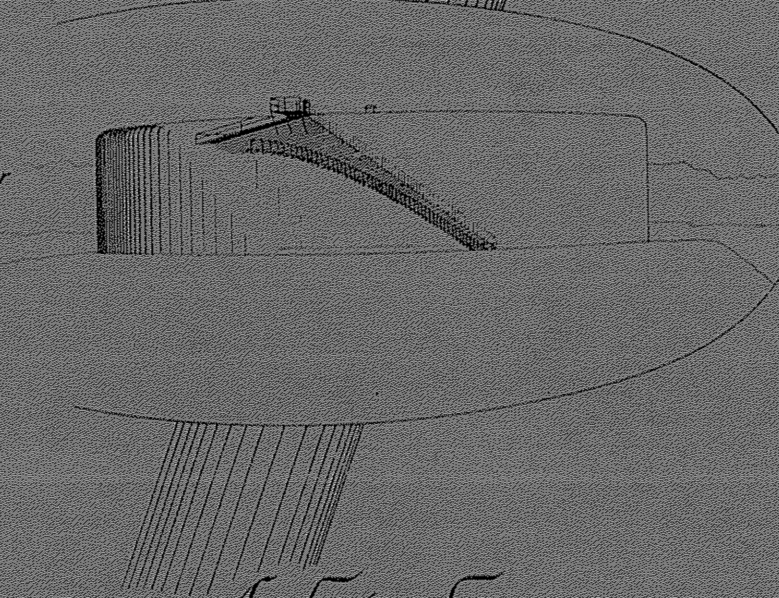
TECHNICAL REPORT 33

New Mexico State Engineer
Santa Fe, New Mexico



Quantitative Analysis of Water Resources in the Albuquerque Area, New Mexico

By H.O. Reeder, L.J. Bjorklund
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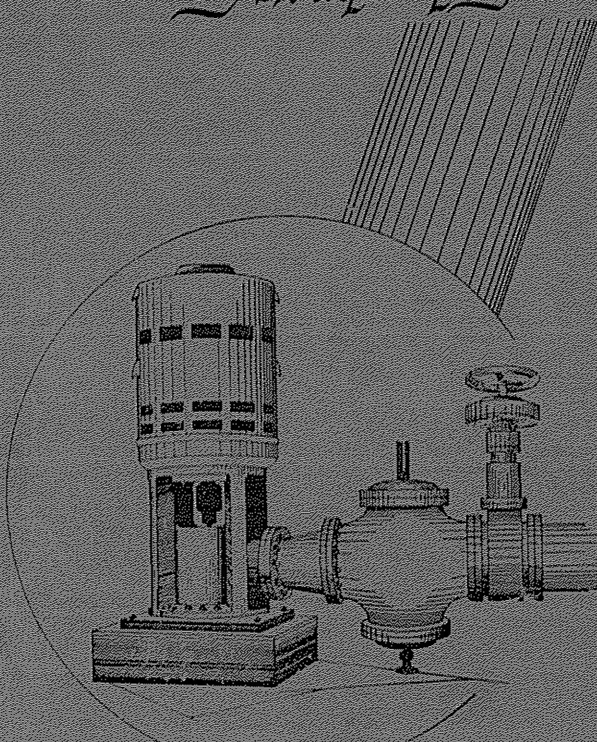

Prepared in cooperation with
the United States Geological Survey

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Quantitative Analysis of Water Resources in the Albuquerque Area, New Mexico

Computed effects on the Rio Grande of pumpage of ground water 1960-2000

By

H. O. Reeder, L. J. Bjorklund, and G. A. Dinwiddie
United States Geological Survey

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QUANTITATIVE ANALYSIS OF WATER RESOURCES IN THE ALBUQUERQUE AREA, NEW MEXICO

By

H. O. Reeder, L. J. Bjorklund, and G. A. Dinwiddie

ABSTRACT

From basic assumptions of water requirements in the Albuquerque area and aquifer characteristics, the greatest lowering of the water level from 1960 to 2000 is computed to be 86 feet in an area about 6 miles east of downtown Albuquerque and 3 miles north of Highway 66 (Central Avenue). It is computed that water levels declined almost 11 feet in this area from 1920 to 1960. West of the Rio Grande, the water levels are expected to decline 34 feet in a small area about 9 miles northwest of downtown Albuquerque from 1960 to 2000. Water levels in that area declined little, if any, before 1960. Outward from these areas the lowering will be less in all directions, particularly toward the Rio Grande.

The water-level declines, as computed in this report, will reverse the water-table gradient east of the Rio Grande, causing ground water to flow away from the river, and the water table 5 to 8 miles east of the Rio Grande at Albuquerque will be lower than the adjacent part of the river.

About 80 percent of the water pumped by the city from 1920 to 1960 was derived from the flow of the Rio Grande, either decreasing the flow to the river or increasing the flow from the river. From 1960 to the year 2000 between 71 and 76 percent of the water pumped will be derived from the Rio Grande. In the decade 1950-60 an average of 46,000 acre-feet of water was pumped annually, of which 37,200 acre-feet was derived from the Rio Grande. In the decade 1990-2000, it is computed that an average of 226,000 acre-feet of water will be pumped annually, of which 165,000 acre-feet will be derived from the Rio Grande. Average flow of

the river at Albuquerque during the 17 years prior to 1959 was 1,006 cfs (cubic feet per second) or about 728,000 acre-feet per year. Part of the decreased flow of the river caused by pumping is offset by effluent from the sewage-disposal plant.

INTRODUCTION

The use of water at Albuquerque is expected to increase rapidly. As pumping continues and increases, ground-water levels and the flow of the Rio Grande will be affected. These effects can be computed from projected aquifer characteristics and ground-water development. This study was made to determine the effects of ground-water pumping on, and the relation of water use in the area to, present and future flow in the Rio Grande.

The study was made by the U.S. Geological Survey in cooperation with the State Engineer of New Mexico. The basic assumptions were formulated and the study was conducted by L. J. Bjorklund from July 1960 to March 1961, at which time Mr. Bjorklund was transferred from New Mexico to Utah. H. O. Reeder resumed the project in April 1962 and G. A. Dinwiddie joined the project in August 1962.

The qualitative report "Availability of Ground Water in the Albuquerque Area, Bernalillo and Sandoval Counties, New Mexico," by L. J. Bjorklund and B. W. Maxwell (1961) is the source and foundation for most of the basic data and most of the assumptions in this report. Data collected in the studies by Theis (1938) and Theis and Taylor (1939) were used to prepare profiles of the water table shown in plate 6 in this report.

Many other reports, most of which were of a qualitative nature, were cited by Bjorklund and Maxwell.

The cooperation of residents of the area and of officials of Federal, State, municipal, and industrial establishments who contributed to the earlier study is gratefully acknowledged. Data on particle-size distribution from sedimentation studies of the Rio Grande channel by the U.S. Bureau of Reclamation were very useful in the preparation of this report.

GENERAL FEATURES OF THE AREA

The area of this study is the same as that investigated by Bjorklund and Maxwell. It is in the middle section of the upper Rio Grande basin, mostly in the "Middle Valley" of the Rio Grande as defined by the

National Resources Committee (1938, Regional Planning, Part VI - The Rio Grande Joint Investigation, p. 7). It includes about 1,400 square miles in Bernalillo and Sandoval Counties (fig. 1). The northern, or upstream, boundary of the project area is at Algodones and along the north side of the Jemez River valley in Sandoval County; the southern boundary is the southern boundary of Bernalillo County, 12 miles south of Albuquerque. The area of investigation is about 26 miles wide and extends westward from the Sandia and Manzano Mountains to the Rio Puerco.

Physiography

The Albuquerque area is drained by one perennial stream, the southward-flowing Rio Grande, and many ephemeral tributaries. The Jemez River, largest tributary in the area, flows southeastward into the Rio Grande near Algodones. The Rio Puerco, along the west side of the project area, flows southward and joins the Rio Grande about 50 miles south of Albuquerque. Many washes drain the mesas, or upland areas.

The Sandia and Manzano Mountains border the Rio Grande valley on the east. The sloping surface of the valley fill from the base of the mountains to the valley floor is referred to locally as the "east mesa." The slope of the east mesa near the mountains is about 250 feet per mile; near the river it is about 20 feet per mile at most places. The distance between the base of the mountains and the inner valley floor ranges from about 3 miles in the northern part of the area to about 9 miles in the southern part. The valley floor is relatively flat, sloping downstream 6 or 7 feet per mile, and ranging in width from 1 to 4 miles. It is separated from the east mesa by a bluff that is breached by washes from which alluvial fans spread out on the valley floor.

A series of cut terraces parallels the Rio Grande on the west, and a broad upland surface about 600 feet above the river borders the terraces on the west. In the vicinity of Albuquerque, the broad upland and cut terraces are called the "west mesa." The upland surface slopes generally southeastward at about 50 to 100 feet per mile.

The area has been described in more detail and with other geographic features by Bjorklund and Maxwell.

General Geology

Reference is made to Bjorklund and Maxwell for a detailed treatment of the geology of the Albuquerque area; however, the parts of their material that are of primary concern in this study are restated briefly.

The Albuquerque area lies mostly within a graben which is part of the Rio Grande depression, a connected series of grabens and structural basins having a general north-south alinement and which is bordered on the east and west by upfaulted blocks. The upfaulted blocks to the east form the Sandia and Manzano Mountains and the block to the west forms the highlands of the Rio Puerco and much of the Rio Puerco valley. The Jemez caldera and the Jemez uplift north of the Jemez River are part of the western,upfaulted, block that borders the depression.

Fault zones trend along the west base of the Sandia and Manzano Mountains. The bedrock thus rises from the floor of the graben to the crest of the mountains in steps. The fault zone bounding the west side of the graben may be similar to that on the east. The bedrock floor of the graben probably is modified by many faults.

The graben, or valley, has been partly filled by sand, gravel, silt, clay, and volcanic rocks of Tertiary and Quaternary age. Near the borders of the depression, beds of the Santa Fe Group dip toward the southward-trending axis of the graben; however, mappable red beds are persistent in the vicinity of the confluence of the Jemez River and the Rio Grande, and dips of these red beds generally are southward to southeastward at about 4 degrees, indicating the possibility that the beds of the Santa Fe Group along the axis of the depression might dip southward. If the red beds continue southward in the subsurface, they probably underlie Albuquerque at depths reaching 4,000 feet. Some of the dip of the Santa Fe Group is depositional; however, later faulting and movement along old faults in older beds has at places steepened the dip and caused faulting in the Santa Fe Group. The Santa Fe Group is easily eroded at most places and fault scarps generally are not preserved.

Although rocks of pre-Tertiary age occur at or near the surface in parts of the area, this study primarily deals with rocks of Tertiary and Quaternary ages. These rocks crop out in most of the valley area. They unconformably overlie rocks of pre-Tertiary age, as stated by Bjorklund and Maxwell, and generally are composed of unconsolidated to loosely consolidated gravel, sand and silt, and a few beds of basalt and tuff; at places, the sequence is more than 6,000 feet thick. All water wells of large capacity are completed in rocks of Tertiary and Quaternary age.

In the Albuquerque area, and for the purposes of this study, the rocks of primary concern are the Santa Fe Group, alluvial fans, and valley alluvium. Bjorklund and Maxwell state that the Santa Fe Group, of middle(?) Miocene to Pleistocene(?) age, underlies the surficial deposits of the Rio Grande valley and crops out on the east and west mesas. Materials of the Santa Fe Group in the Albuquerque area were derived by erosion of the highlands east and west of the Rio Grande depression and by volcanic activity and erosion of the highlands farther north.

The Santa Fe Group consists of beds of unconsolidated to loosely consolidated sediments and interbedded volcanic rocks. The deposits range from boulders to clay and from well-sorted stream-channel deposits to poorly sorted slopewash deposits. Extrusive volcanic rocks of Tertiary and Quaternary ages,mainly basaltic rocks, are interbedded with the sediments.

