed in 1980 because irrigated acreage had steadily increased since the mid-1960's. Some water-budget information was available for 1980; however, water levels were available only for part of 1981-82 in the northern part of the valley.

Transient and predictive simulations were not a part of this analysis. Information concerning water-level and land-use variations with time, which was needed to calibrate a transient model, was not available. Areas beyond Parker Valley were not included in the model because of insufficient data and because hydrologic conditions in those areas were assumed to have a negligible effect on the ground-water system in the valley.

Location, Physical Features, and Climate

The flood plain of the Colorado River in Parker basin, which is in western Arizona and southeastern California, is referred to in this report as Parker Valley. Parker Valley is about 230 mi^2 in area and extends from Headgate Rock Dam south to Palo Verde Dam (fig. 1). The valley is bounded by the Whipple and Buckskin Mountains on the north; Vidal Valley on the northwest; the Riverside and Big Maria Mountains on the west; Palo Verde Valley on the south; and the Dome Rock Mountains, Moon Mountain, Mesquite Mountain, and La Posa Plain on the east.

The Colorado River is the main drainage feature of Parker Valley. Tributaries that drain to the valley include Bouse and Tyson Washes in Arizona and Vidal and Big Washes in California.

The climate of Parker Valley is characterized by mild winters and hot summers. Mean annual precipitation ranges from less than 4 in. in the flood plain to more than 8 in. in the surrounding mountains (Hely and Peck, 1964, pl. 3).

GEOHYDROLOGIC SYSTEM

Geology and Water-Bearing Characteristics of Units

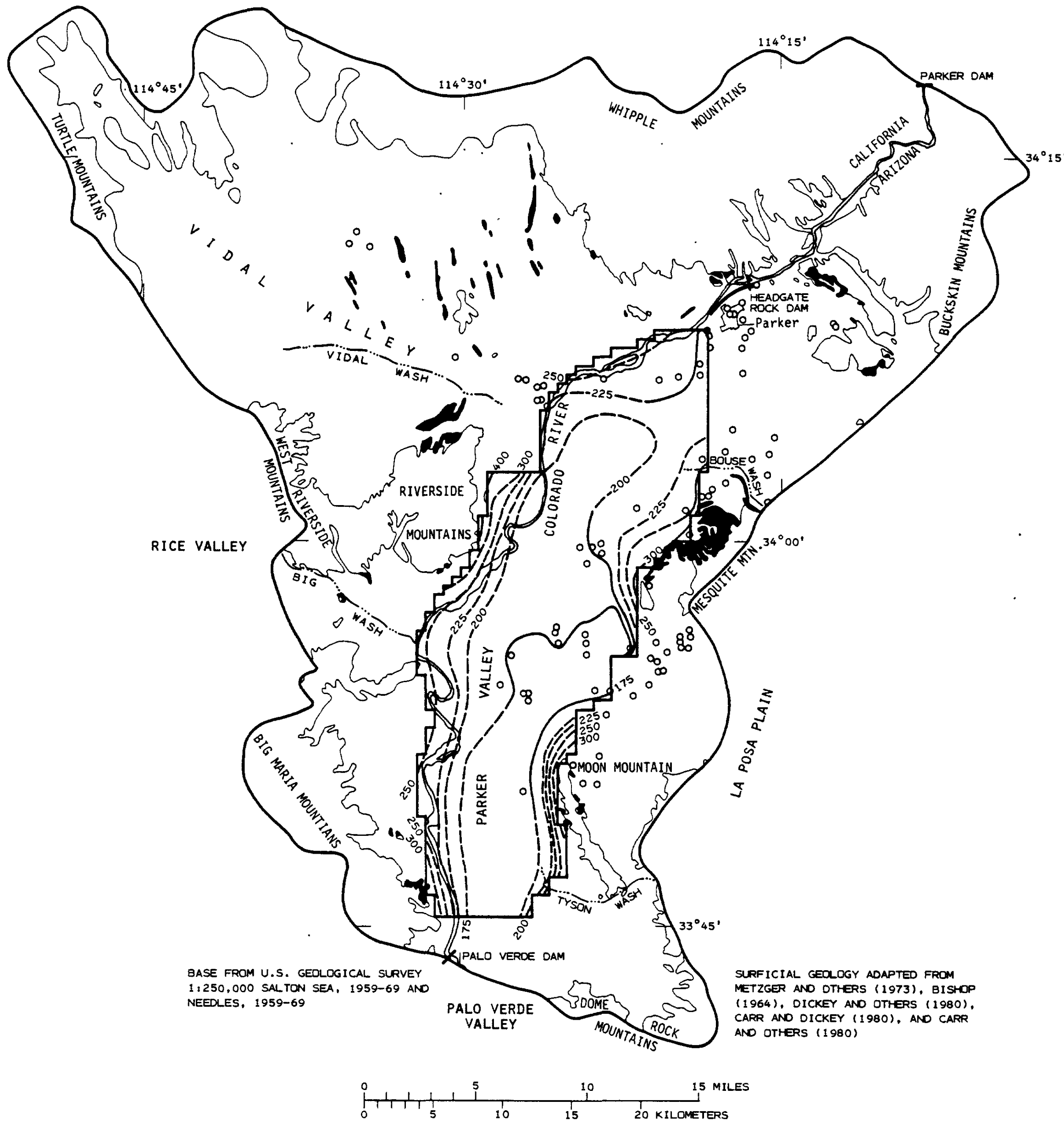
The following generalized discussion is from Metzger and others (1973) except where noted. Interested readers are referred to that report for a more detailed description of the geology of the Parker area.

The geologic units that are important in the evaluation of the ground-water system in Parker Valley include the Miocene(?) fanglomerate, the Bouse Formation, and the alluvium of the Colorado River and its tributaries. The Bouse Formation and the Colorado River alluvium constitute the main aquifer in the valley. Consolidated rocks older than the Miocene(?) fanglomerate are referred to in this report collectively as bedrock and are important only as boundaries to the ground-water system.

The bedrock includes igneous, metamorphic, and sedimentary rocks that range in age from Paleozoic to Tertiary. Maximum depth to bedrock in Parker Valley may be more than 3,200 ft on the basis of an analysis of gravity data by Oppenheimer and Sumner (1980). The bedrock generally is considered to be impermeable, although wells with small yields might be developed in fractured zones.

The Miocene(?) fanglomerate is described as being "composed chiefly of cemented sandy gravel" (Metzger and others, 1973, p. 10). Thin basalt flows are present in the fanglomerate in exposures near Parker. Although subsurface data for the fanglomerate are sparse, the unit may be as much as 2,100 ft thick and may be areally extensive in the subsurface. Ground water occurs under confined conditions in the fanglomerate where it is overlain by the Bouse Formation. The fanglomerate is present in all the basins along the lower Colorado River; however, at present (1982), the fanglomerate is of minor importance as a source of ground water because of the ready availability of surface water and ground water in shallower units.

The Bouse Formation unconformably overlies the fanglomerate and is present in the subsurface throughout Parker Valley. Metzger (1968, p. 13) described the Bouse Formation as a marine to brackish-water sequence that was deposited in an embayment of the Gulf of California. The Bouse consists of three geologic units: a basal limestone; an interbedded clay, silt, and sand unit; and a tufa. The maximum reported thickness of the Bouse in Parker Valley is 767 ft, the major portion of which is the interbedded unit. The configuration of the top of the Bouse, which was needed for model input, was mapped using drillers' logs of wells and altitudes of outcrops (fig. 2).



EXPLANATION

300 — STRUCTURE CONTOUR—Shows altitude of the top of the Bouse Formation. Dashed where uncertain. Contour interval, in feet, is variable. National Geodetic Vertical Datum of 1929

o WELL USED TO DETERMINE OR ESTIMATE TOP OF THE BOUSE FORMATION

GENERALIZED OUTCROP OF BOUSE FORMATION (PLIOCENE AND MIOCENE)

GENERALIZED OUTCROP OF BEDROCK AND (OR) MIOCENE(?) FANGLOMERATE

BOUNDARY OF ACTIVE MODEL

Figure 2.--Altitude of the top of the Bouse Formation.

Metzger and others (1973, p. 18-19) divided the Bouse into upper and lower hydrologic zones in order to discuss the hydraulic characteristics of the formation. The division between the two zones occurs in the interbedded unit. The upper zone, which has a maximum thickness of about 300 ft, is mainly sand and will yield moderate amounts of water to wells. On the basis of three aquifer tests, the average hydraulic conductivity of the upper zone is about 30 ft/d (Metzger and others, 1973, p. 68). The lower zone is mainly clay and silt and serves as a confining unit for the underlying fanglomerate.

The Colorado River alluvium is divided into younger and older alluvium. The older alluvium is further subdivided into five units, which are the result of several broad periods of degradation and aggradation by the Colorado River. Units of the older alluvium are not known to be present beneath Parker Valley but are present in adjacent basins and in outcrops that surround Parker Valley. Where saturated, units of the older alluvium yield water readily to wells and have hydraulic characteristics similar to those of the younger alluvium.

The younger alluvium was deposited during the most recent period of aggradation by the Colorado River before the flow of the river was controlled by dams. This unit is composed of a basal gravel, which is overlain by a fine- to medium-grained sand and some minor lenses of silt and clay. The younger alluvium has a maximum thickness of at least 125 ft and underlies all of Parker Valley; however, its areal extent is confined to the flood plain. The younger alluvium yields water readily to wells and has specific capacities of more than 100 (gal/min)/ft of draw-down. The average hydraulic conductivity of the younger alluvium is 313 ft/d on the basis of the results of eight aquifer tests—six in Parker Valley and two in Palo Verde Valley—reported by Metzger and others (1973, p. 68).

The older alluvium has been almost completely eroded in Parker Valley, and the younger alluvium directly overlies the Bouse Formation in most of the area (fig. 3). The younger alluvium and the upper zone of the Bouse are hydraulically connected and constitute the main aquifer in Parker Valley. Ground water occurs under unconfined conditions in the aquifer.

General Hydrologic Setting

Under predevelopment conditions, the major source of inflow to the ground-water system was infiltration of surface water from the Colorado River. This infiltration was by leakage through the riverbed and by annual flooding of the river and subsequent infiltration in the flood-plain area. Minor sources of inflow were precipitation and resultant surface-water runoff and ground-water underflow from adjacent basins. Discharge from the ground-water system was primarily through evapotranspiration by phreatophytes, mostly mesquite and arrowweed. Ground-water underflow to Palo Verde Valley was only a small percentage of the total discharge from the ground-water system.

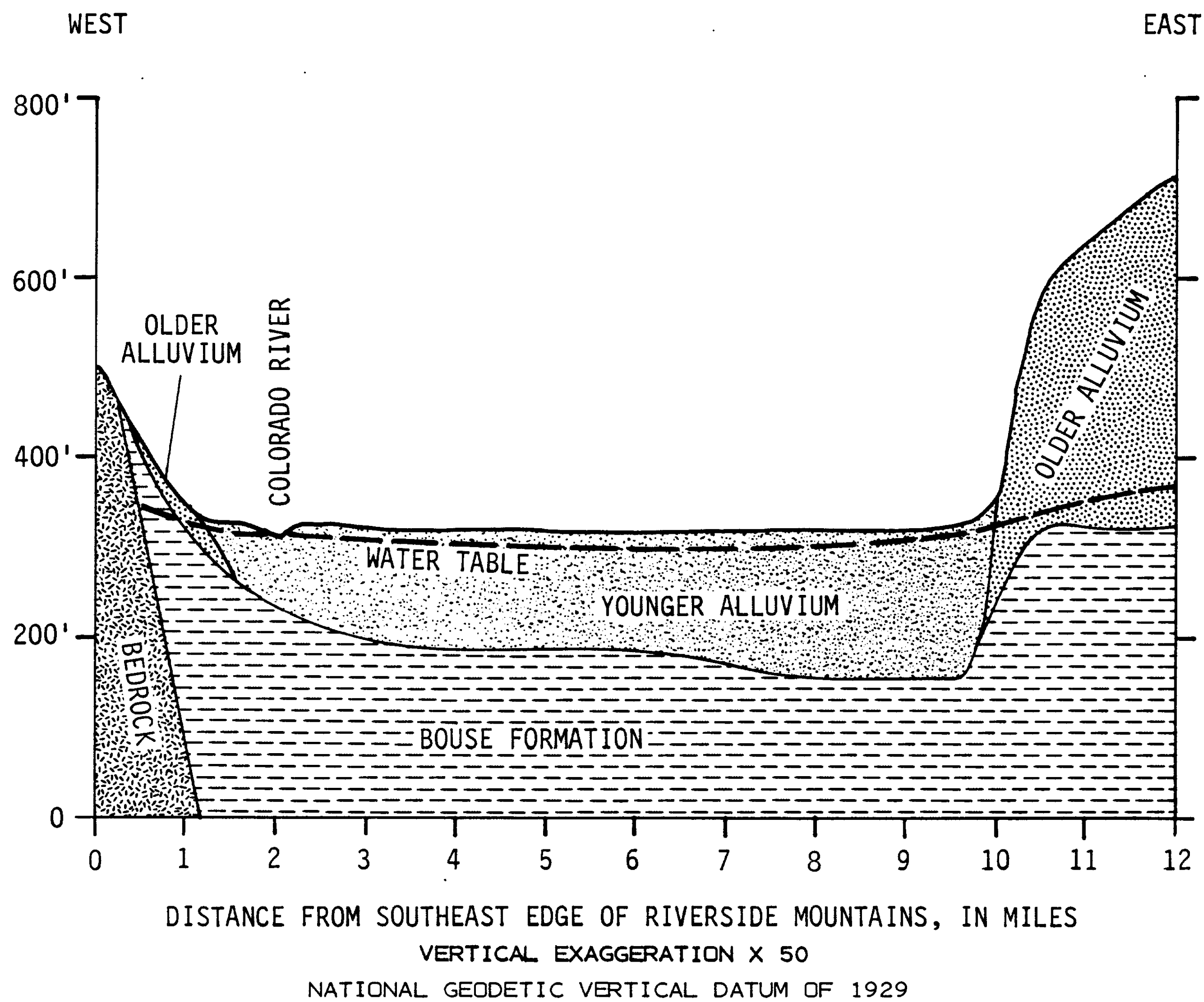


Figure 3.--Generalized geologic section of Parker Valley.

Ground-Water Conditions in 1940-41

Ground-water conditions in 1940-41 probably were similar to those that occurred before development. By 1940, however, dams constructed upstream from Parker Valley had essentially halted the annual flooding, and about 5,000 acres of land was under irrigation in the northern part of the valley (Metzger and others, 1973, fig. 26). Water for irrigation of this land—about 30,000 acre-ft/yr—was obtained by diversion of Colorado River water at Headgate Rock Dam.

A map prepared by the Colorado River Indian Agency showing water-level contours in 1940-41 (Metzger and others, 1973, fig. 25) indicates movement of ground water from the river into the alluvium of Parker Valley (fig. 4). The water levels at that time probably were similar to those that occurred under natural conditions except in the northern part of the valley where recharge from excess applied irrigation water had caused water levels to rise (Metzger and others, 1973, p. 47).

The estimated and model-calculated components of the ground-water flow system are listed in table 1. Total discharge from the ground-water system in 1940-41 was estimated to be 237,000 acre-ft/yr. Discharge through evapotranspiration was estimated to be 235,000 acre-ft/yr, which was based on an area of about 102,000 acres of phreatophytes at an assumed consumptive-use rate of 2.3 (acre-ft/acre)/yr. Evapotranspiration by crops was not included in this estimate because all the water used by crops was assumed to be provided by applied surface water to the irrigated areas. Unmeasured subsurface outflow to Palo Verde Valley to the south was estimated to be about 2,000 acre-ft/yr, which was based on transmissivity of 67,000 ft^2/d (Metzger and others, 1973, p. 64), a hydraulic gradient of 2 ft/mi, and an effective width of 1.5 mi. Although the aquifer is about 3 mi wide at the south end of Parker Valley, the direction of ground-water flow is essentially parallel to the outflow boundary for about half the valley width (fig. 4). The result is a zero gradient in the downvalley direction and therefore no flow across that part of the outflow boundary. The estimated outflow does not account for possible flow on the west side of the river.

Because the system was assumed to be in equilibrium in 1940-41, inflow was equal to outflow. The mechanisms of inflow included infiltration of surface water from the Colorado River, infiltration of excess applied irrigation water, and underflow from adjacent basins. Infiltration from excess irrigation application was estimated to be 12,000 acre-ft/yr and represents the difference between irrigation application of 30,000 acre-ft/yr and consumptive use by crops of 18,000 acre-ft/yr, which is based on an assumed consumptive-use rate of 3.6 (acre-ft/acre)/yr (Metzger and others, 1973, p. 63). Metzger and others (1973, p. 51-52) estimated tributary underflow and runoff into Parker Valley to be 12,000 acre-ft/yr. The remaining inflow necessary to maintain equilibrium conditions—213,000 acre-ft/yr—was assumed to represent infiltration from the Colorado River within Parker Valley. The total estimated inflow to Parker Valley therefore was 237,000 acre-ft (table 1).

