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Description and analysis of the geohydrologic system in western Pinal County, Arizona

By

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DESCRIPTION AND ANALYSIS OF THE GEOHYDROLOGIC SYSTEM IN WESTERN PINAL COUNTY, ARIZONA

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ABSTRACT

Western Pinal County is between Phoenix and Tucson in the Basin and Range physiographic province of southern Arizona and consists of about 2,000 square miles of valley floor with low relief surrounded by mountains. It is the second largest agricultural area in the State, and about 25 percent of the ground water pumped in the State is from this area.

The study area has been divided into four parts. Three of these—the Casa Grande-Florence area, the Eloy area, and the Stanfield-Maricopa area—are in the lower Santa Cruz basin; the fourth—the Gila River area—is a long narrow strip along the Gila River from the Ashurst-Hayden Dam to the confluence of the Gila and Santa Cruz Rivers. The project was undertaken to provide a better understanding of the ground-water supply in relation to the present and potential water use in this area of extensive ground-water development.

The arid climate of western Pinal County—combining high temperatures and low humidity—causes most of the precipitation to be returned to the atmosphere by evapotranspiration, which leaves only a very small part for recharge to the ground-water reservoir. The computed potential evapotranspiration—44.97 inches—is five times greater than the average precipitation.

In general, the subsurface materials in western Pinal County are unconsolidated alluvial deposits underlain by consolidated alluvium and crystalline rocks and bounded by mountains consisting of crystalline and minor sedimentary rocks. The crystalline and sedimentary rocks of the mountains are not known to be water bearing in western Pinal County. The impermeable rocks underlying the basin are called the hydrologic bedrock unit in this report. Although the unit may consist of several different rock types, the distinction between them is relatively unimportant in this study because none of them yield appreciable amounts of water. The lower Santa Cruz basin in western Pinal County is divided into two sections by a buried ridge of the hydrologic bedrock unit, referred to in this report as the Casa Grande Ridge. The ridge trends in a north-south direction from the Sacaton to the Silver Reef Mountains.

The unconsolidated deposits constitute the main storage reservoir for ground water in western Pinal County. The deposits are divided into four units—the local gravel unit, the lower sand and gravel unit, the silt and clay unit, and the upper sand and gravel unit—all of which are major water-yielding units except the silt and clay unit. The local gravel unit, which is present only in the western section of the lower Santa Cruz basin, ranges in thickness from 0 to nearly 1,000 feet and is generally a productive aquifer. The lower sand and gravel unit, which is a heterogeneous mixture of sand, gravel, and clay, ranges in thickness from 0 to about 500 feet. Where the lower sand and gravel unit is overlain by the silt and clay unit, it generally contains water under artesian conditions; where it is not overlain by the silt and clay unit, it is indistinguishable from the upper sand and gravel unit, and the water is under water-table conditions. The silt and clay unit is the least permeable deposit of the unconsolidated alluvium, and ranges in thickness from 0 to about 2,000 feet. Generally it is less productive than the other units of the unconsolidated alluvium, although it yields moderate amounts of water from numerous thin stringers and lenses of highly permeable sand and gravel. The upper sand and gravel unit is at the land surface in most of the area; it ranges in thickness from less than 50 to about 600 feet. The unit has the highest average permeability of all the unconsolidated alluvial units; however, the permeability of the unit varies vertically and laterally, which results in a wide range of well yields. As of 1964, the static water levels in most wells in the basin were still in the upper sand and gravel unit. However, the unit is being dewatered in most of the basin, and water levels in some areas have declined nearly to the bottom of the unit.

Prior to significant ground-water development, the movement of ground water was controlled mainly by the differences in the altitude of the water surface at the extremities of the area; the regional ground-water movement was northwestward from Red Rock and westward along the Gila River. North of Maricopa, the ground water left the area through the narrow Gila River channel between the Sierra Estrella and the Salt River Mountains.

Data derived from well records or tests may be used in several ways to estimate the water-bearing characteristics of the aquifer. For the most part, methods for determining hydrologic characteristics from well data are based directly or indirectly on the specific capacity of wells—the relation of yield to drawdown. Specific capacities, computed from well-completion tests of 539 wells, ranged from 2 to more than 200 gallons per minute per foot of drawdown. Transmissibility of the aquifer based on these specific-capacity data ranged from 5,000 to 300,000 gallons per day per foot.

A flow-net analysis of the area shows that the regional ground-water movement is controlled by the major drainages and is toward the confluence of the Gila and Salt Rivers. Transmissibility, based on the flow net, ranged from about 45,000 gallons per day per foot on the Casa Grande Ridge to about 270,000 in the area between the Palo Verde and Sacaton Mountains.

The amount of ground water pumped from western Pinal County from 1890 through 1963 was about 26.7 million acre-feet. Slightly more than 80 percent of this amount, or nearly 22 million acre-feet, was pumped from 1940 through 1963. The effect of this withdrawal of ground water has been a regional lowering of the water level. From 1923 to 1961, the net change in water level ranged from 0 in a small area west of Casa Grande to a decline of 275 feet in the southwestern part of the Stanfield-Maricopa area. Ground-water pumping has altered the ground-water flow patterns in such a manner that ground water moves into areas of intensive withdrawal. These areas are indicated as depressions in the water table and are discernible on maps showing contours of the water level.

Most of the water pumped in western Pinal County comes from storage in the unconsolidated alluvium. The volume of recoverable ground water in storage beneath an area of about 1,100 square miles in western Pinal County from the static water level (as measured in spring 1960) to 800 feet below the land surface was calculated to be about 44 million acre-feet, based on an estimated average specific yield of the sediments of about 15 percent.

INTRODUCTION

Arizona may be divided into three water provinces (fig. 1): (1) the Plateau uplands in the northern part of the State; (2) the Central highlands; and (3) the Basin and Range lowlands in the southern part of the State. The Basin and Range lowlands province, which includes western Pinal County, contains at least 85 percent of the population and more than 95 percent of the cultivated acreage in the State. Most of the State's water deficiencies at present are in the alluvial basins of the Basin and Range lowlands province. These basins store large amounts of water and, in general, are similar in geohydrologic characteristics, although in detail each is different.