The permeability of the Santa Fe Group generally is high except in

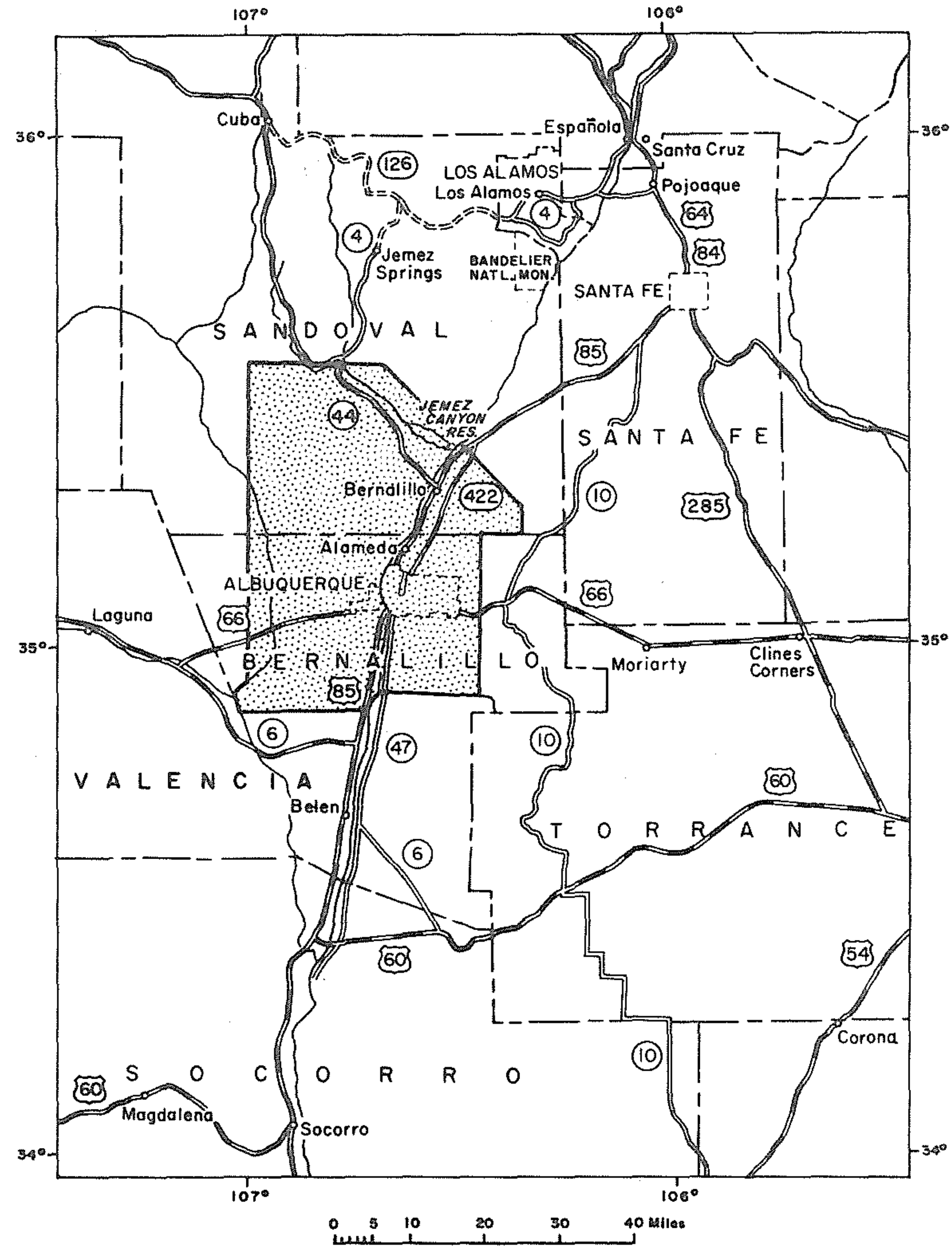

FIGURE 1. -- Area (stippled) described in this report.

the Rio Puerco valley along the west side of the graben and in the lower part of the group along the base of the Sandia and Manzano Mountains. Near the mountain front and in the Rio Puerco valley, the permeability of the group has been decreased by cementation along several fault zones. An area of low permeability, resulting from the presence of fine-grained sediments, extends southward from the Bernalillo-Sandoval County line on the east side of the Rio Puerco and is about 4 or 5 miles wide; another such area occurs just south of Tijeras Arroyo on the east mesa.

Wells properly constructed in the Santa Fe Group will yield several hundred gallons of water per minute except in areas of low permeability. The wells of large capacity generally are screened and gravel packed.

A series of coalescing alluvial fans of Recent age were deposited unconformably on the Santa Fe Group. They extend westward from the base of the Sandia and Manzano Mountains to the bluffs along the east side of the Rio Grande valley. The sediments composing the fan deposits range from poorly sorted mudflow material to well-sorted stream gravel. The beds consist of channel fill and lenticular interchannel deposits. The fan deposits range in thickness from 0 to 200 feet and thicken toward the mountains. The deposits generally are above the water table and are not aquifers; however, along the mountain front they may be saturated and may yield small amounts of water. Much of the floodflow in the arroyos infiltrates into the deposits and percolates downward into the Santa Fe Group.

Valley alluvium of Recent age underlies the flood plain of the Rio Grande and its tributaries. This alluvium is similar in appearance and composition to sediments of the underlying Santa Fe Group and was derived from them in much of the area. Faults and folds are not apparent in the alluvium, and the beds are more nearly horizontal than those of the Santa Fe.

The contact of the alluvium with the underlying Santa Fe Group can be distinguished in well cuttings only with difficulty, but the contact probably is at a change in lithologic character and consolidation, generally between 80 and 120 feet below the land surface. The alluvium probably is thickest where fans from tributary valleys extend into the main valley and is thinnest in the tributary valleys.

Most of the irrigation wells along the Rio Grande tap the alluvium in the main valley; some wells are reported to yield as much as 3,000 gpm (gallons per minute). The alluvium in the tributary valleys generally is not saturated; however, the alluvium is saturated in some arroyos that are tributary to the Rio Puerco and in arroyos along the mountain front, and wells tapping this alluvium have small sustained yields where the alluvium is underlain by relatively impermeable rocks.

General Hydrology

Ground-water hydrology in the Albuquerque area has been described by Bjorklund and Maxwell. The following material on general hydrology in the Albuquerque area, taken largely from the cited source, has direct bearing on the quantitative phases of the study for this report.

The valley fill -- including the Santa Fe Group, the fan deposits, and the valley alluvium -- is the principal aquifer in the Albuquerque area. The Santa Fe Group, fan deposits, and valley alluvium are interconnected hydraulically and, collectively, make up a single aquifer which is referred to as "the ground-water reservoir" in this report. Water moves from one formation into the other in accordance with the local hydraulic gradient.

The ground water in the valley fill generally is unconfined, but locally artesian pressures may exist. The saturated zone in the valley fill has definite natural bounds at each side and the bottom. On the east side, the ground-water reservoir is bounded by the upfaulted blocks that form the Sandia and Manzano Mountains. On the west, the reservoir is bounded by similar, but less spectacular, upfaulted blocks near the Rio Puerco. The bottom of the reservoir is formed by beds of consolidated rock, probably of Mesozoic age, which were downfaulted and formed the depression in which the valley fill was deposited. The ends of the reservoir are open, for the valley fill in the Albuquerque area is only a segment of the ground-water reservoir that extends the length of the Rio Grande.

In nearly all the area underlain by valley fill, there is ground water at some depth in the fill, and in much of the area large supplies of water can be developed from this source. At places where the fill is thin, such as near the Sandia Mountains, and at places where a thick section of silt or clay has been deposited, yields of wells may be moderate to small.

The water table in the Albuquerque area, in general, is an irregular, sloping surface. The irregularities in the surface are caused by differences in permeability and saturated thickness or by additions or withdrawals of water.

The water table slopes at a low gradient diagonally downvalley from the bases of the Sandia and Manzano Mountains on the east and from the Rio Puerco on the west toward a generally southward-trending zone about 8 miles west of the Rio Grande. The water table along this zone is lower than the water table beneath the valley floor. This depression in the water table extends from north to south through most of the project area. A water-table mound, indicated by relatively high ground-water levels in the Jemez River valley, crosses the trough in the northern part of the project area.

The water table fluctuates as water is added to or withdrawn from the ground-water reservoir. Water-level fluctuations in wells may be brief, seasonal, or long term. Intense precipitation and irrigation by surface water diverted from streams tend to raise the water table; drought and pumping from wells tend to lower it.

Recharge, or water added to the ground-water reservoir, in the Albuquerque area is from precipitation, underflow of ground water from adjacent areas, and seepage from streams, drains, canals, surface reservoirs, and applied irrigation water. The order of importance of each type of recharge in the area depends on local conditions.

Recharge directly from precipitation can occur readily in the Albuquerque area at places where land materials are highly permeable, such as sandy-bottomed ephemeral stream channels, rubble-covered slopes, sand dunes, and scoriaceous lava flows. Other factors affecting recharge directly from precipitation include duration and intensity of precipitation, seasonal weather conditions that affect soil temperatures, and growth of vegetation.

Much recharge to the ground-water reservoir comes from streams, particularly the Rio Grande. Recharge occurs also from such ephemeral streams as the Rio Puerco and Jemez River, and from normally dry canyons and arroyos. As the Rio Grande is the only perennial stream and probably is the greatest source of recharge from streams, it is of primary concern in this study.

The channel of the Rio Grande in most of its reach throughout the Albuquerque area is not entrenched into the valley floor but has been built up by sedimentation to an elevation approximately level with, and at some places slightly above, the valley floor. Consequently, the river flows at the level of the general land surface and is higher than the water table on each side because the water table generally is kept a few feet below the land surface by drains. As the bed of the river is above the water table of the adjacent land, the river loses water by infiltration. As the water table builds up under the riverbed, the water spreads out in the fill. Some water is intercepted by drains which conduct it back to the channel; some is consumed by plants; some is evaporated from the soil; and some underpasses the drains and moves outward from the river to other areas.

In addition to evaporation, transpiration, river and drain flow, and the natural underflow of the ground water generally southward out of the area, yet another means of discharge has been superimposed on the system. About 300 large-discharge municipal, industrial, and irrigation wells, and about 1,000 small-discharge wells, also used in yard and garden irrigation, plus a large number of domestic and stock wells, have been drilled in the area. The main effects of pumping water from wells are lowered ground-water levels and decreased flow of streams and drains.

Population

The Albuquerque metropolitan area includes the corporate urban area and several adjoining or outlying towns and communities. The total population in 1960 was about 260,000. Most inhabitants -- about 200,000 in 1960 -- live in Albuquerque proper where population has increased

TABLE 1

POPULATION AND ANNUAL PUMPAGE IN THE ALBUQUERQUE AREA FOR DECADAL YEARS IN THE PERIOD 1920-2000, AND AVERAGE ANNUAL PUMPAGE AND INCREMENTAL PUMPAGE BY DECADE, 1920-2000.

Year	Population (approximate)	Annual pumpage (public and private industrial) discharging to sewer system (acre-feet)	Annual pumpage not discharging to sewer system (acre-feet)	Total annual pumpage (acre-feet)	Average annual pumpage for decade (acre-feet)	Average annual incremental pumpage (acre-feet)
1920	15,000	3,000		3,000		
					4,500	4,500
1930	27,000	6,000		6,000		
					8,000	3,500
1940	35,000	7,900	2,100	10,000		
					19,500	11,500
1950	100,000	22,500	6,500	29,000		
					46,000	26,500
1960	200,000	45,000	18,000	63,000		
					89,500	43,500
1970	400,000	90,000	26,000	116,000		
					131,250	41,750
1980	500,000	112,500	34,000	146,500		
					173,000	41,750
1990	700,000	157,500	42,000	199,500		
					226,250	53,250
2000	900,000	203,000	50,000	253,000		

from about 15,000 since 1920. Table 1 gives municipal population for decadal years from 1920 to 1960 as well as projections of future population for decadal years to A. D. 2000, based upon projections made in 1960 by the U.S. Senate Select Committee on National Water Resources, pursuant to Senate Resolution 48, 86th Congress.

Utilization of Ground Water

Public supply accounts for the greatest use of ground water in the study area, and as the population growth continues this lead will become more pronounced. Ground water also is pumped for irrigation to supplement the surface-water supply from the Rio Grande. In addition to municipal water systems, some business establishments, some industrial and commercial institutions, some urban developments, and some public and private institutions have individual water systems served by wells. Most such organizations, however, have emergency connections with the Albuquerque water-supply system and most are served by the Albuquerque sewer system. For the purpose of this report, all ground-water pumpage is combined and discussed together.

Annual pumpage in the Albuquerque area increased from about 3,000 acre-feet, or 2.7 mgd (million gallons per day), in 1920 to about 10,000 acre-feet in 1940 and to some 63,000 acre-feet, or 55.9 mgd, in 1960 -- primarily as a result of the growth of the city and development of nearby areas. In addition to population, table 1 shows pumpage for public and industrial supplies contributing to the Albuquerque sewer system for decadal years in the period 1920-2000, pumpage not contributing to the sewer system for the same years, total annual pumpage for decadal years, average annual pumpage by decade, and average annual incremental pumpage by decade.

FUNDAMENTALS OF PRESENT STUDY

Principles

The hydraulic principles involved in this study can best be illustrated with a discussion of the effects of a pumping well on the aquifer tapped. A radial hydraulic gradient toward a well is necessarily established in the aquifer as the well is pumped, and that gradient causes the water to flow toward the well. The gradient is established by lowering the water level, and the lowest point on the water table in the vicinity of the well is at the pumped well. The water discharged from the well in the initial period of pumping is released from storage in the aquifer close to the well. As pumping continues, a greater percentage of water is released from storage at increasing distance from the pumped well. The increase in volume of water released from storage at greater distances is accompanied by a decrease in the rate of decline of water level at the pumped well. The decline in water level will continue, at a decreasing rate, unless the discharge rate is changed or unless the area of influence caused by pumping reaches impervious boundaries, or other areas of discharge, or areas of recharge. The effect of pumping a well commonly is noticeable in nearby wells tapping the same aquifer, but the effect in more distant wells is less obvious. Similarly, the stage of the river affects water levels in wells along the river. Also, changes in water levels, such as those caused by pumping from wells, affect the flow of the river.

The shape of the water table is controlled in part by the ease with which water can move through the aquifer, expressed quantitatively by the coefficient of transmissibility. That is, for a given pumping rate, the greater the transmissibility of an aquifer, the more gentle the gradient toward the well and, correspondingly, the less the drawdown in the well. For a given transmissibility, the gradient toward the well increases as the pumping rate increases. The greater the coefficient of storage, which can be expressed as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface, the less water levels need to be lowered to supply a unit volume of water.

In the Rio Grande valley, where ground water occurs in the valley alluvium along the river, recharge to the aquifer from which wells are pumping can be increased by lowering the water levels below the stage of the river and the drains. Conversely, water is discharged from the aquifer to the river or drains at times when their stage is lower than the water table in the valley. In the Albuquerque area, the water comes from storage during the initial phase of pumping. After a well has been pumped for a period of time, the length of time depending upon the aquifer characteristics and distance between the well and the river, more and more pumped water is diverted from inflow to the river or is derived by infiltration from the river. Thus, for a given pumping rate the decline in water level due to pumping diminishes with time, provided the flow of the river continues. The ease with which water moves in the ground (the ease with which it moves from the river to the aquifer or from the aquifer to the river) and the amount of transfer depend largely on the aquifer characteristics.

Aquifer characteristics in the Albuquerque area were determined by a number of pumping tests. The drawdown and recovery of water levels were measured during and after pumping the wells at measured rates. Bjorklund and Maxwell report that the coefficient of transmissibility in 22 wells ranged from 50,000 to 600,000 gpd (gallons per day) per foot of aquifer and at another well was 7,500 gpd per foot. On the basis of these tests and the specific capacities of other wells, average coefficients of transmissibility were determined for ease of use in this study. The coefficients of transmissibility used are 200,000 gpd/ft east of the Rio Grande and 100,000 gpd/ft west of the Rio Grande. The estimated coefficient of storage is 0.2 for both sides of the river (Bjorklund and Maxwell.

