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SIMULATED EFFECTS OF A PROPOSED WELL FIELD ON THE GROUND-WATER SYSTEM IN THE SALT RIVER INDIAN RESERVATION, MARICOPA COUNTY, ARIZONA

By P. P. Ross

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ILLUSTRATIONS

CONVERSION FACTORS

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

Multiply inch-pound unit	By	To obtain 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)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]

SIMULATED EFFECTS OF A PROPOSED WELL FIELD ON THE GROUND-WATER SYSTEM IN THE SALT RIVER INDIAN RESERVATION, MARICOPA COUNTY, ARIZONA

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ABSTRACT

A finite-difference digital model was developed to simulate the effects of a proposed well field on the water levels in existing wells in the Salt River Indian Reservation, which is in the southeastern part of Paradise Valley in central Arizona. The model area includes about 600 square miles in Paradise Valley and the adjoining Salt River Valley. In 1975 about 37,500 acre-feet of ground water was withdrawn for irrigation in the Salt River Indian Reservation. The proposed well field would withdraw as much as 45,000 acre-feet per year of additional irrigation water north of the Arizona Canal.

The model was calibrated by using measured water-level declines for 1923-76 and simulated declines for 1946-75. The calibrated model was then used to predict water-level declines, based on projected amounts of pumpage, after 20 years of pumping. The rate of water-level decline would be an additional 2 to 6 feet per year in existing wells after 20 years of pumping in the proposed well field. The model was more sensitive to changes in pumpage distribution and in pumpage and recharge amounts than to changes in transmissivity and specific yield.

INTRODUCTION

The effects of a proposed well field on the water levels in existing wells in the Salt River Indian Reservation were evaluated by the U.S. Geological Survey, at the request of the U.S. Bureau of Indian Affairs, by use of a finite-difference digital model. The Salt River Indian Reservation is in the southeastern part of Paradise Valley in central Arizona (fig. 1), and the model area includes about 600 mi^2 in Paradise Valley and the adjoining Salt River Valley (fig. 2). The model was designed to simulate changes in water levels in response to stresses applied on the ground-water system. Data used in the development and calibration of the model were obtained from reports and files of the U.S. Geological Survey and from files of the Bureau of Indian Affairs.

In the model area the climate is semiarid and is characterized by mild winters and hot summers. The mean annual precipitation is about 8 in., and about one-third of the precipitation falls in the summer. In 1975 about 37,500 acre-ft of ground water was withdrawn for irrigation in the Salt River Indian Reservation. In addition, the proposed well field, which would consist of two deep wells per square mile, would furnish between 36,000 and 45,000 acre-ft/yr of irrigation water to about 5,700 acres of cropland (O. E. Whelan, Bureau of Indian Affairs, written commun., 1977).

Paradise Valley is a northwest-trending alluvium-filled trough in the Basin and Range physiographic province (Fenneman, 1931). The trough was formed by block faulting typical of that in the rest of the province. The flat-lying valley floor slopes gently southward and includes about 250 mi^2. The valley is bounded on the east by the McDowell Mountains, on the north by bedrock outcrops near Carefree, and on the west by the Phoenix Mountains and Papago Buttes. Paradise Valley abuts the Salt River Valley on the south.

HYDROLOGIC SYSTEM

Rock Units and Their Water-Bearing Properties

In Paradise Valley the main source of ground water is the alluvium, which was informally divided into three units—lower alluvium, middle alluvium, and upper alluvium—by Arteaga and others (1968, p. 9). The upper alluvium is composed of sand and coarse gravel and is present near the recent watercourses. This unit has excellent water-bearing characteristics but generally is dry because of the decline in water levels. The middle alluvium is composed of silt, clay, sand, gravel, and boulders. The lower alluvium is composed of silt, clay, sand, gravel, and conglomerate. The middle and lower units generally yield several hundred to several thousand gallons per minute of water to wells; well yields decrease as the percentage of fine-grained material increases. The combined thickness of the lower, middle, and upper alluvium is a few tens of feet near the mountain fronts and more than 2,000 ft near the center of the valley. Thickness of the units increases rapidly in a short distance owing to the presence of major block faults within a few miles of the mountain fronts.

In places the lower alluvium is underlain by a consolidated unit, referred to as the red unit. The red unit is composed of breccia, conglomerate, sandstone, and siltstone. Wells yield less than 5 to several hundred gallons per minute, depending on the degree of fracturing in the unit. The red unit is more than 2,000 ft thick where exposed at Papago Buttes and as much as 1,400 ft thick in a well in sec. 2, T. 3 N., R. 4 E.

The alluvium and the red unit are hydraulically connected and act as a single aquifer. Vertical differences in head are not apparent in wells in the alluvium and red unit; however, perched ground water is present in a few places, probably as a result of discontinuous clay lenses.