The two most highly developed basins, agriculturally, in the State are the Salt River Valley in central Maricopa County and the lower Santa Cruz basin in western Pinal County. About 50 percent of the ground water pumped in the State is from the Salt River Valley, and 25 percent is from the lower Santa Cruz basin. The lower Santa Cruz basin and the adjacent area along the Gila River (western Pinal County) sustains a multimillion dollar agricultural economy, which is mainly dependent on ground water for its existence and growth. Because of the arid climate in western Pinal County, only small amounts of rainfall and streamflow recharge the ground-water reservoirs.

Ground-water pumpage from the alluvial basins is many times greater than the recharge, and, as a result, ground-water levels are declining, which indicates a depletion of stored water in the basin.

Location and Description of the Area

Western Pinal County is between Phoenix and Tucson in the Basin and Range lowlands province of southern Arizona (fig. 1). The main towns are Florence (the county seat), Coolidge, Eloy, and Casa Grande. The population of Pinal County has increased steadily since 1950 from 43,191 in 1950 to 61,702 in 1960.

The study area consists of about 2,000 square miles of valley floor of low relief surrounded by mountain masses (fig. 2). In part, the boundaries of the area are arbitrary and in part are natural boundaries formed by mountains. The northern boundary extends from near the confluence of the Gila and Santa Cruz Rivers adjacent to the Sierra Estrella eastward along the Maricopa-Pinal County line to Santan Mountain and thence along the base of Santan Mountain to the Ashurst-Hayden Dam. From the dam, the boundary is southward along the east side of the Picacho Mountains to Red Rock and the Pinal-Pima County line, westward along the Silver Bell and Sawtooth Mountains, and northwestward along the Silver Reef Mountains to the Table Top Mountains. The western boundary is formed by the Table

Top Mountains, Haley Hills, Palo Verde Mountains, and the Sierra Estrella. The valley floor, which is pierced by the Sacaton and Casa Grande Mountains, slopes gently from an altitude of about 1,800 feet above sea level near the head of the lower Santa Cruz basin between Picacho Peak and the Silver Bell Mountains to about 1,000 feet above sea level at the confluence of the Gila and Santa Cruz Rivers. The mountains surrounding the area are from a few hundred feet to nearly 3,000 feet above the alluvial valley.

The area has been divided into four parts (fig. 2). Three of these—the Casa Grande-Florence area, the Eloy area, and the Stanfield-Maricopa area—are in the lower Santa Cruz basin; the fourth—the Gila River area—is a long narrow strip along the Gila River from the Ashurst-Hayden Dam to the confluence of the Gila and Santa Cruz Rivers. The Casa Grande-Florence area, which includes about 260 square miles, receives some surface water from the Gila River and the canal systems of the San Carlos Irrigation and Drainage District. The Eloy area, which includes about 440 square miles, is entirely dependent on ground water for its water supply. In the Stanfield-Maricopa area, which includes about 400 square miles, ground water is the chief water supply, although floodwater from the Santa Cruz River, Santa Rosa Wash, and other tributary washes provides a very small amount of water for irrigation. Both ground water and surface water are used for irrigation of crops in the Gila River area.

Purpose and Scope

In 1958 the Geological Survey, in cooperation with the Arizona State Land Department, began a comprehensive analysis of the basic geohydrologic data for western Pinal County. The project was undertaken to provide a better understanding of the ground-water supply in relation to the present and potential water use in this area of extensive ground-water development. An understanding of the geohydrologic characteristics of the area is vital to the efficient development of the water resources.

The overall objectives of the project were: (1) to analyze the characteristics and extent of the subsurface materials in the basin, i.e., to describe the geohydrologic system; (2) to study the occurrence, movement, and discharge of ground water under varying patterns of stress on the system; (3) to determine the amount of ground water available from storage in the basin; and (4) to relate geology and long-term pumping to the quality and change in quality of pumped ground water.

The subsurface geology of the area has been determined mainly from interpretations of drillers' logs of wells, which accounted for about 90 percent of the available data. The other 10 percent was from drill-cutting samples and geophysical logs. The correlation of the logs was extremely tenuous because of the heterogeneity of the sediments and because the logs were made by about 100 different drillers in a 40-year period.

The subsurface geohydrologic studies in western Pinal County have resulted in three reports. The basic ground-water data have been published as Arizona State Land Department Water-Resources Report No. 18; the report describing the quality of the ground water in the area is to be published as U. S. Geological Survey Water-Supply Paper 1819-E. This report contains a description of the subsurface geology as analyzed and correlated from drillers' logs of wells; an analysis of the aquifer system, including the effects of ground-water withdrawal; and a determination of the volume of water available from the system. Geologic interpretations based on drillers' logs include a fence diagram and cross sections; the analysis of the aquifer system includes contour maps of the configuration of the ground-water reservoir and a flow net of the aquifer system.

Figure 3 explains and illustrates the well-numbering system used in Arizona.

Previous Studies

The geology and water resources of western Pinal County are discussed in several published and unpublished reports. Many early reports were not detailed due to the lack of reliable data and discussed geohydrology only broadly or consisted mostly of tabulations of water-level measurements and well logs. Some of the major contributions were by Lee (1904), Smith (1940), Turner and others (1943), Cushman (1952), and annual reports on ground water published by the Arizona State Land Department for the years 1955-63. The reports by Turner and others (1943) and Cushman (1952) include the results of the most recent and detailed studies prior to the present investigation and contain the most comprehensive geohydrologic data for western Pinal County.