Using known or assumed values of aquifer characteristics, quantity of water required, and location of wells, the future lowering of water levels can be predicted for those conditions.

Population Projection and Future Water Requirements

The marked increase in pumpage of ground water in the Albuquerque area in the recent past is expected to continue in the future. The principal factors affecting future water needs of the area are population increase and industrial and agricultural expansion. Projections of future population and economic growth were therefore necessary for the study.

According to estimates by the U.S. Senate Select Committee on National Water Resources (1960, p. 20), the population of Albuquerque will be about 400,000 in 1970; 500,000 in 1980; and 900,000 in the year 2000, as shown in table 1. Actually, the committee cited six U.S. Bureau of the Census projections of Albuquerque population growth in "low," "middle," and "high" categories for the years 1970, 1980, and 2000 -- based on two different assumptions (p. 5) regarding migration, as follows:

> "Assumption No. 1 was that--The average annual migration of the period 1950-58 is assumed to prevail to 1970 and then the average annual amount of migration of the 1940-58 period is assumed to prevail for the period 1970-80.
>
> "Assumption No. 2 was that--Average annual amount of migration during the period 1958 to 1980 is assumed to equal one-half that of the 1940-58 period.
>
> "After 1980, for both assumptions--It was assumed that the change in the proportion of population in each State between 1980 and 2000 will be the same as the change in the proportion that occurred between 1970 and 1980, as implied by the projections for these dates."

In projecting pumpage and behavior of water levels to A.D. 2000, the "middle" category under migration assumption No. 1 was selected as a population base for the present study. Annual pumpage from public-supply wells was projected on the basis of 200 gpd as the average per capita use of water by Albuquerque residents during the period 1960-2000. Although per capita use of water has been increasing during recent years, the percentage of people living in apartments will increase as the city becomes more congested, and this factor should cause a decrease in the area of lawns, trees, and shrubs per capita. Pumpage of water from industrial, irrigation, and other wells is expected to increase at the rate of 8,000 acre-feet every 10 years. The total estimated annual pumpage in the area from 1920 to 2000 is shown in table 1. Population and annual pumpage from 1920 to 1960 and projections of both to the year 2000 are shown graphically in figure 2.

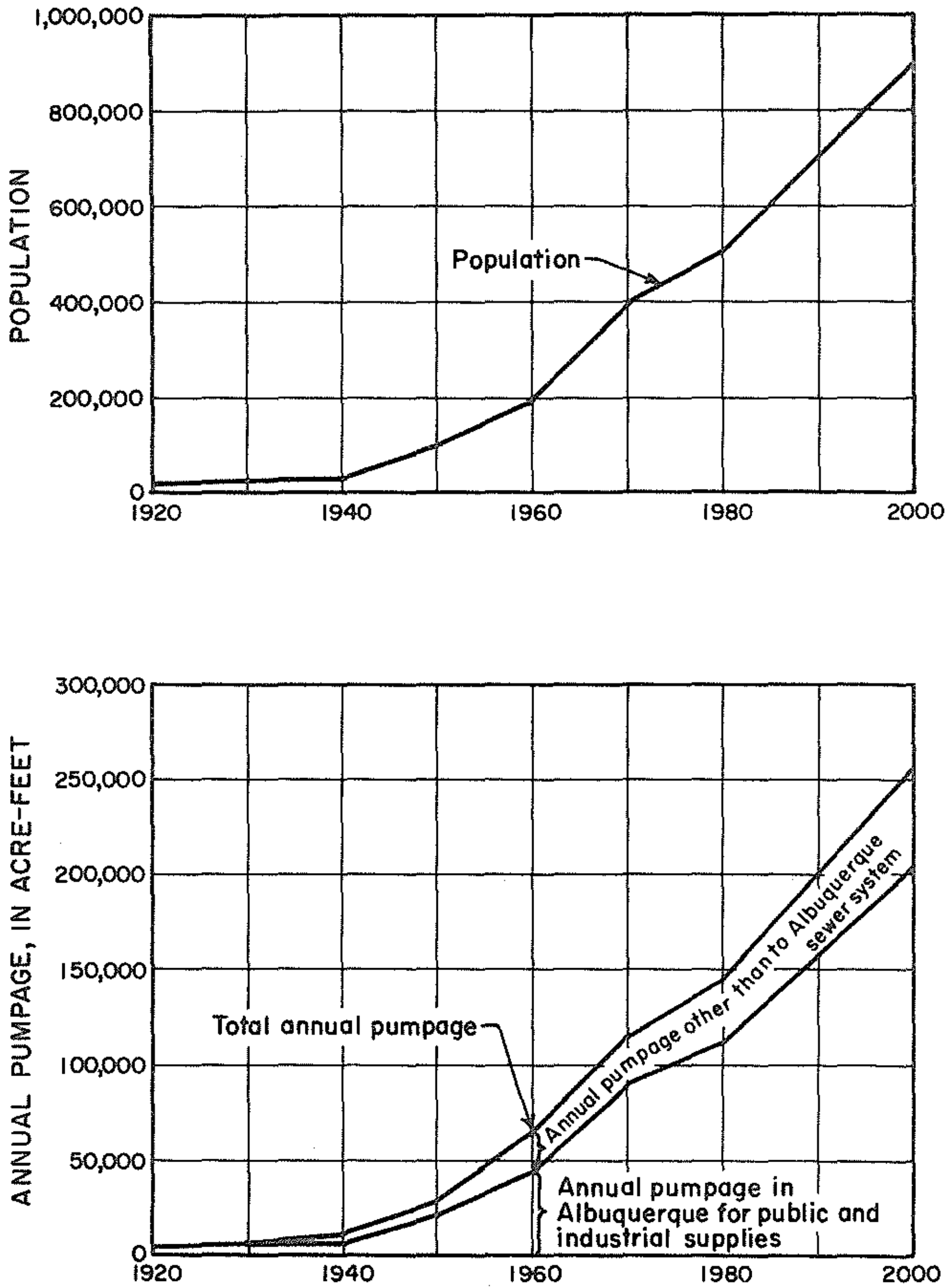

FIGURE 2. -- Population and ground-water requirements of the Albuquerque area, New Mexico, from 1920 to 1960, and projected to A.D. 2000.

Basic Assumptions

Computations of the effects on water levels of past, present, and future pumpage in the Albuquerque area are based on the following assumptions:

1. The average coefficient of transmissibility (T) of the valley fill is about 200,000 gpd/ft east of the Rio Grande and about 100,000 gpd/ft west of the Rio Grande. The coefficient of storage (S) is about 0.2. These estimates are based in general on aquifer tests and are believed to be conservative.

2. The aquifer is bounded on each side by areas of low permeability that reflect pumping effects in the aquifer and cause increased drawdown. The general position of these boundaries, simplified by straight or gently curving lines, is shown in plate 1. The boundary on the east is meant to approximate the position of the western front of the upfaulted Sandia-Manzano mountain blocks. The boundary on the west is meant to approximate, in part, the eastern margin of deposits of relatively low permeability in the valley fill and possibly the eastern front of upfaulted earth blocks at depth.

3. The Rio Grande will function as a recharge boundary, separating the effects of pumping on one side of the river from the effects of pumping on the other side. There will be no drawdown at or immediately adjacent to the river.

4. The population of Albuquerque will be about 400,000 in 1970; 500,000 in 1980; 700,000 in 1990; and 900,000 in 2000.

5. The average per capita gross use of water from municipal wells only will be about 200 gpd for the next 40 years. Additional water will be pumped from irrigation and nonmunicipal industrial and public-supply wells.

6. The pumping pattern will expand first in areas where the possibility of developing wells of large capacity has already been proved (i. e., areas on the east mesa, the valley floor upstream from the city, the valley floor downstream from the city, and areas on the west mesa northwest of the city); thereafter, pumping will spread to other parts of the west mesa where development has been delayed by greater depth to water (500 to more than 900 feet) and locally by the presence of fine sand. Estimated annual pumpage in 1959 and that estimated by decades from 1920 to 2000 are shown in table 2.

COMPUTED LOWERING OF THE WATER TABLE

In order to estimate or compute the future effects of pumping as reflected in the lowering of water levels in the study area, the preceding basic assumptions were utilized. Factors given special consideration are the quantity of water that will be required, the hydraulic characteristics and extent of the aquifer, and the locations of wells -- both those in use in 1960 and the probable locations of future developments. In addition to the computation of future lowering of water levels based on these assumptions, it seems desirable to discuss the modifications that would occur in the expected lowering, should the various factors on which the computation is based differ from those stated.

The Albuquerque area was subdivided into squares of 9 sections or 9 square miles each (four areas to a township), and squares were numbered by a letter-number grid system (plate 1). Pumpage from individual wells was estimated for 1959, and the composite pumpage figure for each area is tabulated opposite 1959 in table 2. Future pumpage, by decades, was estimated (table 2) according to a plan of expansion described in basic assumption 6. Estimated average annual incremental pumpage (increases in pumpage) and, thence, the drawdown factors, also are shown in plate 1, as are pumping centers for each composite pumpage figure, determined for each 9-square-mile area. Image pumping centers that reflect the pumping effects were located opposite the boundaries. Drawdown centers (points at which it is desired to compute changes in water level) were then selected and also are shown in plate 1. The pumping centers and drawdown centers were numbered according to the letter-number grid system adopted.

Changes in water levels at drawdown points were determined by means of 16 drawdown scales constructed for the conditions described above (see also Conover and Reeder, 1957). The scales are based on the Theis nonequilibrium formula (Theis, 1935). Scales for 80, 70, 60, 50, 40, 30, and 10 years were designed for the stated conditions on each side of the Rio Grande. The average annual incremental pumpage for each decade (the increase in pumpage over that of the preceding decade), as shown in table 2, was used -- with the scale representing the number of years from the beginning of the particular decade until the year 2000. The drawdown that would result directly from a pumping center at 100 acre-feet per year, or 66 gpm, was measured first and then the reflected drawdowns from images of that pumping center beyond the boundaries were measured. The algebraic sum of the drawdowns multiplied by the pumpage factor, representing the estimated pumpage of the center in hundreds of acre-feet per year, is the drawdown caused by the pumping center during the particular period of time represented by the scale and drawdown factor. This process was repeated for all pumping centers within scale reach of the particular drawdown point. The process was then repeated for other scales representing other intervals of time and incremental pumpage. The total expected lowering of water levels at a point is the sum of the drawdowns directly resulting from pumping all the wells in the area, plus their image effects as reflected from the boundaries. When the total change in water level at a drawdown point was determined, the complete process was repeated at other points.

The lowering of the water level from 1960 to 2000 cannot be computed directly because of the effects of pumping prior to 1960. The lowering from 1920 (taken as the beginning of pumping) to 2000 was first computed, after which the lowering from 1920 to 1960 was computed. The expected lowering from 1960 to 2000 is the difference between the lowering from 1920 to 2000 and that from 1920 to 1960. The expected lowerings at the drawdown centers from 1960 to 2000, based on the preceding assumptions, are shown in plate 1. The points of equal drawdown were joined by contour lines to indicate graphically the configuration and magnitude of the computed lowering of the water levels.

The greatest water-level decline east of the Rio Grande, 85.9 feet, is expected to occur under the northeast heights about 6 miles east of downtown Albuquerque and about 3 miles north of Highway 66. It was computed that a lowering of almost 11 feet occurred at this point between 1920 and 1960. Water levels west of the Rio Grande are expected to decline most (33.7 feet) about 9 miles northwest of downtown Albuquerque. Water levels declined little, if any, in that area before 1960. Outward from these points the lowering will be less in all directions, particularly toward the Rio Grande. No decline is shown along the river because of basic assumption 3. The boundaries to the east and west of the area have the effect of increasing the lowering because of the assumption of little or no flow of ground water across the boundaries (plate 1).

Although the coefficient of transmissibility west of the Rio Grande is less and would cause greater drawdowns than would result from equal pumpage east of the river, it is assumed (basic assumption 6) that intensive development of ground water west of the river will be somewhat delayed, and that -- consequently -- by the year 2000 water levels west of the river will not have declined at the rate they will have declined east of the river.

Several factors may cause computed lowering of water levels to vary from actual lowering.

1. It is assumed that the parts of the aquifer east and west of the Rio Grande are homogeneous throughout each part, both areally and in depth. Well logs, aquifer tests, and specific capacities of wells indicate that the character of the water-bearing material on both sides of the river varies within short distances and also with depth. For the computations, an estimated average value of the aquifer characteristics within each set of boundaries had to be used.

2. It is assumed that the wells are pumped continuously at a uniform rate. Even though this does not happen, the assumption is reasonable for long-term computations.

3. The boundaries of the aquifer have been idealized. This is necessary for computation because of the greatly increased complexity in dealing with a large number of wells and image wells if complex boundaries are used. Volcanic craters and rock protrusions further complicate the problem, for they may act as local ground-water boundaries.

4. For the purpose of computation it is assumed that the water pumped is from storage, that there is no natural recharge to or discharge from the aquifer except from or to the river. Further, it is assumed that there is no recharge from return flow from irrigation except that

returned through the river. There is no known practical method to measure the amount of return irrigation water, but on the inner valley floor it has been estimated (Bjorklund and Maxwell) at about a third of all water applied.

As additional data become available, it may become apparent that the coefficient of transmissibility used in the computations is not representative. If, for example, the coefficient of transmissibility were found to be 60,000 instead of 100,000 west of the Rio Grande and 120,000 instead of 200,000 east of the Rio Grande, the drawdown at the end of 40 years would be somewhat greater in the center of heavy pumping and somewhat less in the outlying areas than the drawdowns shown in plate 1. The illustration could be modified to take this into account by designating it as a 66.7-year lowering map and multiplying each value of lowering by 1.67. That is, if the coefficient of transmissibility differs from that used in the computations, the interval of time of the drawdown map and the drawdowns shown on plate 1 must be multiplied by the inverse of the ratio of the new coefficient to that used in the computations. Thus, the average rate of lowering for the new period of time would remain the same.