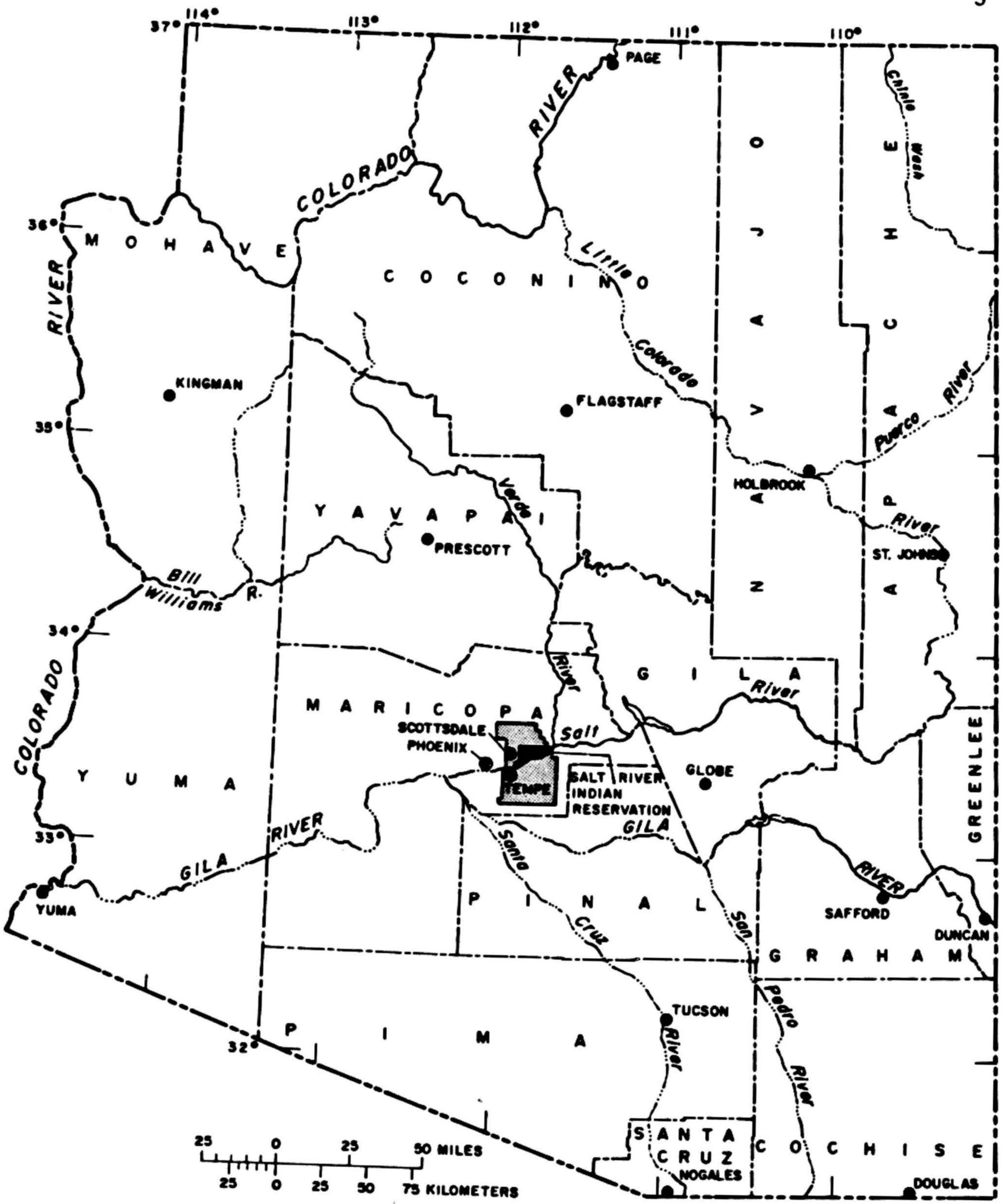
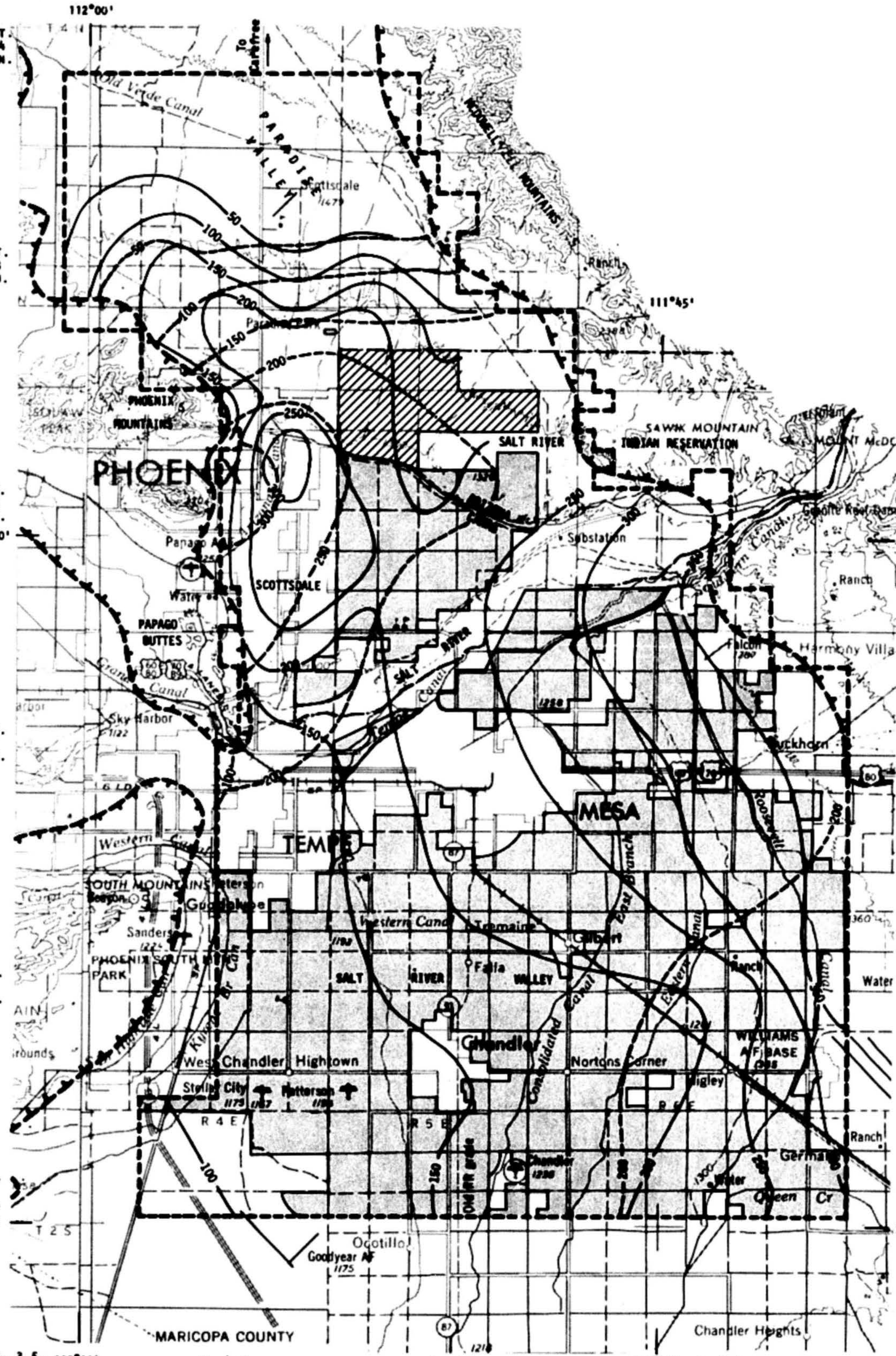


Figure 1.--Area of report (shaded).



BASE FROM U.S. GEOLOGICAL SURVEY
MESA 1:250,000, 1954-69 AND
PHOENIX 1:250,000, 1954-69

Measured declines from
Laney and others (1978)

5 0 5 MILES
5 0 5 10 KILOMETERS

TOPOGRAPHIC CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100-FOOT INTERVALS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 2.--Aquifer and model boundaries and measured and simulated water-level declines.
(In two sheets.)

