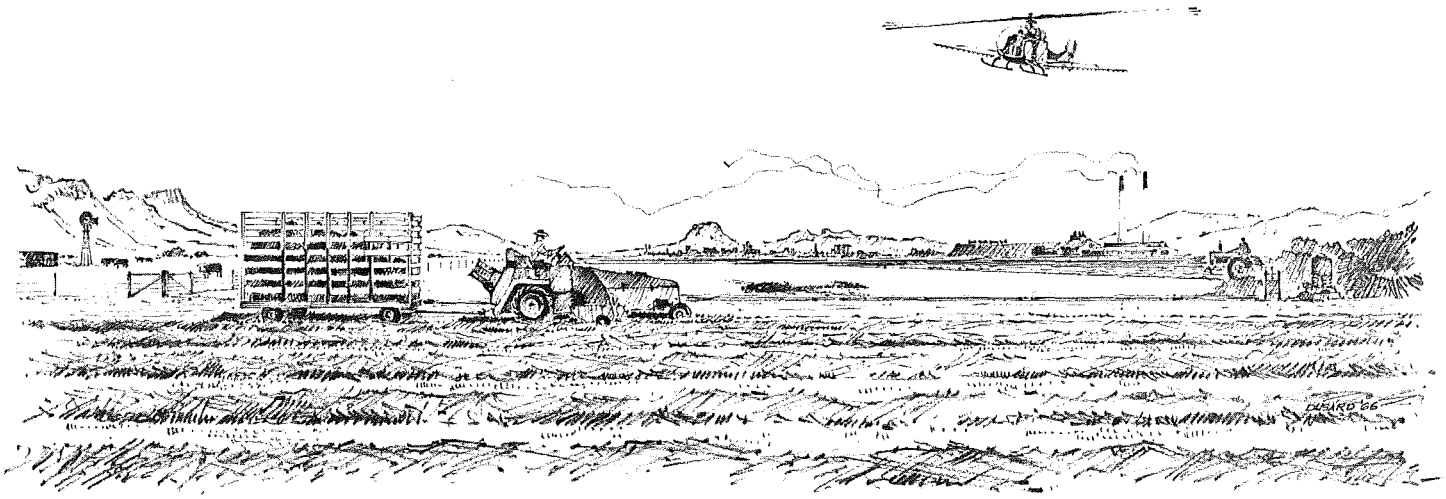
WATER-RESOURCES REPORT NUMBER THIRTY
ARIZONA STATE LAND DEPARTMENT
OBED M. LASSEN, COMMISSIONER

HYDROLOGIC CONDITIONS IN THE DOUGLAS BASIN COCHISE COUNTY, ARIZONA

BY NATALIE D. WHITE
AND DALLAS CHILDERS



PREPARED BY THE GEOLOGICAL SURVEY
UNITED STATES DEPARTMENT OF THE INTERIOR

PHOENIX, ARIZONA
MAY 1967

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HYDROLOGIC CONDITIONS IN THE DOUGLAS BASIN, COCHISE COUNTY, ARIZONA

By

Natalie D. White and Dallas Childers

ABSTRACT

The data on which this study is based were collected as a part of the continuing ground-water program of the U. S. Geological Survey, which is conducted mainly in cooperation with the Arizona State Land Department. The program includes not only the collection of basic data that are an integral part of any ground-water resources study but also the compilation and analysis of these data; the results of the program are summarized each year in the "Annual report on ground water in Arizona." An additional phase of the program is aimed at systematic studies of current ground-water conditions in specified basins or areas. The objective of these studies, which are made at regular intervals for a particular area, is to update the water information available and to analyze the changes in the water regimen that have occurred during the intervening time.

The Douglas basin is in southeastern Arizona and is part of a structural trough that extends from northeastern Sonora, Mexico, to the Gila River in Arizona. In this report, the basin is described as extending from the international boundary northward to a group of low hills that form the surface-drainage divide between it and the Willcox basin. Like most of the areas in southern Arizona, Douglas basin is characterized by isolated fault-block mountain ranges that rise steeply from alluvial-filled valleys. The climate is arid to semiarid, and the low precipitation and high evaporation rates make it necessary to irrigate crops. All water for irrigation in the Douglas basin is obtained from wells.

In the summer of 1965, about 40,000 to 50,000 acres of land was cultivated or cleared for cultivation in the Douglas basin. During 1965, about 90,000 acre-feet of ground water was pumped; the average amount of water pumped in the previous 9 years was about 60,000 acre-feet per

year. The pumping of ground water is causing a progressive decline of the water level as water is removed from storage.

A study of the effects of the withdrawal of ground water indicates that the storage coefficient of the aquifer in Douglas basin probably is about 0.20. Using this value for the coefficient of storage, it is calculated that about 24 million acre-feet of ground water is available from storage in Douglas basin within an area of about 190,000 acres that is underlain by permeable sediments more than 750 feet thick.

INTRODUCTION

The economic growth of any area is related closely to the availability of adequate water supplies. In arid or semiarid regions, such as most of Arizona, the adequacy of the water supply is the principal factor in determining the growth of the economy—or even its continued existence at the present level—particularly where agriculture is an important part of that economy. In arid regions, agriculture cannot depend on rainfall for the growth of crops and, therefore, must resort to irrigation. In parts of Arizona, some water is available from surface reservoirs that store water from runoff or directly from streamflow. The Douglas basin has no developed surface-water supply and no prospects for developing one, so all water for irrigation must be pumped from wells.

The history and economic growth of the Douglas basin parallels that of the rest of southern Arizona in its relation to the availability and development of water resources. Since the beginning of white man's first entry into this part of the country, water has been of prime concern. Meinzer and Kelton (1913, p. 18) stated: "In 1855 the Mexican boundary survey party crossed the southern part of Sulphur Spring Valley, hurriedly, because there was no known watering place along the route followed." They indicated, however, that the development of the valley was delayed not so much by the lack of water as by the presence of hostile Indians and further stated: "* * * for as soon as it became possible for white men to live in the region supplies of water sufficient for domestic use and ranching were rapidly discovered. As early as 1873 the report had become current that the valley was generally underlain by shallow water." The information available at that time, however, did not give any indication of the amount of water available.

In 1910-11, Meinzer and Kelton (1913) made tests on a few pumping plants; these tests indicated capacities of a few hundred gallons per

minute, although one well near Douglas was reported to produce more than 1,000 gpm (gallons per minute). Additional data collected during their investigation included water-level measurements in about 100 wells.

Good management of the ground-water resources in the Douglas basin requires a comprehensive knowledge of the factors that control the occurrence and movement of ground water and the effects of withdrawal and replenishment on the ground-water reservoir. To acquire this knowledge, detailed hydrologic investigations are necessary.

Description of the Basin

The Douglas basin (fig. 1) is in southeastern Arizona and is part of a structural trough that extends from northeastern Sonora, Mexico, to the Gila River in Arizona. The part of the trough that is in Arizona is known as Sulphur Spring Valley, and Douglas basin is the southernmost of the three drainage basins in the valley. In this report, Douglas basin is described as extending from the international boundary northward to a group of low hills that form the surface-drainage divide between it and the Willcox basin. It is bounded on the east by the Chiricahua, Pedregosa, and Perilla Mountains and on the west by the Dragoon and Mule Mountains. The basin is drained by Whitewater Draw, which heads in Rucker Canyon in the Chiricahua Mountains, flows westward around the north end of the Swisshelm Mountains, and then southward into Mexico.

