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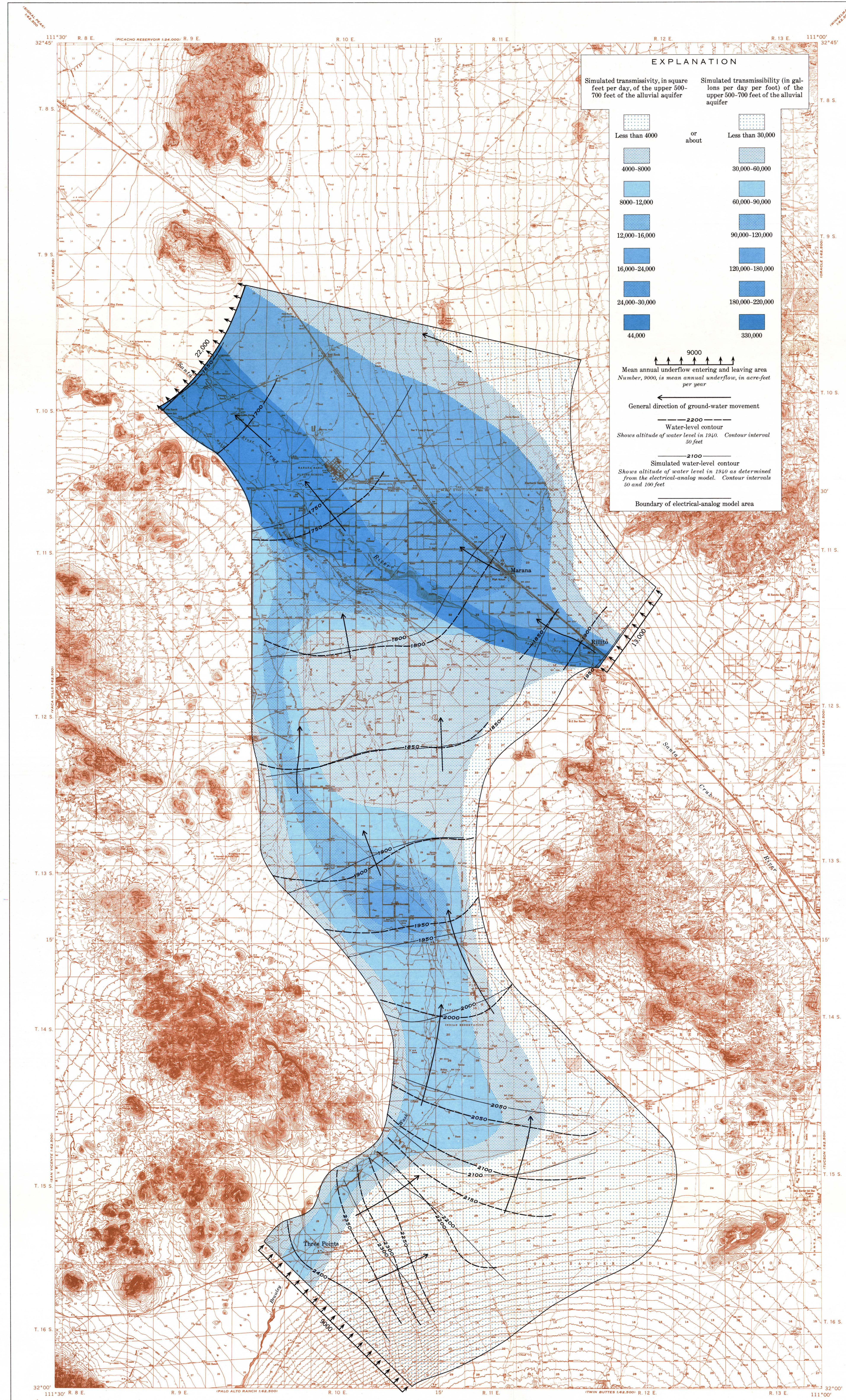