Sheet 1 of figure 2.

E X P L A N A T I O N

IRRIGATED AREA IN WHICH RECHARGE WAS SIMULATED—Shows area in which return of irrigation water to the aquifer was simulated as recharge. Irrigated area as of 1973; generalized from data from the Arizona Crop and Livestock Reporting Service (1974)

AREA OF PROPOSED AGRICULTURAL DEVELOPMENT

APPROXIMATE BOUNDARY OF THE AQUIFER

BOUNDARY OF MODEL

100 — APPROXIMATE LINE OF EQUAL MEASURED WATER-LEVEL DECLINE, SPRING 1923 TO SPRING 1976—Interval 50 feet

10 — LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE, 1946-75—Interval 50 feet

Figure 2.--Aquifer and model boundaries and measured and simulated water-level declines.

(In two sheets.) Sheet 2 of figure 2.

Predevelopment Conditions

Prior to ground-water development in Paradise Valley, the aquifer was in approximate equilibrium—the amount of water that entered the aquifer was balanced by the amount that left the aquifer—and changes in ground-water storage were negligible. The water-table gradient was generally downvalley toward the Salt River, and ground water probably left the valley mainly as underflow into the adjacent Salt River Valley and inflow to the Salt River. Early water-level maps suggest that the river was a gaining stream (Lee, 1905).

Postdevelopment Conditions

Ground-water development began in about 1900 in Paradise Valley, and small amounts of ground water were withdrawn for irrigation in the 1920's. Large ground-water withdrawals began in the early 1940's, but much of the water was carried out of the valley by the Arizona Canal. In Paradise Valley, extensive irrigation development began in the 1950's, when the amount of cultivated acreage was increased south of the Arizona Canal in the Salt River Indian Reservation. About 2 million acre-ft of ground water was withdrawn from the aquifer in Paradise Valley through 1975.

Water levels are declining in response to the withdrawal of water in excess of the rate of replenishment. The overdraft has altered water-table gradients along the Salt River, and a large cone of depression has developed near Scottsdale, where the water level has declined more than 300 ft since 1923 (fig. 2).

Recharge

The main areas of recharge are along the mountain fronts and along the major streams that drain the valleys. Stream channels generally are dry, and the streams flow only in response to precipitation; however, the Salt River may flow as a result of releases from upstream reservoirs. Seepage from the Arizona Canal probably contributed large amounts of recharge to the aquifer in the early years of operation. In 1978, however, recharge from the canal was minimal because much of the canal had been lined with concrete and the unlined part had been effectively sealed by the deposition of fine-grained sediment.

A significant source of recharge is the return of irrigation water from cultivated fields. Although detailed studies have not been made to determine how much of the water applied for irrigation is returned to the aquifer, estimates are as much as 40 percent (P. C. Briggs, Arizona Water Commission, oral commun., 1978).

DIGITAL MODEL

The digital model used in this study was developed by personnel of the U.S. Geological Survey who used the computer program of Trescott and others (1976). The model employs a finite-difference technique to solve the complex partial differential equations for ground-water flow. The strongly implicit procedure is the numerical algorithm used in the simulations.

Finite-Difference Grid

A finite-difference grid of 33 columns and 33 rows was used for the 600-square-mile model area (fig. 3). The center of each intersection of a row and column is represented by a single point called a node, and there are 1,089 nodes in the model. Because the area is north-northwest trending, the grid was oriented north-south and so a minimum of inactive nodes occurred outside the aquifer boundary.

A variable grid spacing was used in the model (fig. 3). The 1-mile-wide spacing used near the north boundary was reduced to half a mile in and near the Salt River Indian Reservation. South of the reservation, the north-south grid spacing was increased to 1, 2, and finally 3 mi to allow the model to expand rapidly into the Salt River Valley while using a minimum number of nodes. In the east-west direction the grid spacing is half a mile in the reservation and increases to 1 mi east and west of the reservation. The variable grid spacing allows a maximum amount of resolution in the reservation and a minimum amount in the rest of the model area.

Boundary Conditions

All the boundaries used in the model represent no-flow conditions. The east and west boundaries are near the mountain fronts, where the aquifer thins to extinction (fig. 3). On the north and south, the boundaries of the aquifer are too far from the study area for practical inclusion in the model, and the boundaries were simulated as no-flow boundaries in Tps. 4 N. and 2 S. Computer-generated drawdowns indicate that the simulated north and south boundaries are far enough away that they will not affect drawdown in the area of proposed ground-water withdrawal. The simulated drawdown at nodes adjacent to the model boundaries is less than 10 percent of the maximum drawdown predicted by the model.