Like most of the areas in southern Arizona, Douglas basin is characterized by isolated fault-block mountain ranges that rise steeply from alluvial-filled valleys. In the central part of the basin, the land surface rises gently from about 3,900 feet above mean sea level at the point where Whitewater Draw crosses the international boundary to about 4,350 feet at the base of the low hills at the north end of the basin (fig. 2). The central part of the basin, which is about 35 miles long and 15 miles wide, is filled with materials that were eroded from rocks in the adjacent mountain areas. In general, the materials, which consist of unconsolidated to poorly consolidated clay, silt, sand, and gravel, are porous and provide storage for large amounts of ground water. The mountains that border the basin include igneous, metamorphic, and sedimentary rocks ranging in age from Precambrian to Tertiary. For the most part, these rocks are dense and impermeable and serve to retain the ground water in the trough. Precipitation on the mountain slopes provides runoff that, in places, is a source of recharge to the ground-water reservoir.

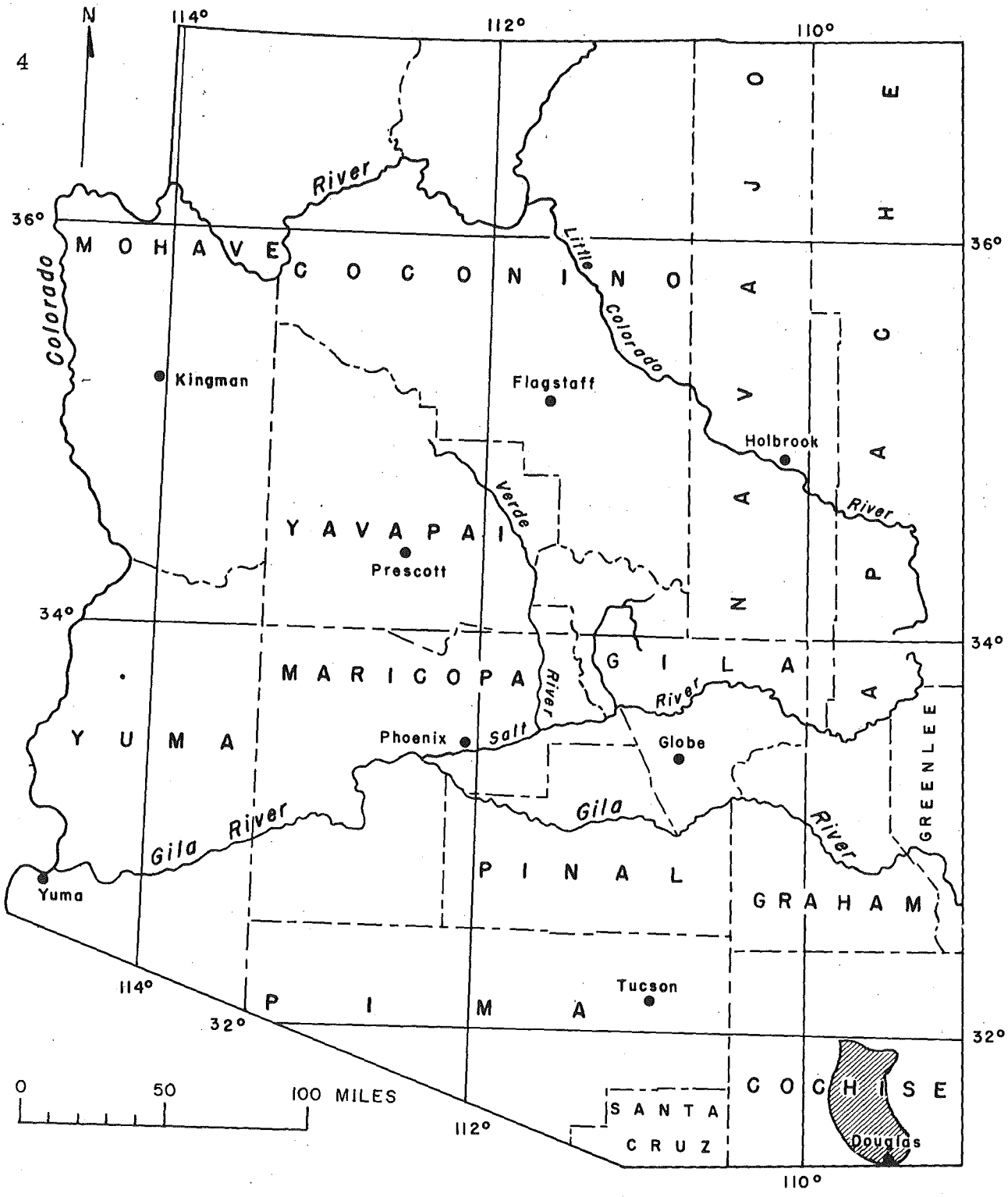
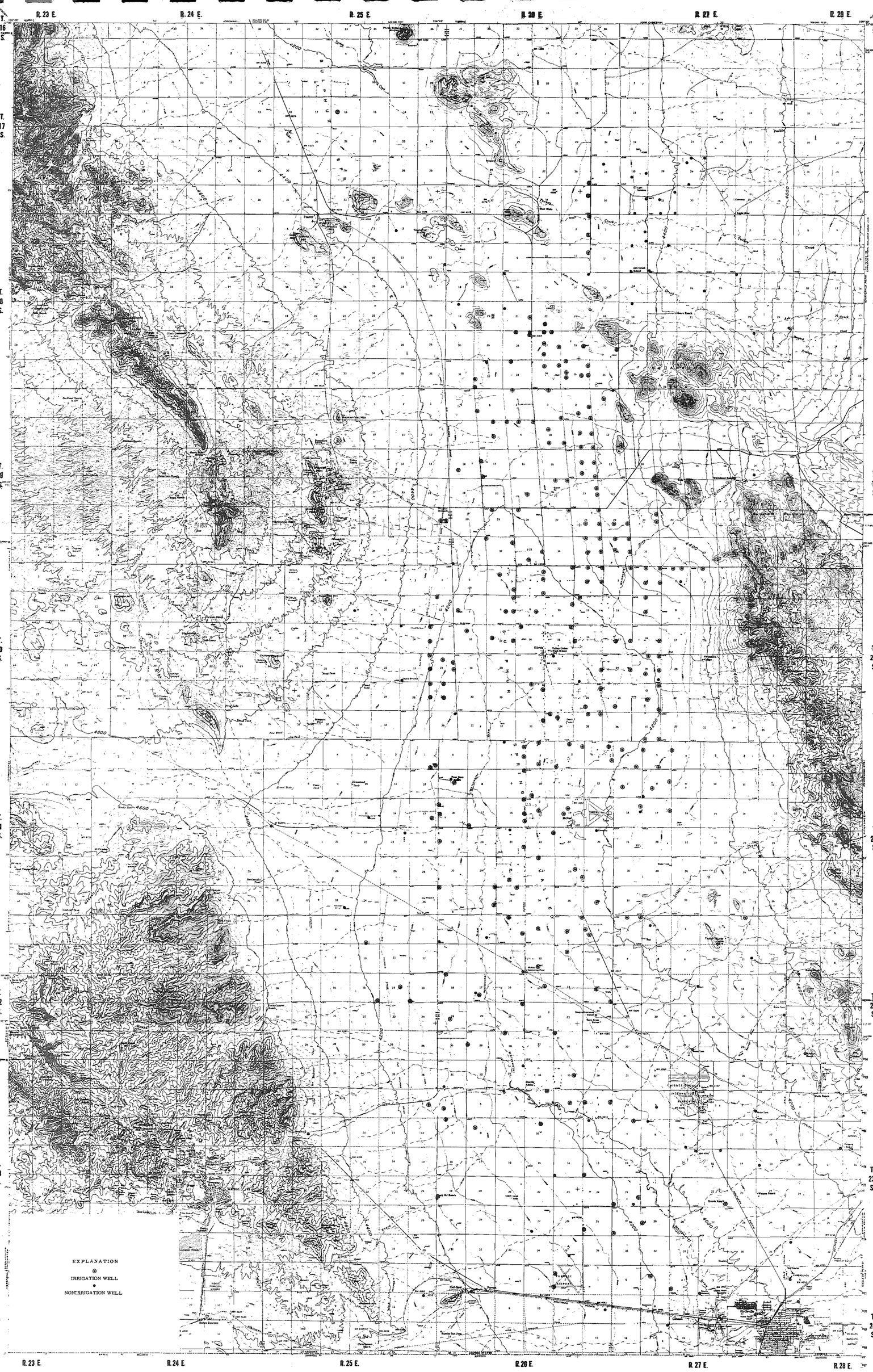