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IDENTIFICATION AND DESCRIPTION OF THE GEOHYDROLOGIC SYSTEM

The physical parameters that influence the geohydrologic system of a basin include climatic factors, geologic features, and flow relations under natural conditions. Evapotranspiration limits the amount of water available for recharge to the ground-water reservoir, particularly in arid regions such as western Pinal County. The impermeable boundaries of a basin confine the ground-water system and determine the size of the ground-water reservoir. The rate at which water can be withdrawn from the ground-water reservoir is a function of the permeability of the water-bearing sediments. The relation of inflow to outflow under natural conditions determines the amount of water available from the system without depletion of the water in storage.

Climate

The climate of western Pinal County is characterized by hot summers, moderate temperatures during the rest of the year, low precipitation and humidity, high evaporation rates, almost no snow, and, usually in the spring, moderate winds. Climatological data from several stations in the area (table 1) indicate that the mean annual temperature ranges from 68.5°F to 70.7°F and averages 69.5°F;

the annual precipitation ranges from 7.39 to 9.85 inches and averages 8.74 inches for the period of record.

The exceptionally long periods of above-freezing temperatures—lasting from March to about October—are very beneficial to agriculture. Average monthly temperatures from April through October generally are more than 65°F, and even midwinter temperatures are mild, ranging from the middle thirties at night to the upper sixties during the day.

Rainfall is moderate except during the summer; July and August are the wettest months, and sporadic thundershowers and heavier and more prolonged rains occur. Winter precipitation usually is light but is steady and longer in duration than the summer rains.

Because high temperatures and low humidity combine to cause high evaporation rates, only a very small part of the total precipitation is available for recharge to the ground-water reservoir. Most of the water that originates as precipitation is returned to the atmosphere by evapotranspiration. The computed potential evapotranspiration—44.97 inches, using the method described by Thornthwaite (1948)—is five times greater than the actual precipitation (table 1). Thus, it is unlikely that any significant amount of precipitation falling on the area is recharged to the aquifer (fig. 4), although a small amount of recharge may occur along stream channels where the materials are permeable and water is concentrated for appreciable periods of time. Figure 5 shows that potential evapotranspiration is greater than precipitation in western Pinal County except in December, January, and February when precipitation is very slightly in excess of potential evapotranspiration.

Impermeable Boundaries of the System

In general, the subsurface materials in western Pinal County are unconsolidated alluvial deposits underlain by consolidated alluvium and crystalline rocks and bounded by crystalline and minor sedimentary rocks of the mountains. The impermeable rocks underlying the basin are called the hydrologic bedrock unit in this report. Precambrian granite, gneiss, and schist constitute more than 75 percent of the mountain area. The other 25 percent consists of granite and related crystalline intrusive rocks of probable Mesozoic age; Tertiary volcanic flows, dikes, and necks composed mainly of rhyolite, andesite, and basalt; and sedimentary and slightly metamorphosed rocks consisting of sandstone, shale, conglomerate, quartzite, and limestone, ranging in age from Precambrian to Cretaceous (Wilson and Moore, 1959). The crystalline and sedimentary rocks of the mountains are not known to be water bearing in western Pinal County. However, where faults or fractures have increased the porosity and permeability, it is possible these rocks could yield a small amount of water to wells.

Most of the hydrologic bedrock unit that underlies the permeable sediments in western Pinal County consists of firmly cemented and relatively impermeable sedimentary rocks. The rocks crop out in only a few places in the area; the largest outcrop is a low hill about 2 miles northwest of Casa Grande. The material in this outcrop is a reddish-brown conglomerate, which contains granitic particles ranging in size from pebbles to very large boulders. Similar material is recognized easily in drill cuttings and well logs because of the characteristic color and texture of the rock. Drillers using cable-tool rigs may describe this material as bedrock, hard rock, granite, mountain top, or cemented conglomerate. In some areas, granite, schist, and other crystalline rocks, commonly called bedrock, may be present. The distinction between the different types of hydrologic bedrock is relatively unimportant in this study because none of the types yield appreciable water for irrigation. Near Red Rock and Florence, the hydrologic bedrock may yield sufficient water for domestic or stock supplies.

A contour map of the hydrologic-bedrock surface (fig. 6) shows that the lower Santa Cruz basin in western Pinal County is divided into two sections by a buried ridge of the hydrologic bedrock unit, referred to in this report as the Casa Grande Ridge (fig. 2). The ridge trends north-south from the Sacaton to the Silver Reef Mountains—2 to 5 miles west of Casa Grande—and is about 200 feet below the land surface in places. The long axis of the eastern section of the basin trends north-south from Coolidge to Eloy; in the deepest part of this section the floor of the basin is more than 2,500 feet below the land surface. The hydrologic bedrock unit also forms a ridge between Picacho Peak and the Silver Bell Mountains. Between the Sacaton and Sawtooth Mountains, the surface of the hydrologic bedrock unit on the flank of the Casa Grande Ridge slopes eastward 200 to 500 feet per mile and is more than 1,000 feet below the land surface in most of the eastern section.

In the western section of the lower Santa Cruz basin, the surface of the hydrologic bedrock unit is at a shallow depth along the edges of the basin adjacent to the mountains and is more than 2,000 feet below the land surface in the center between Stanfield and Maricopa. The long axis of the western section of the basin trends northwest from Stanfield to Maricopa and the Salt River. There are two narrow deeply cut troughs in the southern part of the Stanfield-Maricopa area—one along the west side of the Casa Grande Ridge and the other between the Vaiva Hills and the Table Top Mountains.

Underlying parts of the present Gila River channel, particularly from Florence to Coolidge and near Sacaton, the hydrologic bedrock surface is only about 400 to 600 feet below the land surface.

Permeable Deposits of the System

Unconsolidated alluvial deposits constitute the main storage reservoir for ground water in western Pinal County. For the most part these deposits are Tertiary in age or younger.