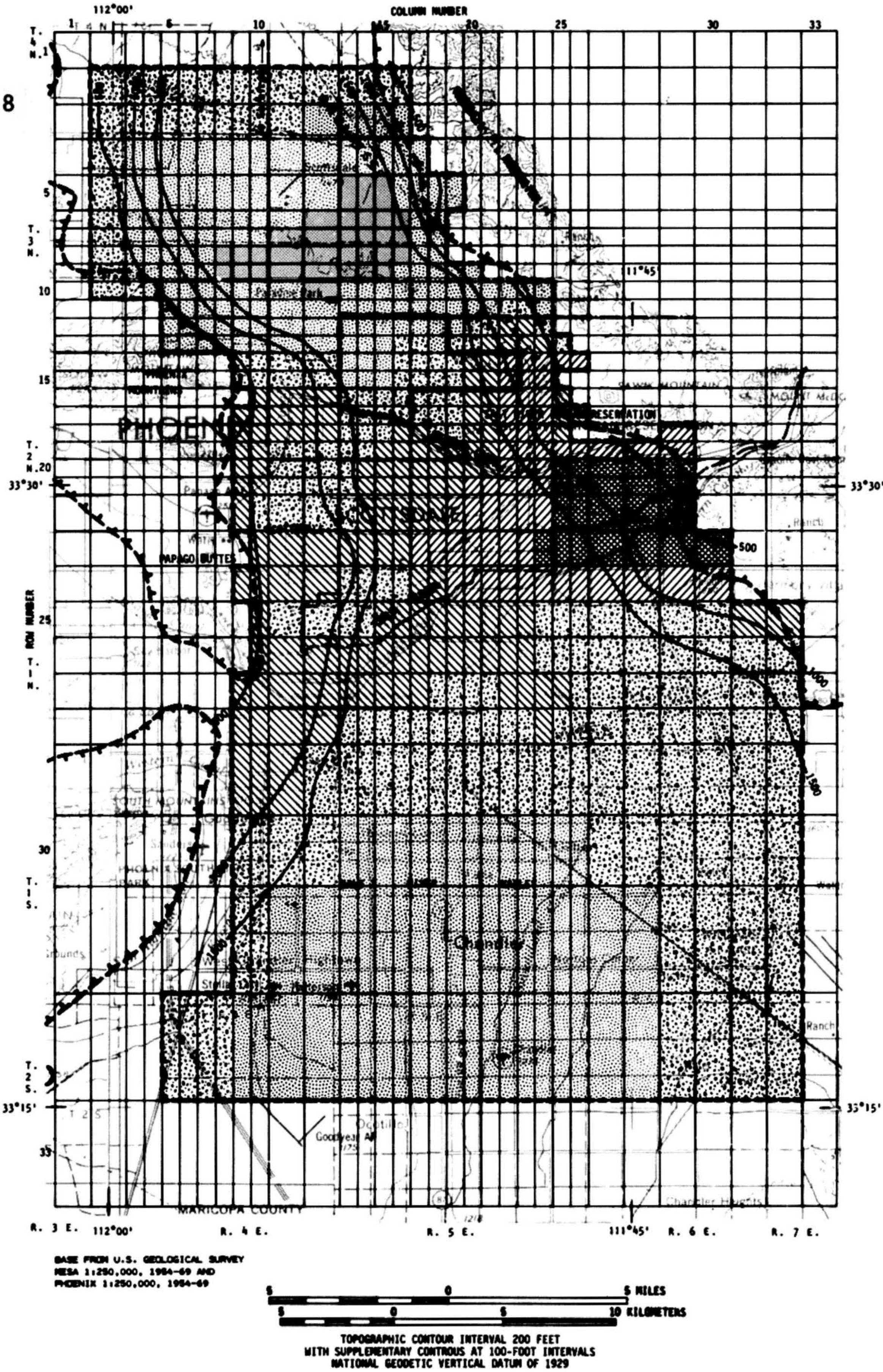


Figure 3.--Distribution of hydraulic conductivity, saturated thickness of the aquifer, and finite-difference grid used in the model. (In two sheets.)

Sheet 1 of figure 3.

EXPLANATION

HYDRAULIC CONDUCTIVITY, IN FEET PER DAY

0

<1

1-5

5-15

15-25

25-40

40-60

—— 500 —— APPROXIMATE LINE OF EQUAL SATURATED THICKNESS OF THE AQUIFER—Interval 500 feet

BOUNDARY OF AREA OF PROPOSED AGRICULTURAL DEVELOPMENT

APPROXIMATE BOUNDARY OF THE AQUIFER

BOUNDARY OF MODEL

Figure 3.--Distribution of hydraulic conductivity, saturated thickness of the aquifer, and finite-difference grid used in the model. (In two sheets.) Sheet 2 of figure 3.

Approximation of Aquifer Properties

Because the model is designed for only a two-dimensional simulation, the hydraulic-conductivity values assigned to each node are an average for the entire thickness of the aquifer. A two-dimensional model was considered representative because a good hydraulic connection exists between the lower, middle, and upper alluvium, and vertical differences in head appear to be insignificant. Hydraulic-conductivity and saturated-thickness data were used to calculate the transmissivity at each node, which allows transmissivity to change as the water level changes.

A preliminary hydraulic-conductivity map was compiled by using the available transmissivity and specific-capacity data from wells—transmissivity ranges from 7,500 to 69,000 ft^2/d, and the specific capacity ranges from 5 to 140 (gal/min)/ft of drawdown. Maps showing the percentage of fine-grained material in the lower and middle alluvium (R. L. Laney, U.S. Geological Survey, written commun., 1977) and a transmissivity map by Anderson (1968) were used to check the general trends. The preliminary hydraulic-conductivity map was modified during calibration of the model, and the estimated hydraulic conductivity ranges from 0 to 60 ft/d.

Cooley's (1973) map showing the thickness of the alluvial deposits in the Phoenix area and Anderson's (1968) water-level map for 1923 in central Arizona were used to estimate the saturated thickness of the aquifer (fig. 3). The maximum thickness of the potential water-bearing units was assumed to be 2,000 ft before pumping started.

The specific yield was estimated on the basis of the type of material present, the values used by Anderson (1968) for central Arizona, and the values used by Osterkamp and Ross (1976) to determine the amount of recoverable ground water in the Phoenix area. Because of insufficient data in the model area, a uniform specific-yield value of 12 percent, which was assumed to be the most representative, was assigned at each node.

Initial Water-Level Conditions

The model was designed to compute the amount of drawdown as a result of pumping from the aquifer. Initial head at each node was assumed to be zero, and the ground-water flow equation was solved directly for drawdown as a function of pumping and decreasing saturated thickness.

Estimated Distribution and Amount of Pumpage and Recharge

The distribution of pumpage in Paradise Valley is based on a report by Arteaga and others (1968), which gives well locations, uses of water from the wells, and annual ground-water withdrawals for 1946-65. Pumpage estimates south of Paradise Valley were obtained from a report by Anderson (1968) that gives pumpage for 1923-64 by township in central Arizona. Annual pumpage values given by Babcock (1977) were used for estimating the pumpage for 1966-75 in the Salt River Valley. The Bureau of Indian Affairs furnished pumpage estimates for 1974-75 and locations of private and tribal irrigation wells in the reservation. The Bureau also furnished pumpage estimates and planned well locations for the proposed development.

In a drawdown model the ground-water system is assumed to be in equilibrium, and predevelopment recharge and discharge values are not simulated. If changes in recharge and discharge occur, only the value of the change is introduced into the system at the appropriate time in the model. In the model area, recharge is by the return of irrigation water to the aquifer. Recharge was introduced in the model at a rate of 37 percent of the pumped irrigation water. The value is based on an estimate of 40 percent (P. C. Briggs, Arizona Water Commission, oral commun., 1978) and trial model runs.

Calibration

The estimated pumpage for 1946-75 for the calibration was divided into four pumping periods (fig. 4) to simulate changes in ground-water withdrawals. South of Paradise Valley, extensive irrigation began in the mid-1940's, and recharge from the return of irrigation water was simulated in the model for the entire calibration period; however, extensive irrigation did not begin in the reservation until the mid-1950's, and recharge from the return of irrigation water was not simulated until the third pumping period. (See fig. 4.)