FIGURE 1.--AREA OF REPORT.



BASE FROM U.S. GEOLOGICAL SURVEY TOPOGRAPHIC QUADRANGLES

1 0 1 2 3 4 5 MILES

TOPOGRAPHIC CONTOURS AT 40-FOOT INTERVALS
(DATUM IS MEAN SEA LEVEL)

HYDROLOGY BY DALLAS CHILDERS
AND NATALIE D. WHITE, 1966

FIGURE 2.-- TOPOGRAPHY AND LOCATION OF SELECTED WELLS IN DOUGLAS BASIN.

The climate of Douglas basin is arid to semiarid; in the central part of the basin the climate is characterized by low precipitation and high evaporation rates. The long-term average annual precipitation near Douglas is 11.72 inches (U.S. Weather Bureau, 1966). On the higher slopes of the mountains that border the basin, precipitation rates are somewhat higher. The average annual precipitation in Rucker Canyon, at an altitude of 5,370 feet, is 18.54 inches. Most of the rain that falls on the basin is evaporated before it can be used beneficially by crops or before it can be recharged to the ground-water reservoir. Some of the precipitation on the mountain ranges, however, reaches the basin as runoff, and part of this percolates downward from the stream channels and recharges the ground-water reservoir.

Precipitation is inadequate to raise crops, and, because the Douglas basin has no developed surface-water supply, it is necessary to irrigate crops with water from wells. Irrigation farming began in the Douglas basin about 1910, when several wells were drilled to provide water; however, only a few acres of land was irrigated at that time. In 1940, only about 3,000 acres of land was irrigated with ground water; by 1951 irrigated land had increased to about 14,300 acres and by 1961 to about 19,200 acres. In late 1964 and early 1965, several hundred new wells were drilled to irrigate more land. In the summer of 1965, reconnaissance mapping by personnel of the U.S. Geological Survey indicated that between 40,000 and 50,000 acres of land was under cultivation or was cleared for cultivation.

Purpose and Scope of the Investigation

The purpose of this investigation was to determine the hydrologic conditions in the Douglas basin and to compare the effects of pumping with changes in ground-water storage. The data on which this study is based were collected as a part of the continuing ground-water program of the U.S. Geological Survey, which is conducted mainly in cooperation with the Arizona State Land Department, Obed M. Lassen, Commissioner. The program includes not only the collection of basic data that are an integral part of any ground-water resources study but also the compilation and analysis of these data; the results of the program are summarized each year in the "Annual report on ground water in Arizona" and in reports on studies of current ground-water conditions in individual basins or areas, which are made at regular intervals.

An inventory of the existing wells in the Douglas basin was made by personnel of the U.S. Geological Survey in the spring of 1966. In

1964-66, hundreds of new wells were drilled, and samples of drill cuttings were collected from many wells. Because many wells were being drilled at the time of the inventory and because a shortage of time did not permit a complete field check of the location of all the wells in the basin, figure 2 shows only selected wells. The wells selected are those in which water-level measurements were made in spring 1966. The data available include the date the well was drilled, depth of well, casing information, water-level information, well discharge, and drillers' logs. In addition, laboratory analyses of drill cuttings were made. These data are not included in this report but are available for inspection at the office of the U. S. Geological Survey, Water Resources Division, Tucson, Ariz.

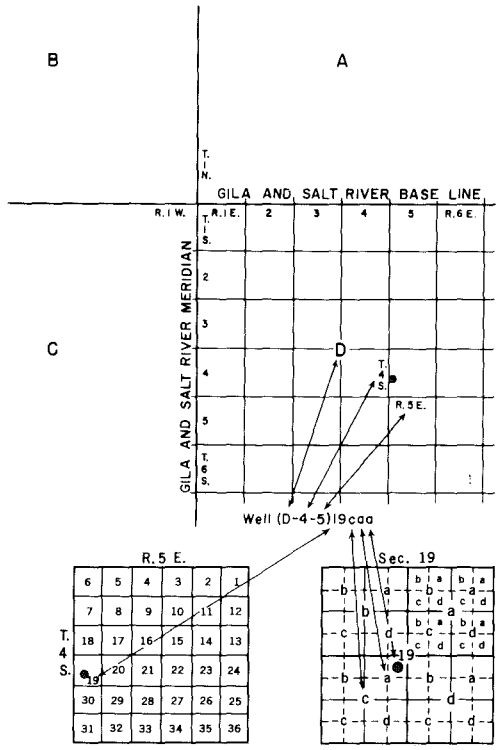
In spring 1966, water levels were measured in about 300 wells in the Douglas basin. All well locations in the basin are described according to the well-numbering system used in Arizona (fig. 3).

For many years, the overall use of ground water in the Douglas basin was fairly constant. Since the latter part of 1964, however, many new wells have been drilled, and many acres of new land has been cleared for cultivation, resulting in a large increase in the amount of ground water pumped. This report describes the current hydrologic conditions in the basin as related to past and present use of ground water. Maps showing contours of the altitude of the water table, depth to water at the current stage of development, and a comparison of these maps to those in earlier reports (Meinzer and Kelton, 1913; Coates and Cushman, 1955) were used for the analyses made in this study. These analyses, the volume of water withdrawn from storage, and other data collected for several years have been used to determine the volume of water available from the aquifer in the Douglas basin.

Previous Investigations

Although the geology, ore deposits, and general geologic characteristics of the Douglas basin have been described in several reports, only a few have dealt extensively with the ground-water resources. The most comprehensive of these are listed below.

1913. Meinzer, O. E., and Kelton, F. C., Geology and water resources of Sulphur Spring Valley, Arizona, with a section on agriculture by R. H. Forbes: U. S. Geol. Survey Water-Supply Paper 320, 231 p.



The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants. These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (D-4-5)19caa designates the well as being in the NE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 19, T. 4 S., R. 5 E. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Figure 3. --Well-numbering system in Arizona.

1952. Coates, D. R., Douglas basin, Cochise County, in Ground water in the Gila River basin and adjacent areas, Arizona—a summary, by L. C. Halpenny and others: U. S. Geol. Survey open-file report, p. 187-194.