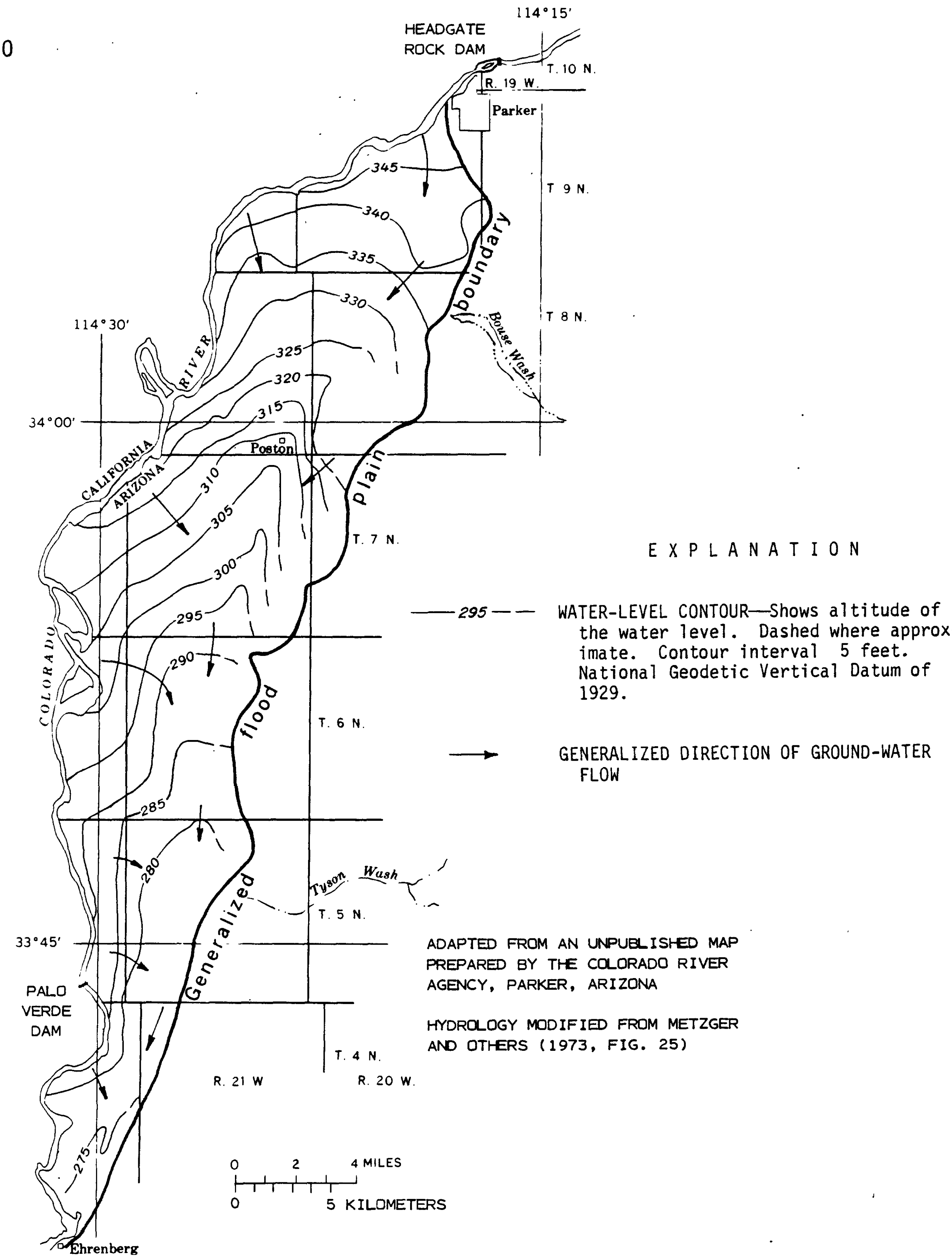


Figure 4.--Generalized water-level contours and direction of ground-water flow, 1940-41.

Table 1.--Estimated and model-calculated water-budget components

[The use of more than two significant figures is for consistency only and should not be construed as an indication of the accuracy of the figures. Values are in acre-feet per year]

Water-budget components	1940-41		Mid-1960's		1980	
	Estimated	Model calculated	Estimated	Model calculated	Estimated	Model calculated
Inflow:						
Recharge	12,000	12,000	225,000	223,000	236,000	235,000
Net river loss	213,000	253,000	92,000	97,000	50,000	82,000
Tributary inflow	12,000	12,000	12,000	12,000	12,000	12,000
Total	237,000	277,000	329,000	332,000	298,000	329,000
Outflow:						
Evapotranspiration	235,000	271,000	163,000	161,000	71,000	120,000
Outflow to Palo Verde Valley	2,000	1,000	3,000	3,000	3,000	2,000
Drain base flow	-------	-------	172,000	168,000	224,000	206,000
Total	237,000	272,000	338,000	332,000	298,000	328,000

Ground-Water Conditions in the Mid-1960's

The ground-water system was altered in the early 1950's in response to increased agricultural development and accompanying redistribution of water. Configuration of the water table and direction of ground-water flow for 1964 are shown in figure 5.

More than 31,000 acres within the model area was irrigated in 1964 (Metzger and others, 1973, p. 64). Diversions from the river for irrigation averaged 436,000 acre-ft/yr for 1959-65. Subtracting the waste flow from the diversion from the river shows that an average of 347,000 acre-ft/yr of water either was diverted to the irrigated land or leaked from the distribution system (Metzger and others, 1973, p. 51). The irrigation application contributed a large part of the inflow to the ground-water system and resulted in a buildup of water levels by 5 to 10 ft over much of the valley. As a result, the hydraulic gradient away from the river decreased, which in turn resulted in a decrease in the infiltration losses from the river. This buildup of water levels also caused a reversal in the direction of ground-water flow resulting in flow toward the river in the reach adjacent to the irrigated area. Drains were constructed to reduce waterlogging by removing ground water from the irrigated lands and returning it to the Colorado River.

The average annual outflow from the valley was 338,000 acre-ft/yr and included an estimated 163,000 acre-ft through evapotranspiration by phreatophytes on the basis of an estimated consumptive use of 2.3 (acre-ft/acre)/yr over an area of 71,000 acres (Metzger and others, 1973, p. 64). Other outflow components included 172,000 acre-ft as base flow to the drains and 3,000 acre-ft of unmeasured underflow out of the area to Palo Verde Valley (Metzger and others, p. 1973, p. 51, 64).

Recharge from excess applied irrigation water was estimated to be 225,000 acre-ft/yr by subtracting the crop consumptive use from the amount applied to the irrigated land. Consumptive use by crops was based on irrigated acreage of major crops from 1959-64 and estimated consumptive-use rates by the crops. The acreages and consumptive-use estimates included 5,600 acres of cotton at 3.6 (acre-ft/acre)/yr, 9,900 acres of alfalfa at 6.4 (acre-ft/acre)/yr, and 15,500 acres of other crop types at 2.5 (acre-ft/acre)/yr (L. H. Applegate, U.S. Geological Survey, written commun., 1982). The average annual consumptive use by crops was therefore estimated to be 122,000 acre-ft for 31,000 acres, or an average rate of 3.9 (acre-ft/acre)/yr.

Metzger and others (1973, p. 51-52) estimated the net infiltration of surface water from the river to the ground-water system to be 72,000 acre-ft/yr for the mid-1960's. Reexamination of the components of surface-water flow for the reach between Parker Dam and Palo Verde Dam and a reevaluation of the water-budget items presented by Metzger and others (1973) indicate the rate of infiltration was about 92,000 acre-ft/yr. The amount of inflow from tributary areas in the mid-1960's was assumed to have remained the same as that estimated for 1940-41. The total average annual inflow to the valley therefore was estimated to be 329,000 acre-ft/yr (table 1).

The water budget for the mid-1960's indicates an outflow of 9,000 acre/yr more than the inflow. This small imbalance is due to the inaccuracies inherent in estimating some of the budget components.

Ground-Water Conditions in 1980

The major changes to the hydrologic setting of Parker Valley between the mid-1960's and 1980 were related to changes in the agricultural development of the area. By 1980, the extent of the area under irrigation had greatly increased. About 76,000 acres was irrigated in 1980 and only 31,000 acres was occupied by native vegetation. Irrigation efficiency had also greatly increased since the mid-1960's (S. A. Leake, U.S. Geological Survey, written commun., 1982).

Areal water levels were not available for 1980; however, some individual water-level measurements were available in the northern part of the valley. These water levels were measured from July 1981 to March 1982 but are thought to be representative of conditions in 1980. Ground-water levels had risen several feet in some areas that were not irrigated in the mid-1960's.

Total average annual outflow from the valley had decreased to 298,000 acre-ft/yr by 1980, mainly because of a decrease in evapotranspiration (table 1). Evapotranspiration by phreatophytes was estimated to have decreased to 71,000 acre-ft because of the decrease in the area occupied by native vegetation. The base flow to drains was estimated to be 224,000 acre-ft. This estimate assumes a waste-flow component to the drains of 15 percent of the total drain flow. The amount of underflow to Palo Verde Valley was assumed to be 3,000 acre-ft/yr as in the mid-1960's.

The amount of recharge to the ground-water system from excess applied irrigation water in 1980 was estimated to be 236,000 acre-ft. This small increase over the amount for the mid-1960's, in spite of the large increase in irrigated acreage and the amount of applied surface water, reflects the improved irrigation efficiency since that time.

Equilibrium conditions were assumed for 1980, although data are insufficient to verify the reliability of this assumption. This assumption allowed the river loss to be calculated as the residual of other known or estimated water-budget components. The river loss thus calculated is 50,000 acre-ft/yr, which is lower than the net loss in the mid-1960's. Increased water levels probably have reduced the ground-water gradient away from the river in the southern part of the valley and increased the amount of ground-water flow to the river adjacent to the irrigated areas. Inflow from tributary areas was assumed to have remained constant since the mid-1960's.

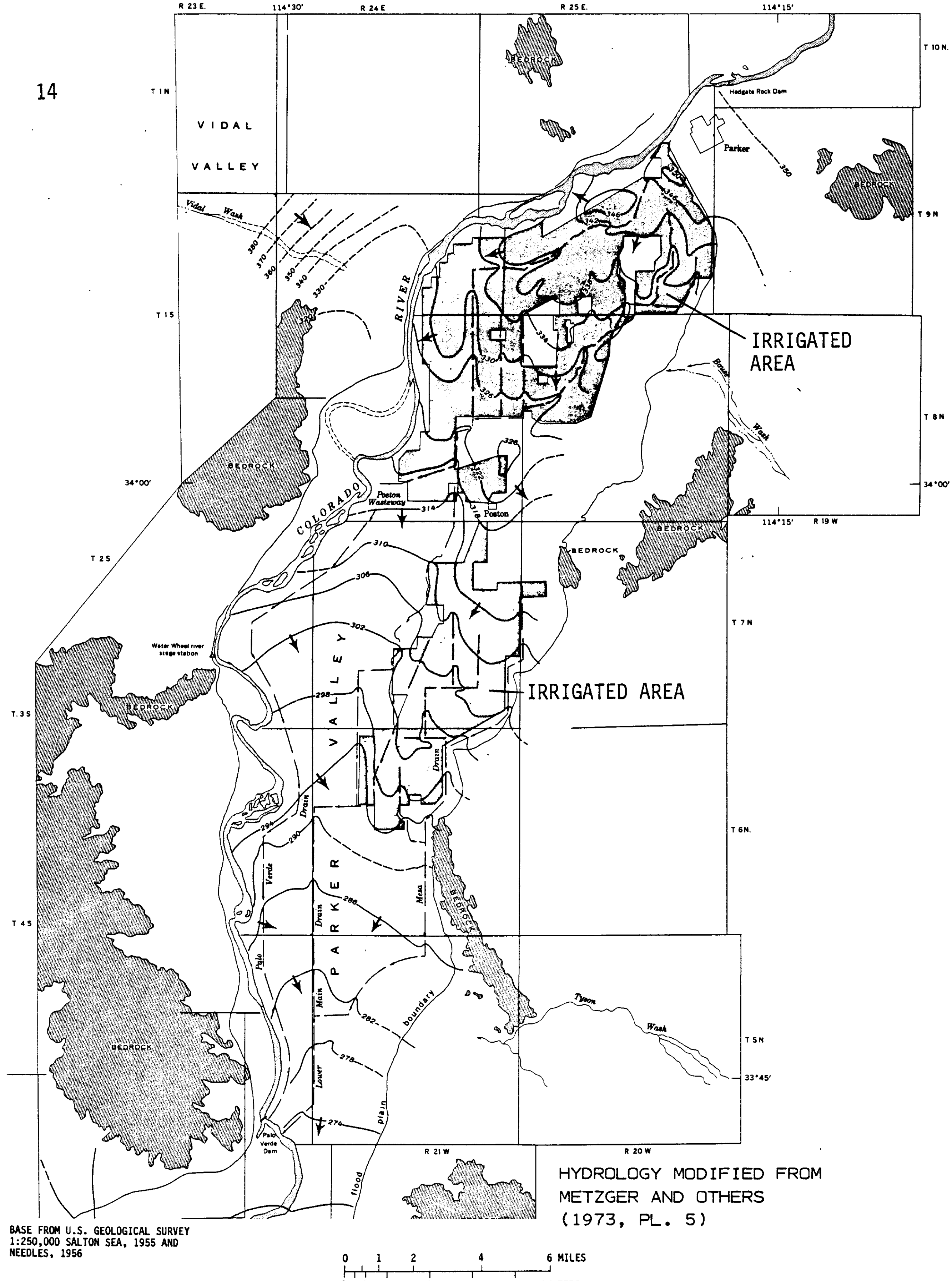


Figure 5.--Generalized water-level contours and direction of ground-water flow, 1964.

EXPLANATION

——— *330* - - - - -	WATER-LEVEL CONTOUR—Shows altitude of the water level. Dashed where approximate. Contour interval 4 feet. National Geodetic Vertical Datum of 1929
—— —→— —→ ——	LOCATION OF DRAIN AND DIRECTION OF FLOW
→	GENERALIZED DIRECTION OF GROUND-WATER FLOW

Figure 5

GROUND-WATER MODEL OF PARKER VALLEY

A computer program developed to simulate three-dimensional ground-water flow (Trescott, 1975) was used to model Parker Valley. The program uses finite-difference techniques to solve the ground-water flow equation for three-dimensional, steady or nonsteady flow in an anisotropic, heterogeneous medium. The three-dimensional model was used in order to simulate and evaluate the possible vertical flow component between the younger alluvium and the upper zone of the Bouse Formation. This flow cannot be represented in a two-dimensional areal model. The three-dimensional model that was used contains a modification to the model program that allows simulation of flow to drains (McDonald and Fleck, 1978).

The calibration scheme for modeling was to match, in a general sense, hydrologic conditions for three periods—1940-41, the mid-1960's, and 1980. The physical properties of the aquifer, such as geometry and hydraulic conductivity, and the relation between evapotranspiration and depth to water were held constant for each period. Water levels and flow quantities were allowed to change in response to simulated changes in irrigation practices in the valley. Agricultural development, which represents the major stress on the steady-state system, was simulated through the use of areal-recharge rates and inclusion of a system of drains for the mid-1960's and 1980 periods.

Ground-water conditions in the mid-1960's were simulated first, and the model was calibrated during this simulation. Estimated water-budget components and measured areal water levels were available for this time period. Water-budget components for this period were thought to be the most accurate of the three simulation periods because of the detailed analysis of the ground-water system by Metzger and others (1973). Ground-water conditions in 1940-41 were simulated next, holding the physical properties of the aquifer and the relation between evapotranspiration and depth to water as they were in the 1960's simulation. Estimates of water-budget components could be extracted from the analysis of Metzger and others (1973), and reported areal water levels for this period were available. Ground-water conditions for 1980 were simulated last because areal water levels were not available. The 1980 simulation was considered as a check on the ability of the model to simulate the the hydrologic system after large changes in agricultural development and associated water-budget components had occurred.

Model Construction

The finite-difference techniques used in the model require that the ground-water system be divided into rectangular blocks. Average values for aquifer characteristics are assigned to each grid block, and average water-level values for each block are assigned at the center, or node, of each block. Because of the large influence exerted by the Colorado River on the hydrologic regime of Parker Valley, the size of the grid blocks was varied areally in order to best approximate the areal extent and alinement of the river. The size of the grid blocks away from the river was expanded by using a ratio of expansion of 1:1.5 or 1:2 in order to reduce computer time and cost. The smallest grid blocks, which were generally along the river, represented an area of 0.16 mi^2, and the largest grid blocks represented an area of 1.4 mi^2. The finite-difference grid used for the Parker Valley model is shown in figure 6.

The model arrays are included in this report in order to make the data available to those who may wish to use the model as a starting point for further modeling in Parker Valley. Model-array data that vary areally are shown in the section entitled "Attachments." Values for maximum effective depth of evapotranspiration, transmissivity of layer 1, hydraulic conductivity of layer 2, river leakance, and drain leakance are discussed in other sections of this report. Location of constant-head, constant-flux, river, and drain nodes are shown in figure 6.

The aquifer was simulated as a two-layer system. Layer 2—the upper layer—represents the younger alluvium. Layer 1—the lower layer—represents the upper zone of the Bouse Formation. The configuration of the top of the Bouse Formation (fig. 2) represents the bottom of layer 2.

A uniform hydraulic conductivity of 310 ft/d, which was based on an average of values reported by Metzger and others (1973, p. 68), was assigned to layer 2. Sufficient data were not available to define the areal distribution of this property. Transmissivity of layer 2 is calculated by the model and is the product of the hydraulic conductivity and the saturated thickness at each node. Transmissivity for this layer for 1940-41 is shown in figure 7. Transmissivities for the mid-1960's and 1980 are slightly greater because of a slight increase in saturated thickness that resulted from rising water levels. Layer 1 was assigned a uniform transmissivity of 9,000 ft^2/d. This value is based on an assumed uniform hydraulic conductivity of 30 ft/d and an assumed uniform thickness of 300 ft, which is approximately equal to the maximum thickness of the upper zone of the Bouse in Parker Valley.

The top of the lower zone of the Bouse was assumed to be the impermeable base of the model. Although the lower zone is not impermeable, the stresses on the ground-water system may be asssumed to be too small to induce any significant flow through this zone.