GROUND-WATER SYSTEM IN 1940 AND PATTERN OF REGIONAL TRANSMISSIVITY, 1940–65

INTRODUCTION

Avra Valley is in the arid to semiarid Basin and Range lowlands of south-central Arizona. The valley encompasses about 450 square miles and is elongated in a generally north-south direction. The average annual precipitation ranges from 8 to 12 inches. Two major streams drain the area—the Santa Cruz River and Brawley Wash. The major streams and their tributaries are ephemeral and flow only in response to intense precipitation in the valley, in the surrounding mountains, or in adjoining basins.

Dense relatively impermeable bedrock forms the mountains that bound the valley; bedrock benches occur at shallow depth at the base of the mountains and extend for different distances into the valley. The central part of the valley is underlain by alluvial deposits to a depth of at least 2,000 feet (White, Matlock, and Schwalen, 1966, p. 18).

In general the water-bearing alluvial deposits are interconnected hydraulically, at least to a depth of 700 feet, and form a single water-table aquifer. In parts of the valley, water below a depth of about 1,100 feet is confined below less permeable material and may rise above the regional water table.

Ground-water development began in the late 1930's and reached a maximum in the early 1950's; by 1954, more than 100 wells were being pumped for the irrigation of about 30,000 acres. In 1954 Avra Valley was declared a critical ground-water area, which limited further development of ground water for agricultural use. Since 1955, the amount of land under cultivation has remained essentially the same, and the average annual withdrawal of ground water has been more than 120,000 acre-feet per year. Withdrawal of ground water for uses other than irrigation has been less than 5 percent of the total withdrawal.

The purposes of this study were to approximate the water budget prior to extensive ground-water development, to determine the effect of pumping on water levels from quantitative field data, and to construct and analyze an electrical-analog model that simulates these effects. Subsequently, the model can be used as a tool to predict future water-level conditions. The model was used to predict the 1985 water levels in Avra Valley that will result (1) if pumping continues at the average 1955–65 rate, and (2) if the proposed additional pumpage for the city of Tucson is added.

The study of the ground-water system in Avra Valley was made by the U.S. Geological Survey in cooperation with the Arizona State Land Department, Obed M. Lassen, Commissioner. The investigation was under the immediate supervision of H.M. Babcock, district chief of the Water Resources Division in Arizona. The electrical-analog model was constructed by personnel of the U.S. Geological Survey's Analog-Model Unit, Phoenix, Ariz., under the supervision of E.P. Patten.

ELECTRICAL-ANALOG MODEL AS A TOOL IN HYDROLOGIC ANALYSES

The electrical-analog model, as used in this study, is a working-scale model of the ground-water system. The construction of a model requires evaluation of the different physical and hydrologic characteristics of the system and simulation of these characteristics by electrical components. The elements of the hydrologic system that must be simulated are (1) extent of the area, (2) transmissivity (T) and storage coefficient (S), (3) recharge, (4) pumping history, and (5) effects of pumping on the water table.

The areal extent of the valley can be defined by direct measurement. The transmissivity (T), storage coefficient (S), and recharge generally cannot be measured directly but can be approximated by indirect methods. The pumping history can be determined if sufficient data are available. The effects of pumping on the water table can be measured by comparing the water-table altitudes at different times in the pumping history.

After mathematical definition of these elements is attained, the electrical-analog model of the hydrologic system is designed by the use of appropriate scale factors. The model and the hydrologic system are considered to be analogous if the simulated and actual water-level declines are in reasonable agreement.