Discrimination of the Alluvial Units

In order to facilitate interpretation of the drillers' logs from which the following geologic interpretation was made, the drillers' descriptions of the deposits were grouped under six general headings: (1) gravel and similar materials; (2) sand; (3) sand, gravel, and clay—primarily sand or gravel with lesser amounts of clay; (4) clay, sand, and gravel—primarily fine sand, silt, or clay with lesser amounts of sand and gravel; (5) clay—primarily fine sand, silt, or clay; and (6) rocks—primarily conglomerate and other tightly cemented rocks or volcanic flows and crystalline rocks.

The subsurface material in the basin is divided into five geohydrologic units, based primarily on the described size of the material and its permeability. The hydrologic bedrock unit, described in the preceding section, is separated from the overlying water-bearing unconsolidated alluvium, which is subdivided into the local gravel unit, the lower sand and gravel unit, the silt and clay unit, and the upper sand and gravel unit. All these are major water-yielding units except the silt and clay unit. However, the silt and clay unit stores a large amount of water because the saturated part of this unit is of great areal extent and is extremely thick.

Electric and gamma-ray logs were available for about 30 wells in the area; these were used to corroborate the geohydrologic interpretations based on the drillers' logs. Figure 7 shows typical examples of geophysical logs of wells indicating the division of the alluvium into the different geohydrologic units.

The fence diagram of western Pinal County (fig. 8) shows the relation of the geohydrologic units. The fence was constructed from 107 drillers' logs chosen on the basis of location, general correlation with logs of surrounding wells, greater than average well depth, and completeness of the drillers' descriptions. Sections A-A', B-B', and C-C' (fig. 9) show the vertical relation of the geohydrologic units to the position of the water table before and during development.

Local gravel unit

The local gravel unit is present only in the western section of the lower Santa Cruz basin where it is a fan-shaped wedge that widens and thins toward the center of the basin. The wedge extends northward for about 20 miles from the Vaiva Hills and Tat Momoli Mountains and westward for about 12 miles from the Casa Grande Ridge. The deposit is primarily gravel and sand with lesser amounts of clay and locally is firmly cemented. The local gravel unit ranges in thickness from 0 to nearly 1,000 feet; the lower part may be equivalent in age to the lower sand and gravel unit, as it occupies about the same stratigraphic position. The unit is generally a productive aquifer except where well cemented.

Lower sand and gravel unit

The lower sand and gravel unit is a heterogeneous mixture of sand, gravel, and clay. As of 1964, only a few wells had penetrated this unit, particularly in the deepest parts of the basin. The unit ranges in thickness from 0 to about 500 feet but generally is about 100 to 250 feet thick. The depth to the top of the lower sand and gravel unit in the western part of the lower Santa Cruz basin ranges from about 300 to 1,100 feet below the land surface; in the eastern part of the basin it is from 300 to nearly 2,000 feet below the land surface. The lower sand and gravel unit is deepest in the center of both parts of the basin and apparently is absent on the Casa Grande Ridge.

Where the lower sand and gravel unit is overlain by the silt and clay unit, it generally contains water under artesian conditions; where it is not overlain by the silt and clay unit, the unit is indistinguishable from the upper sand and gravel unit and the water is under water-table conditions. This essentially untapped aquifer potentially can yield 1,000 to 2,000 gpm (gallons per minute) of generally fair- to good-quality water, although the water temperature may be 100°F or more. Locally, however, the lower sand and gravel unit may be very firmly cemented, or it may contain fine-grained material of low water-yielding potential.

Because of the declining water table and lower well yields at depth in the silt and clay unit, many wells have been deepened to depths of 1,000 feet or more and penetrate the lower sand and gravel unit. In early 1964, a number of replacement wells 2,000 to 2,600 feet deep were drilled in the Casa Grande-Florence area to the lower sand and gravel unit. If these wells prove to be economically feasible, it is anticipated that similar deep wells will be drilled elsewhere in the area.

Silt and clay unit

The silt and clay unit is a fluviatile and lacustrine deposit composed of fine sand, silt, and clay. Drillers generally report the fine-grained deposits as clay, although they range from silty fine sand to silty clay. The silt and clay unit is the least permeable deposit of the unconsolidated alluvium and ranges in thickness from 0 to about 2,000 feet.

Areally, the silt and clay unit is separated by the Casa Grande Ridge into two bodies (fig. 10). The larger body underlies most of the Casa Grande-Florence and Eloy areas. The top of the unit ranges from about 100 to about 600 feet below the land surface. In the western section of the basin—the Stanfield-Maricopa area—the areal extent of the silt and clay unit is less than half that in the eastern section. In this area the top of the unit is from 200 to 400 feet below the land surface, and the unit ranges in thickness from 200 to 800 feet. The thickest part of the section is in T. 5 S., R. 3 E., and in part of T. 6 S., R. 3 E., where wells penetrate as much as 800 feet of the unit. In the eastern and western sections, the unit is thickest in the center and thins toward the edges of the basin.

The silt and clay unit generally is less productive than the other units of the unconsolidated alluvium. However, the unit yields moderate amounts of water from numerous thin stringers and lenses of highly permeable sand and gravel.

Upper sand and gravel unit

The upper sand and gravel unit is at the land surface in most of the area; it ranges in thickness from less than 50 to about 600 feet but is generally 300 to 400 feet thick. The deposit is similar in lithology to the lower sand and gravel unit, but it is not as firmly cemented and areally is more extensive. The unit has the highest average permeability of all the unconsolidated alluvial units, and well yields generally are high. The permeability of the unit varies vertically and laterally, however, resulting in a wide range of well yields. The contact between the upper and lower sand and gravel units was not defined where the two units are not separated by the silt and clay unit.

As of 1964, the static water levels in most wells in the basin were still in the upper sand and gravel unit (fig. 9). However, the unit is being dewatered in most of the basin, and water levels in some areas have declined nearly to the bottom of the unit. As the water levels continue to decline, yields from this unit will decrease.

Depositional History of the Alluvium

The lower Santa Cruz basin probably was formed by major faulting during late Tertiary time—about 10 to 15 million years ago.