The north and west boundaries of the model were assumed to be impermeable. Although ground water does flow toward Parker Valley from Vidal Valley in the northwestern part of the model area, the amount of flow is only 250 acre-ft/yr (Metzger and others, 1973, p. 61). This flow may be consumed by plants or withdrawn by pumping at the southeast end of Vidal Valley before it reaches Parker Valley; this amount of flow is

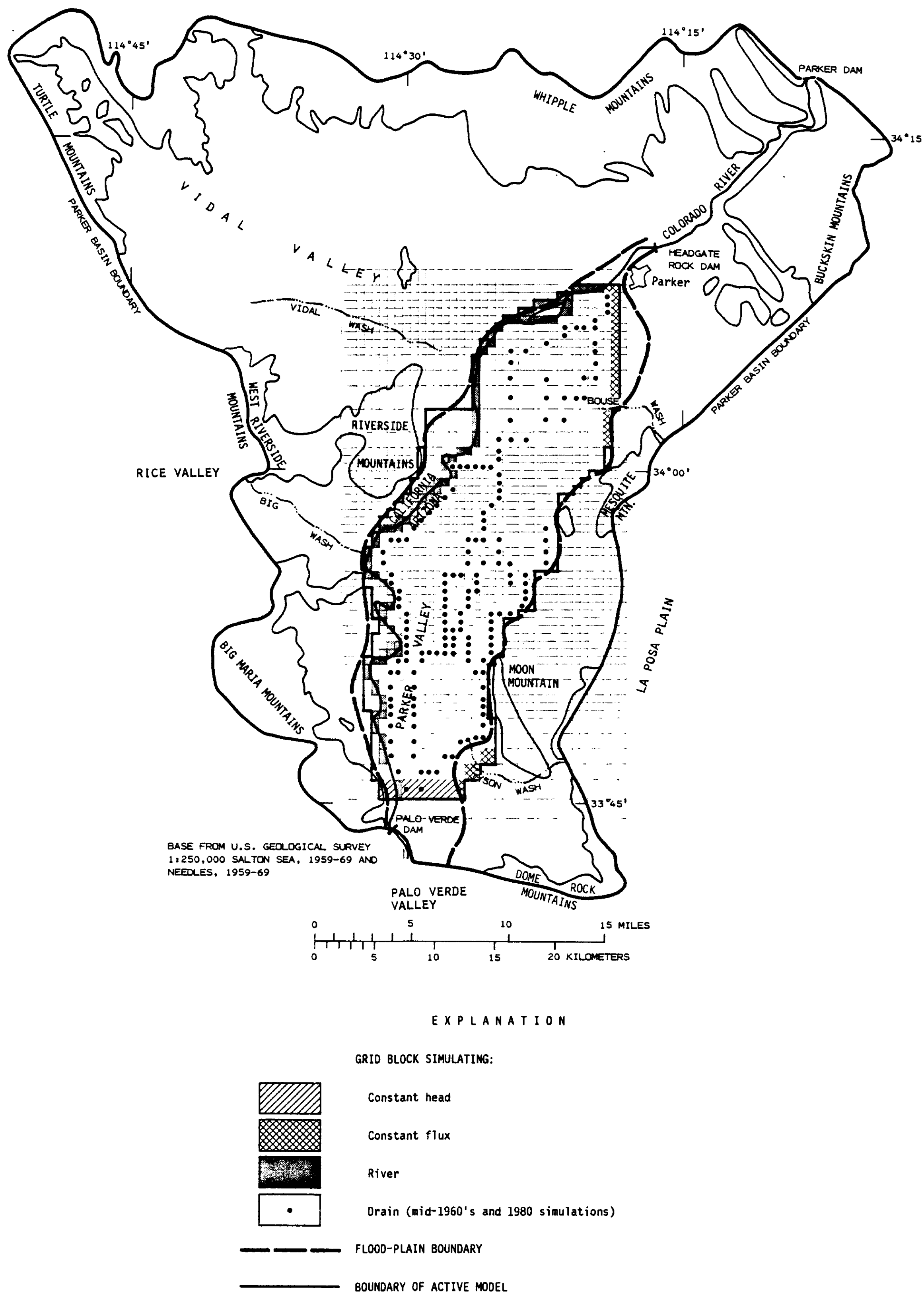
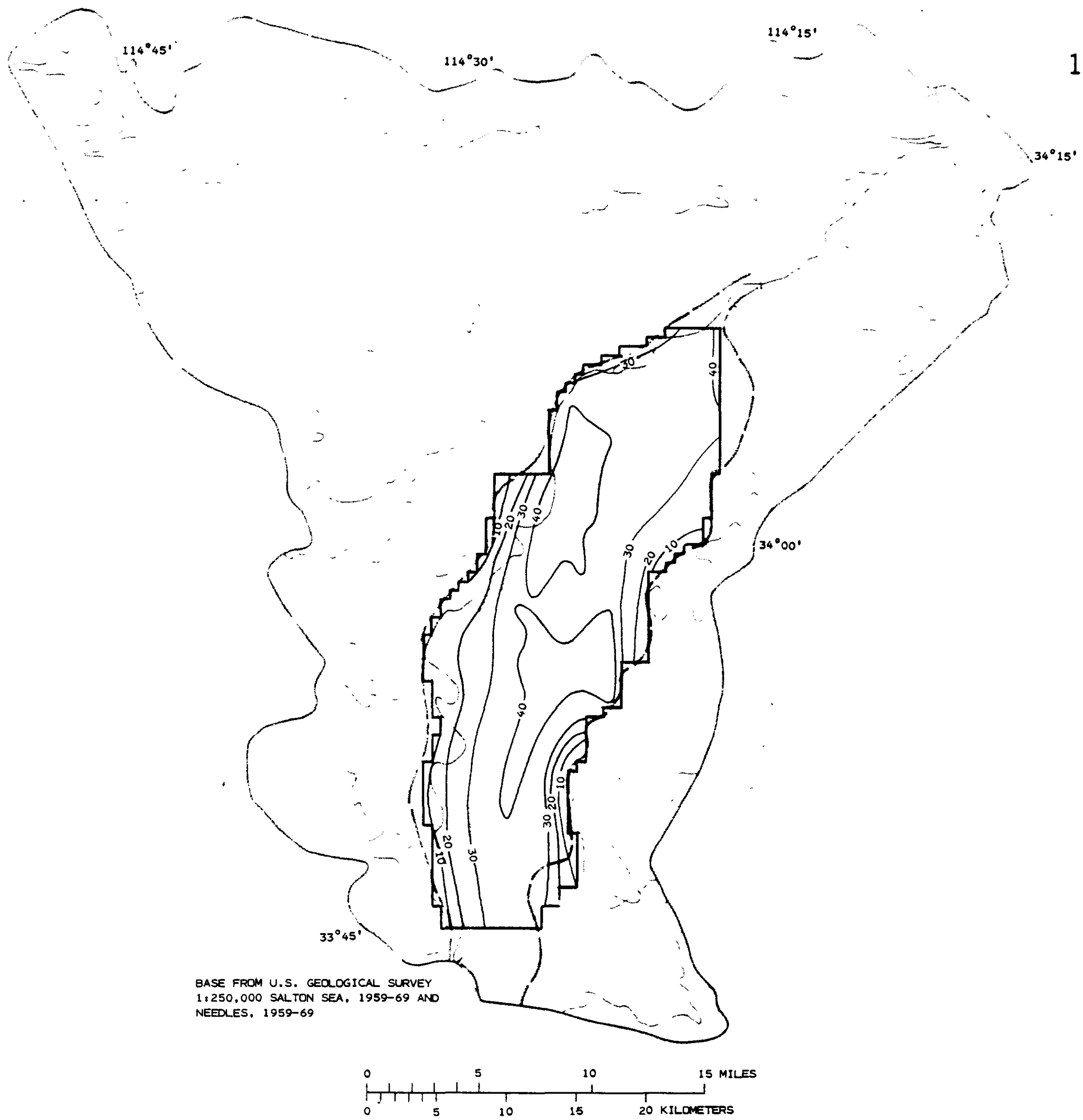


Figure 6.--Finite-difference grid for the Parker Valley model.



EXPLANATION

——40—— LINE OF EQUAL TRANSMISSIVITY IN THOUSANDS OF FEET SQUARED PER DAY—Contour interval 10,000 feet squared per day

———— BOUNDARY OF ACTIVE MODEL

Figure 7.--Model-calculated transmissivity of layer 2 for conditions in 1940-41.

insignificant compared to the large amount of leakage from the river in that area.

The grid blocks that correspond to bedrock areas were assumed to be impermeable because ground-water flow through the bedrock in the Parker basin is not evident (Metzger and others, 1973, p. 9). Ground-water flow through bedrock, if it occurs at all, will be primarily through fractures and therefore localized and is assumed to be of negligible quantity.

The grid blocks that represent inflow from tributary areas along the east boundary were modeled as constant fluxes in both layers (fig. 6). The amount of flow estimated by Metzger and others (1973, p. 51-52) was used to represent the flux in the areas where Bouse and Tyson Washes enter the valley and the area north of Bouse Wash. Ninety percent of the inflow was assumed to be through layer 2, and the total inflow estimated for each area was distributed equally among the nodes in each layer. Constant-head values were assigned to the grid blocks in both layers along the south boundary of the model (fig. 6), and ground-water outflow across this boundary was calculated by the model for all simulation periods.

The river-aquifer connection was simulated in layer 2 as leakage through a confining layer. In order to simulate this flow, a value for river leakance must be assigned to each river node. This leakance is calculated by dividing the vertical hydraulic conductivity of the riverbed by the riverbed thickness, which was assumed to be 1 ft. Metzger and others (1973, p. 52) estimated the vertical hydraulic conductivity to be 0.13 ft/d. This estimate apparently was based on an assumed 1-ft head difference between the river and underlying alluvium. This assumption is not supported by field data; head differences actually are much less than 1 ft (S. A. Leake, U.S. Geological Survey, oral commun., 1981). The smaller head difference indicates a vertical hydraulic conductivity of the river bed greater than that estimated by Metzger and others (1973). The vertical hydraulic conductivity was initially estimated to be one-tenth the horizontal hydraulic conductivity of layer 2. The resultant leakance value of 31 (ft/d)/ft was subsequently reduced to 2 (ft/d)/ft during model calibration. For model input, the leakance value must also be reduced proportionally to reflect the difference in actual river area and grid-block area. In the Parker Valley model, the river area was measured from topographic maps and averaged about 30 percent of the nodal area; therefore, the area-corrected river leakance was equal to about 0.6 (ft/d)/ft.

In order to simulate drains, average elevation of the drain bottom and a leakance value are assigned to each drain node. The drain leakance must be corrected for area in the same manner as the river leakance. As a result of model calibration, the drain leakance was set equal to 2 (ft/d)/ft; the value used in the model was 1.4×10^{-2} (ft/d)/ft, which represents the value corrected for the areal extent of drains.

Flow between layers was calculated by the model (Trescott, 1975) on the basis of the vertical hydraulic conductivity and the thickness of the model layers. The ratio of horizontal to vertical hydraulic conductivity was assumed to be 100:1 for layer 1 and 10:1 for layer 2.

The simulation of evapotranspiration was added to the model program by adapting program logic from the two-dimensional model developed by Trescott and others (1976). A linear relation between evapotranspiration rate and depth to water is used in the model through the use of a maximum rate at the land surface and a depth below land surface at which evapotranspiration ceases (Trescott and others, 1976, fig. 6). Simulated outflow from the ground-water system by evapotranspiration was applied only to layer 2. The maximum effective depth of evapotranspiration was assumed to be 20 ft (Metzger and others, 1973, p. 79). The maximum evapotranspiration rate was selected so that the average model-calculated rate was equal to the average estimated rate of 2.3 (acre-ft/acre)/yr (Metzger and others, 1973). In order to exclude the simulation of evapotranspiration in irrigated areas, the altitude of the land surface was arbitrarily set to a value hundreds of feet above the water table.

Recharge to the aquifer through applied irrigation water was simulated using areal-recharge rates for each simulation period. This recharge was applied to the grid blocks in layer 2 coincident with areas that were irrigated with water diverted from the Colorado River. Direct recharge to the aquifer from precipitation was assumed to be negligible because of the low annual precipitation rate and the high rate of evapotranspiration by plants.

Model Simulation of Conditions in the Mid-1960's

Steady-state ground-water conditions were assumed for the mid-1960's. The amount of irrigated acreage had remained fairly constant during the preceding 10 years (Metzger and others, 1973, fig. 26), and ground-water levels, which were affected by agricultural development, were thought to have stablized by this time.

Model results were compared to measured water levels (fig. 8) and to estimates of water-budget components based on those reported by Metzger and others (1973) for this time period (table 1). Water-budget components were considered more important than water levels in the calibration of the model because a large percentage of the model-calculated water levels are controlled by drain and river elevations. Drain flow was thought to be the most reliable component of the water budget because most flow is measured; therefore, drain flow was used as the principal control in the model-calibration process.

The model-calculated components of the water budget compared well to those based on estimates by Metzger and others (1973). The model calculated water-budget components generally were within ±5 percent of the estimated components. Model-calculated water-budget components supported the conceptual model of the system in that the major sources of recharge to the system were excess applied irrigation water and infiltration of river water. The major mechanisms of discharge were drain flow and evapotranspiration.

The model-calculated water levels generally were within ±5 ft of those based on measured levels (fig. 8). Model-calculated levels generally were lower than measured levels except near the areas of simulated tributary inflow. The higher model-calculated levels in these areas may indicate that the inflow estimated by Metzger and others (1973, p. 51-52) is too large. The lower model-calculated water levels at the east boundary of the model may indicate that tributary inflow from the area between Moon Mountain and Mesquite Mountain is occurring, although not simulated or included in the estimates of Metzger and others (1973).

The model-calculated water levels also indicate that the river is gaining water from the ground-water system in the northern part of Parker Valley. The model-calculated inflow to the river in that area is about 7,000 acre-ft/yr. This inflow is less than that estimated by Metzger and others (1973, p. 51), who stated that their estimate is a maximum value and actual inflow may be considerably less.

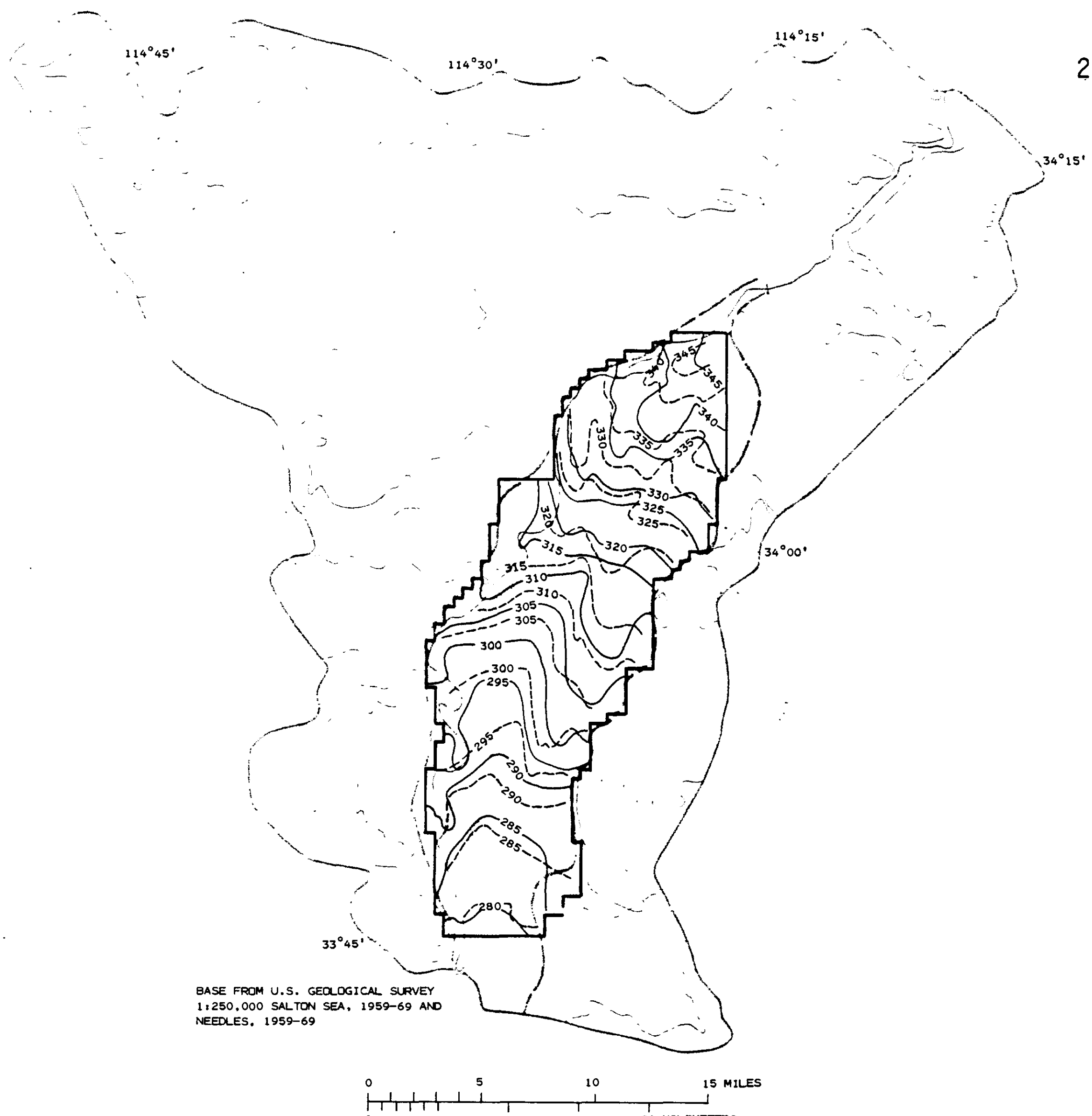
The difference between model-calculated water levels in the aquifer below the river and river stages generally was less than 0.01 ft, indicating a good hydraulic connection between the aquifer and the river. This condition is similar to conditions found in the field (S. A. Leake, U.S. Geological Survey, oral commun., 1981).

Model Simulation of Conditions in 1940-41

Steady-state ground-water conditions also were assumed for the 1940-41 time period, although water levels in the northern part of the valley had risen above predevelopment levels as a result of recharge to the aquifer by excess applied irrigation water. Water levels were assumed to have stabilized by 1940-41 because irrigated acreage had been fairly constant during the preceding 20 years (Metzger and others, 1973, fig. 26).

The model simulation of ground-water conditions in 1940-41 included the same physical parameters—hydraulic conductivity of layer 2, transmissivity of layer 1, and river leakance—that were used in the simulation of mid-1960's conditions. The relation between evapotranspiration and depth to water was also the same. The system of drains did not exist in 1940-41, and the area of recharge from excess applied irrigation water was much smaller.

Model results for this simulation were compared to the reported water levels for 1940-41 (fig. 9) and to the water budget (table 1), which was based on estimates by Metzger and others (1973). Water-budget



EXPLANATION

——325——	MODEL-CALCULATED WATER-LEVEL CONTOUR—Shows altitude of the water level. Contour interval 5 feet. National Geodetic Vertical Datum of 1929
– – – 325 – – –	MEASURED WATER-LEVEL CONTOUR—Shows altitude of the water level. Adapted from Metzger and others (1973, pl. 5). Contour interval 5 feet. National Geodetic Vertical Datum of 1929
————	BOUNDARY OF ACTIVE MODEL

Figure 8.--Comparison of measured and model-calculated water levels for conditions in the mid-1960's.

components were considered more important than water levels in the calibration of the model for this time period. Metzger and others (1973, p. 47) stated that "A detailed analysis of the shape and gradients of the contours [of water levels for 1940-41] is not warranted because the control that was used by the Colorado River Indian Agency is not known." An attempt to match exactly the model-calculated water levels to those reported for 1940-41 was therefore not justified. Duplication of the general shape of the contours and water-table gradients by the model was considered acceptable.

A model-calculated water budget generally within ±20 percent of the estimated budget was considered acceptable for model calibration. Errors inherent in the estimates of Metzger and others (1973) are thought to be of the same order of magnitude. The major components of the model-calculated water budget were within this limit.