1955. Coates, D. R., and Cushman, R. L., Geology and ground-water resources of the Douglas basin, Arizona, with a section on chemical quality of the ground water by J. L. Hatchett: U. S. Geol. Survey Water-Supply Paper 1354, 56 p.

In addition to the above reports, the ground-water conditions in the Douglas basin have been discussed in the "Annual report on ground water in Arizona." For 1961-65, the discussion was given under the heading "Sulphur Spring Valley" and the subheading "Douglas basin." Data from the surface-water gaging station on Whitewater Draw near Douglas have been published in the U. S. Geological Survey water-supply paper series entitled "Surface-water supply of the United States, pt. 9, Colorado River basin" and, more recently, in U. S. Geological Survey open-file reports entitled "Surface water records of Arizona."

WATER RESOURCES

The total water resources of the Douglas basin include ground water and surface water that originate from precipitation within the drainage area. Turkey Creek contributes a small amount of recharge to the ground-water reservoir in the northeastern part of the basin. Coates and Cushman (1955, p. 26) stated: "The only avenue of known movement of ground water into the basin occurs in the vicinity of Turkey Creek, at the surface-water divide that separates the Douglas and Willcox basins (pl. 2). In a strip about a mile or so wide infiltration of surface water into the alluvium of Turkey Creek eventually moves as ground water into Douglas basin. The hard-rock barriers that separate the Douglas basin from other basins on the east and on the west effectively prevent movement of ground water between basins."

Surface Water

In the Douglas basin, surface water is limited to runoff in Whitewater Draw and its tributaries. For the most part, the tributaries are intermittent streams that add only small amounts of water to the main drainage. Whitewater Draw is intermittent except for a short reach at

its headwaters in Rucker Canyon and from a point near Douglas southward into Mexico. In dry years, there may be no flow for long periods even in these reaches.

The drainage area of Whitewater Draw above the gaging station near Douglas is 1,023 square miles. A total of 36 years of record is available for this gaging station (1915-19, 1930-33, 1935-46, and 1947-65). The average runoff for the periods of record was 7,820 acre-feet per year; the maximum recorded discharge was 5,060 cfs (cubic feet per second) on August 7, 1955. In most years, there are times when there is no flow in Whitewater Draw.

The base flow of a stream is the sustained or fair-weather runoff and is composed mostly of ground-water effluent. Only a small part of the flow in Whitewater Draw near Douglas is base flow. For the most part, this occurs during the winter months. Figure 4 shows the minimum sustained 5-day winter flow for 1933-65. A gradual depletion in base flow in Whitewater Draw occurred in 1933-65 (fig. 4), which is attributed to the gradual lowering of the water table in the basin upstream from the gaging station. The progressive southward expansion of the area of decline caused by pumping is shown by contours indicating zero change in water levels in the southern end of the basin (figs. 7 and 8).

Ground Water

Ground water is one phase of the hydrologic cycle, and the ultimate source of all ground water is precipitation. When precipitation falls on the earth's surface, part flows overland and becomes runoff in the major stream drainages, part is evaporated and returned to the atmosphere, and the remainder infiltrates into the ground. Part of the precipitation that infiltrates into the ground may be transpired by vegetation or returned to the surface by capillarity, where it is evaporated back into the atmosphere; the rest percolates to the ground-water reservoir. The small amount of recharge that takes place occurs through the more permeable sediments underlying the major stream channels near the mountain fronts. Little, if any, of the precipitation that falls on the basin slopes escapes below the root or capillary zone and percolates to the ground-water reservoir. In the Douglas basin, the ground water in the subsurface is the result of an accumulation of these small amounts of recharge over a long period of time. The process of recharge is continuing today, much as it has in the past.

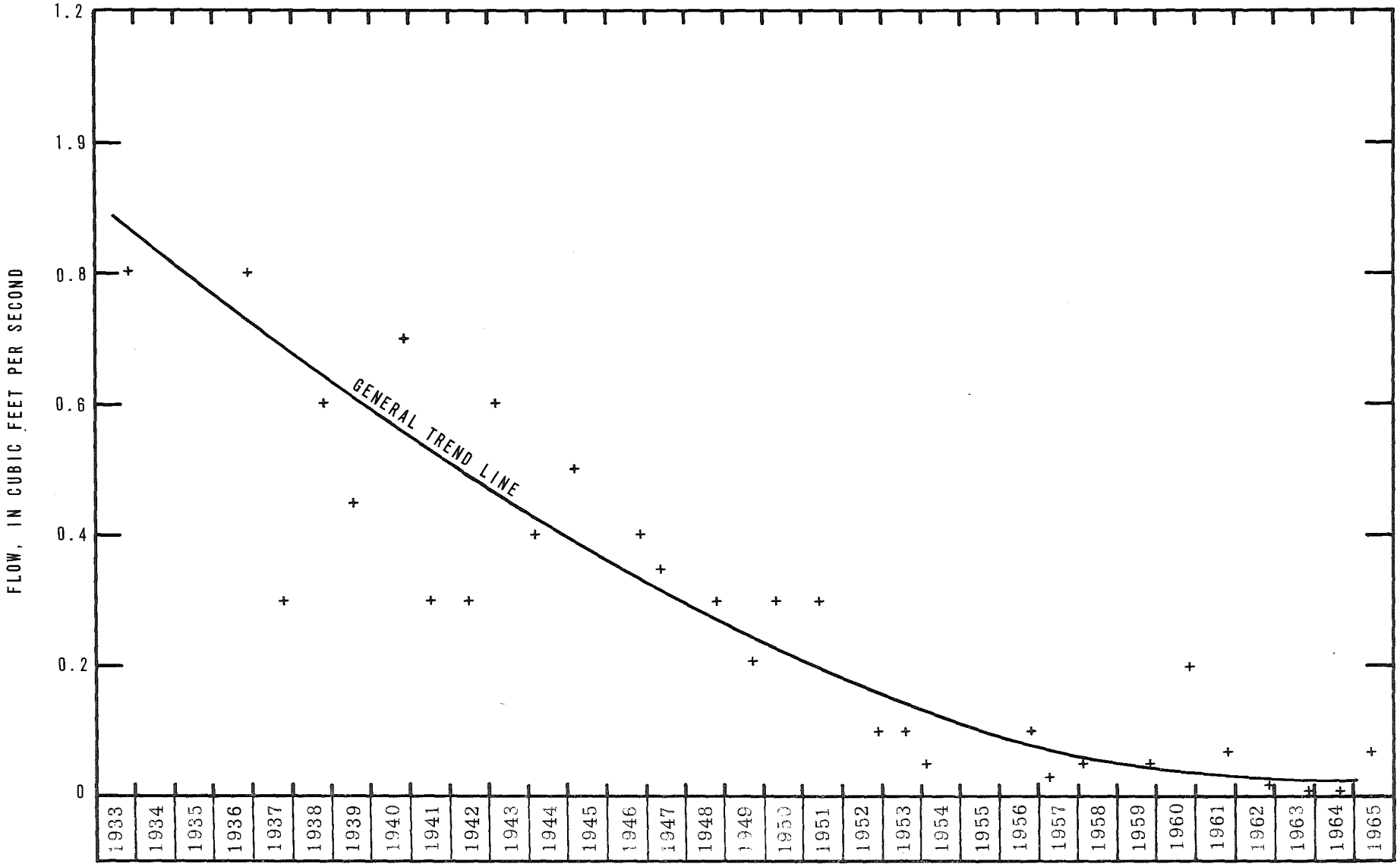


FIGURE 4.-MINIMUM SUSTAINED WINTER (DECEMBER 22-MARCH 21) FLOW IN WHITEWATER DRAW NEAR DOUGLAS.