The model was calibrated by comparing the model-generated drawdown with the measured historical drawdown and adjusting simulated hydraulic-conductivity values to obtain a better match between the model-generated and historical drawdown data. Final calibration of the model was made by comparing the measured water-level declines for 1923-76 with the simulated water-level declines for 1946-75 (fig. 2); the small amount of pumpage from Paradise Valley prior to the 1940's made the comparison valid. The simulated water-level decline north of the Salt River generally is within 50 ft of the measured decline. The disparity between the simulated and measured declines south of the Salt River probably was caused by erroneous assumptions based on insufficient data for pumpage, recharge, or aquifer properties.

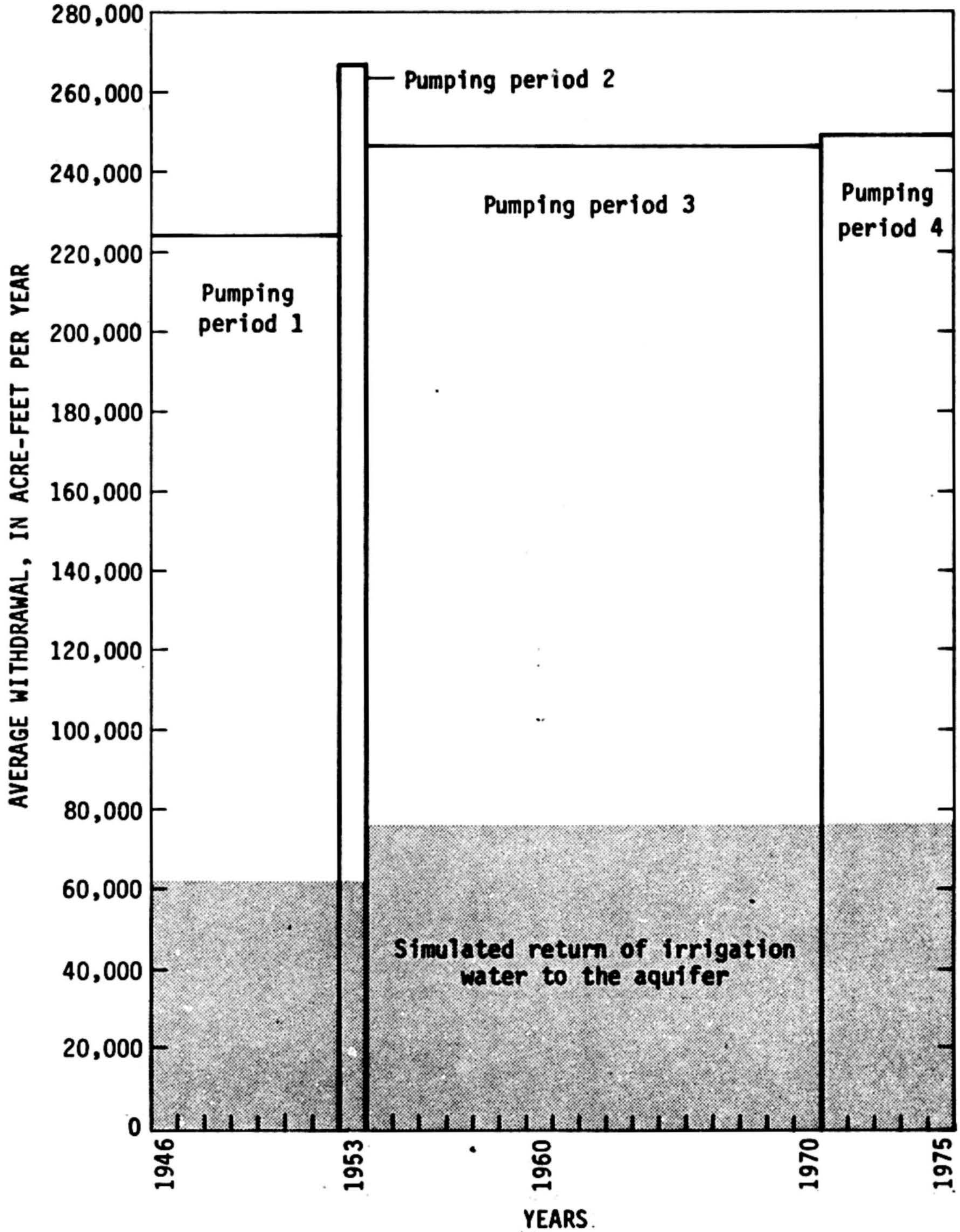


Figure 4.--Estimated ground-water withdrawals and simulated return of irrigation water to the aquifer in the model area.

A sensitivity analysis was made to evaluate the responsiveness of the calibrated model to changes in initial transmissivity and specific yield. Input for the analysis was the maximum pumpage of 37,500 acre-ft/yr for the reservation for 1974-75 and the estimated maximum recharge of 13,900 acre-ft/yr from the return of irrigation water for 1974-75. The transmissivity was doubled and then halved; in both instances the shape of the contours was the same, and the values changed radially from the center of pumping by only a few feet per year. The specific yield was increased from 12 to 19 percent, and the transmissivity was returned to the original value, which had the effect of decreasing the drawdown by slightly more than 1 ft/yr while the contours maintained their shape. The results indicate that the disparity between the measured declines for 1923-76 and the simulated declines for 1946-75 south of the Salt River is caused more by improper pumpage distribution or inaccurate pumpage and recharge estimates than by inaccuracies in transmissivity and specific-yield values.

LIMITATIONS AND APPLICATION OF THE MODEL

The model was designed as a management tool to give an approximate solution to a complex problem. The accuracy of the solution depends on how well the assumed conditions—two-dimensional flow, no-flow boundaries, isotropy and homogeneity of the aquifer, and recharge from the return of irrigation water to the aquifer—approximate the actual conditions. Although sufficient information on pumpage, recharge, and aquifer properties is not available to assess the validity of the assumptions used in the model, the model can be used to estimate the effects of additional ground-water withdrawals on water levels near existing wells in the reservation.