The formation of the mountains and valleys or basins was due mainly to this faulting, and the surface of the hydrologic bedrock was eroded to its present form after this period of faulting. In late Tertiary, Quaternary, and Recent time—about 10 million years ago to the present—the lower Santa Cruz basin was filled with unconsolidated alluvium, of which the local gravel unit and the lower sand and gravel unit are the oldest.

The materials of the local gravel and the lower sand and gravel units were eroded from nearby mountains by stream and sheet runoff originating in the mountains. As the slope of the land surface flattened away from the mountains toward the center of the valley, the carrying power of the water diminished; thus, the coarse materials, such as boulders, were dropped first, followed by gravel, sand, silt, and clay. Therefore, the deposits generally grade in texture from coarse material near the mountains to fine-grained material toward the axis of the valley. This depositional pattern has been modified by the action of through-flowing streams, and shifting of the stream channels from place to place during the filling of the basin resulted in irregular depositional patterns.

The local gravel unit has been found only in the western section of the basin where Santa Rosa Wash now enters the basin. The coarsest material of this unit was deposited near the mountain fronts and the finest material was carried to the north. Contemporaneously with the deposition of the local gravel unit, the lower sand and gravel unit was laid down over much of the rest of the basin. After the deposition of the lower sand and gravel unit, renewed differential uplift accentuated the previously formed troughs, ranges, and ridges. The depression in the eastern section of the basin is several times as large as the one in the western section, and through drainage may have been blocked or diverted as a result of the renewed differential uplift. The ancestral Santa Cruz River probably entered the eastern section of the lower Santa Cruz basin between Picacho Peak and the Silver Bell Mountains, flowed into the eastern depression, and the silt and clay unit was deposited in a lake or sluggish-stream environment. Some of the silt and clay in the eastern depression may have been contributed by the Gila River. After the Casa Grande Ridge was buried and the depression filled to nearly its present altitude, the Santa Cruz River found its way across the ridge and flowed into the western section of the basin. The depression in the western section also was filled by this time, and the Santa Cruz River was able to follow a course similar to the one it takes today, joining the Gila River near the Sierra Estrella. Deposition of the upper sand and gravel unit over the entire basin began at the time throughgoing stream systems were renewed. The upper surface of the upper sand and gravel unit is at the present land surface, and, in places where the silt and clay unit is absent, it overlies the lower sand and gravel unit.

Inflow-Outflow Relations Under Natural Conditions

Ground water moves under the force of gravity from areas of high head to areas of low head in the aquifer. Although minor readjustments in the natural ground-water flow system are constantly taking place, equilibrium tends to be established between the amount of water entering and the amount of water leaving an area. Under natural conditions, prior to significant ground-water development, the movement of ground water was controlled mainly by the differences in the altitude of the water surface at the extremities of the area; and the regional ground-water movement was northwestward from Red Rock and westward along the Gila River. North of Maricopa, the ground water left the area through the narrow Gila River channel between the Sierra Estrella and the Salt River Mountains. Primarily, ground water moved into western Pinal County from three general localities. (1) From the Picacho Mountains to the Gila River underflow moved toward Coolidge; included in this is the recharge from the Gila River. (2) Ground water moved northwestward into the basin through a constricted channel between the Silver Bell Mountains and Picacho Peak. (3) Ground water moved into the western part of the basin from the Santa Rosa and Vekol Washes.

The main avenue of underflow out of the basin was along the alluvial-filled channels of the Santa Cruz and Gila Rivers. However, some underflow was forced to the surface in the narrow channel between the Santan and Sacaton Mountains and left the area as surface flow in the Gila River. Some ground water was discharged by evapotranspiration where it rose to near the surface in the narrow channel between the Salt River Mountains and the Sierra Estrella.

ANALYSIS OF THE AQUIFER SYSTEM

Western Pinal County contains a large ground-water reservoir, typical of an arid-land environment. The recharge rate is very small and many thousands of years were required to fill the reservoir. In this area ground water is stored in the unconsolidated alluvial material to considerable depths below the land surface. In order to fully understand the hydrologic system, it is necessary to determine the hydrologic characteristics of the aquifer that control the occurrence, movement, recharge, and discharge of ground water and to study the cause and effect of the operation of the system.

Hydrologic Characteristics of the Aquifer

The hydrologic properties that control the occurrence and movement of ground water in the aquifer are the coefficients of permeability, transmissibility, and storage. The coefficient of permeability of the aquifer, as defined by Meinzer (Stearns, 1928), is the rate of flow of water, in gallons per day at a temperature of 60°F, through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent. In field practice, determinations generally are made under prevailing conditions of varying water temperature, and the adjustment to the standard temperature is commonly ignored;

this value is called the field coefficient of permeability. The field coefficient of transmissibility of the aquifer is defined as the rate of flow, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent. The transmissibility is equal to the permeability multiplied by the saturated thickness of the aquifer. The coefficient of storage of the aquifer is defined as the volume of water released from or taken into storage from a vertical column of aquifer 1 foot square extending the height of the saturated portion of the aquifer, when the hydraulic pressure on the column is reduced 1 foot.

For water-table conditions the water released from or taken into storage in response to a change in head is attributed partly to gravity drainage or refilling of the zone through which the water table moves, and partly to compressibility of the water and aquifer material in the saturated zone (Ferris and others, 1962). As the volume of water attributable to compressibility is a negligible part of the total volume of water released or stored, the storage coefficient is virtually equal to the specific yield. For artesian conditions, the water released from or taken into storage in response to a change in head is attributed solely to compressibility of the aquifer and of the water. The coefficient of storage for an artesian aquifer is much smaller than for a water-table aquifer. When the head in an artesian aquifer is lowered below the top of the aquifer, water-table conditions prevail. In western Pinal County ground water occurs under both water-table and artesian conditions.

Many methods have been devised for determining the values of these aquifer characteristics. The methods used in this study and the results obtained from them are described below.