The ground-water reservoir constitutes the main water supply in the Douglas basin. The major aquifer in the Douglas basin is the alluvial fill, which consists of permeable lenses of sand and gravel interbedded with silt and clay. The alluvium underlies about 500 square miles of valley floor and is present to depths of more than 750 feet in places in the central part of the basin. For the most part, the ground water in the alluvium is unconfined, although there are a few places where wells yield water under artesian pressure. The water-table aquifer provides most of the ground water used in the Douglas basin; therefore, the occurrence of artesian conditions will not be discussed further in this report.

The direction of movement of ground water is dependent upon the distribution of head in the aquifer, i. e., ground water moves from areas of higher to areas of lower head. The rate of movement is controlled by the difference in head in the direction of movement and the permeability of the aquifer material. The direction of movement is at right angles to contours of equal head in the aquifer. In 1910-11, conditions in the aquifer were almost unaffected by the small amount of ground-water withdrawal (Meinzer and Kelton, 1913). At that time, ground water moved from the recharge areas along the mountain fronts toward the central part of the basin and southward toward Mexico; the slope of the water table was from the mountain fronts and southward down the basin at an average gradient of 9 feet per mile.

In 1952, when a small amount of ground-water development had occurred, only minor changes in the flow pattern had developed (Coates and Cushman, 1955). The overall gradient of the water table and the direction of movement of ground water remained much the same as it was in 1910-11. In a few places, a steepening of the gradient and a flexure of the contours indicated that slight depressions in the water table had developed because of ground-water withdrawal.

Contours of the water level based on measurements made in the spring of 1966 show greater changes in the pattern of ground-water movement (fig. 5). In general, the depression in the water table along the central axis of the basin has deepened. The changes in the shape of the contours are more pronounced where large amounts of ground water have been withdrawn from the aquifer. The contours show that the slope of the water table is less uniform than in the earlier periods and that the gradient at the mountain fronts has steepened. In a few places, concentric cones of depression have formed, and water moves into the cones from all sides. Accelerated withdrawal of ground water in these places will cause the areas of decline to deepen and expand.

The amount of annual recharge to the ground-water reservoir is not known. Coates and Cushman (1955) indicated, however, that the annual recharge may be about 20,000 acre-feet.

The discharge of ground water from the basin takes place as evaporation and transpiration, as underflow and surface flow, and by pumping from wells. Because the water table is far below the land surface in the Douglas basin, discharge by evaporation directly from the ground-water reservoir is negligible. Coates and Cushman (1955) estimated that in 1951 about 8,000 to 13,000 acre-feet of ground water was lost to the atmosphere by transpiration from phreatophytes. At the present time, however, the amount probably is negligible, because the water table is farther below the land surface and land that formerly was covered with phreatophytes has been cleared for cultivation. The amount of ground water that leaves the basin as surface flow in Whitewater Draw and as underflow across the Mexican boundary is small compared to the amount discharged by pumping. Pumping from wells is the greatest source of discharge of ground water from the basin.

EFFECTS OF GROUND-WATER DEVELOPMENT

Most of the ground water pumped in Douglas basin is for irrigation, although some is pumped for industrial (mining and smelting) and municipal uses. In 1946, about 12,500 acre-feet of ground water was pumped in the basin; the amount pumped annually has increased greatly since that time, mostly due to increased irrigation. In the summer of 1965, about 40,000 to 50,000 acres of land was cleared or under cultivation, and the amount of ground water pumped increased to about 90,000 acre-feet; the average rate of pumping was 60,000 acre-feet a year for the previous 9 years. As a result of the pumping, there has been a decline in water levels and an accompanying decrease in the amount of ground water in storage.

Changes in Water Level Related to Ground-Water Withdrawal

Changes in water levels in Douglas basin are shown by hydrographs (fig. 6) and by decline maps (figs. 7 and 8). In figure 6, the cumulative net changes in water levels are compared with the annual ground-water pumpage from 1946 through 1965 and with the water levels in seven representative wells. The correlation between pumpage and changes in water levels is apparent. Figures 7 and 8 show water-level

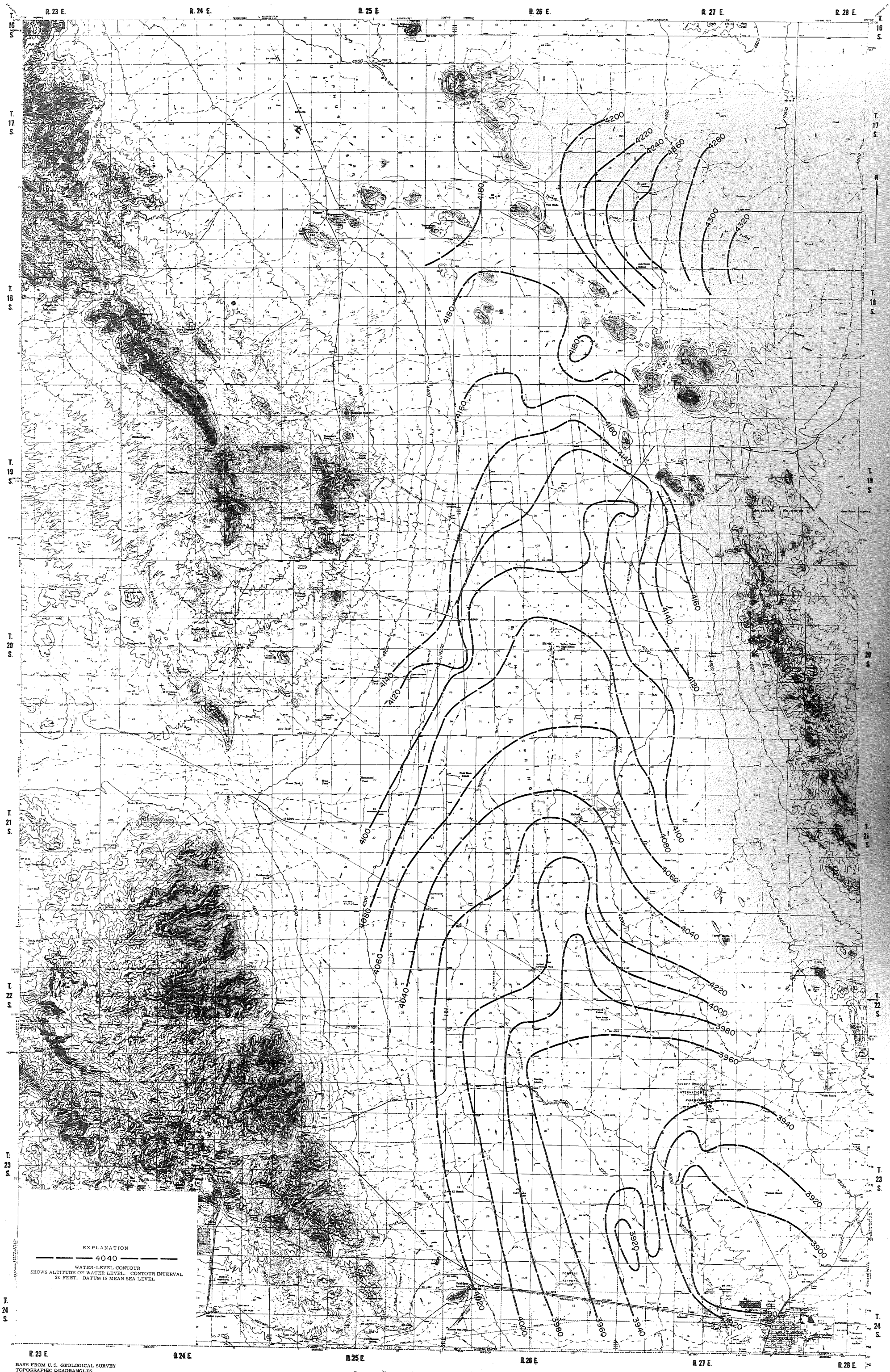


FIGURE 5.—WATER-LEVEL CONTOURS, SPRING 1966, IN DOUGLAS BASIN.