If the coefficient of storage were found to be other than 0.20, appropriate corrections to the computed lowering would again be necessary. For example, if 0.12 were determined to be more representative, the map would be correct if the time were changed from 40 years to 24 years. Also, if coefficients of transmissibility of 60,000 west of the Rio Grande and 120,000 east of the Rio Grande and a coefficient of storage of 0.12 were found to be more representative, the map could be corrected for the 40-year period by multiplying the values of the lowering by 1.67.

Further, if actual consumptive use (gross pumpage less return to the water table) differs from computed consumptive use, actual decline in the water levels will be to the computed declines as the ratio of actual use is to computed use. That is, if the unit use of water is smaller than computed use by decades as shown in table 2, the actual declines in 40 years would be proportionately less than the computed declines.

The boundaries of the aquifer have an appreciable effect on the lowering of water levels in parts of the area. With locations as assumed in plate 1 and as used in the computations, about half the computed lowering in the vicinity of the relatively impermeable boundaries on the east and west sides of the area will be caused by pumping near the impermeable boundaries. In the area of greatest decline under the east mesa, about 30 percent of the computed drawdown is due to pumping near the impermeable boundary on the east, but the recharging boundary on the west has an opposite effect of about 25 percent in that area. There will be no drawdown immediately adjacent to the river. The boundaries of the aquifer are not idealized as in plate 1, and they may be at greater or lesser distances from the center of pumping than has been assumed. If the relatively impermeable boundaries are at lesser distances from the pumping, the water levels will decline more than calculated and additional reflected boundary effects would occur in a shorter time, resulting in still further lowering of water levels. Conversely, if the impermeable boundaries are farther from pumping than assumed, the lowering of water levels will be less than computed.

Form of the Water Table as Affected by Pumping

The form of the water table is changed as pumping lowers water levels. Plate 2, from Bjorklund and Maxwell, shows by contour lines the configuration of the water table in 1960 and, by inference, the direction of movement of ground water. The ground water moves generally downgradient at right angles to the contour lines. The irregular shape of the contours, particularly east of the Rio Grande near Albuquerque, reflects the effects of pumping before 1960. The computed change in water levels from 1960 to 2000 (pl. 1) as a result of expected future pumping has been superimposed on the water-table contours in 1960 (pl. 2) to obtain the map of the expected form of the water table in the year 2000 (pl. 3), as resulting from conditions set forth in the basic assumptions.

The pumping, as indicated in plate 3, will cause the water-table gradient east of the Rio Grande in the vicinity of Albuquerque to be reversed and the altitude of the water table 5 to 8 miles east of the river to decline below the altitude of the adjacent reach of the river. As the water-table gradient is reversed, ground water will move eastward from the Rio Grande, and a larger part of the water pumped from wells will be derived from the river. In 1960, part of the pumped water was derived from the river; of greater significance, probably, was interception of ground water that otherwise would have reached the river.

Water-table contours of the same elevation will be displaced upgradient as the water table lowers. The extent of this displacement between 1960 and 2000 for the given conditions can be noted by comparing plates 2 and 3.

The computed water-level change is shown also in figure 3 -- a profile of the water table in 1960 and computed water table in 2000 on an east-west line through Albuquerque. The profile of the ground surface and a few landmarks are shown for reference.

Depths to Water in the Year 2000

Plate 4 shows estimated depths to water in the year 2000, based on water-table contours in 1960 and computed changes in water levels from 1960 to 2000. Plate 4 was constructed by subtracting the altitude of the computed water table in 2000 (pl. 3) from the altitude of the land surface at section corners and intermediate points where necessary throughout the area. The depth to water near the river in 2000 will not change appreciably from that shown for 1960 by Bjorklund and Maxwell for

TABLE 2

PROJECTED AVERAGE ANNUAL PUMPAGE, AVERAGE ANNUAL INCREMENTAL PUMPAGE, AND DRAWDOWN FACTORS BY DECADES FROM 1920 TO 2000, BASED ON PUMPAGE IN 1959 IN THE ALBUQUERQUE AREA, NEW MEXICO.

		R. 1. E.						R. 2 E.					
		1			2			3			4		
	Decade or year	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors
	1920-1930												
	1930-1940												
	1940-1950												
	1950-1960												
N	(1959)												
	1960-1970												
	1970-1980												
	1980-1990												
T.	1990-2000												
13 N.	1920-1930												
	1930-1940												

		R. 3 E.						R. 4 E.					
		5			6			7			8		
	Decade or year	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors
	1920-1930												
	1930-1940												
	1940-1950												
	1950-1960										1,000	1,000	10 0
N	(1959)										(1,013)		
	1960-1970										1,500	500	5.0
	1970-1980										3,000	1,500	15.0
	1980-1990							1,000	1,000	10.0	4,000	1,000	10.0
T.	1990-2000							2,000	1.000	10.0	5,000	1,000	10 0
13 N.	1920-1930												
	1930-1940							100	100	1.0			

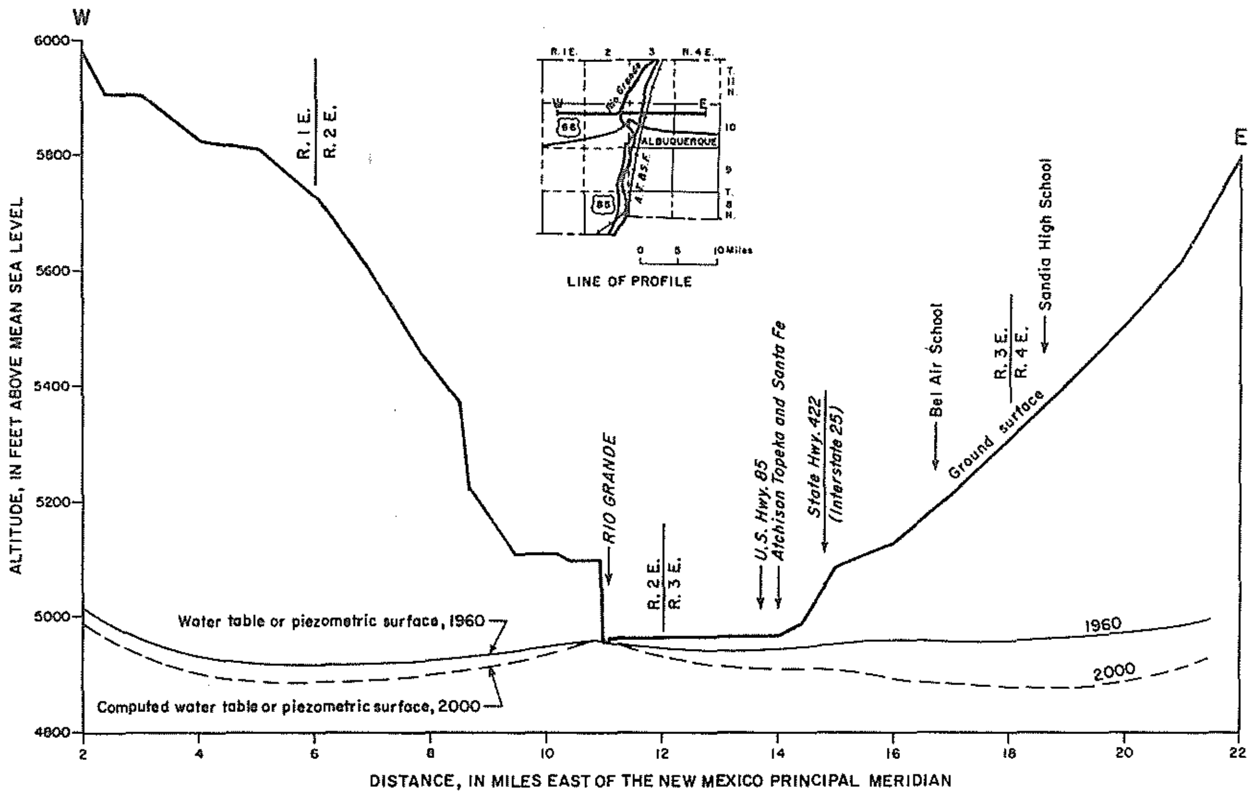

FIGURE 3. -- Profile of the water table in 1960, of the computed water table in 2000, and of the ground surface of the Rio Grande valley at Albuquerque, New Mexico.

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reasons set forth in basic assumption 3. The greatest difference in the two maps is that under the mesas the contours of depth to water for the year 2000 are generally closer to the elevation of the river channel than the corresponding contours for 1960. Minor variations in the contour alinement due to variations in technique of map construction may be noted.

PUMPING EFFECTS ON THE RIO GRANDE

As the pumping of ground water in the Albuquerque area eventually affects the flow of the Rio Grande, it is desirable to know to what extent the river is affected. The effects on the river were computed from the same basic assumptions of aquifer characteristics and rate and pattern of ground-water development as were used in previous computations.

Pumped Water Derived from the Rio Grande

The effect of pumping on the river (Theis, 1953) was computed for each pumping center shown in plate 1 and for each decade from 1920 to 2000; that is, the percentage of water pumped that is derived from the river for each decade of pumping from each center was determined and multiplied by the appropriate average annual incremental pumpage to give the amount of the pumped water that was or will be derived from the river. The sum of the increments of pumped water derived from the river and the sum of the average annual incremental pumpages are expressed as the percentage of pumped water that is derived from the river for each pumping center. The total water pumped and the amounts of water derived from the river for all pumping centers in the area were then determined and expressed as overall percentages for decades from 1920 to 2000. The results are shown by graphs in figure 4.

The top curve in figure 4 shows the computed percentages of the pumped water that are derived from the river during each decade. The curve is nearly flat during the first and last parts because of pumpage at increasing distances from the river. The greatest change in location of pumpage in distance from the river apparently occurs in the decades 1950-60 and 1960-70. About 80 percent of the water pumped from 1920 to 1960 was derived from the river. From 1960 to 2000 between 71 and 76 percent of the water will be derived from the river.

The bottom two curves in figure 4 show the average annual pumpage and the part of the pumped water derived from the river for each decade from 1920 to 2000. The illustration shows that in the decade 1950-60 an average of 46,000 acre-feet of water was pumped annually, of which 37,200 acre-feet was derived from the river. These quantities will increase. In the decade 1990-2000, it is computed that an average of 226,000 acre-feet of water will be pumped annually; of this quantity, 165,000 acre-feet (230 cfs) will be derived from the river.

The average flow of the Rio Grande at Albuquerque during the 17 years prior to 1959 was 1,006 cfs (U.S. Geol.Survey, 1960, p. 414). These figures indicate the flow of the Rio Grande is sufficient to support the basic assumption of continuous flow of the Rio Grande past Albuquerque. Part of the decreased flow of the Rio Grande caused by pumping ground water is offset, as a considerable part of the water pumped is released to the river. Björklund and Maxwell (p.56) state that slightly more than half the water used by installations served by Albuquerque sewers is discharged as effluent from the sewage-disposal plant. Also, the consumption of water pumped for industrial use and not routed through the sewage plant ranges from about 50 percent to almost nothing. Additionally, it is estimated that about 30 percent of the water pumped for irrigation of cropland returns to the ground-water reservoir.

The quantity of water pumped for rural domestic and livestock use in the area is small compared with the quantity pumped for other uses. Perhaps 50,000 people live beyond the reach of the public water system.

TABLE 2

PROJECTED AVERAGE ANNUAL PUMPAGE, AVERAGE ANNUAL INCREMENTAL PUMPAGE, AND DRAWDOWN FACTORS BY DECADES FROM 1920 TO 2000, BASED ON PUMPAGE IN 1959 IN THE ALBUQUERQUE AREA, NEW MEXICO.