Specific Capacity of Wells

Data derived from well records or tests may be used in several ways to determine or estimate the water-bearing characteristics of the aquifer. Although the information from individual wells ranges from poor to good in accuracy, reliability, usefulness, and importance, taken in its entirety, it may effectively describe the hydrologic characteristics of the aquifer system. For the most part, methods for determining hydrologic characteristics from well data are based directly or indirectly on the specific capacity of wells.

The specific capacity of a well is the relation of yield to drawdown, i.e., its yield in gallons per minute per foot of drawdown caused by pumping. The specific capacity of a well is a function not only of the hydrologic characteristics of the aquifer but also of factors such as depth of penetration into the aquifer, well construction, duration of pumping, and well efficiency and, therefore, is not an exact measure of the characteristics of the aquifer. Within limitations, however, specific-capacity data are useful in evaluating the aquifer. Analysis of specific capacity provides an approximate value of transmissibility of the aquifer in a small area around a well; using many such determinations, the relative transmissibility values of the aquifer can be correlated.

The productivity of wells (yields and specific capacities) in western Pinal County varies with saturated thickness of the aquifer, efficiency of the wells, and the permeability of the sediments penetrated by the wells. To aid in evaluating the aquifer in western Pinal County, specific capacities determined from completion tests of 539 wells drilled from 1945 to 1950 were analyzed. Specific capacities ranged from 2 to more than 200 gpm per foot of drawdown (table 2).

The specific-capacity data were plotted on a map of western Pinal County without regard to well depth, and areas of high aquifer productivity—specific capacities of more than 25 gpm per foot of drawdown—were delineated (fig. 11). The map shows large areas of high specific capacity along the Gila River and in the northern half of the Casa Grande-Florence area. In the Eloy area specific capacities were high between the Silver Bell Mountains and Picacho Peak and westward toward the Sawtooth Mountains, east of Eloy toward the Picacho Mountains, and along the south side of the Casa Grande Mountains. In the Stanfield-Maricopa area, specific capacities were high from Stanfield

Table 3.--Range in specific capacities of wells in western Pinal County [1/]

Specific capacity of well (gpm per ft of drawdown)	Number of wells, according to depth of well						
	0–200 (feet)	200–400 (feet)	400–600 (feet)	600–800 (feet)	800–1,000 (feet)	>1,000 (feet)	Total wells
0– 20	12	54	47	35	19	6	173
20– 40	15	32	29	12	5	4	97
40– 60	5	36	25	9	5	2	82
60– 80	5	27	16	5	1	2	56
80–100	3	14	5	1	2	-	25
100–150	7	32	12	10	-	1	62
150–200	4	9	7	7	-	-	27
>200	-	4	5	6	2	-	17
Total	51	208	146	85	34	15	539

1/ Data from well-completion tests, 1945-50.

south to Santa Rosa Wash and eastward to the Casa Grande Ridge, from the Haley Hills northeast to Maricopa, and along the southwestern part of the Sacaton Mountains.

The transmissibility of the aquifer can be estimated from the specific-capacity data by a method described by Thomasson and others (1960, p. 220-222). The method consists of multiplying the specific capacity by an empirical factor to obtain an approximate value for the coefficient of transmissibility. The studies by Thomasson and others (1960, p. 222) indicate the factor ranges from 1,500 for water-table aquifers to 2,000 for artesian aquifers in California; an average factor of 1,700 is indicated for semiartesian conditions. The unconsolidated alluvium in western Pinal County is similar to that in the study area in California, and a factor of 1,700 has been used in determining the approximate transmissibility of the aquifer in this area. Transmissibilities computed by this method may be lower than the actual values because the efficiency of the individual well—which is always less than 100 percent—affects the specific capacity. However, as all the well data have been analyzed on the same basis, variations in average transmissibility figures indicate gross differences in aquifer productivity in western Pinal County.

The transmissibilities of the unconsolidated alluvium in western Pinal County, as determined from specific-capacity data from tests made from 1945 to 1950, ranged from 5,000 to 300,000 gpd (gallons per day) per foot. The transmissibility values were averaged for individual township units and grouped by subareas. For the Casa Grande-Florence area, the transmissibility ranged from 8,000 to 180,000; from 7,000 to 300,000 for the Eloy area; from 5,000 to 270,000 for the Stanfield-Maricopa area; and from 37,000 to 245,000 for the Gila River area (table 3).

As water does not enter a well uniformly with depth in the alluvium, most of the water produced by a well may be derived from only a few water-bearing zones. Transmissibility values based on data from wells open to several water-bearing zones are not necessarily indicative of the total water potential of the aquifer and should not be used to determine the permeability of any particular zone of the subsurface material. For example, a transmissibility of 50,000 gpd per foot may be computed from data for a well in a heterogeneous mixture of sand, gravel, and clay. However, the few water-bearing zones penetrated by the well might have permeabilities of several thousand gpd per square foot, whereas the low-yielding silt and clay deposits might have permeabilities of less than 10 gpd per square foot.

The specific-capacity information (and transmissibility values derived from it) from well-completion tests from 1945 to 1950, described above, may not be indicative of hydrologic conditions in 1963,

Table 3. --Average coefficients of transmissibility, western Pinal County

[Data from well-completion tests, 1945-50]

Location	Total number of wells	Average coefficient of transmissibility[1] (gpd per foot)
CASA GRANDE-FLORENCE AREA		
T. 5 S., R. 7 E.	22	148,000
T. 5 S., R. 8 E.	35	128,000
T. 5 S., R. 9 E.	10	119,000
T. 6 S., R. 6 E.	27	52,000
T. 6 S., R. 7 E.	33	57,000
T. 6 S., R. 8 E.	31	67,000
T. 6 S., R. 9 E.[2]	2	59,000
Total wells	160	
ELOY AREA		
T. 7 S., R. 6 E.	25	52,000
T. 7 S., R. 7 E.	19	35,000
T. 7 S., R. 8 E.	22	76,000
T. 8 S., R. 6 E.	12	89,000
T. 8 S., R. 7 E.	22	27,000
T. 8 S., R. 8 E.	14	79,000
T. 9 S., R. 6 E.	2	52,000
T. 9 S., R. 7 E.	22	107,000