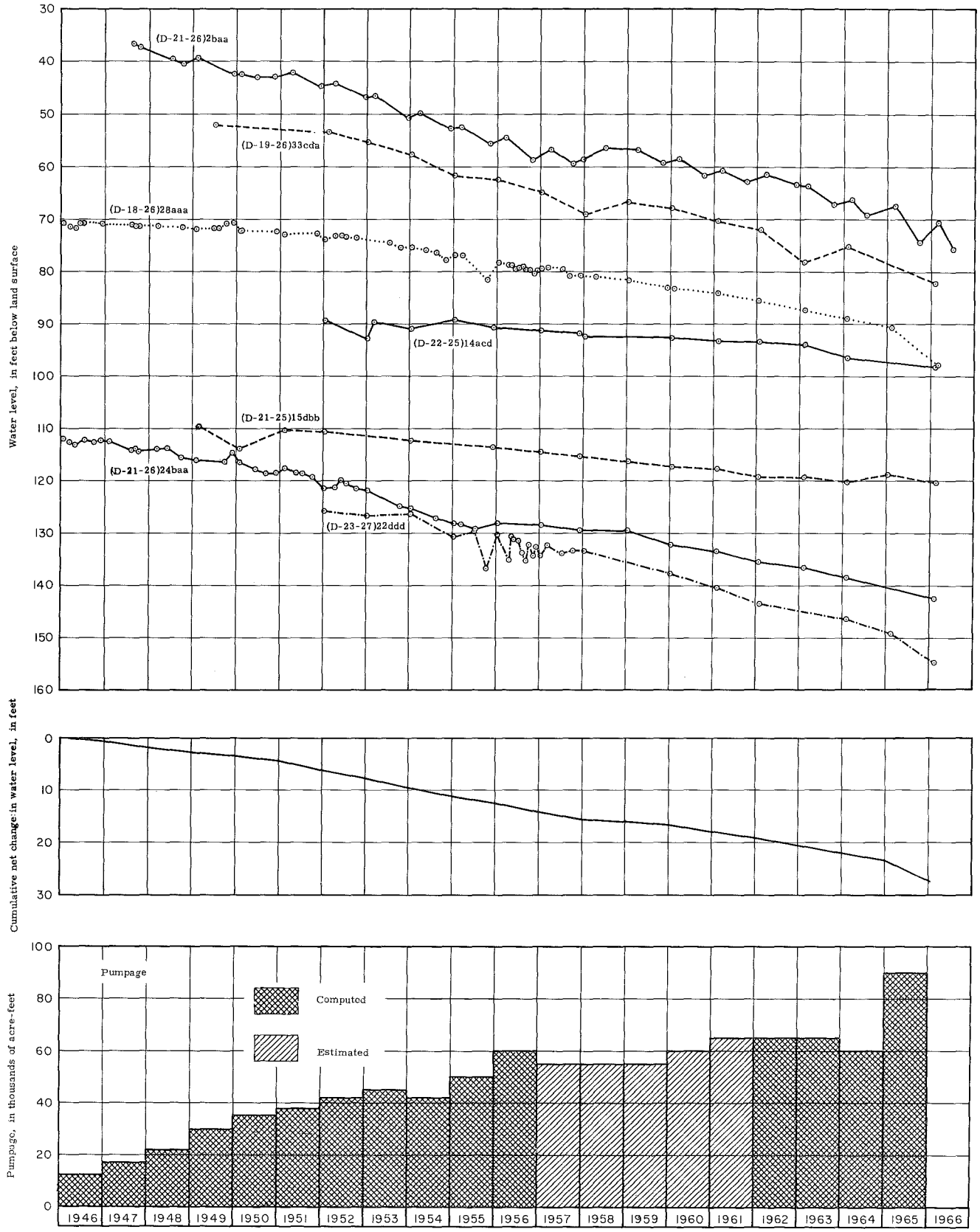


Figure 6.--Water levels in selected wells, cumulative net change in water level, and annual pumpage.

changes in Douglas basin for 1911-66 and 1952-66, respectively. These maps were prepared by superimposing water-level altitude maps for the respective dates. The 1911 water-level altitude map is from Meinzer and Kelton (1913), and the 1952 map is from Coates and Cushman (1955). The map showing the altitude of the water level in spring 1966 (fig. 5) was prepared for this report by the authors from measurements of water levels made in more than 300 wells.

Contours of the change in water level in 1911-66 show that the amount of water-level decline during that period ranged from zero in the southwestern part of the basin to as much as 60 feet in a small area in the north end of the basin (fig. 7). Water-level declines as great as 50 feet took place during this period in a large area in the central part of the basin.

In 1952-66, the amount of change in the water level in Douglas basin ranged from zero in areas on the west, south, and east to as much as 50 feet in a small area at the north end of the basin (fig. 8). This is about the same area in which there was 60 feet of decline in 1911-66. The major part of the long-term water-level change has taken place since 1952 (figs. 7 and 8).

Storage of Water in the Aquifer

Good management of ground water requires a knowledge of the amount of water available from storage in the aquifer. In order to calculate the amount of water that can be pumped from the aquifer, it is necessary to determine the volume of material available for the storage of water and the storage coefficient of the aquifer. The coefficient of storage of an aquifer is defined as the volume of water that the aquifer releases from or takes into storage per unit surface area per unit change in head normal to that surface; thus, it is a dimensionless ratio.

Figure 9 shows contours of the depth to water in the Douglas basin in spring 1966. The depth to water was between 40 and 60 feet below the land surface in the central part of the basin, where Whitewater Draw forms the topographic low along the axis. The depth to water was more than 200 feet below the land surface along the east side of the basin and more than 160 feet along the west side near the mountain fronts. The approximate area of the ground-water reservoir, in terms of the thickness of the permeable alluvium, also is shown on figure 9. The map shows that the thickness of the alluvium ranges from less than 250 feet along the mountain fronts to more than 750 feet in a large area in the