GROUND-WATER SYSTEM IN 1940 AND PATTERN OF REGIONAL TRANSMISSIVITY, 1940–65

In 1940 the ground-water system in Avra Valley was in a steady-state condition—that is, inflow was equal to outflow—and the small amount of pumping prior to that time had not caused any appreciable change in water levels. The 1940 water-level altitudes (White, Matlock, and Schwalen, 1966, fig. 6) varied less than 10 feet from the 1915 water-level altitudes (Smith, 1938, pl. 3) in the area from Rillito to T. 10 S., R. 9 E.—the only part of the valley in which there was any significant ground-water development. In Avra Valley the water surface sloped generally northeastward and then northward and conformed with the general slope of the land surface and the trend of the main drainage. The water-level gradient was nearly 100 fpm (feet per mile) north and east of Three Points, about 10 fpm in the northern part of the valley, and within these limits in other parts of the valley.

The generalized pattern of transmissivity for Avra Valley is based on a small number of aquifer tests (White, Matlock, and Schwalen, 1966) and on the analog-model steady-state (1940) analysis. In the undeveloped areas near the periphery of the valley the transmissivity is proportioned between the known values in the center of the area and zero at the mountain fronts and is modified where necessary to enable the model-derived water-level data to match the field data.

In most of the valley the transmissivity ranges from 4,000 ft^2 per day (square feet per day) to 30,000 ft^2 per day. The values are a measure of the transmissivity for only the upper 500 to 700 feet of material because the aquifer tests on which the values were based were made in wells that are only 500 to 700 feet deep. In an area parallel to the Santa Cruz River, from T. 12 S., R. 12 E., to T. 10 S., R. 9 E., the transmissivity pattern used in the construction of the model transects the regional pattern and is as much as 44,000 ft^2 per day. Although a two-layer model simulating a very permeable upper alluvium superimposed on the regional alluvial aquifer of lower permeability would have been more suitable for the area parallel to the river, data were insufficient to construct such a model.

The water-level altitudes determined from the model generally are in good agreement with the measured water-level altitudes. Except in a few places, the match is generally within 10 feet, and the differences do not introduce serious error into the analysis.

It was not necessary to simulate ground-water recharge in the construction of the model, which verifies the assumption by White, Matlock, and Schwalen (1966, p. 27) that "recharge to the ground-water reservoir probably is negligible in relation to ground-water withdrawal by pumping." Average annual recharge along the mountain fronts and from infiltration in the main alluvial channels may be a few thousand acre-feet per year; the degree of sensitivity of the model and the amount of ground-water data available preclude a more accurate determination.

In order to match the modeled water-level gradients with the measured gradients it was necessary to simulate 9,000 acre-feet per year of underflow entering the area southwest of Three Points and 13,000 acre-feet per year entering the area from the Tucson basin near Rillito. The north boundary of the model area is parallel to the direction of ground-water movement, and no signifieant amount of ground water moves in or out of the area along this boundary. Therefore, all the underflow leaving Avra Valley crosses the northwest boundary and was about 22,000 acre-feet in 1940. The 13,000 acre-feet per year of underflow entering the area near Rillito compares favorably with Anderson's (1968, fig. 4) 17,500 acre-feet per year of outflow from the Tucson basin.

GROUND-WATER WITHDRAWAL AND MEASURED AND SIMULATED WATER-LEVEL DECLINES IN AVRA VALLEY, 1940–65

In 1940 ground-water withdrawal in Avra Valley was confined to the Marana area and was only about 10,000 acre-feet. Withdrawal increased steadily until 1951 and increased greatly from 1951 through 1955. Since 1955, the average annual withdrawal has been more than 120,000 acre-feet per year and has been relatively stable. From 1940 to 1965, about 2 million acre-feet of water was pumped in Avra Valley, most of which was withdrawn near Marana and in the central part of the valley.