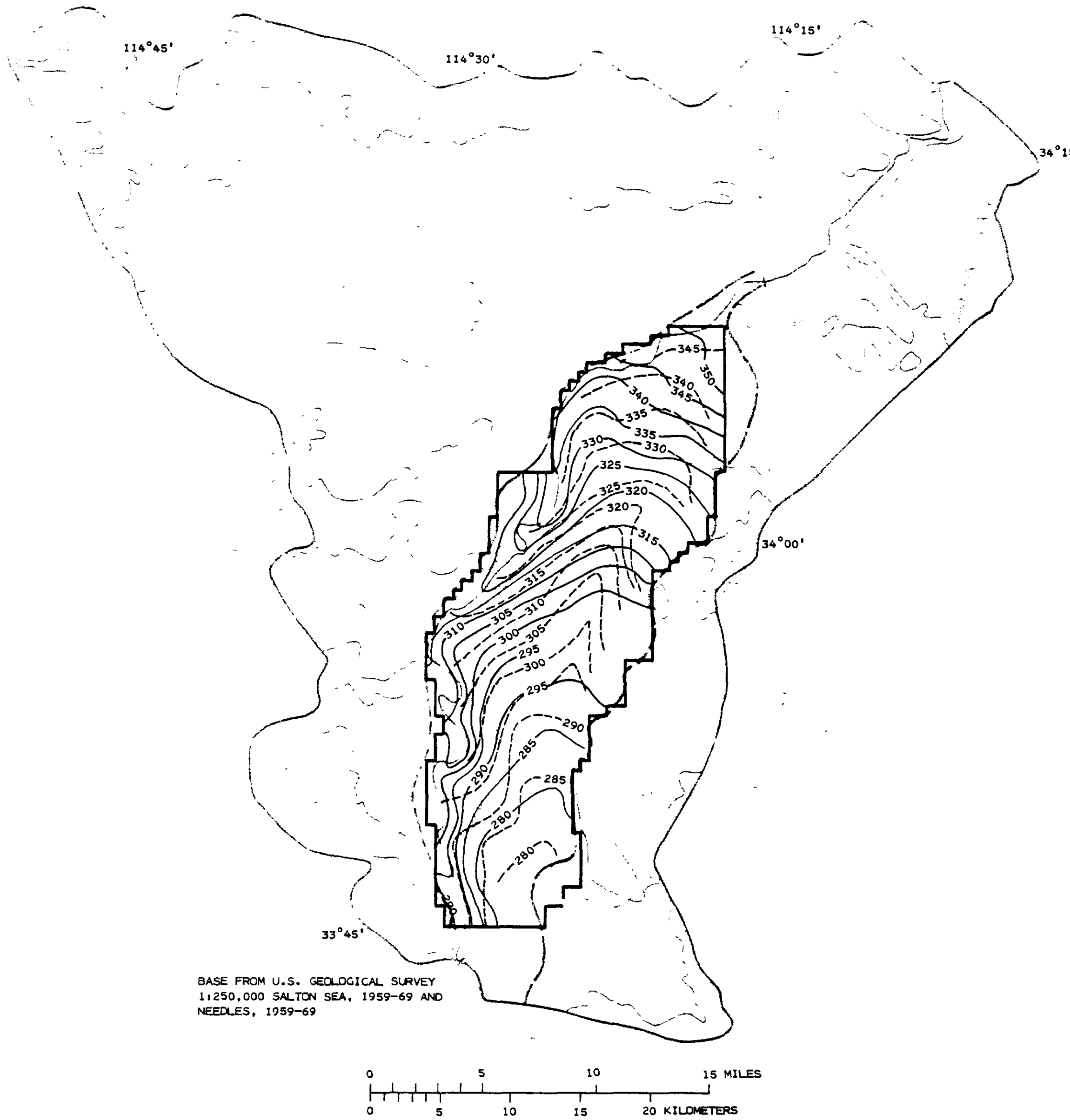
The model-calculated water budget (table 1) indicated that infiltration of surface water from the river was the major source of inflow to the ground-water system. Tributary inflow and recharge by excess applied irrigation water were only minor sources. Model results indicated that the dominant mechanism of discharge was through evapotranspiration by phreatophytes. Ground-water underflow south to Palo Verde Valley was only a minor discharge from the system.

The model-calculated water levels generally were within ±10 ft of reported levels (fig. 9). Model-calculated water levels generally were lower than reported levels, especially along the center of the east boundary. As in the mid-1960's simulation, this difference probably indicates that some tributary inflow along this area was not simulated. In the northern part of the valley model-calculated water levels generally were higher than reported levels, which may indicate that the recharge estimate for this area is too large.

Overall, the model-calculated water-level contours and gradients are similar to reported contours and gradients (fig. 9). Model-calculated water-level contours support the conceptual model in that the Colorado River was a losing stream throughout the valley. Ground water flowed from the river toward the center of the valley where it was discharged through evapotranspiration by phreatophytes.

Model Simulation of Conditions in 1980

Ground-water conditions in 1980 were simulated in order to determine if the model would adequately simulate the system subsequent to the major changes in agricultural development that had occurred since the mid-1960's. Rigid calibration criteria were not imposed on the 1980 simulation because of uncertainties in some water-budget components and a lack of areal water levels for this period.



EXPLANATION

———325——— MODEL-CALCULATED WATER-LEVEL CONTOUR—Shows altitude of the water level. Contour interval 5 feet. National Geodetic Vertical Datum of 1929

----325---- REPORTED WATER-LEVEL CONTOUR—Shows altitude of the water level. Contour interval 5 feet. National Geodetic Vertical Datum of 1929

———————— BOUNDARY OF ACTIVE MODEL

Figure 9.--Comparison of reported and model-calculated water levels for conditions in 1940-41.

The physical parameters, the relation between evapotranspiration and depth to water, and the system of drains used in the mid-1960's simulation also were used in the 1980 simulation. The rate and area of recharge from excess applied irrigation water were altered to reflect the changes from conditions in the mid-1960's.

The simulated changes in the ground-water system compared favorably to those that occurred since the mid-1960's. Simulated base flow in the drains increased in response to shallower water levels (table 1). Simulated evapotranspiration by phreatophytes was reduced, although not to the extent estimated. The assumed average evapotranspiration rate of 2.3 (acre-ft/acre)/yr that was used for comparison to model results may be too low. This average rate assumes that water levels remained constant between the mid-1960's and 1980; however, water levels have risen since the mid-1960's. The actual average evapotranspiration rate probably is higher than that estimated for the previous periods because of the general relation of increasing evapotranspiration rate with decreasing depth to water. The model-calculated average annual evapotranspiration rate of 120,000 acre-ft/yr probably is a more realistic estimate for this water-budget component than the annual rate based on the average rate of 2.3 (acre-ft/acre)/yr.

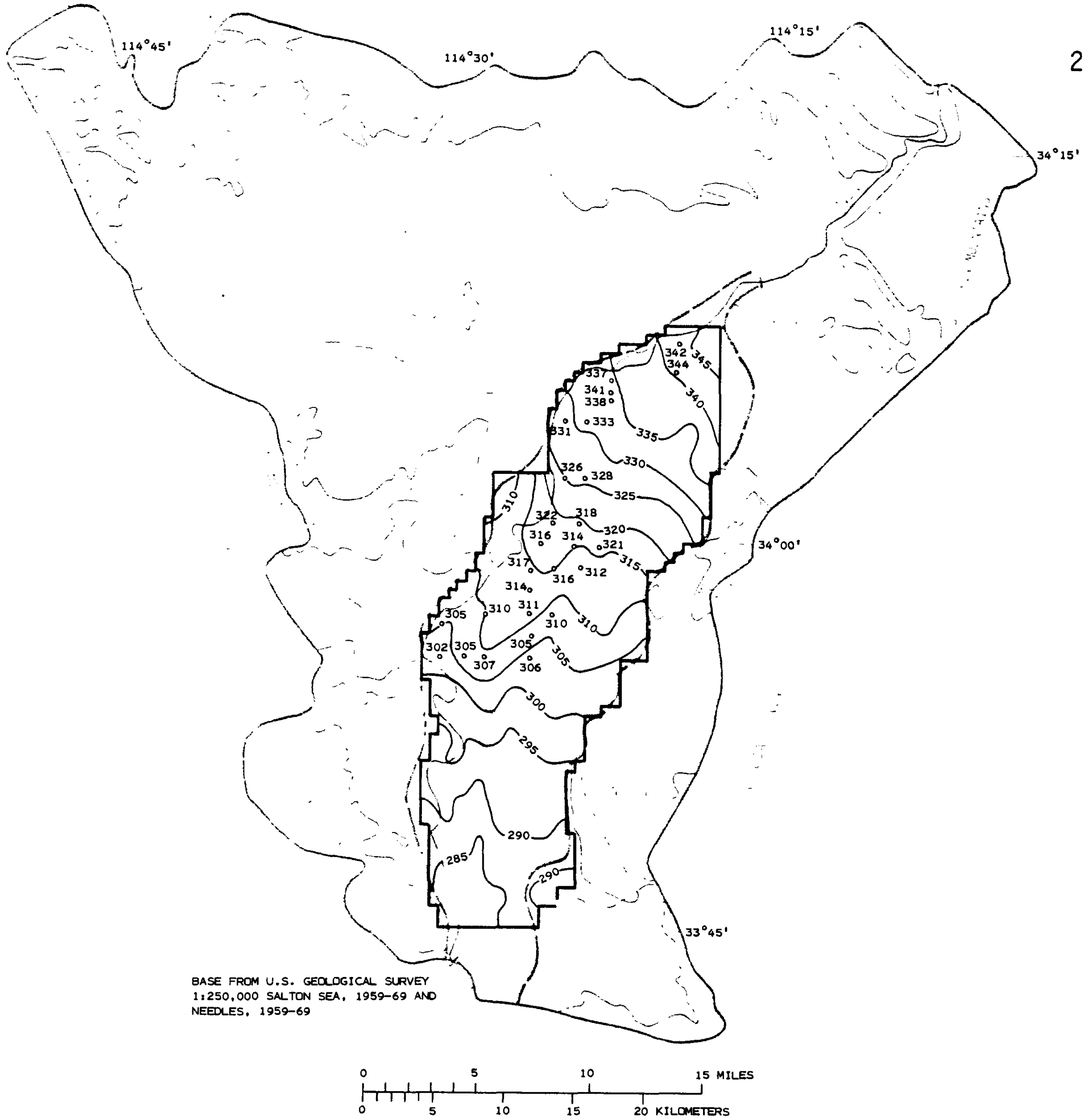
Model results also indicated a reduction in the net river loss, although the model-calculated river loss was greater than the estimated loss. The model results did not show an increase in ground-water flow to the river, which may indicate that the estimated recharge was too low. An increased recharge in the model should cause water levels to rise, resulting in a decrease in river loss, an increase in base flow to drains, and a potential increase in evapotranspiration.

Model results indicated a rise in water levels of several feet over much of the previously nonirrigated land. The model-calculated water levels generally were within ±5 ft of the average measured levels for July 1981 to March 1982 (fig. 10). Water levels for 1980 probably are not much different from the measured levels for 1981-82; therefore, the measured levels may be assumed to be representative of conditions in 1980.

The comparison of model results to known or estimated water-budget components and to measured water levels is acceptable. The model reasonably simulated the system with the alteration to the water budget caused by the intensified agricultural development that had occurred since the mid-1960's.

Model Sensitivity

Tests of model sensitivity to variations in input parameters were made as an integral part of the model-calibration process for the mid-1960's. The procedure was to hold all input values constant except the one being analyzed and to vary that value through a range that included



EXPLANATION

——300—— MODEL-CALCULATED WATER-LEVEL CONTOUR—Shows altitude of the water level. Contour interval 5 feet. National Geodetic Vertical Datum of 1929

°305 WELL—Number, 305, is average altitude of the water levels measured from July 1981 to March 1982. National Geodetic Vertical Datum of 1929

———— BOUNDARY OF ACTIVE MODEL

Figure 10.--Comparison of measured and model-calculated water levels for conditions in 1980.

the uncertainty in the value. Because of constraints on the range of model-calculated water levels imposed by head-controlling features, such as river and drain nodes, variations in components of the model-calculated water budget from acceptable calibrated values were used to analyze model sensitivity. Properties that were varied included evapotranspiration rate, hydraulic conductivity, drain leakance, and river leakance. The model was most sensitive to changes in the average evapotranspiration rate, moderately sensitive to drain leakance, and generally insensitive to variations in hydraulic conductivity and river leakance.

Small changes in the simulated average evapotranspiration rate of phreatophytes resulted in large changes in the model-calculated water-budget components (fig. 11). The changes affected the model-calculated net river loss more than the base flow to drains. Model-calculated water levels were changed by only ±2 ft by changes in the average evapotranspiration rate.

The model-calculated water budget generally was insensitive to increases in drain leakance but became more sensitive as the drain leakance was decreased (fig. 12). Increasing the uncorrected drain leakance from 2 to 8 (ft/d)/ft increased the model-calculated base flow to drains by only 12 percent. Water levels generally were lowered by 1-2 ft except in the northern part of the model area where they were lowered by 2-5 ft. Reduction of the uncorrected drain leakance from 2 to 0.5 (ft/d)/ft resulted in a reduction of the model-calculated base flow to drains of 27 percent and caused water levels to rise by 2-5 ft over most of the model area and 5-10 ft in the northern part.

Model results generally were insensitive to variations in hydraulic conductivity of layer 2. Variations in hydraulic conductivity of ±50 percent resulted in changes to the model-calculated water-budget components of less than 10 percent (fig. 13) and water levels were affected by only ±2 ft. The range of values tested—155 to 460 ft/d—is within the range resulting from aquifer tests of the younger alluvium—40 to 590 ft/d—reported by Metzger and others (1973, p. 68) and produced acceptable model-calculated water levels and water-budget components.

The model-calculated water budget was least sensitive to changes in the river leakance. Increasing the uncorrected river leakance from 2 to 20 (ft/d)/ft produced no significant changes in the model results (fig. 14). Decreasing the uncorrected river leakance from 2 to 0.02 (ft/d)/ft reduced the model-calculated net river loss by 37 percent, but model-calculated evapotranspiration and base flow to drains were reduced by only 15 and 6 percent respectively (fig. 14). Over most of the model area, water levels were reduced by only 1-2 ft, but near the river, water levels were reduced by 2-5 ft.

Maximum effective depth of evapotranspiration and vertical hydraulic conductivity also were included in the sensitivity analysis. The model was only locally sensitive to the maximum effective depth of evapotranspiration. Changing this depth by ±5 ft resulted in local changes in model-calculated water levels but did not significantly affect the calculated

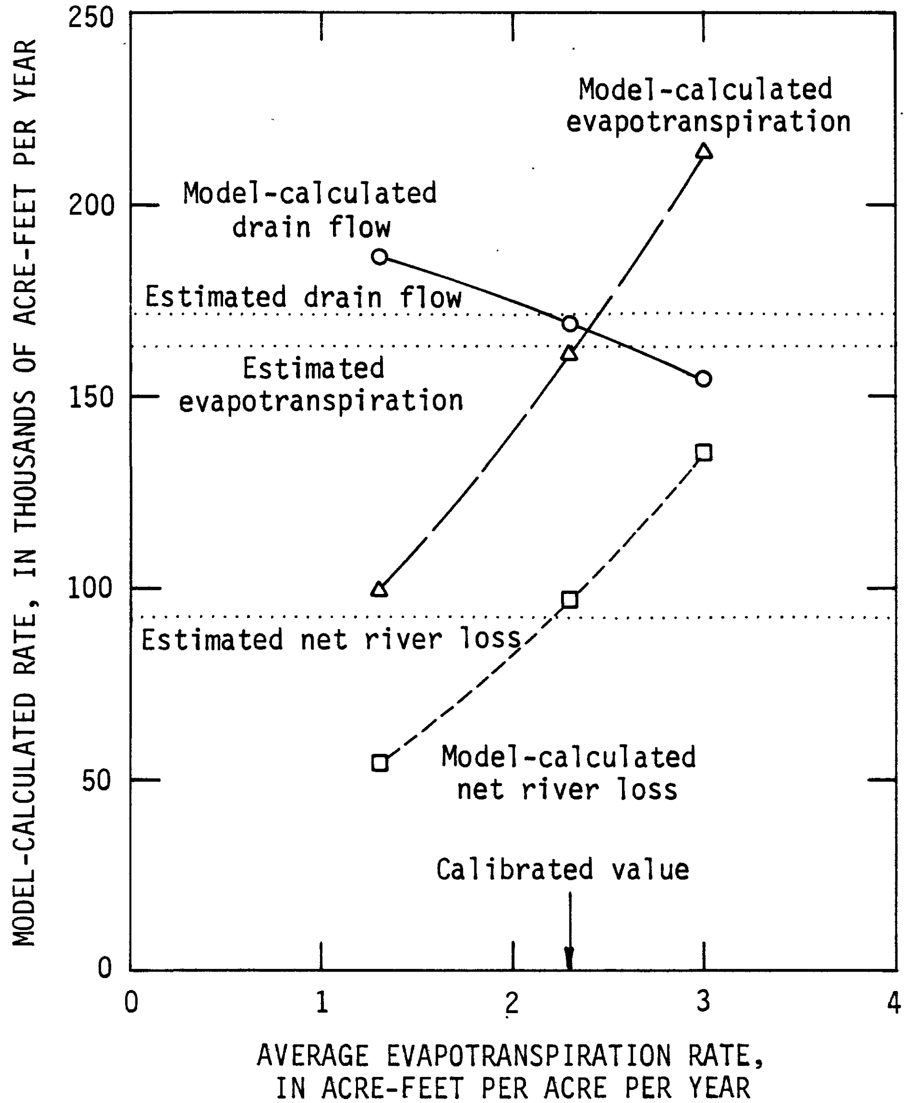


Figure 11.--Variation of model-calculated water-budget components as affected by changes in average evapotranspiration rate.

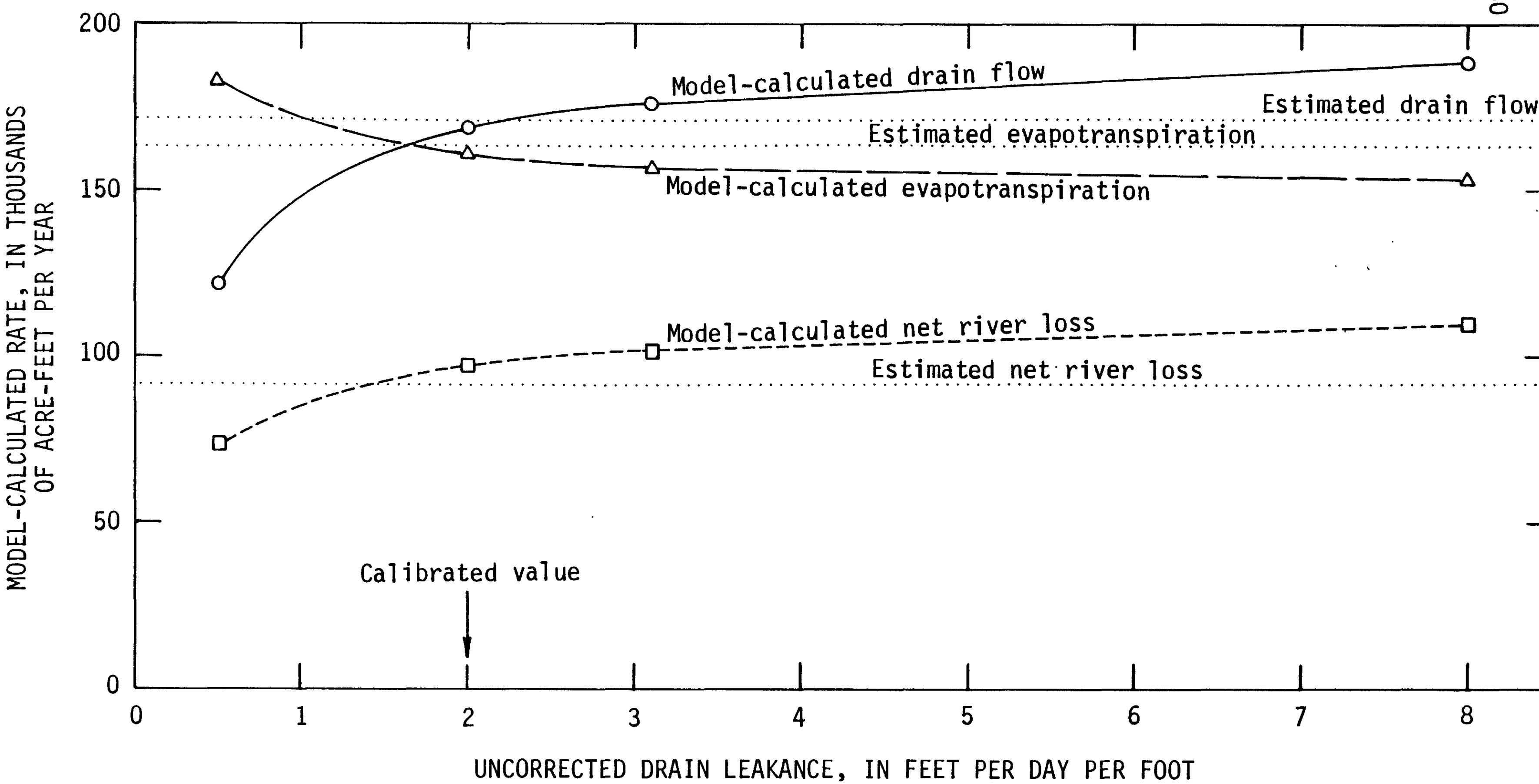


Figure 12.--Variation of model-calculated water-budget components as affected by changes in drain leakance.