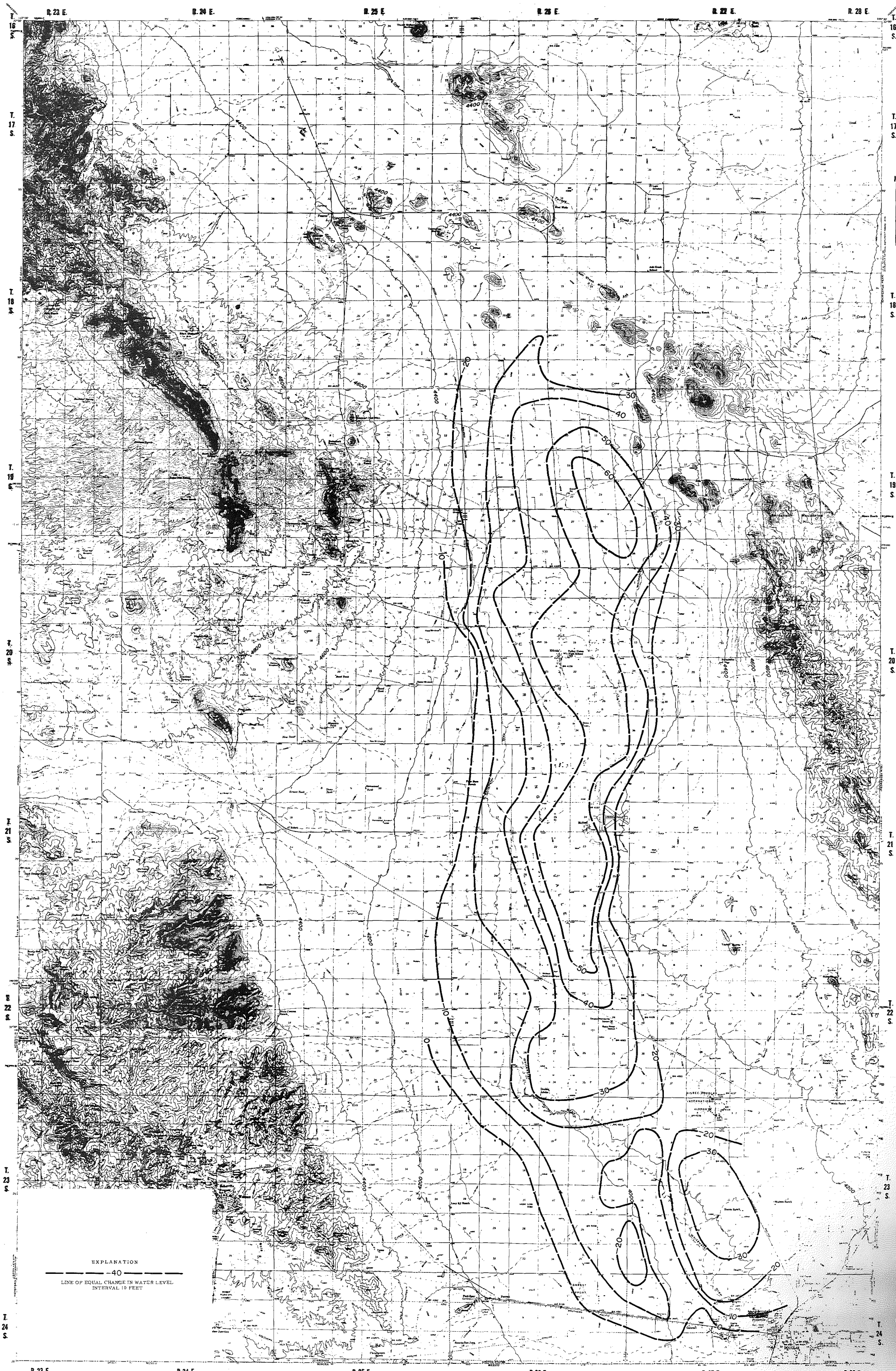


FIGURE 7.-- CHANGE IN GROUND-WATER LEVELS FROM 1911 TO 1966 IN DOUGLAS BASIN.

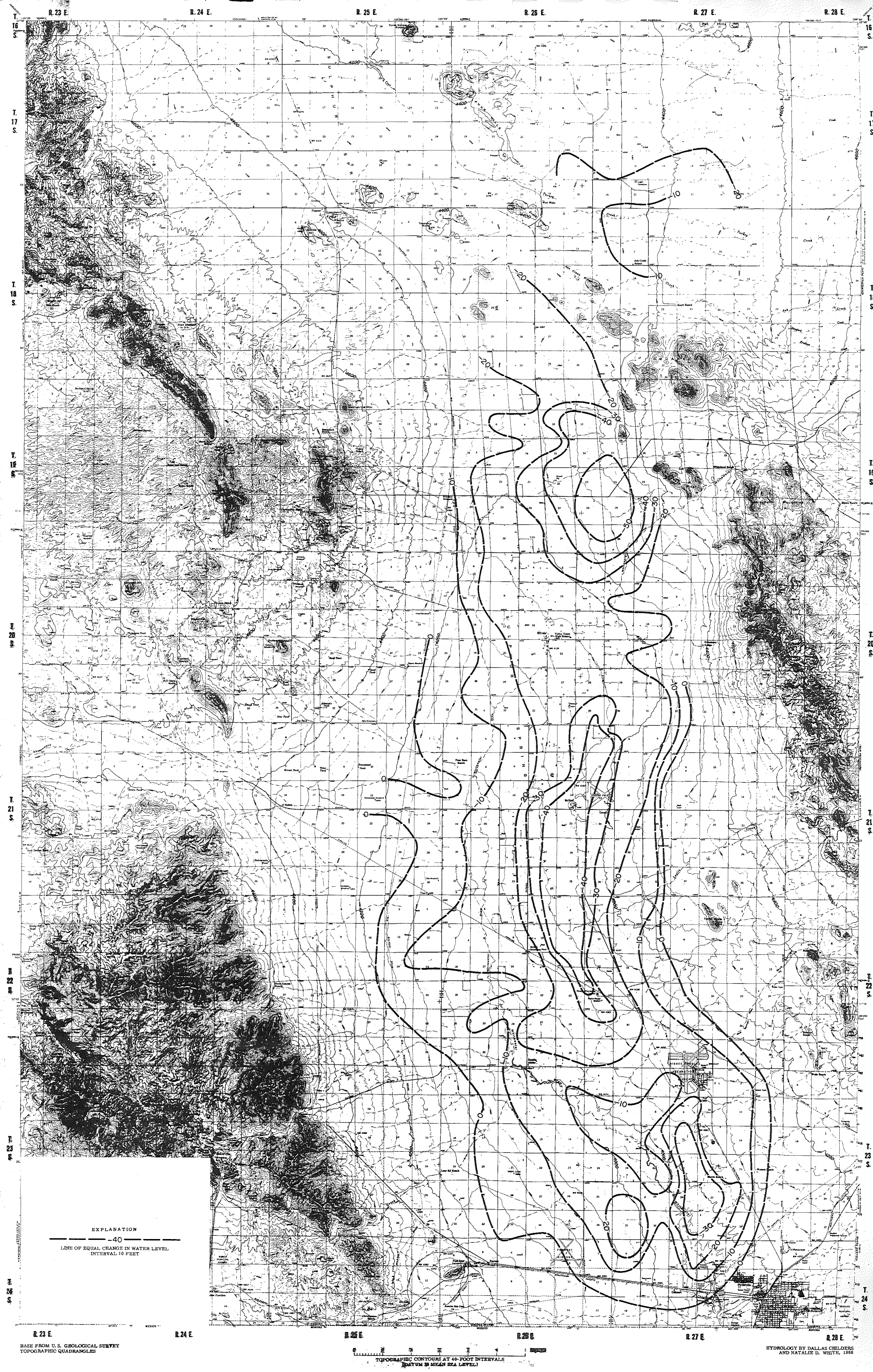
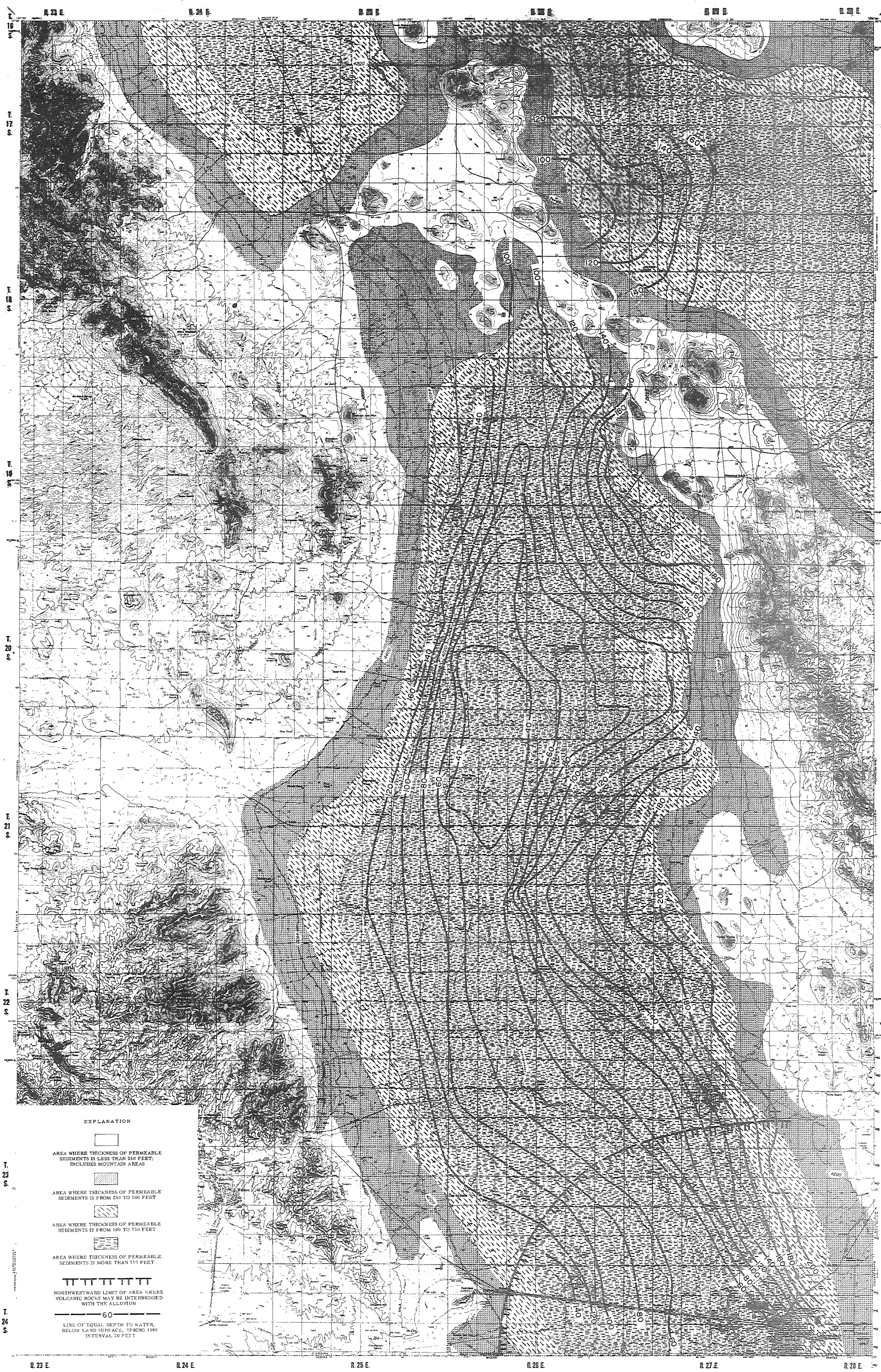