Table 3.--Average coefficients of transmissibility, western Pinal County—Continued

Location	Total number of wells	Average coefficient of transmissibility[1] (gpd per foot)
ELOY AREA—Continued		
T. 9 S., R. 8 E.	10	193,000
T. 9 S., R. 9 E.[2]	2	211,000
T. 9 S., R. 10 E.	3	12,000
T. 10 S., R. 8 E.	3	70,000
T. 10 S., R. 9 E.	7	201,000
Total wells	163	
STANFIELD-MARICOPA AREA		
T. 4 S., R. 2 E.[2]	2	46,000
T. 4 S., R. 3 E.[2]	16	72,000
T. 4 S., R. 4 E.[2]	9	32,000
T. 5 S., R. 2 E.	14	198,000
T. 5 S., R. 3 E.	16	117,000
T. 5 S., R. 4 E.	17	67,000
T. 5 S., R. 5 E.	1	49,000
T. 6 S., R. 2 E.	6	218,000
T. 6 S., R. 3 E.	16	57,000
T. 6 S., R. 4 E.	26	71,000
T. 6 S., R. 5 E.	21	80,000

Table 3. --Average coefficients of transmissibility, western Pinal County—Continued

Location	Total number of wells	Average coefficient of transmissibility[1/] (gpd per foot)
STANFIELD-MARICOPA AREA—Continued		
T. 7 S., R. 4 E.	15	82,000
T. 7 S., R. 5 E.	6	63,000
Total wells	165	
GILA RIVER AREA		
T. 3 S., R. 4 E.	1	167,000
T. 3 S., R. 5 E.	9	145,000
T. 3 S., R. 6 E.	1	37,000
T. 4 S., R. 6 E.	7	109,000
T. 4 S., R. 7 E.	6	119,000
T. 4 S., R. 9 E.	10	179,000
T. 4 S., R. 10 E.	8	175,000
T. 4 S., R. 11 E.	2	150,000
Total wells	44	

1/ Computed by multiplying the specific capacity of the well by a factor of 1,700.

2/ Partial township.

because water levels have continued to decline in the area and a substantial part of the aquifer has been dewatered in some wells. Some data were available from well-completion tests made from 1956 to 1960. Specific-capacity values derived from these tests generally were lower than those derived from 1945 to 1950. Specific capacities for the later period generally ranged from 30 to 80 gpm per foot of drawdown along the Gila River from Ashurst-Hayden Dam to Sacaton in the Gila River area; from 10 to 20, although locally a few as high as 50 or 60, in the Casa Grande-Florence area; from 10 to 45 in the Eloy area; and from 10 to 50 in the Stanfield-Maricopa area.

Analysis of Changes in Ground-Water Storage

Any change in head or water level in an aquifer that takes place as a result of the draining or refilling of the saturated zone indicates a change in the ground-water storage in the area. The volume of aquifer material dewatered or saturated by a given amount of withdrawal or refilling is a function of the storage characteristics of the aquifer materials. The coefficient of storage of an aquifer has been defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface (Ferris and others, 1962, p. 74). In areas where water levels are declining, maps showing the change in ground-water levels for a specified period of time can be used to determine the volume of sediments dewatered owing to the withdrawal of ground water during that period. Assuming that natural discharge is of the same order of magnitude as recharge, the amount of ground water pumped (acre-feet) divided by the volume of sediments dewatered (acre-feet) determines a value of the coefficient of storage (nondimensional).

In western Pinal County, the aquifer is being dewatered as a result of the withdrawal of ground water in excess of the rate of replenishment. The flow system has been affected by the long-term pumping. Where the inflow and outflow are significantly different the storage coefficient, computed as described above, will be higher than the true storage coefficient of the aquifer materials; the difference will depend on the amount of recharge in excess of natural discharge. The storage coefficient computed by this method may be called the apparent storage coefficient. In the Eloy and Stanfield-Maricopa areas, the flow systems are similar. The amount of inflow and the recharge to these areas are negligible in comparison to the amount of ground water pumped; there is almost no natural discharge. The water levels were deep even under nonpumping conditions; thus, it is improbable that any significant amount of recharge from water that has been applied to the land surface for irrigation has as yet reached the water table. Conditions in the Casa Grande-Florence area are somewhat different. Here, in addition to the amount of ground water pumped each year, an average of about 190,000 acre-feet of surface water is diverted into the area annually; the water pumped from the aquifer and the surface water are transported through unlined canals and used for irrigation. A substantial amount of this water seeps downward and recharges the ground-water reservoir. Also, under nonpumping conditions, water levels in the area were comparatively shallow; thus the long-term application of irrigation water to the land may have contributed a significant amount of recharge to the water table. Thus, for the Casa Grande-Florence area the apparent storage coefficient will be higher than the true value to the extent of the recharge. In the Eloy and Stanfield-Maricopa areas the apparent coefficient of storage will closely approximate the true value, because of the relatively small amount of recharge. Using data for 1942 through 1960, the apparent storage coefficients were determined as follows:

Area	Sediments dewatered (millions of acre-feet)	Ground water pumped (millions of acre-feet)	Apparent storage coefficient
Casa Grande-Florence	19.2	5.9	0.31
Eloy	29.2	6.1	.21
Stanfield-Maricopa	32.3	6.0	.19

The apparent storage coefficients of 0.21 and 0.19 for the Eloy and Stanfield-Maricopa areas, respectively, can be assumed to be very near the true values. However, it is possible that they should be reduced slightly to account for a small amount of underflow from the upper Santa Cruz basin (into the Eloy area) and from Santa Rosa Wash (into the Stanfield-Maricopa area). These values compare fairly well with an average value of 0.15 obtained by an empirical method of grain-size analysis. The grain-size analysis method shows that there is a general reduction in storage coefficient with an increase in depth. (See section entitled "Volume of Recoverable Ground Water in Storage.") The apparent storage coefficient is for the materials that have already been dewatered by pumping. Generally, the sediments underlying the area are finer grained at depth, and, thus, the storage coefficient will decrease with depth. If we assume that the true storage coefficient for the Casa Grande-Florence area is about the same as it is for the Eloy and Stanfield-Maricopa areas, then the amount of recharge is slightly less than 120,000 acre-feet per year.