			R. 1 E.						R. 2 E.					
			1			2			3			4		
		Decade or year	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960												
	N	(1959)												
		1960-1970												
		1970-1980												
		1980-1990												
T. 13 N.		1990-2000												
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960												
	M	(1959)												
		1960-1970												
		1970-1980												
		1980-1990												
		1990-2000												
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960												
	L	(1959)												
		1960-1970												
		1970-1980												
		1980-1990												
T. 12 N.		1990-2000							150	150	1.5	1,000	1,000	10.0
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960												
	K	(1959)												
		1960-1970												
		1970-1980										300	300	3.0
		1980-1990										1,000	700	7.0
		1990-2000				500	500	5.0	1,000	1,000	10.0	2,000	1,000	10.0
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960												
	J	(1959)												
		1960-1970							1,000	1,000	10.0	1,000	1,000	10.0
		1970-1980							3,000	2,000	20.0	3,000	2,000	20.0
		1980-1990				300	300	3.0	4,000	1,000	10.0	4,000	1,000	10.0
T. 11 N.		1990-2000				1,000	700	7.0	5,000	1,000	10.0	5,000	1,000	10.0
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960										1,000	1,000	10.0
	H	(1959)										(1,530)		
		1960-1970										2,000	1,000	10.0
		1970-1980				500	500	5.0	2,000	2,000	20.0	3,000	1,000	10.0
		1980-1990				1,000	500	5.0	3,000	1,000	10.0	4,000	1,000	10.0
		1990-2000				2,000	1,000	10.0	4,000	1,000	10.0	6,000	2,000	20.0
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960										5,000	5,000	50.0
	F	(1959)										(7,740)		
		1960-1970							700	700	7.0	8,000	3,000	30.0
		1970-1980				500	500	5.0	2,000	1,300	13.0	9,000	1,000	10.0
		1980-1990				1,000	500	5.0	3,000	1,000	10.0	10,000	1,000	10.0
T. 10 N.		1990-2000				2,000	1,000	10.0	4,000	1,000	10.0	10,000	0	0
		1920-1930												
		1930-1940												
		1940-1950										500	500	5.0
		1950-1960										5,000	4,500	45.0
	E	(1959)										(6,860)		
		1960-1970							1,000	1,000	10.0	7,000	2,000	20.0
		1970-1980				500	500	5.0	2,000	1,000	10.0	8,000	1,000	10.0
		1980-1990				1,000	500	5.0	3,000	1,000	10.0	9,000	1,000	10.0
		1990-2000				1,000	0	0	3,000	0	0	10,000	1,000	10.0
		1920-1930												
		1930-1940												
		1940-1950										500	500	5.0
		1950-1960										1,000	500	5.0
	D	(1959)										(1,510)		
		1960-1970										2,000	1,000	10.0
		1970-1980							500	500	5.0	3,000	1,000	10.0
		1980-1990							1,000	500	5.0	4,000	1,000	10.0
T. 9 N.		1990-2000				1,000	1,000	10.0	2,000	1,000	10.0	6,000	2,000	20.0
		1920-1930												
		1930-1940												
		1940-1950										500	500	5.0
		1950-1960										2,000	1,500	15.0
	C	(1959)										(2,420)		
		1960-1970										2,500	500	5.0
		1970-1980										3,000	500	5.0
		1980-1990							500	500	5.0	4,000	1,000	10.0
		1990-2000				500	500	5.0	1,000	500	5.0	4,000	0	0
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960										100	100	1.0
	B	(1959)										(101)		
		1960-1970										100	0	0
		1970-1980										200	100	1.0
		1980-1990										500	300	3.0
T. 8 N.		1990-2000				500	500	5.0	500	500	5.0	1,000	500	5.0
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960												
	A	(1959)												
		1960-1970												
		1970-1980												
		1980-1990												
		1990-2000												

			R. 3 E.						R. 4 E.					
			5			6			7			8		
		Decade or year	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors	Average annual pumpage (acre-feet)	Average annual incremental pumpage (acre-feet)	Drawdown factors
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960										1,000	1,000	10 0
	N	(1959)										(1,013)		
		1960-1970										1,500	500	5.0
		1970-1980										3,000	1,500	15.0
		1980-1990							1,000	1,000	10.0	4,000	1,000	10.0
T. 13 N.		1990-2000							2,000	1,000	10.0	5,000	1,000	10 0
		1920-1930												
		1930-1940												
		1940-1950							100	100	1.0			
		1950-1960				100	100	1.0	300	200	2.0			
	M	(1959)				(81)			(294)					
		1960-1970				100	0	0	500	200	2.0			
		1970-1980				1,000	900	9.0	1,000	500	5.0			
		1980-1990	1,000	1,000	10.0	2,000	1,000	10.0	2,000	1,000	10.0	1,000	1,000	10.0
		1990-2000	2,000	1,000	10.0	3,000	1,000	10.0	3,000	1,000	10.0	1,000	0	0
		1920-1930							200	200	2.0			
		1930-1940							200	0	0			
		1940-1950							1,000	800	8.0			
		1950-1960				100	100	1.0	2,000	1,000	10.0			
	L	(1959)				(183)			(2,170)					
		1960-1970				300	200	2.0	2,500	500	5.0			
		1970-1980				1,000	700	7.0	3,000	500	5.0			
		1980-1990	1,000	1,000	10.0	2,000	1,000	10.0	4,000	1,000	10.0			
T. 12 N.		1990-2000	2,000	1,000	10.0	4,000	2,000	20.0	5,000	1,000	10.0			
		1920-1930												
		1930-1940												
		1940-1950				300	300	3.0						
		1950-1960	100	100	1.0	300	0	0						
	K	(1959)	(101)			(492)								
		1960-1970	300	200	2.0	500	200	2.0						
		1970-1980	1,000	700	7.0	1,000	500	5.0	300	300	3.0			
		1980-1990	2,000	1,000	10.0	2,000	1,000	10.0	1,000	700	7.0			
		1990-2000	3,000	1,000	10.0	4,000	2,000	20.0	2,000	1,000	10.0			
		1920-1930												
		1930-1940												
		1940-1950	200	200	2.0									
		1950-1960	500	300	3.0	100	100	1.0						
	J	(1959)	(780)			(81)								
		1960-1970	1,000	500	5.0	200	100	1.0						
		1970-1980	3,000	2,000	20.0	1,000	800	8.0	50	50	0.5			
		1980-1990	4,000	1,000	10.0	2,000	1,000	10.0	100	50	0.5			
T. 11 N.		1990-2000	5,000	1,000	10.0	3,000	1,000	10.0	1,000	900	9.0			
		1920-1930												
		1930-1940												
		1940-1950	1,000	1,000	10.0	400	400	4.0						
		1950-1960	3,000	2,000	20.0	500	100	1.0						
	H	(1959)	(4,240)			(943)								
		1960-1970	6,000	3,000	30.0	6,000	5,500	55.0	6,000	6,000	60.0			
		1970-1980	8,000	2,000	20.0	7,000	1,000	10.0	7,000	1,000	10.0			
		1980-1990	9,000	1,000	10.0	8,000	1,000	10.0	8,000	1,000	10.0			
		1990-2000	10,000	1,000	10.0	10,000	2,000	20.0	10,000	2,000	20.0			
		1920-1930	2,300	2,300	23.0									
		1930-1940	4,800	2,500	25.0									
		1940-1950	9,000	4,200	42.0	500	500	5.0						
		1950-1960	11,000	2,000	20.0	1,000	500	5.0	500	500	5.0			
	F	(1959)	(12,820)			(1,301)			(756)					
		1960-1970	12,000	1,000	10.0	4,000	3,000	30.0	2,000	1,500	15.0			
		1970-1980	12,000	0	0	7,000	3,000	30.0	7,000	5,000	50.0			
		1980-1990	12,000	0	0	8,000	1,000	10.0	8,000	1,000	10.0			
T. 10 N.		1990-2000	12,000	0	0	9,000	1,000	10.0	9,000	1,000	10.0			
		1920-1930	2,000	2,000	20.0									
		1930-1940	3,000	1,000	10.0									
		1940-1950	4,000	1,000	10.0	500	500	5.0						
		1950-1960	5,000	1,000	10.0	1,500	1,000	10.0	1,000	1,000	10.0			
	E	(1959)	(5,020)			(2,490)			(4,320)			(548)		
		1960-1970	5,000	0	0	4,000	2,500	25.0	5,000	4,000	40.0	600	600	6.0
		1970-1980	7,000	2,000	20.0	6,000	2,000	20.0	5,000	0	0	1,000	400	4.0
		1980-1990	8,000	1,000	10.0	7,000	1,000	10.0	6,000	1,000	10.0	2,000	1,000	10.0
		1990-2000	9,000	1,000	10.0	8,000	1,000	10.0	7,000	1,000	10.0	2,000	0	0
		1920-1930												
		1930-1940												
		1940-1950	500	500	5.0	500	500	5.0						
		1950-1960	1,500	1,000	10.0	1,500	1,000	10.0	600	600	6.0	200	200	2.0
	D	(1959)	(1,842)			(1,862)			(650)			(324)		
		1960-1970	2,000	500	5.0	2,000	500	5.0	1,000	400	4.0	400	200	2.0
		1970-1980	3,000	1,000	10.0	2,000	0	0	1,000	0	0	400	0	0
		1980-1990	4,000	1,000	10.0	3,000	1,000	10.0	2,000	1,000	10.0	600	200	2.0
T. 9 N.		1990-2000	6,000	2,000	20.0	4,000	1,000	10.0	2,000	0	0	600	0	0
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960	100	100	1.0									
	C	(1959)	(101)						(51)					
		1960-1970	700	600	6.0	400	400	4.0	200	200	2.8			
		1970-1980	1,000	300	3.0	800	400	4.0	200	0	0			
		1980-1990	2,000	1,000	10.0	1,000	200	2.0	500	300	3.0			
		1990-2000	4,000	2,000	20.0	2,000	1,000	10.0	1,000	500	5.0			
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960												
	B	(1959)												
		1960-1970												
		1970-1980												
		1980-1990	500	500	5.0									
T. 8 N.		1990-2000	1,000	500	5.0	500	500	5.0						
		1920-1930												
		1930-1940												
		1940-1950												
		1950-1960												
	A	(1959)												
		1960-1970												
		1970-1980												
		1980-1990												
		1990-2000												

Accretion to or from Rio Grande, Computed by Gradient-River-Gain Method

The amount of water diverted from the Rio Grande, either by decreasing the natural flow to the river or by water infiltrating from the river, by wells pumping in the Albuquerque area was computed by using the water-table-gradient component to the river and the coefficient of transmissibility. A 35-mile reach of the Rio Grande through the Albuquerque area was used in the computation. The water-table gradient to or from the river in this reach was determined from the contour maps for 1960 (pl. 2) and 2000 (pl. 4). The coefficients of transmissibility used were as stated in the basic assumptions. The computation showed that in 1960 some 3 cfs of water flowed to the river from the east and 16 cfs flowed from the river to the west, for a net loss from the river of about 13 cfs or 10,000 acre-feet. In the year 2000, there is indicated a loss of 175 cfs from the river to the east and a loss of 68 cfs to the west for a

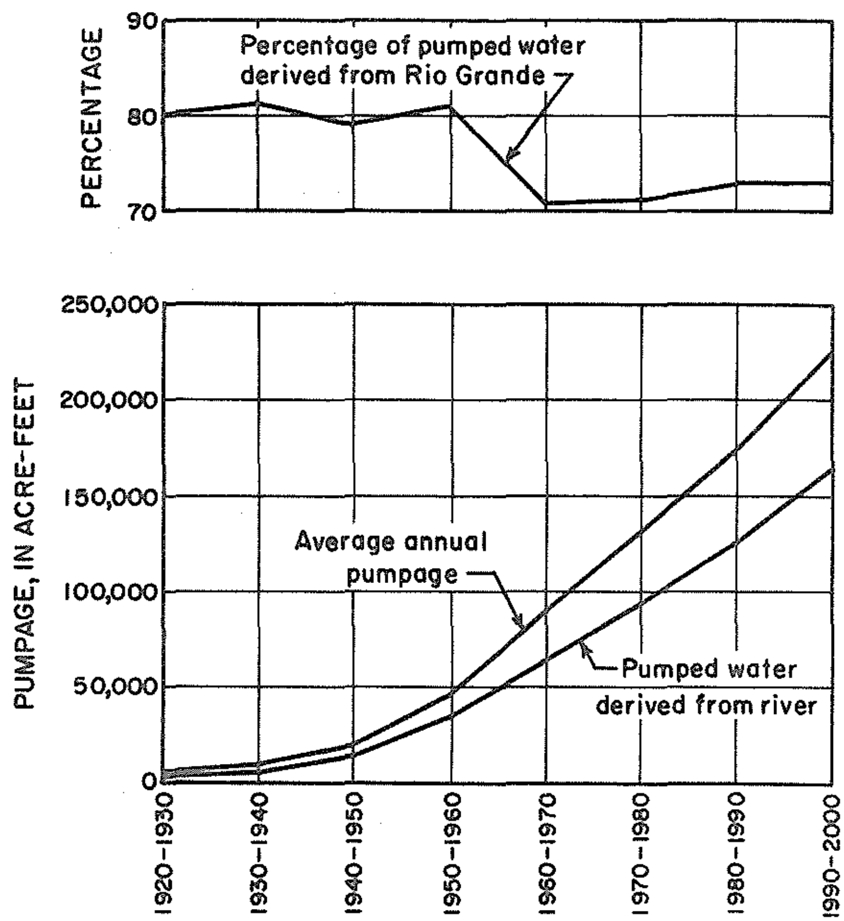


FIGURE 4. -- Average annual pumpage, by decade, and amount and percentage of pumped water derived from the Rio Grande from 1920 to 2000 in the Albuquerque area, New Mexico.

total flow from the river of 243 cfs or 175,000 acre-feet in the 35-mile reach.

Volume of Water Pumped versus Volume of Unwatered Sediments

The volume of water pumped, the volume of sediments unwatered by the pumping, and the coefficients of storage can be utilized as a further check of the computations. This check is based on the principle that the product of the coefficient of storage for an area and the volume of unwatered sediments in the area for a period of time should equal the actual volume of water pumped from the area for the same period of time, minus ground-water inflow to the area. If all the area within the contour of zero lowering is used, the ground-water inflow is zero and need not be considered in the computation; however, the inflow from a recharging boundary, such as the Rio Grande in this area, must be considered. The contour of zero lowering can be estimated, though it is not shown on the map of changes in water levels. The map of computed lowering of water levels from 1960 to 2000 (pl. 1) was used to compute the volume of unwatered sediments.

During the period 1960-2000, it is computed that 6,200,000 acre-feet of water will be pumped (table 1), of which 4,470,000 acre-feet will be derived from the Rio Grande (pumpage times the percentage derived from the river shown in figure 4). The pumpage minus inflow is 1,730,000 acre-feet, which compares favorably with the 1,810,000 acre-feet of water from the unwatered volume in plate 1, times the coefficient of storage of 0.20 (basic assumption 1). The estimated position of the contour of zero lowering has a significant effect on the computation and could account for the difference in the two answers.

Particle-Size Distribution of Sedimentation Along the Rio Grande

Sedimentation studies of the channel of the Rio Grande have been made by the U.S. Bureau of Reclamation. Some of the Bureau's basic data were used in this report in an attempt to evaluate the assumption that the character of the riverbed is such that water can be transmitted from the river to the aquifer as pumping lowers the water levels adjacent to the river. Plate 5 is a graphic presentation of sedimentation data at selected locations along the reach of the river that is pertinent to this report. The particle-size distribution of the sediments at a location is the average of all samples taken for the profile at that location.