FIGURE 8.-- CHANGE IN GROUND-WATER LEVELS FROM SPRING 1952 TO SPRING 1966 IN DOUGLAS BASIN.



BASE FROM U. S. GEOLOGICAL SURVEY TOPOGRAPHIC QUADRANGLES

THICKNESS OF PERMEABLE SEDIMENTS BY M. E. COOLEY, 1966
HYDROLOGY BY DALLAS CHILDERS AND NATALIE D. WHITE, 1966

FIGURE 9.—— THICKNESS OF PERMEABLE SEDIMENTS AND DEPTH TO WATER, SPRING 1966, IN DOUGLAS BASIN.

central part of the basin. Only the area in the central part of the basin, where the thickness of the sediments is more than 750 feet, has been included in the calculation of the volume of sediments available for the storage of ground water because of the paucity of depth-to-water data for the outlying areas. The depth-to-water contours for spring 1966 were used with the 750-foot thickness of alluvium to determine the thickness of saturated material below the 1966 water level. From these data, it was determined that the total volume of saturated material below the 1966 water table and above the 750-foot level was about 120 million acre-feet within the area (about 190,000 acres) where the permeable alluvium is 750 feet thick or more.

The relation between the amount of ground water withdrawn and the resultant dewatering of the aquifer can be used to determine the coefficient of storage of the aquifer provided that natural inflow is of the same order of magnitude as natural outflow. Recharge and natural discharge are small in relation to pumping; there has been no significant change in the rate of recharge and only a very slight change in the rate of underflow out of the basin, and these values are considered to be essentially constant. Contours of the change in water level for a specified time interval can be used to determine the volume of sediments dewatered during that interval; the volume of water withdrawn divided by the volume of sediments dewatered gives the apparent storage coefficient of the aquifer.

About 3.6 million acre-feet of sediments was dewatered in the Douglas basin in 1952-66 (fig. 8). During this time, about 809,000 acre-feet of ground water was pumped from the aquifer. Using these data, a coefficient of storage of 0.22 was calculated for the aquifer. From computations based on other periods—1947-66 and 1911-66—values of 0.18 and 0.23, respectively, were calculated. The apparent discrepancy between these computed values for the storage coefficient probably is not significant, because the amount of ground water pumped was estimated for several of the years involved in the computations. Therefore, a reasonable value for the storage coefficient of the aquifer is about 0.20. Using this value, the amount of water available from the aquifer can be computed. Based on the calculated volume of about 120 million acre-feet of sediments available for ground-water storage, about 24 million acre-feet of water is available from that part of the storage reservoir previously described. In addition, a few million acre-feet of water is available from storage where the permeable sediments are less than 750 feet thick. The actual volume of water that can be pumped from the ground-water reservoir, however, is less than the computed volume, depending on the effectiveness of the removal of water from storage. Several physical

factors——such as the well depth, distribution, and rate and schedule of pumping——will affect the amount of water that can be withdrawn from the available storage.

SUMMARY

In the Douglas basin, all irrigation water is obtained from wells. In 1965, about 90,000 acre-feet of ground water was pumped; the average amount of water pumped in the previous 9 years was about 60,000 acre-feet per year. Recharge to the ground-water reservoir in the Douglas basin is negligible compared to these amounts of pumping; therefore, the pumping of ground water is causing a progressive decline of the water level as water is removed from storage. Water levels declined as much as 50 feet in 1911-66 in a large area in the central part of the basin. The major part of the long-term water-level change has taken place since 1952. A study of the effects of the withdrawal of ground water indicates that the storage coefficient of the aquifer in Douglas basin probably is about 0.20. Using this value for the coefficient of storage, it is calculated that about 24 million acre-feet of ground water is available from storage within an area of about 190,000 acres that is underlain by permeable sediments more than 750 feet thick.

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