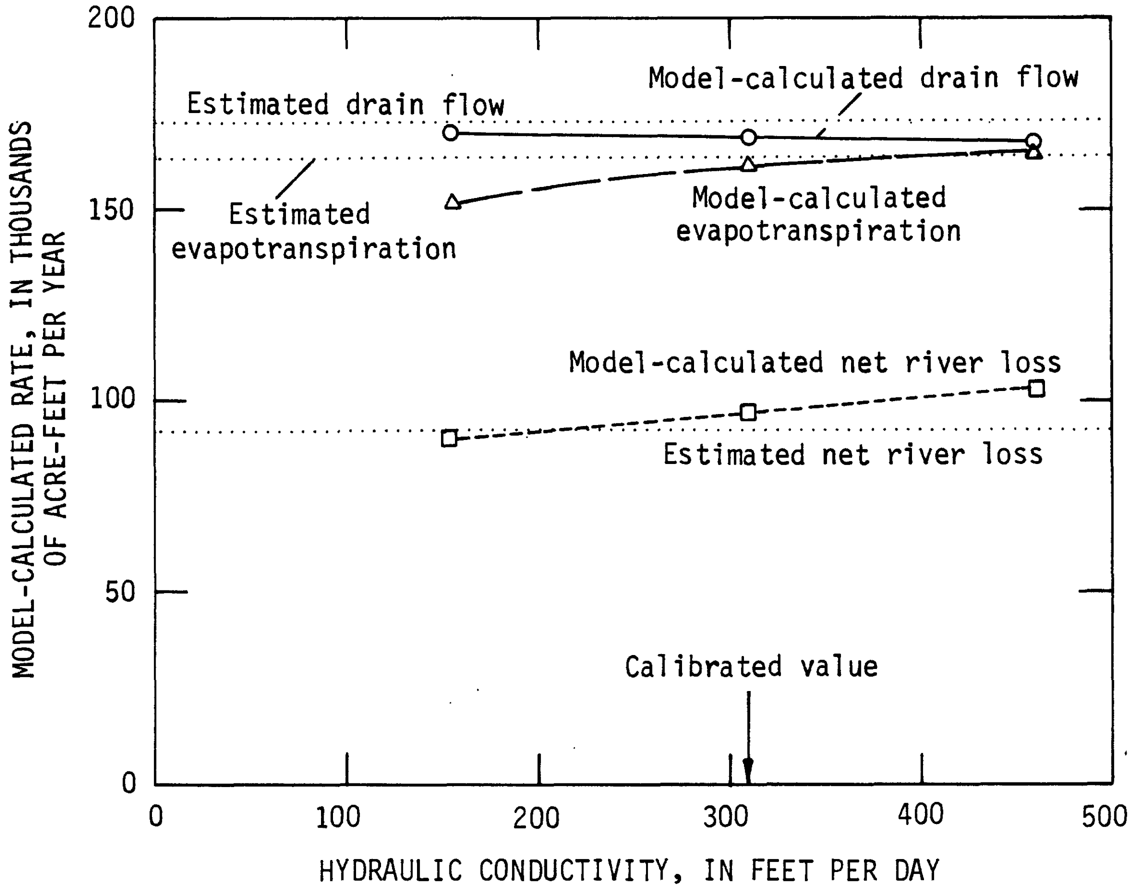


Figure 13.--Variation of model-calculated water-budget components as affected by changes in hydraulic conductivity.

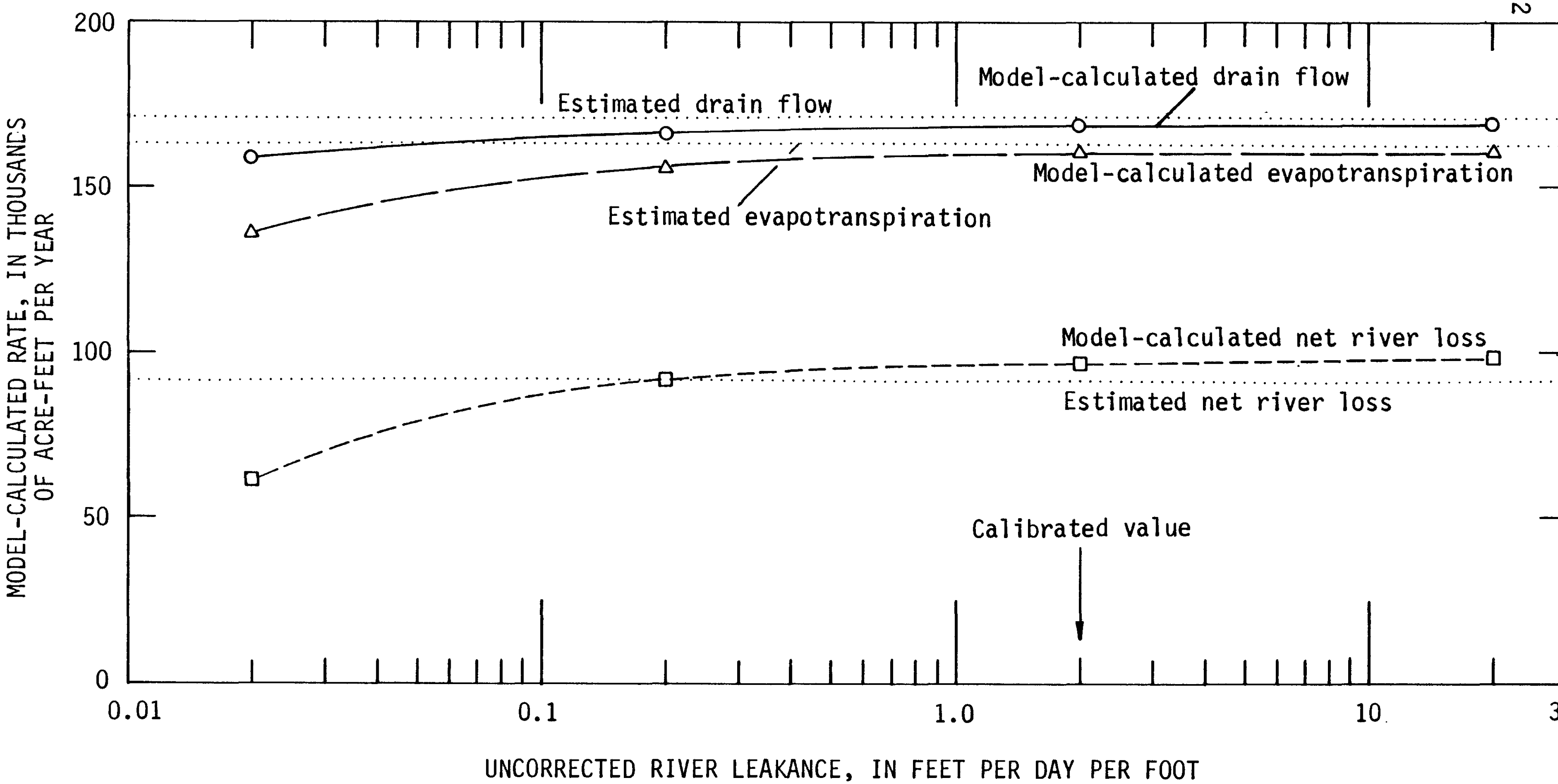


Figure 14.--Variation of model-calculated water-budget components as affected by changes in river leakance.

average evapotranspiration rate. The model results also were insensitive to the vertical hydraulic conductivity of the model layers. The ratio of horizontal to vertical hydraulic conductivity for layer 2 was assumed to be 10:1 but could be as large as 100:1 or as small as 1:1 without significantly affecting model results. The ratio for layer 1, which represents a more layered and fine-grained geologic unit, was assumed to be 100:1; however, ratios as large as 100,000:1 produced equally acceptable model results.

Variation in the amount of inflow from La Posa Plain resulted in only local changes in water levels. Because this inflow is small in relation to the other inflow sources, the overall water budget was not significantly affected.

Reliability and Potential Transfer Value of Results

The model-calculated water levels for the three simulation periods generally are within ±10 ft of the water levels reported or measured for those periods. The reliability of the model results cannot be evaluated solely on the basis of the similarity in water levels because the water levels are, to a large extent, controlled by river and drain elevations and constant-head values input to the model. The similarity of model-calculated water levels, gradients, and shape of water-level contours to those based on measured levels does suggest, however, that the flow quantities and aquifer characteristics used in the model are within reason. The model-calculated water-budget components generally are similar to the components based on estimates by Metzger and others (1973). The model values are thought to be as reliable as the estimates reported in that study.

The relation between evapotranspiration and depth to water is one of the least known factors in this study and therefore the most open to question. The model approximates a curvilinear function with a straight-line function. The model approximation is most prone to error at shallow depths to water where the model-calculated evapotranspiration rate probably is lower than the actual rate or at greater depths to water where the model-calculated evapotranspiration rate probably is greater than the actual rate. The use of a single average relation to simulate evapotranspiration by a variety of phreatophytes may be considered a rough approximation at best.

Although the simulated relation between evapotranspiration and depth to water produced acceptable model results when compared to ground-water conditions in the mid-1960's, model-calculated evapotranspiration loss deviated from estimated losses for 1940-41 and 1980. The use of an average rate of 2.3 (acre-ft/acre)/yr to estimate evapotranspiration by phreatophytes for those periods may be inappropriate. A different average rate may be required to estimate this component of the water budget, especially if phreatophyte types or density and depth to water for those periods was significantly different from the mid-1960's.

The average evapotranspiration rates calculated by the model for the periods of varying depth to water should be more realistic than a single average rate because the model-calculated rate varies according to varying depth to water. Uncertainties related to evapotranspiration also affect the estimated recharge in irrigated areas because the consumptive use by crops is incorporated into that estimate.

The value used in the model for hydraulic conductivity is within the range of values, which are based on aquifer-test data, reported by Metzger and others (1973, p. 68) and is considered reliable. The hydraulic conductivity may vary areally in Parker Valley; however, the use of a uniform hydraulic-conductivity value resulted in an acceptably calibrated model for a regional study.

The value used in the model for hydraulic conductivity of layer 2 is essentially an average value for the basal gravel and the overlying finer-grained sands of the younger alluvium. These two subunits actually may have substantially different hydraulic conductivities. Changes in the saturated thickness of the younger alluvium occur in the upper finer-grained zone and therefore may have only a small influence on the total transmissivity of the unit. In the model, however, changes in the saturated thickness will result in a change in the calculated transmissivity greater than that which will occur in the field because of the use of an average hydraulic conductivity. This difference between model-simulated and field conditions is assumed to be small and to have a negligible effect on the overall model results.

The estimated base flows to drains used for comparison to model-calculated flow are based in part on measured flows and probably are accurate within ±20 percent. The use of a drain-leakance value of 2 (ft/d)/ft therefore may be considered a reasonable value for use in simulating removal of water from the system by drains because the model-calculated base flow to drains were within the estimated range of error for this water-budget component.

The model is not as sensitive to the river leakance as it is to the drain leakance. A wide range of values for the river leakance produces similar results in the model. Streamflow-depletion data between Headgate Rock Dam and Palo Verde Dam for the 1940-41 time period that could be used to calibrate the model are not available; therefore, the ability of the model to realistically simulate the river-aquifer connection is uncertain.

The overall comparisons of the model results to the analysis of the ground-water system reported by Metzger and others (1973) and to conditions in 1980 are good. The model reasonably simulated ground-water conditions in Parker Valley for three different stages of agricultural development, and the model may be considered as a reasonable representation of the ground-water system under equilibrium conditions. The model should not be considered for use in a transient simulation without an evaluation of the storage properties of the aquifer, which were not incorporated into the present model.

The model should not be considered for analyses of site-specific hydrologic problems in Parker Valley, such as local drainage or irrigation problems. The model grid is too large in scale to accurately address these types of problems. The grid size is also too large to undertake a detailed analysis of estimated return flow of irrigation water to the Colorado River. More detailed information on local small-scale aquifer conditions is required for these types of analyses; such detail was beyond the scope of this study.

A basic assumption of the Swab/RASA Project is that certain physical characteristics and hydrologic relations in a basin may be transferable to another hydrologically similar basin. Knowledge gained in the modeling of a basin that has sufficient data for model calibration may be transferable to a model of another basin that has less data for calibration. Model simulation of other basins is part of the next phase of the Swab/RASA Project. The actual transfer value of the aquifer characteristics and modeling assumptions and approaches developed in this first phase of modeling will be evaluated in the next phase.

The same geologic units are present in all the basins along the lower Colorado River in the Swab/RASA study area, and the hydraulic characteristics of these units are assumed to be similar. The aquifer characteristics used in the Parker Valley model for these units probably are representative of those in other basins along the lower Colorado River. These characteristics will be used as a first approximation of the aquifer characteristics in future models of other lower Colorado River basins as a part of the next phase of the Swab/RASA Project. Their use should lessen the number of simulations required for model calibrations.

One difference between Parker Valley and other valleys along the lower Colorado River is the absence of the older alluvium beneath the flood plain in Parker Valley. This is not the case in Palo Verde Valley to the south and may not be the case in other basins. This difference probably is not significant because of similarities in the hydraulic properties of the older and younger alluviums. The presence of the older alluvium below the younger alluvium will result primarily in an increase in the transmissivity of the aquifer due to an increase in saturated thickness.

Three-dimensional simulation of the aquifer in Parker Valley with two layers, although a realistic approach, may not be necessary for steady-state simulations. The model-calculated water levels in both layers are similar, which indicates a good hydraulic connection between the two layers. This conclusion is in agreement with Metzger and others (1973, p. 77), who stated that ". . . all the water-bearing rocks beneath the flood plain and terraces of the Colorado River above the less permeable part of the Bouse Formation constitute a single ground-water reservoir that is hydraulically connected to the Colorado River." The model-calculated net vertical flow to layer 1 from layer 2 is less than 2 percent of the total calculated outflow. Neglecting this vertical flow by use of a two-dimensional model to simulate a single-layer aquifer probably would not significantly affect the regional assessment of the ground-water system.

The assumption that the mountain masses surrounding the model area are impermeable appears to be reasonable because simulation of flow through these areas was not required to improve the model results. The amount of flow that may actually occur through the bedrock is estimated to be too small to significantly affect the flow system. The similarity of bedrock types in other basins along the Colorado River supports the assumption that bedrock boundaries may be simulated as impermeable boundaries in models of those basins.

The ground-water inflow along the east boundary is small in relation to the total inflow to the ground-water system. Variations in the amount of this inflow affect water levels in the immediate area of assumed inflow but does not significantly affect water levels over the rest of the model area. Ground-water inflow to other basins along the Colorado River also is probably small in relation to the total flow in these basins; therefore, detailed knowledge of the amount of ground-water inflow to those basins should not be required in the regional analysis of their ground-water flow systems and water budgets.

The transfer value of the relation between evapotranspiration and depth to water used in this study to models of other lower Colorado River basins will depend on the similarities in vegetation type and density in other basins to those in Parker Valley in the mid-1960's.

Recharge to the ground-water system from precipitation is assumed to be negligible in Parker Valley. The model produces reasonable results without simulation of recharge from precipitation and therefore supports this assumption. The amount of annual precipitation in other basins along the Colorado is similar to that in Parker Valley (Hely and Peck, 1964, pl. 3); therefore, use of an areal-recharge rate for simulation of recharge from precipitation should not be required in models of those basins.

RECOMMENDATIONS FOR FURTHER STUDY

To provide a more complete and detailed analysis of the ground-water system in Parker Valley, further study is required. Areas of study include evapotranspiration, storage properties of the aquifer, the Miocene(?) fanglomerate, and inflow from tributary areas.

A better knowledge of the relations between evapotranspiration and depth to water for both phreatophytes and crops is needed. Those relations are the least understood factors in the study; however, the model is most sensitive to variations in the average simulated evapotranspiration rate. Knowledge of consumptive use by crops is necessary to better estimate the amount of recharge to the ground-water system by applied irrigation water. Small errors in estimated evapotranspiration or recharge may result in errors of several tens of thousand acre-feet of water in the water budget.

A further evaluation of the storage properties of the aquifer is necessary to study short-term or time-dependent changes to the ground-water system in the valley. Knowledge of these storage properties is essential if the model is to be used further as a predictive tool.

The present study did not address the problem of modeling the ground-water system below the upper zone of the Bouse Formation. In order to assess the total ground-water resources of the Parker basin, the Miocene(?) fanglomerate should be studied in more detail. Information concerning the subsurface extent and thickness of the fanglomerate as well as its hydraulic characteristics is needed. Information concerning the potentiometric surface in the fanglomerate also is needed in order to know the direction and rate of ground-water flow in that unit.

Although not critical to this study, more information on ground-water inflow from adjacent basins is necessary for a more detailed analysis of the ground-water system in Parker Valley and as a check on the values simulated in the model. The information necessary to evaluate this ground-water inflow includes detailed water-level data, hydraulic-conductivity values, and saturated thickness of the unconsolidated deposits at the inflow points. Inflow from the area between the Moon and Mesquite Mountains, which is indicated by the model, should be verified.