Inspection of plate 5 reveals two interesting facts: 1) the largest percentage of the sediment at all locations but one is in the size range of 0.25 to 0.5 mm (millimeters), which is classified as medium sand; and 2) the percentage of sediment that is gravel (2 to 64 mm) is less at the downstream locations than at the upstream locations. It seems reasonable to assume, on the basis of the particle-size-distribution graphs, that the river could yield large quantities of water readily to the aquifer; however, the sorting of the different particle sizes was not determined. That is, the gravel may be evenly distributed, in layers or in pockets, and the silt and clay may be evenly distributed or in layers of low permeability. Therefore, the ability of the river to yield water to the aquifer may depend, at least in part, on local conditions of particle-size distribution and sorting.

In the course of this study, 10 to 15 holes were augered in the river's bed or flood plain. The cuttings were generally well sorted, indicating that the sediments had a high permeability that would allow water to infiltrate readily.

Profiles of Water Levels Near the Rio Grande

Water-level data from many observation wells in the vicinity of the Rio Grande were collected prior to 1938, as a part of the Rio Grande Joint Investigation. Some of these data, from selected points along the reach of the river pertinent to this report, together with data from later studies, are presented graphically in plate 6. The illustration shows that the gradient of the water table is from the river to the riverside drains. Although the water-level profiles do not indicate the position of the water table across the flood plain of the river, they do generally indicate a hydraulic connection between the river and the aquifer. Farther from the river, the gradient of the water table is from the riverside drains to the interior drains at some places, and from the interior to the riverside drains at other places. This difference in direction of water-table gradient may be due to local conditions of recharge, hydraulic barriers, and surface-water control.

In September 1962, two lines of auger holes were drilled in the east side of the river's flood plain in order to supplement available data on water levels in the valley and try to determine whether the river contributes water to the drains through the underlying aquifer. One line of holes was drilled south of Bernalillo from a pond of water on the flood plain to the riverside drain east of the river. The river was not flowing in this reach when the line of holes was drilled, but flow of a few hours' duration each occurred 4, 6, and 12 days prior to drilling of the holes. The other line of holes was drilled at the U.S. Highway 66 Rio Grande bridge at Albuquerque, beginning at the east side of the flow in the river and extending to the riverside drain east of the river. The water levels in the holes of both lines indicated a water-table gradient from the river to the riverside drain. In the line of holes at the Highway 66 bridge, one was drilled within a few inches of the flow in the river. The water level in this hole was about a foot lower than the river stage. This indicates that the vertical component of inflow to the aquifer from the river may be greater than the lateral component of inflow at the edge of the stream; however, periodic measurements were not made in the auger holes to determine whether the water levels in the holes had reached equilibrium with the river level at the time of the measurement.

River Loss

The flow of the Rio Grande was measured at several places in October 1962 to determine river loss or gain. Two reaches were selected in which water was not being diverted from the river to ditches nor being returned to the river from ditches.

The first section measured was from Old Town Bridge to Barelas Bridge, a distance of 1.8 miles. The riverflows were 50.2 cfs at the upper bridge and 40.5 cfs at the lower bridge. Considering the falling stage of the river at the time of measuring, the loss from the river was about 10 cfs in the reach, or about 5.6 cfs per mile. The second reach measured was from Barcelona Bridge to the Isleta lateral diversion, a distance of 4.1 miles. The measured flow in this reach dropped from 63.8 to 57.2 cfs. As the river stage was falling at the time of measurement, the loss in the reach was about 7 cfs or 1.7 cfs per mile. These measurements, too, were made at low stages of riverflow. Losses at higher stages of the river likely would be greater, especially when the flow spreads over the entire river channel. The stages of the riverside drains fluctuate with the stage of the river, indicating greater loss from the river to the drains during periods of high flow.

Using the above values as guides, it can be inferred that loss from the Rio Grande to the drains or aquifer at average stage of the river in the study area probably ranges from near zero to about 10 cfs per mile. If the average value is 2 cfs per mile for the 40-mile reach, about 58,000 acre-feet of water per year percolates from the river. If the average is 5 cfs, about 145,000 acre-feet of water per year percolates from the river in the reach. As water levels are lowered by pumping, the infiltration rate from the river probably will be increased.

A large part of the water infiltrating from the river is used by vegetation. No field work was done during this study to determine water loss to phreatophytes; however, such a determination was made in the Rio Grande Joint Investigation, wherein it was noted that large quantities of water are transpired by vegetation of little or no monetary value. Part of the water used directly from the water table by such vegetation could be salvaged by lowering the water table below the root zone of the plants. Lowering the water table may not be practical in some areas as a direct effort; however, as water levels are lowered in the course of pumping water for municipal and other uses, as discussed earlier in this report, water normally lost to evapotranspiration may be salvaged in some areas. Because continuous flow in the Rio Grande is probable, salvage may not be effective near the river channel.

Figure 5 is an aerial (downstream) view of the Rio Grande at the new bridge on Interstate Highway 40(66), in a sparsely populated part of west Albuquerque. The photo was taken at an altitude of 500 feet on June 25, 1965, by R. E. Rowen of the Bureau of Reclamation. Runoff during 1965 was above average and flow on June 25 was 5,360 cfs. (In times of high flow, the Rio Grande is, indeed, a grande [Spanish: big, large, great] river. In times of low flow, particularly during summer

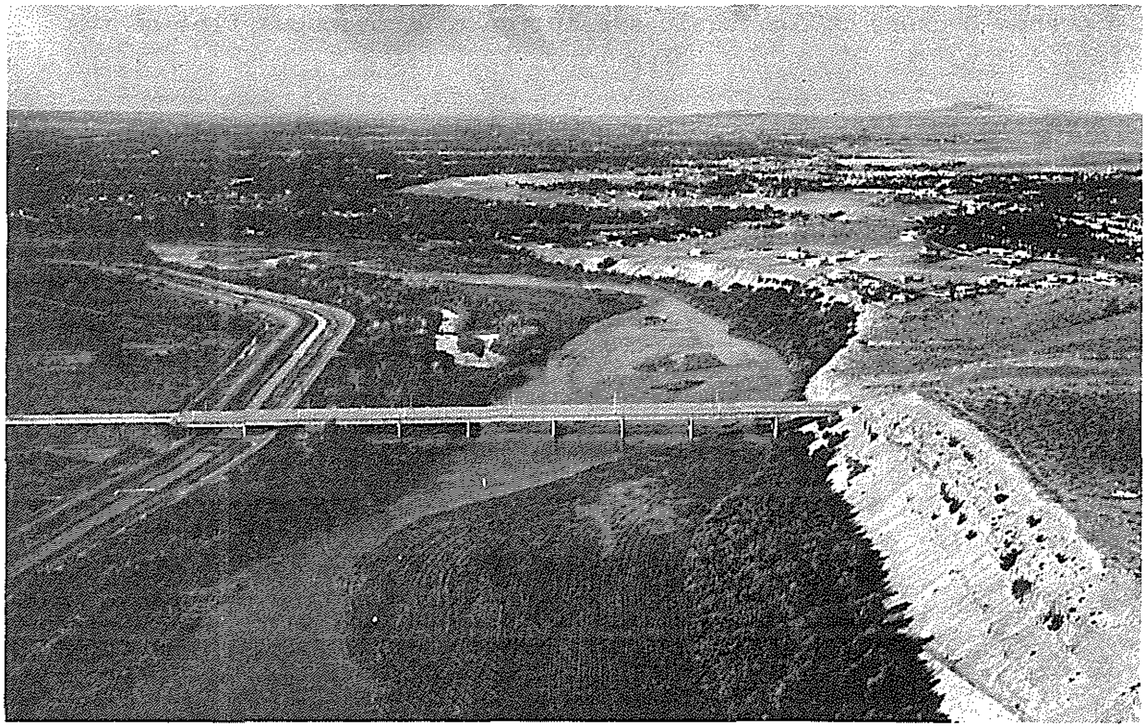


FIGURE 5. -- Rio Grande at Interstate Highway 40(66) Bridge in west Albuquerque on June 25, 1965. View is downstream. Furrows in foreground are from root-plowing of floodway growths. Riverside drain is visible at left. Bureau of Reclamation photograph.

when large upstream diversions are made for irrigation, the channel at Albuquerque sometimes is dry.) The photo also shows a section of the cleared floodway and, at left, a section of the riverside drain which helps to regulate the water table under the low-lying flood plain east of the river.

CONCLUSIONS

The future lowering of water levels in the Albuquerque area was computed for the basic assumptions of water requirements and aquifer characteristics formulated from this study and a previous study by Bjorklund and Maxwell. From these basic assumptions, the greatest lowering of the water level in the area from 1960 to 2000 -- about 86 feet -- is expected under the east mesa about 6 miles east of downtown Albuquerque and 3 miles north of Central Avenue. A computed lowering of almost 11 feet occurred at this point between 1920 and 1960. West of the Rio Grande, about 9 miles northwest of downtown Albuquerque, the water levels are expected to decline almost 34 feet between 1960 and 2000. Water levels in that area declined little, if any, before 1960. Outward from these points the lowering will be less in all directions, particularly toward the Rio Grande. No decline is indicated along the channel of the Rio Grande because of the basic assumption of continuous flow of the river.

The most significant anticipated effects of pumping, estimated from the assumed form of the water table in the year 2000, are 1) that the water-table gradient east of the Rio Grande in the vicinity of Albuquerque will be reversed and the water table 5 to 8 miles east of the river will be lower than the level of the river, and 2) that ground water will move eastward from the Rio Grande, indicating that increasing quantities of the pumped water will be derived from the river.

About 80 percent of the water pumped in the area between 1920 and 1960 was derived from the flow of the Rio Grande by either decreasing the flow to the river or increasing the flow from the river. From 1960 to 2000 between 71 and 76 percent of the water will be derived from the Rio Grande. The percentage would increase with time except that newer wells are being developed at increasing distances from the river.

In the decade 1950-60, an average of 46,000 acre-feet of water was pumped annually for all purposes, of which 37,200 acre-feet was derived from the Rio Grande. These quantities will increase with population growth and further municipal-industrial development in the area. In the decade 1990-2000, about 226,000 acre-feet of water will be pumped annually, of which 165,000 acre-feet (230 cfs) will be derived from the Rio Grande. The average flow of the Rio Grande at Albuquerque during the 17 years prior to 1959 was 1,006 cfs. Part of the decreased flow of the Rio Grande due to pumping ground water is offset by return to the river of more than half the water used by installations served by Albuquerque sewers as effluent from the sewage-disposal plant (Bjorklund and Maxwell).

Studies of sediment-particle sizes along the Rio Grande, profiles of water levels near the Rio Grande, and river losses indicate that the character of the riverbed is such that water will infiltrate readily from the river to the aquifer as water levels are lowered.

REFERENCES

Bjorklund, L. J., and Maxwell, B. W., 1961, Availability of ground water in the Albuquerque area, Bernalillo and Sandoval Counties, New Mexico: N. Mex. State Engineer Tech. Rept. 21, 117 p.

Conover, C. S., and Reeder, H. O., 1957, Construction and use of special drawdown scales for predicting water-level changes throughout heavily pumped areas: U.S. Geol. Survey open-file rept., Ground Water Note 30, 9 p.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of a well using ground-water storage: Am. Geophys. Union Trans., pt. 2, p. 519-534.

__________ 1938, Ground water in the middle Rio Grande valley, New Mexico, in [U.S.] National Resources Committee, Regional Planning Part VI -- The Rio Grande Joint Investigation in the upper Rio Grande basin in Colorado, New Mexico, and Texas: Washington, U.S. Govt. Printing Office, v. 1, pt. 2, sec. 3, p. 268-291.

__________ 1952, Chart for computation of drawdown in wells in vicinity of a discharging well: U.S. Geol. Survey open-file rept., Ground Water Note 6, 6 p.

__________ 1953, The effect of a well on the flow of a nearby stream: U.S. Geol. Survey open-file rept., Ground Water Note 14, 10 p.

Theis, C. V., and Brown, R. H., 1951, Use of slide rule in solving ground-water problems involving application of the nonequilibrium formula: U.S. Geol. Survey open-file rept., 4 p.

Theis, C. V., and Taylor, G. C., Jr., 1939, Ground-water conditions in the middle Rio Grande valley, New Mexico: N. Mex. State Engineer 12th and 13th Bienn. Repts., 1934-38, p. 263-270.

U.S. Congress, Senate Select Committee on National Water Resources, 1960, Population projections and economic assumptions: U.S. 86th Cong., 2nd sess., Comm. Print 5, 49 p., Washington, U.S. Govt. Printing Office.

U.S. Geological Survey, 1960, Surface-water supply of the United States, 1959; pt. 8, Western Gulf of Mexico basins: U.S. Geol. Survey Water-Supply Paper 1632, 529 p.

[U.S.] National Resources Committee, 1938, Regional Planning, Part VI -- The Rio Grande Joint Investigation in the upper Rio Grande basin in Colorado, New Mexico, and Texas: Washington, U.S. Govt. Printing Office, 566 p.