The effects of pumping from the proposed well field were evaluated by using the calibrated model. Because the transmissivity of the aquifer will change constantly as water levels decline, two simulations were necessary to isolate the effects of pumping 45,000 acre-ft/yr from the proposed well field. The initial water levels used in the simulations were those calculated by the model at the end of the calibration period. The first simulation assumed that the estimated pumpage and recharge for 1975 in the model area would remain constant for an additional 20 years (fig. 5). The second simulation assumed the same constant pumpage and recharge in the model area and 45,000 acre-ft/yr of pumpage from the proposed well field (fig. 6). The water-level declines obtained from the two simulations were then subtracted to give the water-level declines that would occur near existing wells in the reservation as a result of the additional withdrawals from the proposed well field (fig. 7). The rate of simulated water-level decline is about 2 to 6 ft/yr after 20 years of pumping. The confidence level for the simulated water-level declines decreases toward the Salt River, where the declines simulated in the calibration period begin to depart significantly from the measured declines (fig. 2).

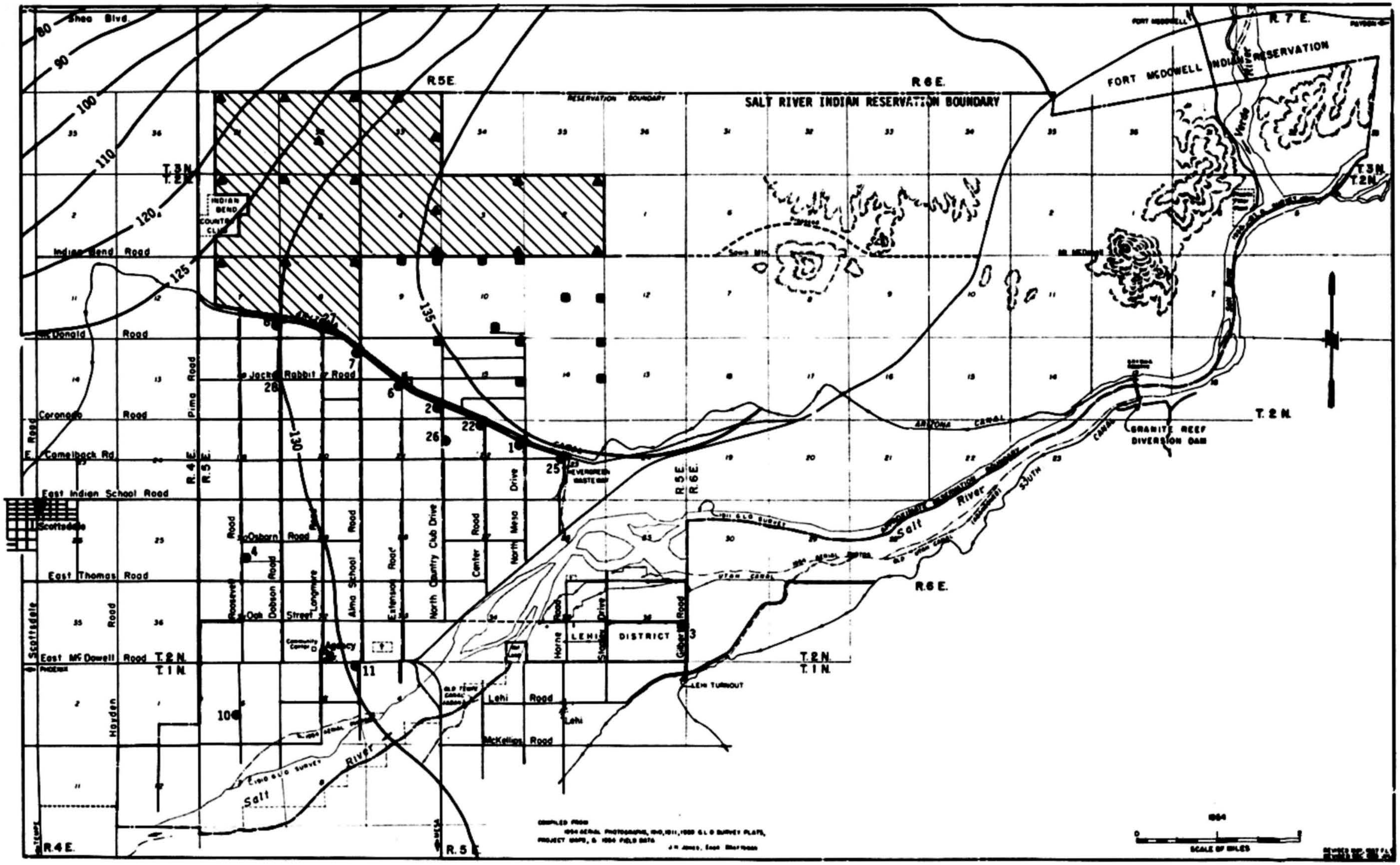


Figure 5.--Simulated water-level declines in and near the Salt River Indian Reservation after 20 years of pumping, using estimated pumpage and recharge for 1975 in the model area.
(In two sheets.) Sheet 1 of figure 5.

EXPLANATION

AREA OF PROPOSED AGRICULTURAL DEVELOPMENT

110 LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 5 and 10 feet

8 BUREAU OF INDIAN AFFAIRS WELL AND NUMBER

PRIVATE WELL

PROPOSED WELL

Figure 5.--Simulated water-level declines in and near the Salt River Indian Reservation after 20 years of pumping, using estimated pumpage and recharge for 1975 in the model area.
(In two sheets.) Sheet 2 of figure 5.