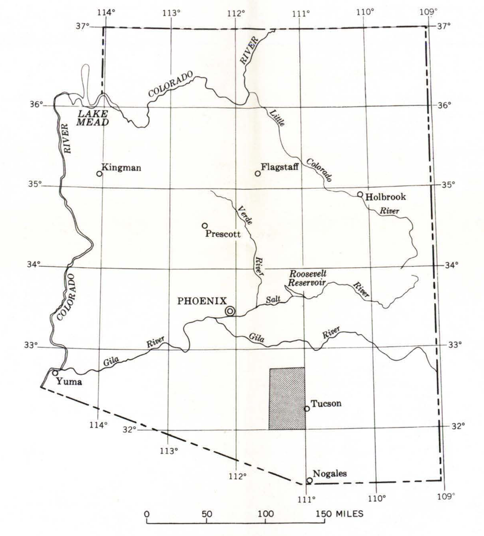
Pumpage was calculated from power-consumption records. The average volume of water pumped per kilowatt hour of electricity used was derived from field measurements, and the relation was used to calculate the total pumpage. Where no power records were available, the pumpage was estimated on the basis of the measured or reported well yields. In the model pumpage data were grouped for each square of four sections. Pumpage, by township, for 1940–65 is as follows:

Township	*Pumpage, in acre-feet [Rounded to the nearest 100 acre-feet]*
T. 10 S., R. 9 E.	6,100
T. 10 S., R. 10 E.	14,500
T. 10 S., R. 11 E.	11,000
T. 11 S., R. 10 E.	349,600
T. 11 S., R. 11 E.	609,900
T. 11 S., R. 12 E.	100
T. 12 S., R. 10 E.	189,500
T. 12 S., R. 11 E.	205,100
T. 13 S., R. 10 E.	268,800
T. 13 S., R. 11 E.	58,600
T. 14 S., R. 10 E.	11,800
T. 14 S., R. 11 E.	152,700
T. 15 S., R. 10 E.	24,000
T. 15 S., R. 11 E.	18,400
T. 16 S., R. 10 E.	45,300