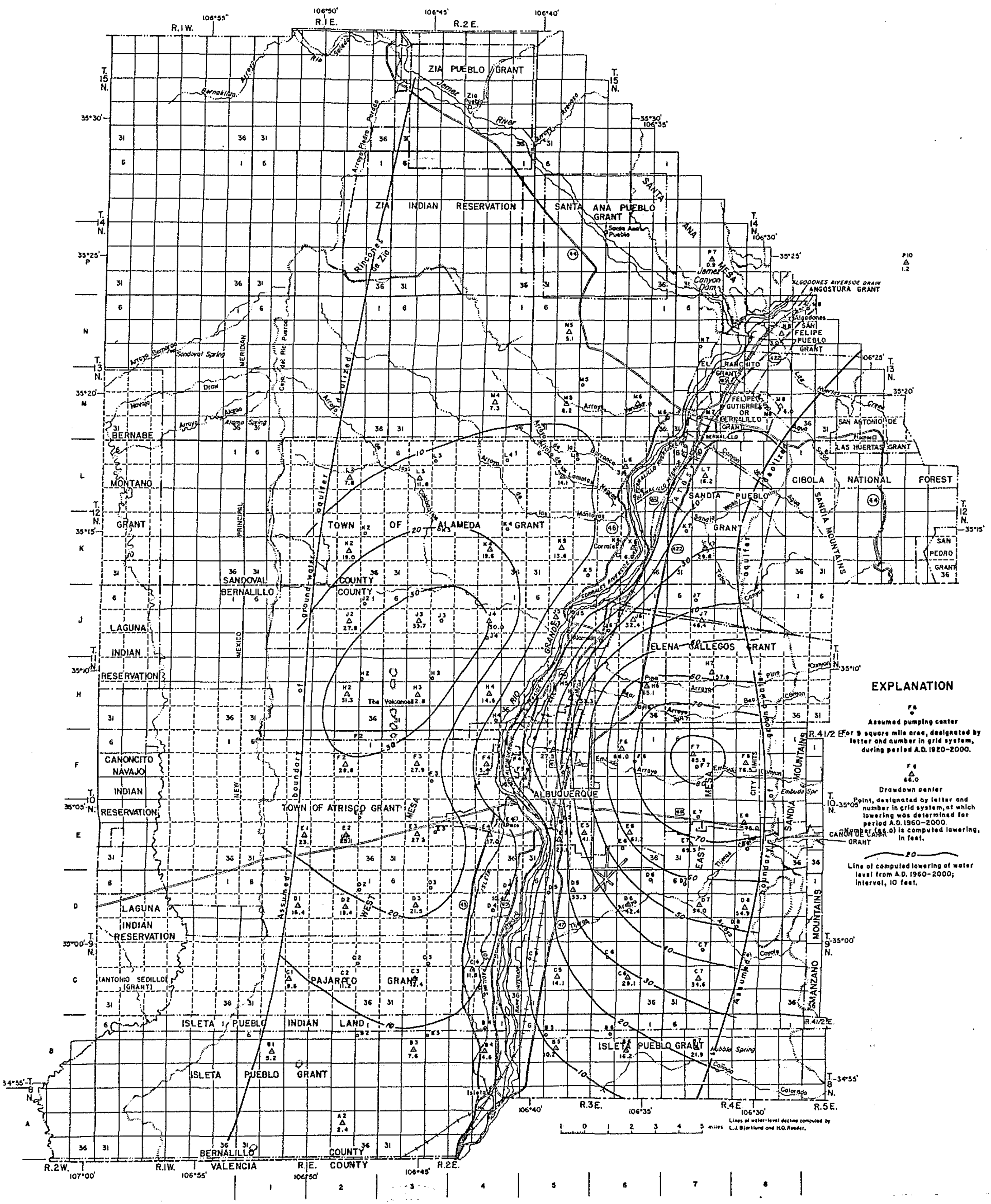
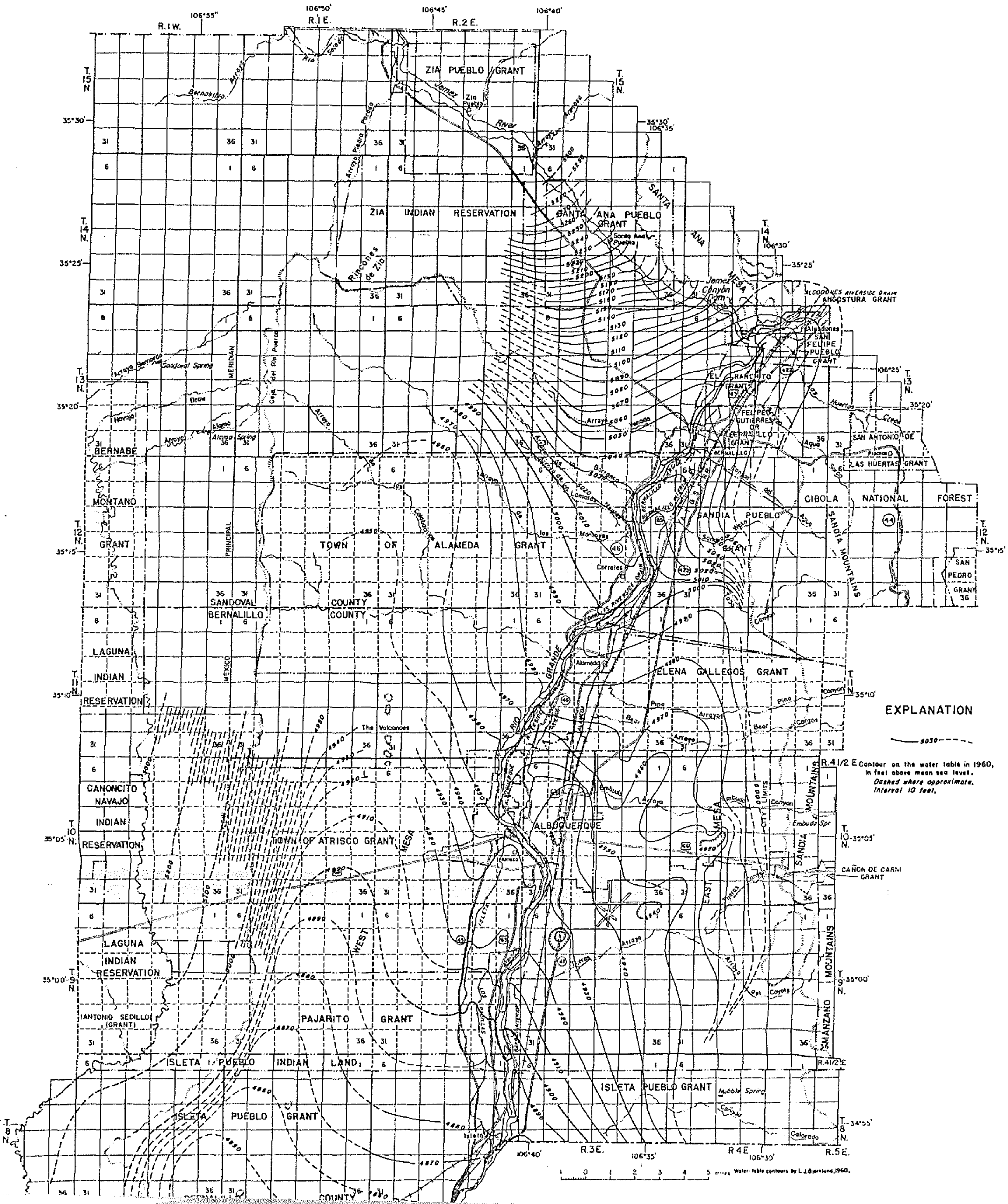


PLATE I.--IDEALIZED BOUNDARIES, PUMPING CENTERS, AND CONTOURS OF PREDICTED LOWERING OF WATER LEVELS FROM 1960 TO 2000 IN THE ALBUQUERQUE AREA, NEW MEXICO.



EXPLANATION
5030
Contour on the water table in 1960, in feet above mean sea level. Dashed where approximate. Interval 10 feet.
ZIA PUEBLO GRANT
ZIA INDIAN RESERVATION
SANTA ANA PUEBLO GRANT
ANGOSTURA GRANT
SAN FELIPE PUEBLO GRANT
EL RANCHITO GRANT
SAN ANTONIO DE LAS HUERTAS GRANT
CIBOLA NATIONAL FOREST
SANDIA PUEBLO GRANT
SANDIA MOUNTAINS
TOWN OF ALAMEDA GRANT
BERNABE MONTANO GRANT
SANDOVAL COUNTY
BERNALILLO COUNTY
LAGUNA INDIAN RESERVATION
ELENA GALLEGOS GRANT
CANONCITO NAVAJO INDIAN RESERVATION
TOWN OF ATRISCO GRANT
ALBUQUERQUE
WEST MESA
EAST MESA
CAÑON DE CARNUE GRANT
PAJARITO GRANT
ISLETA PUEBLO INDIAN LAND
ISLETA PUEBLO GRANT
MANZANO MOUNTAINS
RIO GRANDE
Jemez River
Jemez Canyon Dam
The Volcanoes
Corrales
Alameda
Isleta
R.1W.
R.1E.
R.2E.
R.3E.
R.4E.
R.4 1/2 E.
R.5E.
Water-table contours by L.J. Bjorklund, 1960.

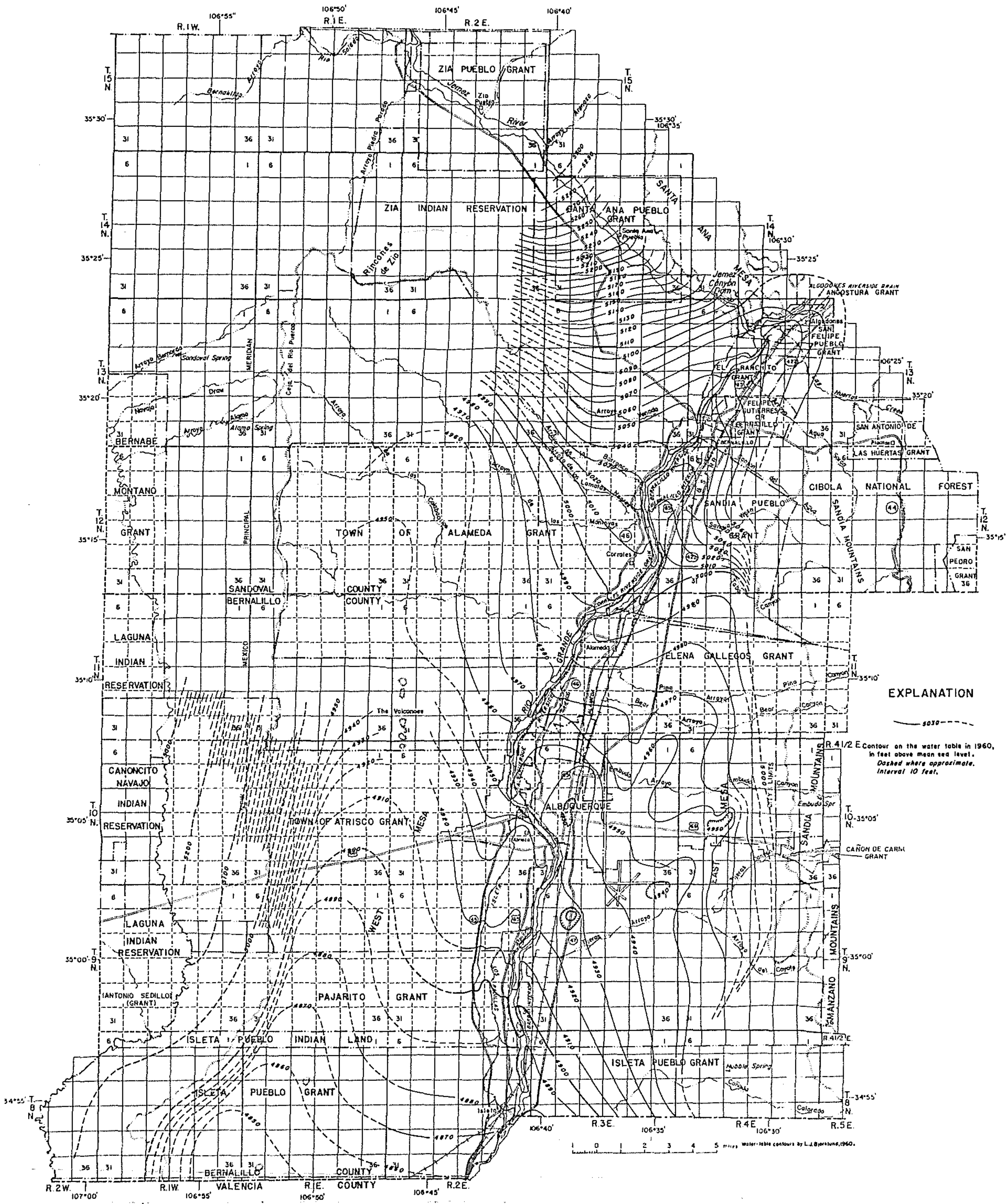


PLATE 2.--WATER-TABLE CONTOURS IN 1960 IN THE ALBUQUERQUE AREA, NEW MEXICO.