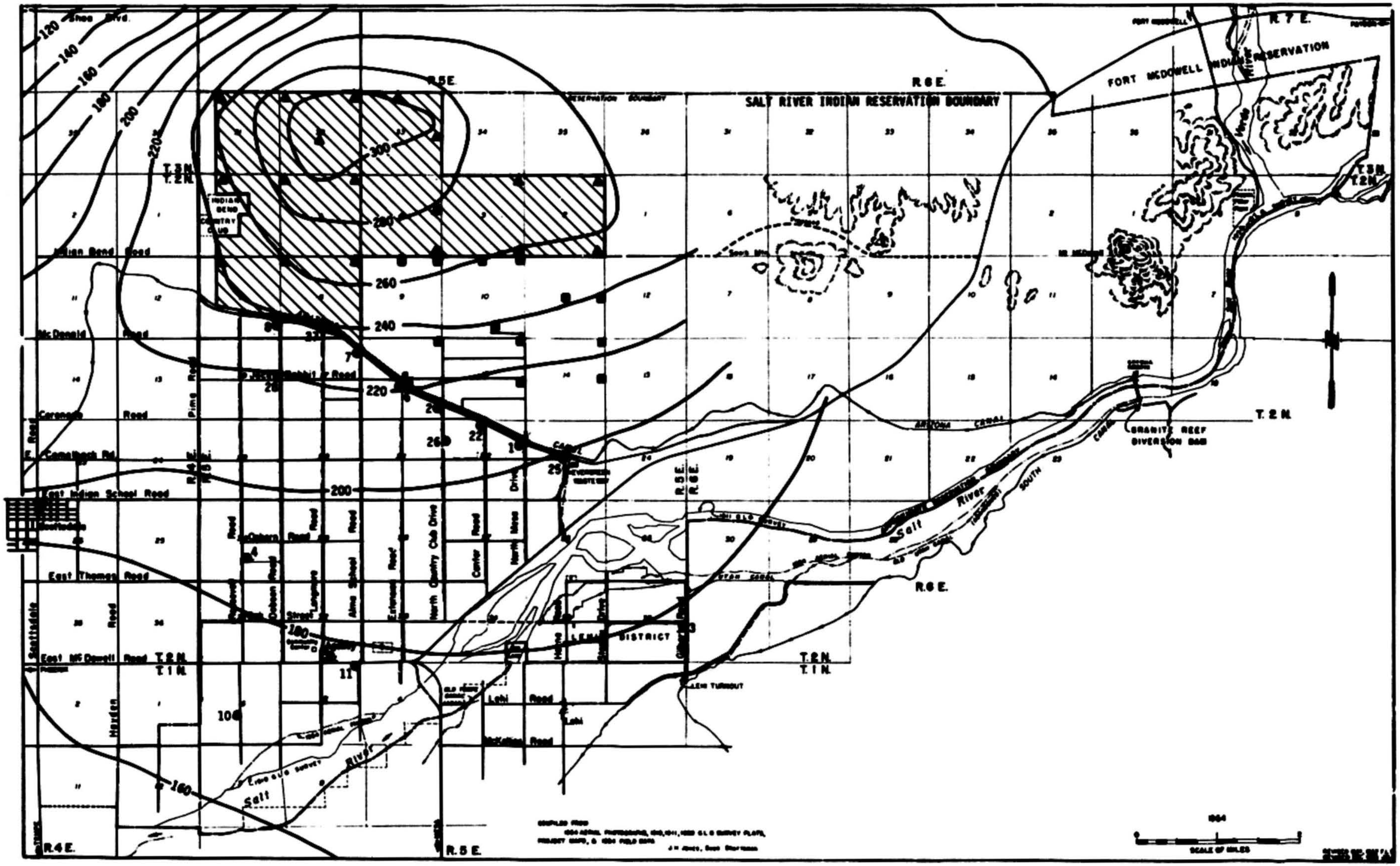


Figure 6.--Simulated water-level declines in and near the Salt River Indian Reservation after 20 years of pumping, using estimated pumpage and recharge for 1975 in the model area and estimated pumpage from the proposed well field.
(In two sheets.) Sheet 1 of figure 6.

EXPLANATION

AREA OF PROPOSED AGRICULTURAL DEVELOPMENT

—280— LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 20 feet

8● BUREAU OF INDIAN AFFAIRS WELL AND NUMBER

■ PRIVATE WELL

▲ PROPOSED WELL

Figure 6.--Simulated water-level declines in and near the Salt River Indian Reservation after 20 years of pumping, using estimated pumpage and recharge for 1975 in the model area and estimated pumpage from the proposed well field.
(In two sheets.) Sheet 2 of figure 6.