SUMMARY

As part of the Southwest Alluvial Basins, Regional Aquifer-System Analysis Project, a three-dimensional finite-difference model was used to simulate the ground-water system in Parker Valley. The purpose of the study was to evaluate present knowledge and concepts of the ground-water system and the ability of a generalized model to reasonably represent the system. Generalized aquifer parameters and modeling approaches, which may have transfer value in the construction and calibration of models of other lower Colorado River basins, were evaluated. Most of the data required for the model and for the analysis of model results were obtained from a detailed report on the geohydrology of the Parker area by Metzger and others (1973).

The younger alluvium and the upper zone of the Bouse Formation form the major aquifer in Parker Valley. Ground water in this aquifer is unconfined. These units are separated from the fanglomerate, which may be of local importance as an aquifer, by the lower zone of the Bouse Formation, which acts as a confining unit.

For ground-water conditions in 1940-41, which were similar to predevelopment conditions, the major source of inflow to the ground-water system was infiltration of surface water from the Colorado River. Inflow from adjacent basins and excess applied irrigation water were minor sources of recharge to the system. The major mechanism of discharge from the ground-water system was through evapotranspiration by

phreatophytes. A minor amount of ground water flowed south to Palo Verde Valley.

Application of surface water for irrigation of more than 31,000 acres, lower river stages, and construction of an extensive system of drains resulted in significant changes to the ground-water system by the mid-1960's. Increased recharge to the ground-water system by applied irrigation water caused water levels to rise 5 to 10 ft in the irrigated areas in the northern part of the valley. This buildup of water levels reversed the direction of ground-water flow in that area, and ground water flowed toward the river. In order to prevent damage to crops by the high water levels, a system of drains was constructed. These drains removed water from the ground-water system and returned it to the river south of Palo Verde Dam. The reduced gradient of the water table from the river reduced the net loss of surface water from the Colorado River to the ground-water system. The total annual evapotranspiration of ground water by phreatophytes decreased because a large area of phreatophytes was replaced with crops.

By 1980, the irrigated acreage in Parker Valley had increased greatly at the expense of the area occupied by phreatophytes. Recharge to the ground-water system increased because of increased application of surface water. Water levels rose by several feet in previously nonirrigated areas, which caused an increase in base flow to drains and a decrease in the net river loss. Because of the decreased area occupied by phreatophytes, total evapotranspiration by phreatophytes decreased.

Model simulations were made for ground-water conditions in 1940-41, the mid-1960's, and 1980. The aquifer was simulated in the model by two layers, which corresponded to the younger alluvium—layer 2—and the upper zone of the Bouse Formation—layer 1. A uniform hydraulic conductivity of 310 ft/d was assigned to layer 2, and a uniform transmissivity of 9,000 ft^2/d was assumed for layer 1. The lower zone of the Bouse was assumed to be impermeable in relation to the aquifer and was used as the base of the model.

The model was first calibrated to conditions in the mid-1960's. Conditions in 1940-41 and 1980 were subsequently simulated using the same aquifer properties and relation between evapotranspiration and depth to water that was used in the 1960's simulation.

Water levels and water budgets calculated by the model for all simulations agreed favorably with measured and reported water levels and estimates of most water-budget components. Model-calculated water levels generally were within ±10 ft of measured and reported levels, and model-calculated water budgets generally were within ±20 percent of the estimated budgets. The model reasonably simulated ground-water conditions for three different stages of agricultural development and may be considered as a reasonable representation of the ground-water system under equilibrium conditions.

Model results indicated several items that differed from the estimates by Metzger and others (1973). Their estimated riverbed hydraulic conductivity of 0.13 ft/d may be too low, and estimates of inflow from tributary areas may be too high. Some tributary inflow may be occurring in the area between Moon Mountain and Mesquite Mountain, although none was included in the estimates of Metzger and others (1973). Use of an average evapotranspiration rate for phreatophytes of 2.3 (acre-ft/acre)/yr may not be appropriate in estimating evapotranspiration for periods other than the mid-1960's because of differences in water levels from that period.

The model was most sensitive to changes in the average evapotranspiration rate, although this rate is the most uncertain factor in this study and should be studied further. The model was less sensitive to changes in river and drain-leakance values, although changes to these values locally affected model-calculated water levels by as much as ±10 ft.

The aquifer characteristics used in this model may have transfer value in models of other basins along the lower Colorado River because of the similarities of the geologic units in those basins. Values for the hydraulic conductivity of the younger alluvium—310 ft/d—and river and drain leakance—2 (ft/d)/ft—may be used as first approximations of those parameters in other lower Colorado River basins. Basic assumptions, such as impermeable bedrock and negligible recharge from precipitation, used in the Parker Valley model may also be used in models of other lower Colorado River basins.

SELECTED REFERENCES

Anderson, T. W., 1980, Study plan for the regional aquifer-system analysis of alluvial basins in south-central Arizona and adjacent states: U.S. Geological Survey Open-File Report 80-1197, 22 p.

Bishop, C. C., compiler, 1964, Geologic map of California, Olaf P. Jenkins edition, Needles sheet: Sacramento, California Division of Mines and Geology, 2 sheets.

Carr, W. J., and Dickey, D. D., 1980, Geologic map of the Vidal, California, and Parker SW, California-Arizona quadrangles: U.S. Geological Survey Miscellaneous Investigations Series Map I-1125, 1 sheet.

Carr, W. J., Dickey, D. D., and Quinlivan, W. D., 1980, Geologic map of the Vidal NW, Vidal Junction, and parts of the Savahia Peak SW and Savahia Peak quadrangles, San Bernardino County, California: U.S. Gelogical Survey Miscellaneous Investigations Series Map I-1126, 1 sheet.

Dickey, D. D., Carr, W. J., and Bull, W. B., 1980, Geologic map of the Parker NW, Parker, and parts of the Whipple Mountains SW and Whipple Wash quadrangles, California and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1124, 1 sheet.

Hely, A. G., and Peck, E. L., 1964, Precipitation, runoff and water loss in the lower Colorado River-Salton Sea area: U.S. Geological Survey Professional Paper 486-B, 16 p.

McDonald, M. G., and Fleck, W. B., 1978, Model analysis of the impact on ground-water conditions of the Muskegon County wastewater disposal system, Michigan: U.S. Geological Survey Open-File Report 78-99, 63 p.

Metzger, D. G., 1968, The Bouse Formation (Pliocene) of the Parker-Blythe-Cibola area, Arizona and California: U.S. Geological Survey Professional Paper 600-D, p. D126-D136.

Metzger, D. G., Loeltz, O. J., and Irelan, Burdge, 1973, Geohydrology of the Parker-Blythe-Cibola area, Arizona and California: U.S. Geological Survey Professional Paper 486-G, 130 p.

Oppenheimer, J. M., and Sumner, J. S., 1980, Depth-to-bedrock map, Basin and Range province, Arizona: Tucson, University of Arizona, Laboratory of Geophysics, 1 sheet.

Trescott, P. C., 1975, Documentation of finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geological Survey Open-File Report 75-438, 32 p.

Trescott, P. C., Pinder, G. F., and Larson, S. P., 1976, Finite-difference model for aquifer simulation in two dimensions with results of numerical experiments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 7, Chapter C1, 116 p.

U.S. Geological Survey, 1954, Compilation of records of surface waters of the United States through September 1950, Part 9, Colorado River Basin: U.S. Geological Survey Water-Supply Paper 1313, 749 p.

A T T A C H M E N T S

ROW	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
1																										
2																										
3								298	299	301	304	305										310	312	312	312	
4			291	294	296	298	301	301	301	303	302	305	304	304	304			311	311	311	312	314	312	312	312	312
5		290	292	297	298	285	301	301	302	299	300	306	306	306	306	308	310	311	311	311	312	314	312	312	312	312
6		290	298	292	292	291	294	295	296	295	298	303	307	308	308	309	307	308	312	313	313	310	310	312	312	313
7		294	289	288	287	288	291	292	293	295	296	301	307	308	308	308	303	303	305	307	307	307	308	311	312	315
8		287	287	287	287	287	290	291	292	294	297	298	300	301	302	302	302	302	303	304	305	307	307	310	312	314
9		283	285	285	285	285	288	290	282	293	296	297	297	298	298	298	299	300	302	303	303	304	306	308	311	313
10		280	282	282	283	283	287	289	291	292	294	295	295	296	297	297	297	298	298	300	302	302	304	307	310	312
11		278	278	280	282	283	286	287	290	291	292	292	292	293	293	295	296	297	297	298	300	302	303	308	308	311
12		277	277	278	281	282	285	287	287	298	289	289	289	290	291	292	293	294	298	297	298	300	303	305	308	310
13		277	277	277	280	282	284	285	285	285	287	287	287	288	288	289	290	292	293	296	298	300	302	305	307	309
14		278	277	277	278	281	283	283	283	283	285	287	287	287	287	298	289	292	292	294	297	298	302	303	306	308
15		280	278	277	277	280	282	282	282	283	285	287	287	287	287	287	288	292	292	293	296	297	300	302	304	307
16			280	278	278	280	282	282	282	283	285	287	287	287	287	288	289	292	292	293	296	287	298	302	303	305
17			280	278	280	281	282	282	282	283	296	287	287	287	287	298	290	292	292	293	295	297	298	301	302	303
18				280	281	282	283	283	283	284	287	287	287	287	287	288	291	292	292	292	293	295	296	300	302	302
19				282	282	282						287	287	287	288	290	292	293	292	293	293	293	295	298	301	302
20													288	289	290	292	293	294	294	295	296	297	297	297	299	301
21																		297	298	298	300	302	303	303	303	303
22																			303	303	304	305	306	308	308	308
23																								312	313	314
24																										
25																										
26																										
27																										
28																										
29																										
30																										

ROW	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
1																										
2																										
3																										
4																										
5	315	315																								
6	317	317	317																							
7	317	317	317	317																						
8	317	317	317	317	317																					
9	316	317	317	317	317	318	318																			
10	315	317	317	318	319	320	320	318	318	318	318															
11	313	315	317	318	321	322	322	322	322	323	324	325	327													
12	312	314	317	318	321	322	322	323	325	327	328	330	328													
13	312	312	315	317	318	322	322	323	328	330	332	332	330													
14	311	312	313	315	317	320	322	325	328	332	332	332	332													
15	308	311	312	313	315	317	318	322	325	330	332	332	333													
16	307	308	310	312	313	315	317	319	323	328	332	332	333													
17	306	307	308	308	310	313	315	318	320	325	328	332	335	337	337	337										
18	303	306	307	307	308	310	314	317	320	323	325	330	333	335	337	338	340	342								
19	302	304	306	307	307	308	312	315	318	320	322	328	332	333	335	338	342	342	343							
20	302	303	303	305	307	308	310	313	316	317	320	324	328	332	333	337	340	343	345	347						
21	303	303	303	303	305	307	308	312	313	315	317	322	327	330	332	335	338	340	345	347	347					
22	308	309	309	309	309	309	310	312	313	315	317	320	327	328	333	337	337	338	340	343	345	347				
23	315	315	317	318	320	321	322	322	321	321	320	320	325	328	332	335	337	337	338	342	344	345	347			
24						322	322	322	322	322	322	322	325	329	332	335	337	337	338	342	343	345	347	348		
25							323	323	323	323	323	323	327	330	332	336	337	337	340	342	342	343	347	347	348	
26								324	325	325	325	325	328	332	333	337	337	338	341	342	342	343	347	347	348	
27									327	328	330	330	332	333	335	338	338	340	342	342	343	343	347	347	348	
28												332	333	335	337	340	342	342	343	343	343	343	347	347	348	
29														337	338	342	342	343	343	343	343	343	347	347	348	
30																										

COLUMN

A. Starting head array for layers 1 and 2 for conditions in 1940-41. Values are in feet above National Geodetic Vertical Datum of 1929.

ROW	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	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
1																																																				
2																																																				
3								296	299	301	304	305										310	312	312	312																											
4			281	294	296	296	301	301	301	303	302	305	304	304	304			311	311	311	312	314	312	312	312	312																										
5		279	292	297	298	295	301	301	302	299	300	306	306	308	306	306	310	311	311	311	312	314	312	312	312	312	315	315																								
6		279	296	292	292	291	294	295	296	295	298	303	307	308	306	309	307	306	312	313	313	310	310	312	312	313	317	317	317																							
7		280	289	288	287	288	291	292	293	295	296	301	307	306	306	306	303	303	305	307	307	307	308	311	312	315	317	317	317	317																						
8		278	287	287	287	287	290	291	292	294	297	296	300	301	302	302	302	302	303	304	305	307	307	318	312	314	317	317	317	317	317																					
9		279	285	285	285	285	288	290	292	293	296	297	287	296	298	296	299	300	302	303	303	304	306	306	311	313	316	317	317	317	317	318	318																			
10		278	282	282	283	283	287	289	291	292	294	295	295	296	297	297	297	298	298	300	302	302	304	307	310	312	315	317	317	318	319	320	320	318	318	318	318															
11		279	278	280	282	283	286	287	290	291	292	292	292	293	293	295	296	297	297	298	300	302	303	306	306	311	313	315	317	318	321	322	322	322	322	323	324	325	327													
12		279	277	278	281	282	285	287	287	288	289	289	289	290	291	292	293	294	296	297	296	300	303	305	306	310	312	314	317	318	321	322	322	323	325	327	328	330	328													
13		280	277	277	280	282	284	285	285	285	287	287	287	288	288	289	290	292	293	296	298	300	302	305	307	309	312	312	315	317	318	322	322	323	328	330	332	332	330													
14		281	277	277	278	281	283	283	283	283	285	287	287	287	287	288	289	292	292	294	297	298	302	303	306	308	311	312	313	315	317	320	322	325	328	332	332	332	332													
15		282	278	277	277	280	282	282	282	283	285	287	287	287	287	287	288	292	292	293	296	297	300	302	304	307	306	311	312	313	315	317	318	322	325	330	332	332	333													
16			283	278	278	280	282	282	282	283	285	287	287	287	287	288	289	292	292	293	296	297	298	302	303	305	307	308	310	312	313	315	317	319	323	328	332	332	333													
17			284	278	280	281	282	282	282	283	286	287	287	287	287	288	290	292	292	293	295	297	298	301	302	303	306	307	308	308	310	313	315	318	320	325	328	332	335	337	337	337										
18				284	281	282	283	283	283	284	287	287	287	287	287	288	291	292	292	292	293	295	296	300	302	302	303	306	307	307	308	310	314	317	320	323	325	330	333	335	337	338	340	342								
19				285	282	282						287	287	287	288	290	292	293	292	293	293	293	295	298	301	302	302	304	306	307	307	308	312	315	318	320	322	328	332	333	335	338	342	342	343							
20													296	296	299	300	301	294	294	295	296	297	297	297	299	301	302	303	303	305	307	308	310	313	316	317	320	324	328	332	333	337	340	343	345	347						
21																		303	298	296	300	302	303	303	303	303	303	303	303	303	305	307	308	312	313	315	317	322	327	330	332	335	338	340	345	347	347					
22																			305	306	307	308	309	308	308	308	308	309	309	309	309	309	310	312	313	315	317	320	327	328	333	337	337	338	340	343	345	347				
23																								311	313	315	318	315	317	318	320	321	322	322	321	321	320	320	325	328	332	335	337	337	338	342	344	345	347			
24																																322	322	322	322	322	322	322	325	329	332	335	337	337	338	342	343	345	347	348		
25																																	323	323	323	323	323	323	327	330	332	336	337	337	340	342	342	343	347	347	348	
26																																		324	325	325	325	325	328	332	333	337	337	338	341	342	342	343	347	347	348	
27																																			327	328	330	330	332	333	335	338	338	340	342	342	343	343	347	347	348	
28																																						333	334	335	337	340	342	342	343	343	343	343	347	347	346	
29																																								335	336	337	338	339	341	342	343	345	346	347	349	
30																																																				

COLUMN

B. Starting head array for layers 1 and 2 for conditions in the mid-1960's. Values are in feet above National Geodetic Vertical Datum of 1929.

COLUMN (1–26)

ROW	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
1																										
2																										
3								298	299	301	304	305										310	312	312	312	
4			281	294	296	298	301	301	301	303	302	305	304	304	304			311	311	311	312	314	312	312	312	312
5		280	292	287	298	295	301	301	302	299	300	308	306	306	308	308	310	311	311	311	312	314	312	312	312	312
6		280	296	292	292	291	294	295	296	295	298	303	307	308	308	309	307	308	312	313	313	310	310	312	312	313
7		281	289	288	287	288	291	292	293	295	298	301	307	308	308	308	303	303	305	307	307	307	308	311	312	315
8		280	287	287	287	287	290	291	292	294	297	298	300	301	302	302	302	302	303	304	305	307	307	310	312	314
9		281	285	285	285	285	288	290	292	293	296	297	297	298	298	298	299	300	302	303	303	304	306	308	311	313
10		281	282	282	283	283	287	289	291	292	294	295	295	298	297	297	297	298	298	300	302	302	304	307	310	312
11		285	278	280	282	283	286	287	290	291	292	292	292	293	293	295	296	297	287	298	300	302	303	306	308	311
12		286	277	278	281	282	285	287	287	288	289	289	289	290	291	292	293	294	298	297	298	300	303	305	306	310
13		287	277	277	280	282	284	285	285	285	287	287	287	288	288	289	290	292	293	296	298	300	302	305	307	308
14		287	277	277	278	281	283	283	283	283	285	287	287	287	287	288	289	292	292	294	297	298	302	303	306	308
15		282	278	277	277	280	282	282	282	283	285	287	287	287	287	287	288	292	292	293	298	297	300	302	304	307
16			283	278	278	280	282	282	282	283	285	287	287	287	287	288	289	292	292	293	296	297	298	302	303	305
17			284	278	280	281	282	282	282	283	286	287	287	287	287	288	290	292	292	293	285	297	298	301	302	303
18				284	281	282	283	283	283	284	287	287	287	287	287	288	291	292	292	292	293	295	298	300	302	302
19				285	282	282						287	287	287	288	290	292	293	292	293	283	293	295	298	301	302
20													298	298	299	300	301	294	294	295	298	297	297	297	299	301
21																		303	298	298	300	302	303	303	303	303
22																			305	306	307	308	309	308	308	308
23																								311	313	315
24																										
25																										
26																										
27																										
28																										
29																										
30																										

COLUMN (27–52)

ROW	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
1																										
2																										
3																										
4																										
5	315	315																								
6	317	317	317																							
7	317	317	317	317																						
8	317	317	317	317	317																					
9	316	317	317	317	317	317	318	318																		
10	315	317	317	318	319	320	320	318	318	318	318															
11	313	315	317	318	321	322	322	322	322	323	324	325	327													
12	312	314	317	318	321	322	322	323	325	327	328	330	328													
13	312	312	315	317	318	322	322	323	328	330	332	332	330													
14	311	312	313	315	317	320	322	325	328	332	332	332	332													
15	308	311	312	313	315	317	318	322	325	330	332	332	333													
16	307	308	310	312	313	315	317	319	323	328	332	332	333													
17	306	307	308	308	310	313	315	318	320	325	328	332	335	337	337	337										
18	303	306	307	307	308	310	314	317	320	323	325	330	333	335	337	338	340	342								
19	302	304	306	307	307	308	312	315	318	320	322	326	332	333	335	338	342	342	343							
20	302	303	303	305	307	308	310	313	316	317	320	324	328	332	333	337	340	343	345	347						
21	303	303	303	303	305	307	308	312	313	315	317	322	327	330	332	335	338	340	345	347	347					
22	308	309	309	309	309	309	310	312	313	315	317	320	327	328	333	337	337	338	340	343	345	347				
23	318	315	317	318	320	321	322	322	321	321	320	320	325	328	332	335	337	337	338	342	344	345	347			
24						322	322	322	322	322	322	322	328	329	332	335	337	337	338	342	343	345	347	348		
25							323	323	323	323	323	323	327	330	332	336	337	337	340	342	342	343	347	347	348	
26								324	325	325	325	325	328	332	333	337	337	338	341	342	342	343	347	347	348	
27									327	328	330	330	332	333	335	338	338	340	342	342	343	343	347	347	348	
28												333	334	335	337	340	342	342	343	343	343	343	347	347	346	
29														335	338	337	338	339	341	342	343	345	346	347	349	
30																										

C. Starting head array for layers 1 and 2 for conditions in 1980. Values are in feet above National Geodetic Vertical Datum of 1929.