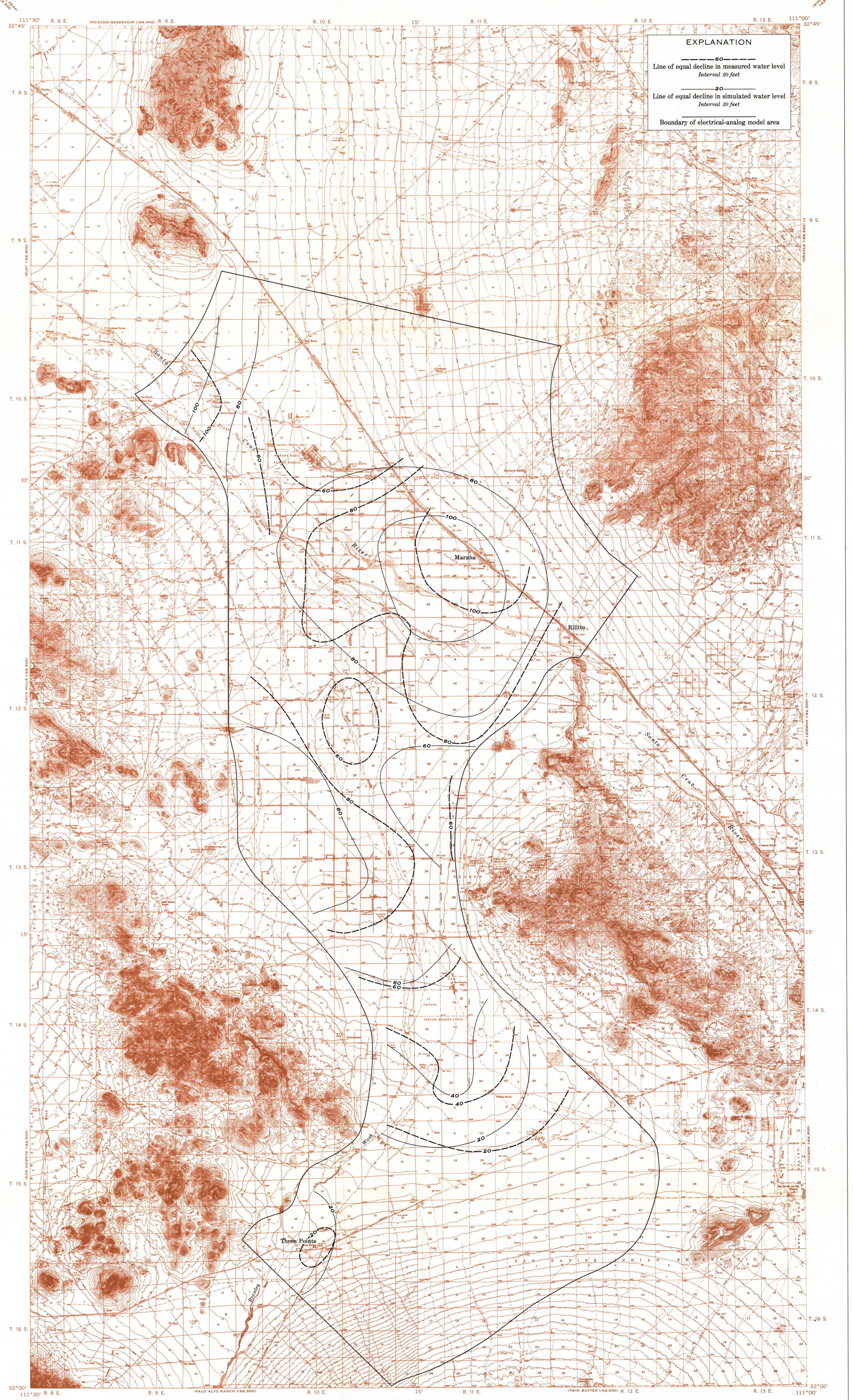
The magnitude and areas of water-level decline generally correspond well with the magnitude and areas of ground-water withdrawal in Avra Valley. The two main exceptions are at the boundary between Avra Valley and the Eloy area, which is northwest of the report area, and at the boundary between Avra Valley and the Tucson basin near Rillito. The cone of depression caused by extensive pumping in the Eloy area has expanded and caused additional water-level declines in the northwest part of Avra Valley. At the boundary between Avra Valley and the Tucson basin near Rillito, the underflow from the Tucson basin into the valley has lessened the declines in comparison with the magnitude of pumpage.

Water-level declines greater than 100 feet have occurred in two areas in Avra Valley since 1940—in the Marana area and in the northwest part of the valley. Water-level declines in the west-central part of Avra Valley range from 60 to nearly 100 feet. South of the east-west line that separates Tps. 14 and 15 S., water levels generally declined less than 20 feet.

The measured water-level declines and the simulated water-level declines correspond well in most places. For 1940–65 the simulated water-level declines were within 20 feet of the measured declines throughout the valley and were within 10 feet in most places. In most of the valley the difference between measured and simulated water-level declines is less than 10 percent; however, in a few places the difference is as much as 25 percent. The main contributing factors to the difference between the measured and the simulated water-level declines are the areal variability of the storage coefficient from the average value of 0.13, the uncertainty of the pumping data, or a combination of both.



MAP SHOWING LOCATION OF REPORT AREA



MEASURED AND SIMULATED WATER-LEVEL CHANGES, 1940–65

Base from U.S. Geological Survey, 1:62,500
Cocoraque Butte, 1941; Cortaro, 1946–57; Red Rock, 1946; Silver Bell Peak, 1959; Tortolita Mountains, 1959; and San Xavier Mission, 1940–57

SCALE 1:125 000

2 0 2 4 6 8 10 MILES

2 0 2 4 6 8 10 KILOMETERS

CONTOUR INTERVALS 25, 40, AND 50 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

ANALYSIS OF THE GROUND-WATER SYSTEM BY ELECTRICAL-ANALOG MODEL, AVRA VALLEY, PIMA AND PINAL COUNTIES, ARIZONA

By
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1972