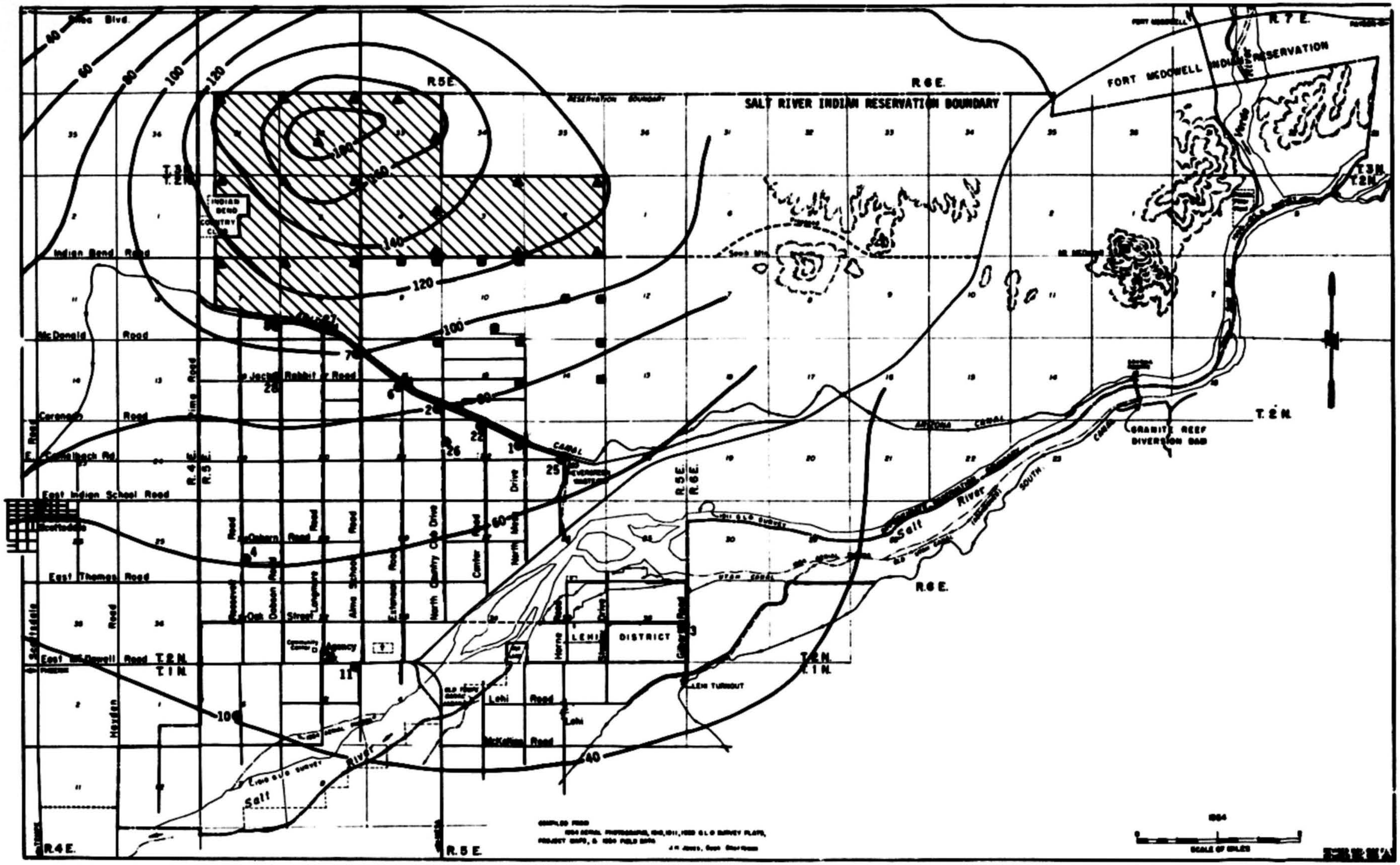


Figure 7.--Simulated water-level declines attributable to pumping from the proposed well field for 20 years.
(In two sheets.) Sheet 1 of figure 7.

E X P L A N A T I O N

AREA OF PROPOSED AGRICULTURAL DEVELOPMENT

180 — LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 20 feet

8 — BUREAU OF INDIAN AFFAIRS WELL AND NUMBER

PRIVATE WELL

PROPOSED WELL

Figure 7.--Simulated water-level declines attributable to pumping from the proposed well field for 20 years.
(In two sheets.) Sheet 2 of figure 7.

SUMMARY

The effects of a proposed well field on the water levels in existing wells in the Salt River Indian Reservation were evaluated by use of a finite-difference digital model. The Salt River Indian Reservation is in the southeastern part of Paradise Valley, and the model area includes about 600 mi^2 in Paradise Valley and the adjoining Salt River Valley. In 1975 about 37,500 acre-ft of ground water was withdrawn for irrigation from the existing wells in the reservation; in addition, the proposed well field would withdraw as much as 45,000 acre-ft/yr of water for the irrigation of about 5,700 acres of cropland.

In Paradise Valley the main source of ground water is the alluvium, which is more than 2,000 ft thick near the center of the valley. The alluvium is informally divided into the lower alluvium, middle alluvium, and upper alluvium and in places is underlain by a red unit of consolidated rock. The alluvium and red unit are hydraulically connected and act as a single aquifer. The upper alluvium generally is dry, and the middle and lower alluvium generally yield several hundred to several thousand gallons per minute to wells; the red unit yields less than 5 to several hundred gallons per minute.

Ground-water development for irrigation began in Paradise Valley in about 1900, but extensive development did not begin until the 1950's, when the amount of cultivated acreage was increased in the Salt River Indian Reservation. About 2 million acre-ft of ground water was withdrawn from the aquifer in Paradise Valley through 1975. Water levels are declining, and a large cone of depression has developed near Scottsdale, where the water level has declined more than 300 ft since 1923.

The digital model employs a finite-difference technique to solve the complex partial differential equations for ground-water flow. A variable grid spacing was used in the model, and all the boundaries used in construction of the model represent no-flow conditions. Hydraulic-conductivity values of 0 to 60 ft/d were assigned at each node, and the hydraulic-conductivity and saturated-thickness data were used to estimate the transmissivity. A specific-yield value of 12 percent was assigned at each node. Recharge was introduced into the model at a rate of 37 percent of the amount of pumped irrigation water.

Final calibration of the model was made by comparing the measured water-level declines for 1923-76 with the simulated water-level declines for 1946-75. The results of the sensitivity analysis indicated that the disparity between the measured declines for 1923-76 and the simulated declines for 1946-75 south of the Salt River is caused more by improper pumpage distribution or inaccurate pumpage and recharge estimates than by inaccuracies in transmissivity and specific-yield values. The model then was used to predict the water-level declines that would occur near existing wells in the reservation as a result of additional withdrawals of 45,000 acre-ft/yr from the proposed well field.

The rate of simulated additional water-level decline is about 2 to 6 ft/yr after 20 years of pumping. The confidence level for the simulated water-level declines decreases toward the Salt River, where the declines simulated in the calibration period begin to depart significantly from the measured declines.

SELECTED REFERENCES

Anderson, T. W., 1968, Electrical-analog analysis of ground-water depletion in central Arizona: U.S. Geological Survey Water-Supply Paper 1860, 21 p.

Arizona Crop and Livestock Reporting Service, 1974, Cropland atlas of Arizona: Phoenix, Arizona Crop and Livestock Reporting Service duplicated report, 68 p.

Arteaga, F. E., White, N. D., Cooley, M. E., and Sutheimer, A. F., 1968, Ground water in Paradise Valley, Maricopa County, Arizona: Arizona State Land Department Water-Resources Report 35, 76 p.

Babcock, H. M., 1977, Annual summary of ground-water conditions in Arizona, spring 1975 to spring 1976: U.S. Geological Survey Water-Resources Investigations 77-10, maps.

Cooley, M. E., 1973, Map showing distribution and estimated thickness of alluvial deposits in the Phoenix area, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-845-C, 1 sheet.

Fenneman, N. M., 1931, Physiography of Western United States: New York, McGraw-Hill, 534 p.

Laney, R. L., Ross, P. P., and Littin, G. R., 1978, Maps showing the ground-water conditions in the eastern part of the Salt River Valley area, Maricopa and Pinal Counties, Arizona—1976: U.S. Geological Survey Water-Resources Investigations 78-61, maps.

Lee, W. T., 1905, Underground waters of Salt River Valley, Arizona: U.S. Geological Survey Water-Supply Paper 136, 196 p.

McDonald, H. R., Wolcott, H. N., and Bluhm, F. I., 1947, Geology and ground-water resources of Paradise Valley, Maricopa County, Arizona, _with a section on_ Quality of water, by J. D. Hem: U.S. Geological Survey open-file report, 34 p.

Meinzer, O. E., and Ellis, A. J., 1916, Ground water in Paradise Valley, Arizona, _in_ Contributions to the hydrology of the United States—1915: U.S. Geological Survey Water-Supply Paper 375, p. 51-75.

Osterkamp, W. R., and Ross, P. P., 1976, Map showing distribution of recoverable ground water in the Phoenix area, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-845-K, 1 sheet.

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.