ROW	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1																							
2																							
3								300	300	300	293	293										310	310
4			293	300	300	290	290	290	291	292	303	294	297	300	300			300	301	303	305	307	305
5		293	292	288	289	292	292	291	291	302	302	294	295	297	298	300	299	299	301	303	305	304	305
6		293	287	290	290	292	292	293	295	301	301	300	295	295	297	298	303	303	302	303	303	304	310
7		287	290	287	288	292	295	295	297	302	302	302	295	296	297	303	305	305	305	307	310	312	312
8		290	287	287	287	292	295	295	297	300	302	302	303	303	303	305	305	305	307	307	310	311	315
9		287	285	287	287	290	295	295	295	297	300	303	305	305	305	305	305	305	305	307	307	310	312
10		285	285	287	287	290	295	295	295	297	300	305	305	305	305	305	305	305	305	305	307	309	312
11		295	285	287	287	290	295	295	295	300	300	305	305	305	305	305	305	307	307	305	307	307	311
12		287	287	290	290	295	297	300	300	300	300	300	300	305	305	305	307	310	307	307	307	307	310
13		290	290	290	295	295	297	300	300	300	300	305	305	305	305	305	307	310	307	307	307	307	310
14		285	290	280	290	293	297	300	300	300	300	300	302	302	302	302	305	307	308	308	307	307	309
15		310	310	290	282	285	290	292	293	290	290	292	282	292	293	293	295	305	308	311	310	311	312
16			320	310	295	300	303	304	303	302	302	302	302	302	303	303	293	295	308	310	312	315	315
17			330	320	297	300	303	304	303	300	302	302	302	302	303	303	303	297	310	310	315	315	315
18				320	297	300	298	300	305	310	310	307	307	307	307	305	305	298	300	302	302	310	315
19				330	305	310						315	310	307	307	305	305	305	308	310	302	302	305
20													320	320	320	320	350	310	312	315	315	315	305
21																		330	310	312	315	315	315
22																			320	312	312	315	315
23																							
24																							
25																							
26																							
27																							
28																							
29																							
30																							

ROW	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
1																													
2																													
3	305	308																											
4	310	310	307																										
5	312	312	310	308	310																								
6	315	315	315	309	309	315																							
7	315	315	315	310	311	315	325																						
8	320	320	320	315	312	315	318	325																					
9	320	320	320	322	322	313	314	318	330	330																			
10	320	320	320	322	320	322	314	315	316	325	325	330	330	330															
11	320	320	320	322	320	325	323	311	317	325	325	325	325	325	321	321													
12	320	320	320	322	322	322	323	323	317	318	325	325	325	320	325	322													
13	312	315	315	317	319	321	323	323	323	318	319	320	320	325	325	322													
14	310	315	315	315	317	320	323	325	323	323	319	320	325	325	325	323													
15	312	315	315	315	317	320	323	325	325	325	325	327	327	325	325	323													
16	315	315	315	317	317	320	323	325	325	325	327	330	332	330	327	324													
17	315	315	315	317	319	321	323	325	325	327	328	332	333	332	330	325	327	329	330										
18	315	315	315	317	319	322	325	325	325	327	330	335	335	335	333	330	335	342	343	330	331								
19	310	315	317	319	321	325	320	320	325	327	339	335	335	335	335	335	337	343	345	343	331	332							
20	305	305	307	315	315	315	315	320	320	322	330	335	335	335	335	335	337	343	345	345	345	332	333						
21	315	317	308	309	305	307	310	310	320	322	325	330	330	335	335	335	337	345	345	345	345	343	335	334					
22	315	317	320	322	325	325	315	315	317	317	320	325	335	335	335	335	338	900	900	900	345	347	345	335	340				
23	320	317	320	350	350	350	350	350	350	350	350	350	340	335	335	335	900	900	900	900	900	347	347	336	340	337			
24									350	350	350	350	340	335	335	335	900	900	900	900	900	900	900	348	337	338	339		
25										350	350	350	340	335	335	335	340	345	900	900	900	900	900	900	353	353	350	340	
26											360	350	350	350	337	340	345	345	900	900	900	900	900	900	355	352	350	341	
27												385	360	355	350	350	355	345	900	900	900	900	900	900	355	357	360	342	
28															360	360	365	355	900	900	900	900	900	900	900	355	355	355	
29																	370	360	900	900	900	900	900	900	900	900	900	900	
30																													

COLUMN

D. Land-surface array for conditions in 1940-41. Values are in feet above National Geodetic Vertical Datum of 1929. A land-surface altitude of 900 feet was arbitrarily selected to exclude simulation of evapotranspiration from grid blocks representing irrigated land.

ROW	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	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
1																																																				
2																																																				
3								300	300	300	293	293										310	310	305	306																											
4			293	300	300	290	290	290	291	292	303	294	297	300	300			300	301	303	305	307	305	310	310	307																										
5		293	292	288	289	292	292	291	291	302	302	294	295	297	298	300	299	299	301	303	305	304	305	312	312	310	308	310																								
6		293	287	290	290	292	292	293	295	301	301	300	295	295	297	298	303	303	302	303	303	304	310	315	315	315	309	309	315																							
7		287	300	302	302	305	305	306	307	302	302	302	295	296	297	303	305	305	305	307	310	312	312	315	315	315	310	311	315	325																						
8		302	302	303	303	305	305	306	307	305	302	302	303	303	303	305	305	305	307	307	310	311	315	320	320	320	315	312	315	318	325																					
9		302	302	303	303	305	305	306	307	307	305	303	305	305	305	305	305	305	305	307	307	310	312	320	320	320	322	322	313	314	318	330	330																			
10		302	302	303	303	305	305	305	305	307	305	305	305	305	305	305	305	305	305	305	307	309	312	320	320	320	322	320	322	314	315	316	325	325	330	330	330															
11		302	302	303	303	302	305	305	305	305	305	305	305	305	305	305	305	307	307	305	307	307	311	320	320	320	322	320	325	323	311	317	325	325	325	325	325	321	321													
12		302	301	301	301	305	307	305	305	305	305	305	306	305	305	305	307	310	307	307	307	307	310	320	320	320	322	322	322	323	323	317	318	325	325	325	320	325	322													
13		300	300	305	307	307	307	305	305	305	305	305	900	900	900	900	900	900	307	307	307	307	310	312	315	315	317	319	321	323	323	323	318	319	320	320	325	325	322													
14		300	305	305	305	305	307	305	305	305	305	900	900	900	900	900	900	307	308	308	307	307	309	310	315	315	315	317	320	323	325	323	323	319	320	325	325	325	323													
15		310	310	305	305	305	305	305	305	305	305	900	900	900	900	900	900	900	308	311	310	311	312	312	315	315	315	317	320	323	325	325	325	325	327	327	325	325	323													
16			320	310	305	305	308	308	308	307	307	900	900	900	900	900	900	900	900	900	900	900	900	900	315	315	317	317	320	323	325	325	325	327	900	900	330	327	324													
17			330	320	307	305	308	308	308	305	307	307	307	900	900	900	900	900	900	900	900	900	900	900	315	315	317	319	321	323	325	325	327	900	900	900	900	330	325	327	329	330										
18				320	307	307	308	308	305	310	310	307	900	900	900	900	900	900	900	900	900	900	900	900	315	900	900	900	322	325	325	325	327	900	900	900	900	900	900	900	900	900	330	331								
19				330	305	310						315	310	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	325	320	320	325	327	900	900	900	900	900	900	900	900	900	900	331	332							
20													320	320	320	320	350	900	900	900	900	900	900	900	900	900	900	900	315	315	320	320	322	900	900	900	900	900	900	900	900	900	900	900	332	333						
21																		900	900	900	900	900	900	900	900	900	900	900	900	900	900	320	322	900	900	900	335	335	900	900	900	900	900	900	343	335	334					
22																			900	900	900	900	900	900	900	900	900	325	325	315	315	317	317	900	900	900	335	335	900	900	900	900	900	900	900	345	335	340				
23																								320	317	320	900	350	350	350	350	350	350	350	350	340	335	335	900	900	900	900	900	900	900	900	336	340	337			
24																																350	350	350	350	340	335	338	900	900	900	900	900	900	900	900	900	337	338	339		
25																																	350	350	350	340	335	335	900	900	900	900	900	900	900	900	900	900	353	350	340	
26																																		360	350	350	350	337	340	900	900	900	900	900	900	900	900	900	352	350	341	
27																																			365	360	355	350	350	355	900	900	900	900	900	900	900	900	900	360	342	
28																																						360	360	365	355	900	900	900	900	900	900	900	900	900	355	
29																																								370	360	355	355	355	355	355	355	355	355	355	355	
30																																																				

COLUMN

E. Land-surface array for conditions in the mid-1960's. Values are in feet above National Geodetic Vertical Datum of 1929. A land-surface altitude of 900 feet was arbitrarily selected to exclude simulation of evapotranspiration from grid blocks representing irrigated land.

ROW	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
1																										
2																										
3								300	300	300	293	293										310	310	305	306	
4			293	300	300	290	290	290	291	292	303	294	297	300	300			300	301	303	305	307	305	310	310	307
5		293	292	289	288	292	292	291	291	302	302	294	295	297	299	300	299	299	301	303	305	304	305	312	312	310
6		293	287	290	900	900	900	900	295	301	301	300	295	295	297	298	303	303	302	303	303	304	310	900	900	900
7		297	300	900	900	900	900	900	900	900	900	900	295	296	297	303	305	305	305	307	310	900	900	900	900	900
8		302	900	900	900	900	900	900	900	900	900	900	303	303	303	305	305	305	307	307	900	900	900	900	900	900
9		302	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
10		302	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
11		302	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
12		302	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
13		300	900	900	307	307	307	305	305	305	305	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
14		300	900	900	900	305	307	305	305	305	305	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
15		310	900	900	305	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
16			320	900	305	305	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
17			330	320	307	305	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
18				320	307	307	308	308	305	310	310	307	900	900	900	900	900	900	900	900	900	900	900	900	900	900
19				330	305	310						315	310	900	900	900	900	900	900	900	900	900	900	900	900	900
20													320	320	320	320	350	900	900	900	900	900	900	900	900	900
21																		330	900	900	900	900	900	900	900	900
22																			320	900	900	900	900	900	900	900
23																								320	317	900
24																										
25																										
26																										
27																										
28																										
29																										
30																										

ROW	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
1																										
2																										
3																										
4																										
5	308	310																								
6	309	309	315																							
7	310	311	315	325																						
8	900	312	315	318	325																					
9	900	900	313	314	318	330	330																			
10	900	900	900	314	315	316	325	325	330	330	330															
11	900	900	900	323	311	317	325	325	325	325	325	321	321													
12	900	900	900	323	323	317	318	325	325	325	320	325	322													
13	900	900	900	900	323	232	318	319	320	320	325	325	322													
14	900	900	900	900	900	900	323	319	320	325	325	325	323													
15	900	900	900	900	900	900	900	900	327	327	325	325	323													
16	900	900	900	900	900	900	900	900	900	900	900	327	324													
17	900	900	900	900	900	900	900	900	900	900	900	330	325	327	328	330										
18	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	330	331								
19	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	331	332							
20	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	332	333						
21	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	343	335	334					
22	900	325	325	315	315	317	317	320	900	900	900	900	900	900	900	900	900	900	900	345	335	340				
23	900	350	350	350	350	350	350	350	350	340	335	335	900	900	900	900	900	900	900	900	336	340	337			
24						350	350	350	350	340	335	335	900	900	900	900	900	900	900	900	900	900	900	339		
25							350	350	350	340	335	335	900	900	900	900	900	900	900	900	900	900	900	350	340	
26								360	350	350	350	337	340	900	900	900	900	900	900	900	900	900	900	900	341	
27									365	360	355	350	900	900	900	900	900	900	900	900	900	900	900	900	342	
28												360	390	900	900	900	900	900	900	900	900	900	900	900	355	
29														900	900	900	900	355	355	355	355	355	900	900	355	
30																										

COLUMN

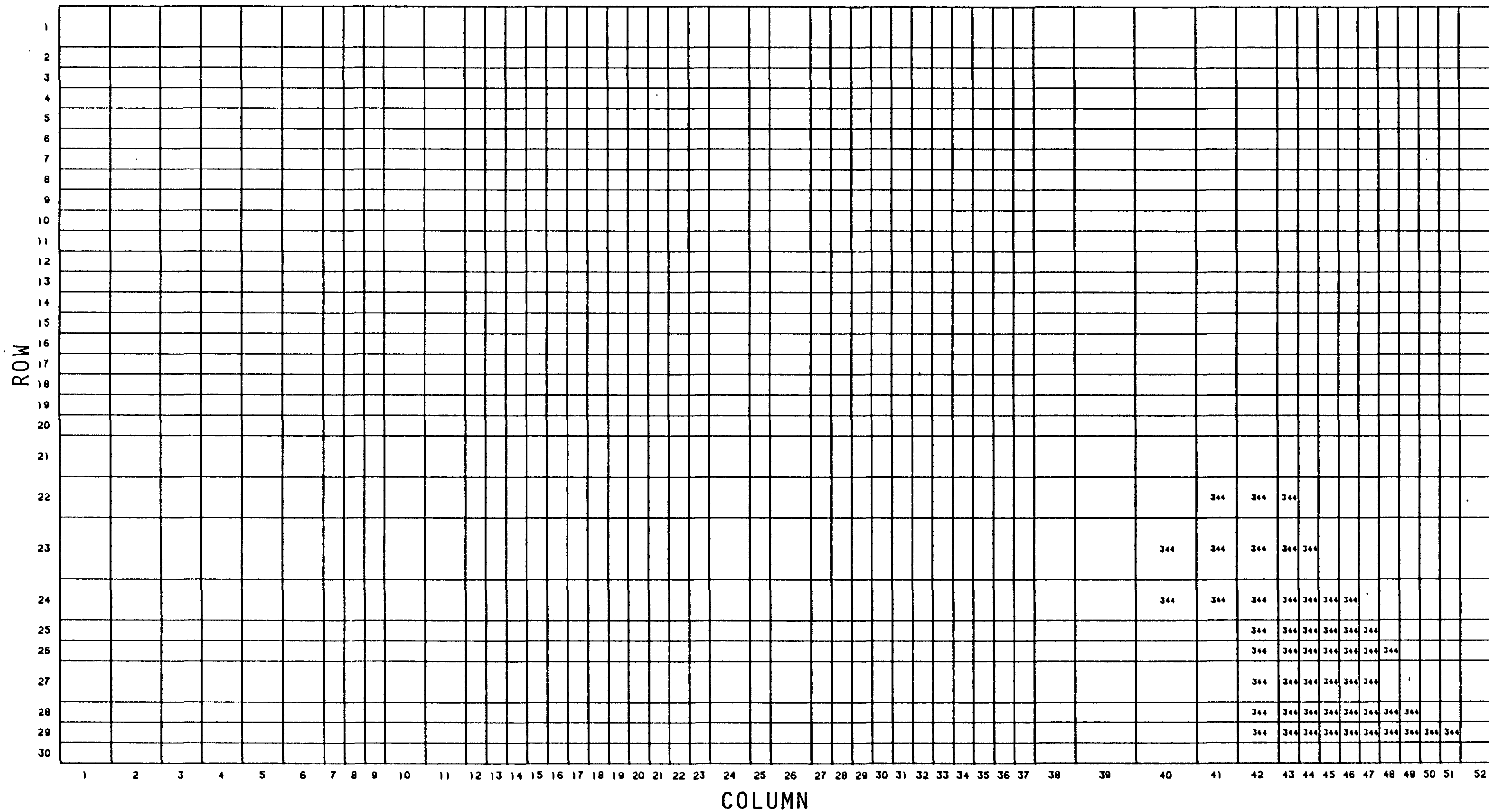
F. Land-surface array for conditions in 1980. Values are in feet above National Geodetic Vertical Datum of 1929. A land-surface altitude of 900 feet was arbitrarily selected to exclude simulation of evapotranspiration from grid blocks representing irrigated land.