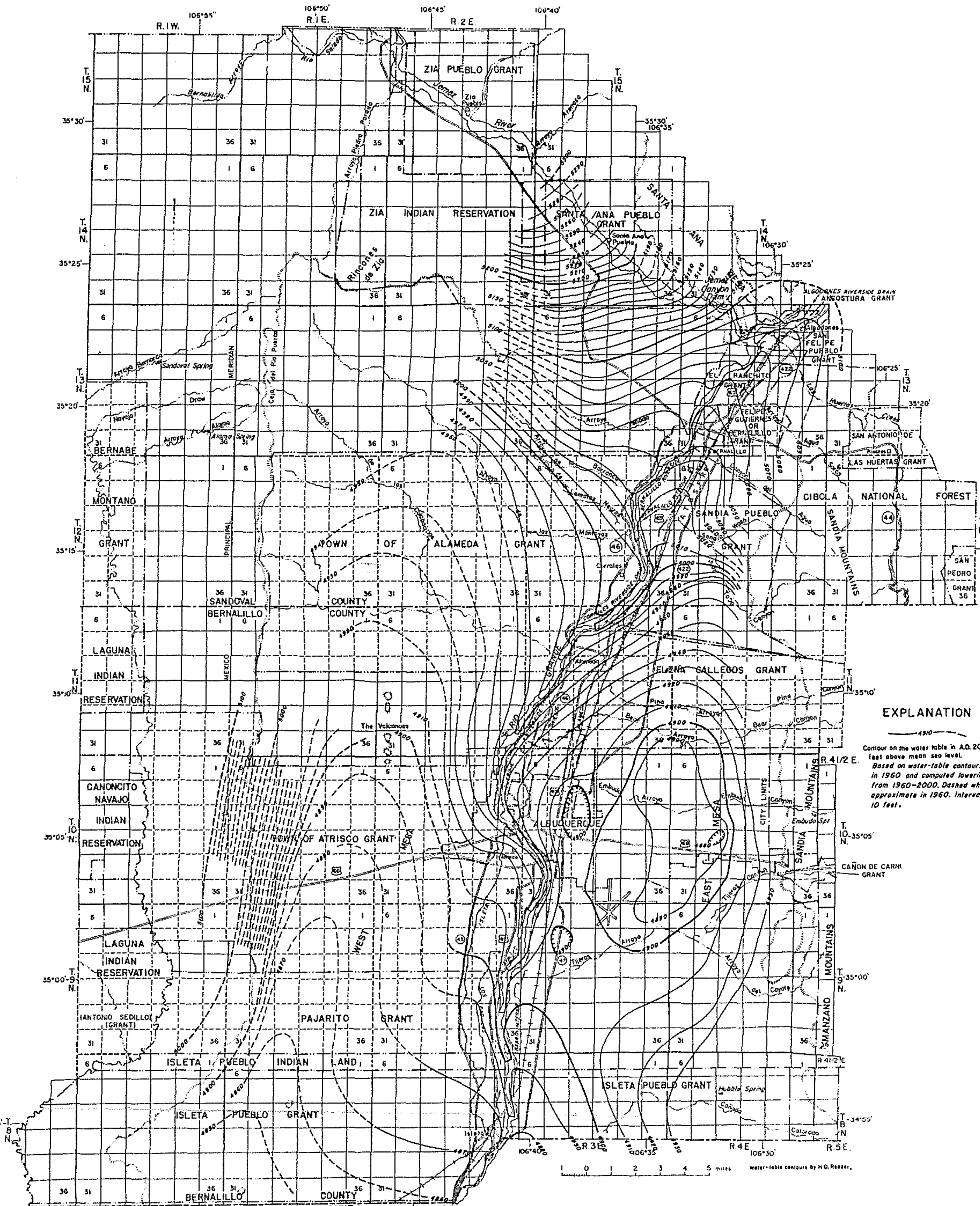


PLATE 3.--COMPUTED WATER-TABLE CONTOURS IN THE YEAR 2000 IN THE ALBUQUERQUE AREA, NEW MEXICO.

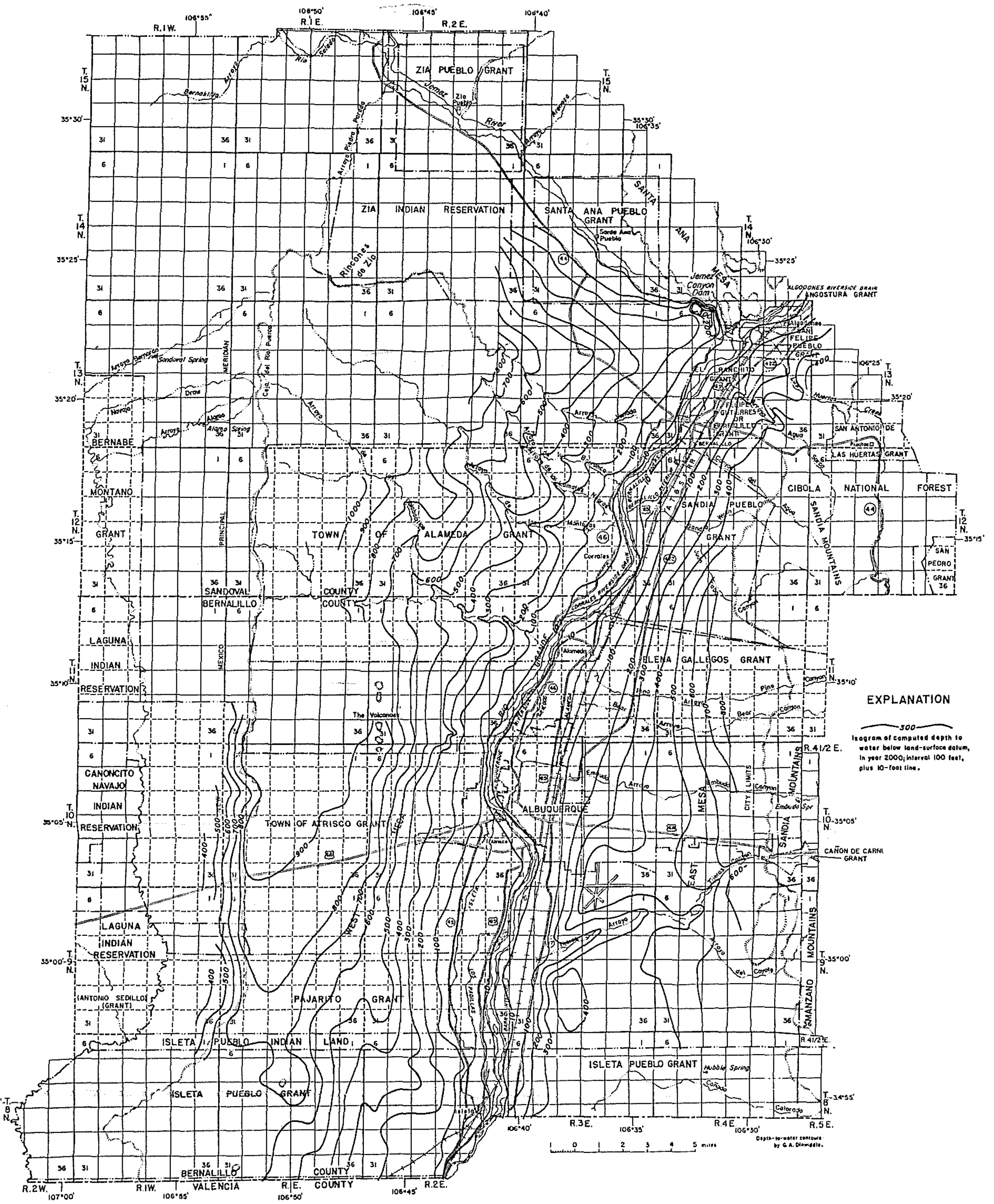


PLATE 4.--COMPUTED DEPTH TO WATER IN THE YEAR 2000 IN THE ALBUQUERQUE AREA, NEW MEXICO.

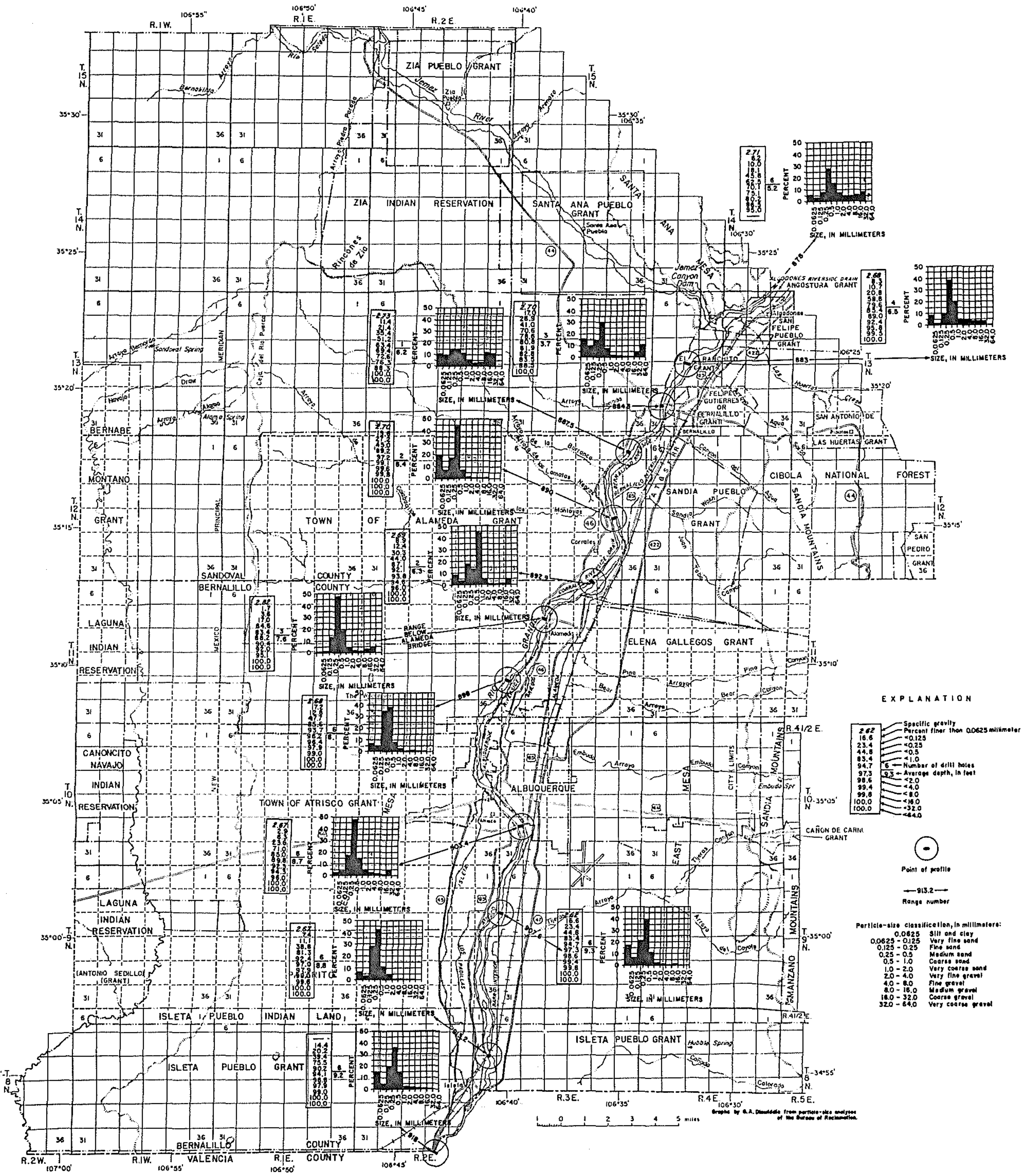


PLATE 5.--PARTICLE-SIZE DISTRIBUTION AT POINTS ALONG THE RIO GRANDE NEAR ALBUQUERQUE, NEW MEXICO.

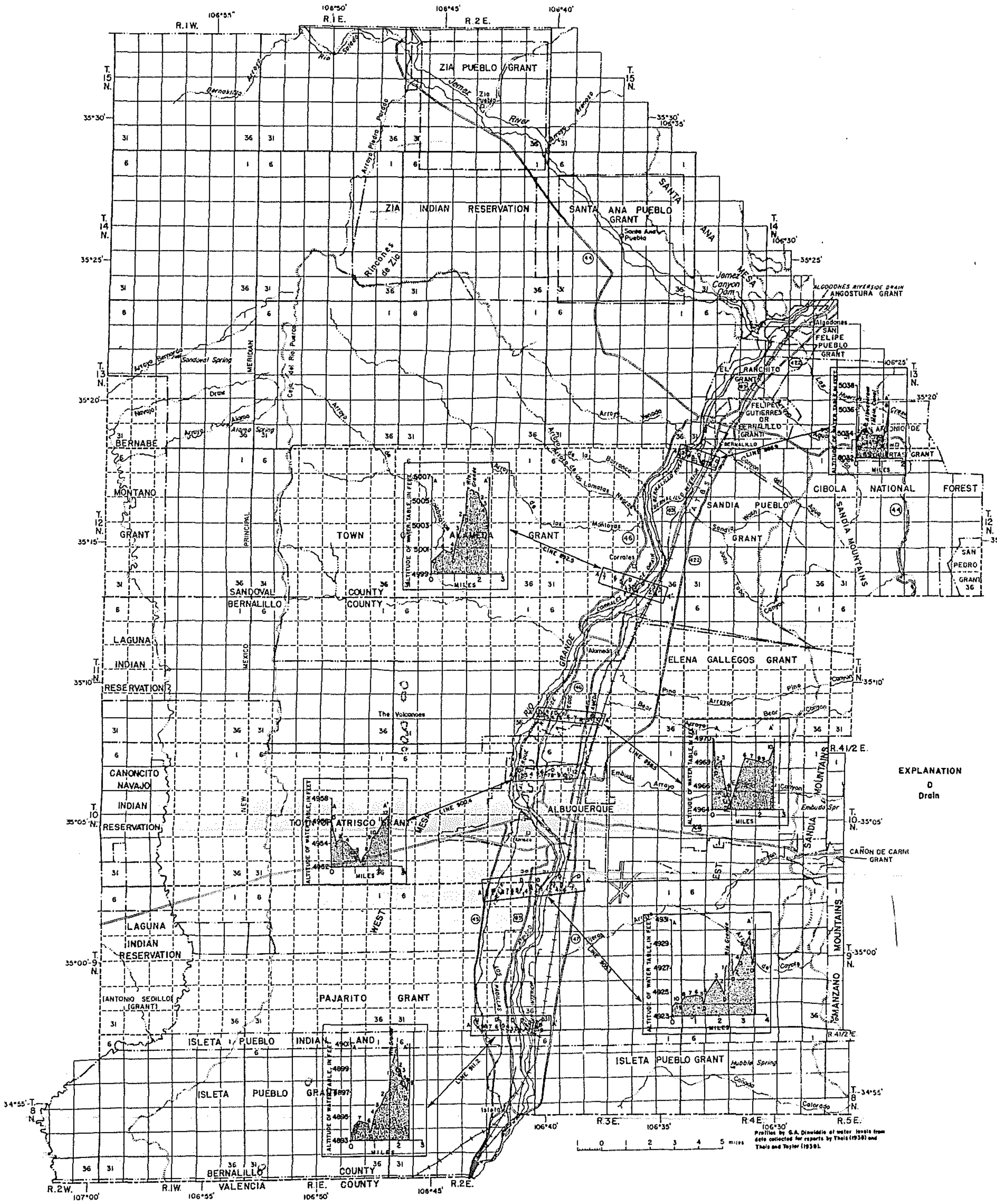


PLATE 6.--PROFILES OF WATER LEVELS IN 1936 AT SELECTED PLACES ALONG THE RIO GRANDE IN THE ALBUQUERQUE AREA, NEW MEXICO.