ROW	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
1																										
2																										
3								270	275	275	275	280										300	290	265	280	
4			285	285	275	265	260	260	260	260	260	270	270	275	275			270	275	275	280	280	280	275	275	275
5		280	275	250	240	240	235	235	235	240	240	245	250	250	260	265	265	265	265	265	265	265	265	260	260	265
6		240	235	225	225	225	220	220	220	225	230	235	235	235	240	250	260	260	260	260	260	260	250	245	250	260
7		225	215	210	210	210	210	210	215	215	215	220	225	225	230	235	235	240	245	245	240	240	240	235	240	250
8		200	200	200	190	185	185	185	190	190	200	210	210	215	215	215	220	225	230	235	235	230	230	230	235	240
9		185	185	190	185	180	180	180	185	185	190	190	190	190	190	200	210	215	215	215	215	215	215	220	225	230
10		165	175	180	175	175	175	175	175	190	190	180	180	180	185	185	190	195	200	205	210	210	215	215	215	220
11		180	165	165	165	165	165	165	165	170	170	170	170	175	180	180	185	185	185	190	190	195	200	205	210	215
12		160	160	160	180	160	160	160	160	180	180	160	165	185	170	170	175	180	180	185	185	185	185	185	190	200
13		165	160	180	180	180	160	160	160	180	180	160	180	160	160	180	165	175	175	180	175	170	185	185	185	185
14		170	165	160	160	160	180	160	165	185	185	160	160	160	160	160	160	165	165	170	165	165	160	180	180	180
15		185	170	170	165	170	170	170	170	170	170	165	185	165	165	160	160	185	165	185	160	160	160	160	175	180
16			185	175	175	190	160	180	185	185	185	185	180	175	170	170	185	160	165	165	160	160	160	160	165	180
17			210	190	190	190	200	210	230	235	225	200	190	180	175	170	165	160	160	160	160	160	160	185	175	190
18				225	225	245	275	280	280	280	280	280	250	225	195	185	180	170	165	165	160	160	160	170	180	185
19				250	260	280						285	265	250	225	200	185	175	170	170	165	160	180	185	180	180
20													280	280	235	225	190	180	170	170	185	185	160	160	170	180
21																		190	175	170	165	165	185	185	160	175
22																			175	170	170	170	175	175	180	180
23																								250	250	250
24																										
25																										
26																										
27																										
28																										
29																										
30																										

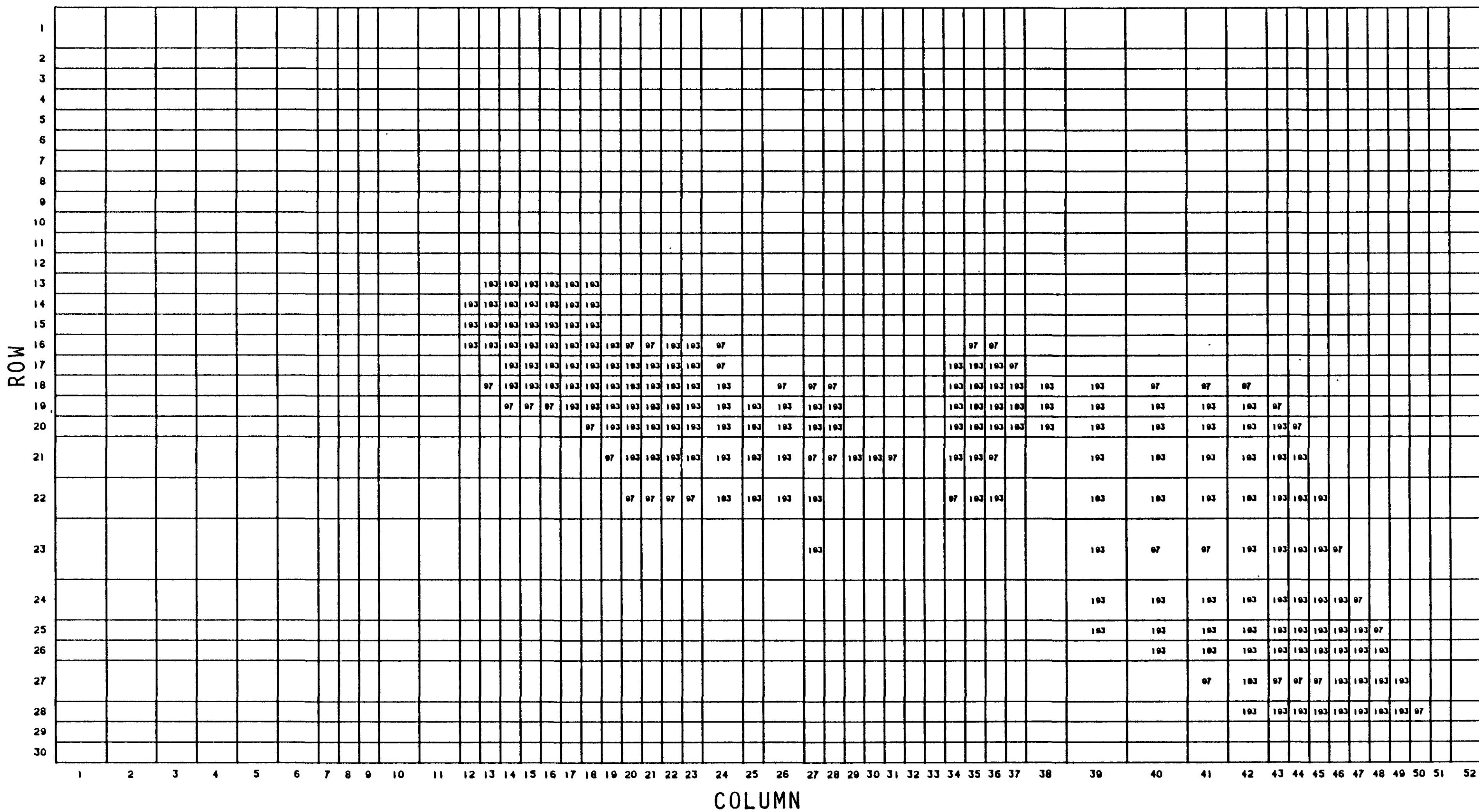
ROW	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
1																										
2																										
3																										
4																										
5	275	280																								
6	270	270	285																							
7	265	265	280	300																						
8	260	265	275	285	300																					
9	240	260	265	275	280	300	310																			
10	230	235	250	265	270	275	280	300	300	300	300															
11	215	220	230	235	240	250	250	260	275	260	280	300	310													
12	210	215	215	220	225	235	235	240	245	265	265	270	300													
13	185	190	200	200	210	215	215	220	230	235	240	250	290													
14	185	185	190	190	190	190	195	200	200	215	215	225	260													
15	180	185	185	185	185	185	190	190	190	190	190	200	230													
16	185	185	185	185	185	185	185	185	185	185	185	190	200													
17	185	185	185	185	185	185	185	185	185	185	185	185	190	220	225	225										
18	185	185	185	185	185	185	185	185	185	185	185	185	185	205	210	215	220	225								
19	180	180	185	185	185	185	185	185	185	185	185	185	185	200	205	210	215	220	230							
20	180	180	180	180	180	180	180	185	185	185	185	185	185	200	205	210	215	220	230	250						
21	180	180	180	180	180	180	185	190	190	195	190	190	190	200	205	210	215	220	230	245	260					
22	190	185	185	185	185	190	205	205	205	205	205	205	205	205	205	215	215	220	230	235	250	260				
23	250	250	250	250	240	235	235	235	230	225	215	210	205	210	210	215	215	225	230	235	235	250	275			
24						300	275	265	250	235	225	220	215	215	215	215	220	230	235	235	235	240	250	275		
25							300	275	265	250	240	230	220	215	215	215	220	230	235	240	235	235	240	250	265	
26								300	275	265	240	240	225	215	215	215	220	225	230	235	235	235	235	240	250	
27									300	280	250	240	240	225	220	215	215	220	230	235	235	235	235	235	235	
28												260	250	240	225	220	215	215	220	225	225	230	230	230	230	
29														250	235	225	220	215	215	215	215	215	220	220	220	
30																										

COLUMN

G. Bottom array for layer 2 for all model periods. Values are in feet above National Geodetic Vertical Datum of 1929.



H. Recharge array for conditions in 1940-41. Values are x 10^{-10} feet per second.



I. Recharge array for conditions in the mid-1960's. Values are x 10^{-9} feet per second.

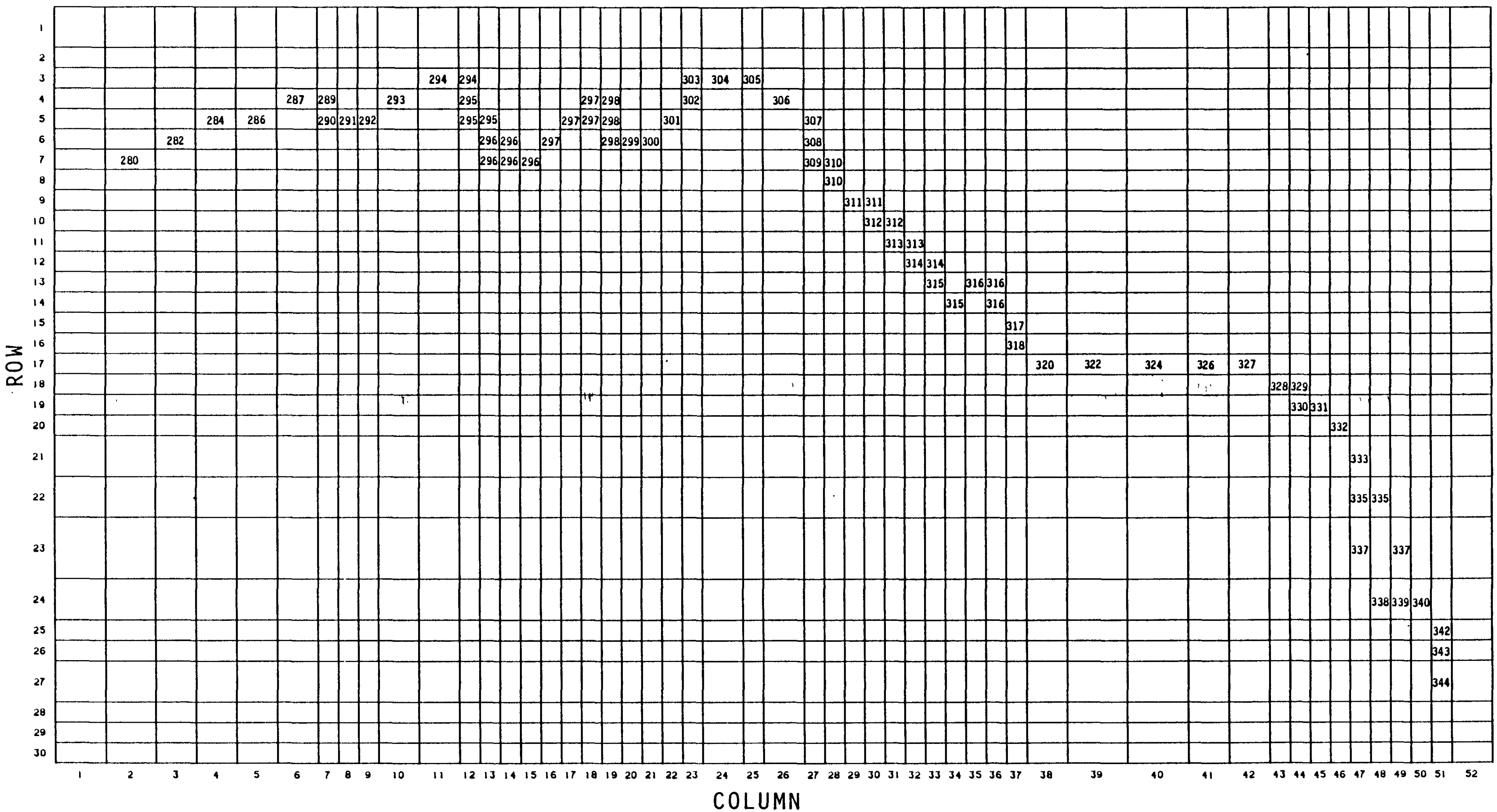
COLUMN (1–26)

ROW	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
1																										
2																										
3																										
4																										
5																										
6					970	970	970	970	970	970														970	970	970
7				970	970	970	970	970	970	970	970	970										970	970	970	970	970
8			970	970	970	970	970	970	970	970	970	970									970	970	970	970	970	970
9			970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970
10			970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970
11			970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970
12			970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970
13			970	970								970	970	970	970	970	970	970	970	970	970	970	970	970	970	970
14			970	970	970							970	970	970	970	970	970	970	970	970	970	970	970	970	970	970
15			970	970	970		970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970
16				970			970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970
17							970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970
18													485	970	970	970	970	970	970	970	970	970	970	970	970	970
19														485	970	970	970	970	970	970	970	970	970	970	970	970
20																		485	970	970	970	970	970	970	970	970
21																			485	970	970	970	970	970	970	970
22																				485	485	485	485	970	970	970
23																										485
24																										
25																										
26																										
27																										
28																										
29																										
30																										

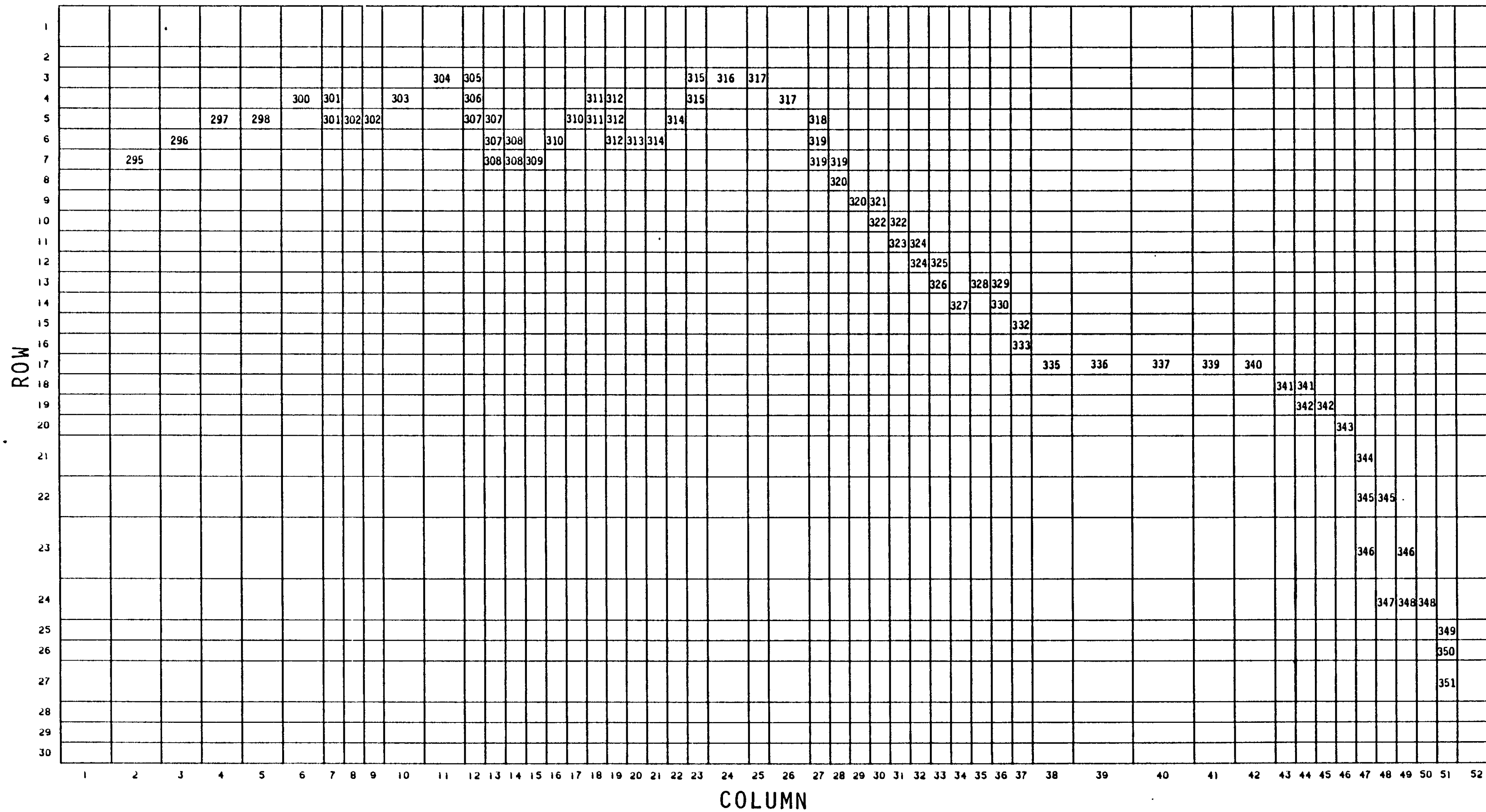
COLUMN (27–52)

ROW	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
1																										
2																										
3																										
4																										
5																										
6																										
7																										
8	970																									
9	970	970																								
10	970	970	970																							
11	970	970	970																							
12	970	970	970																							
13	970	970	970	970																						
14	970	970	970	970	970	970																				
15	970	970	970	970	970	970	970	970																		
16	970	970	970	970	970	970	970	970	970	970	970															
17	970	970	970	970	970	970	970	970	970	970	485															
18	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970										
19	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970									
20	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970								
21	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970	970								
22	970							485	485	495	485	485	970	970	970	970	970	970	970							
23	485												970	485	485	970	970	970	970	485						
24													970	970	970	970	970	970	970	970	970	970	970			
25													485	970	970	970	970	970	970	970	970	970	970			
26														970	970	970	970	970	970	970	970	970	970	970		
27													970	970	970	970	970	970	970	970	970	970	970	970		
28														485	970	970	970	970	970	970	970	970	970	485		
29														485	970	970	485						970	970		
30																										

J. Recharge array for conditions in 1980. Values are 10^{-10} feet per second.



K. River stages for conditions in the mid-1960's and 1980. Values are in feet above National Geodetic Vertical Datum of 1929 and are rounded to nearest foot.



L. River stages for conditions in 1940-41. Values are in feet above National Geodetic Vertical Datum of 1929 and are rounded to nearest foot.

ROW \ COLUMN	1	2	3	4	5	6	7	8	9	10	11	12	13
1													
2													
3													
4													
5													
6				282	282	285	286	287	288	289	291		
7			281								291	292	
8		279										292	293
9				280	281	281	282	283	284	285	287		
10		278	280									288	288
11			282										289
12			281										289
13				284									290
14				286									291
15					286								
16					286							293	294
17					287						291		
18					288	289	289	290	291	292	293	294	
19													295
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													

ROW \ COLUMN	14	15	16	17	18	19	20	21	22	23	24	25	26
1													
2													
3													
4													
5											302	303	
6									301	302			303
7						299	300	300					304
8	294	295	296	297	298								305
9													
10													
11													
12													
13	291	291	292	293	293	294	295	296	297	297			
14	293	295	296							298			
15			297	298	298					299			
16	295	296				299	300	301			300	301	302
17								301	302	302			302
18					299	300	300	301			304		303
19	296	297	297	299	299								
20					299						305	306	307
21					300				303	304	304		
22						300	301	301	302	303			
23											305	306	307
24													
25													
26													
27													
28													
29													
30													

ROW \ COLUMN	27	28	29	30	31	32	33	34	35	36	37	38	39
1													
2													
3													
4													
5													
6													
7													
8													
9	306												
10		308											
11			309										
12				310									
13					311								
14						312			312				
15									313				
16									313				
17									314				
18	304	305	306						315				
19				307					316				
20					308	308	309	310		317	318	319	
21												320	321
22												322	
23	308												324
24													325
25													
26													
27													
28													
29													
30													

ROW \ COLUMN	40	41	42	43	44	45	46	47	48	49	50	51	52
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21	325	326	328	329									
22				330									
23	328	330			333								
24	326					335	336						
25	327						337						
26	328	329					338						
27		330	330	331	332		339	341					
28								343	345	346			
29													
30													

M. Drain-bottom elevation for conditions in the mid-1960's and 1980. Values are in feet above National Geodetic Vertical Datum of 1929.