Flow-Net Analysis

A flow net is a two-dimensional portrayal of the ground-water flow pattern, which can help to evaluate the hydrologic system of an alluvial basin. It is composed of two sets of perpendicularly intersecting curves—equipotential lines that represent contours of equal head in the aquifer and streamlines or flow lines that represent the path that, under natural conditions, a particle of water would follow as it moves through the aquifer in the direction of decreasing head to the point of discharge. The total quantity of underflow is divided equally between adjacent pairs of flow lines, and similarly, the total drop in head across the system is divided evenly between adjacent pairs of equipotential lines. The drop in head between two equipotential lines divided by the distance between them is the hydraulic gradient of the water surface in that part of the net.

If the amount of water added to or removed from the aquifer is known, the coefficient of transmissibility of the aquifer can be computed. A simplified form of Darcy's law allows transmissibility to be calculated if it is applied to a part of the flow net where the rectangles formed by the intersecting flow lines and equipotential lines are essentially square; that is, the ratio of their length to their width is unity. The form of Darcy's law that may be applied to parts of a flow net is:

$$T = \frac{Q}{Nh}$$

where

T = Coefficient of transmissibility, in gallons per day per foot.

Q = Discharge, in gallons per day.

N = Number of flow channels.

h = Difference in head between two equipotential lines.

For parts of the flow net where the intersecting equipotential lines and streamlines do not form squares, the transmissibility of the aquifer varies as the ratio of the length of the flow line in that area to the length of the flow line in the area where the flow net is essentially square. For further discussion of flow-net analysis see Taylor (1948).

The flow net for the present study covers a 3,500-square-mile area from Red Rock to Phoenix; the water-level contours (equipotential lines) are based on data for 1930 to 1940 when near-equilibrium conditions prevailed in the aquifer (fig. 12). For the part of the area south of the Gila River, the water-level contours were taken from an unpublished map of about 1930 (written communication, J. F. Deeds); north of the Gila River, contours are based on water levels measured in about 125 wells from 1930 to 1940. The flow system has been confined by a generalized boundary of no ground-water flow, which includes the surface exposure of the mountains, impermeable deposits, buried pediments, and alluvium that is not water bearing. Adjacent to the hard-rock area or boundary of no flow, water-level data were insufficient or nonexistent, and some assumptions were necessary to complete the flow net.

The flow net shows that the regional ground-water movement was controlled by the major drainages and that the mountains influenced the flow system only in places. The Picacho, Casa Grande, Sacaton, Santan, and Salt River Mountains are relatively impermeable islands in a sea of permeable alluvium. Regional ground-water movement was toward the confluence of the Gila and Salt Rivers, and recharge was generally from intermittent streams that drained the mountains and from underflow in the alluvial channels from upstream basins.

The flow net was constructed so that squares were formed by the intersection of the flow lines with the 1,440- and 1,480-foot equipotential lines between the Sawtooth Mountains and the Gila River and with the 1,320- and 1,360-foot equipotential lines between the Goldmine and Superstition Mountains. Because the transmissibility of the alluvium is not uniform and because the pattern formed by the flow lines and equipotential lines changes as a function of the transmissibility, other parts of the flow net contain rectangles of different dimensions.

According to Turner and others (1943), the amount of underflow into the lower Santa Cruz basin through the alluvial channel between the Silver Bell Mountains and Picacho Peak was about 25,000 acre-feet per year. The magnitude of the yearly underflow from 1930 to 1940 used in the flow-net analysis was estimated to be about the same. This underflow was assumed to move equally through a section of squares consisting of 5-1/2 flow channels having a drop in head of 40 feet between the 1,440- and 1,480-foot contour lines. Thus, based on the form of Darcy's law described above, the average coefficient of transmissibility for the strip would be about 100,000 gpd per foot.

The coefficient of transmissibility in the alluvial channel between the Silver Bell Mountains and Picacho Peak was computed to be nearly 300,000 gpd per foot, assuming a channel width of 5 miles, a ground-water gradient of 15 feet per mile, and underflow of 25,000 acre-feet per year.

About 18,000 acre-feet per year, or about 70 percent of the ground water that entered the basin through the Santa Cruz channel, moved between the Silver Reef and Sacaton Mountains into the Stanfield-Maricopa area and thence to the Gila River. The average coefficient of transmissibility of the alluvium in this channel between the 1,320- and 1,360-foot contours was computed to be about 45,000 gpd per foot, based on the ratio of the sides of the rectangles as described above. Most of the ground-water movement was concentrated in the center of the Stanfield-Maricopa area, as indicated by the close spacing of the flow lines. Geologic data interpreted from drillers' logs indicate this is the thickest saturated section of water-bearing material in the Stanfield-Maricopa area. South of Maricopa, across a section of about 12 miles from the east edge of the Palo Verde Mountains to the west side of the Sacaton Mountains, the transmissibility of the aquifer was computed to be about 270,000 gpd per foot. From the flow net, a similar transmissibility was computed between the 1,120- and 1,160-foot contours across the Stanfield-Maricopa area. Between Stanfield and Maricopa in the center of the basin, transmissibilities of as much as 600,000 gpd per foot were computed.

Some additional water enters the Stanfield-Maricopa area by underflow from Santa Rosa and Vekol Washes; Turner and others (1943) estimated the amounts as 1,500 and 500 acre-feet per year, respectively.

The remaining 7,000 acre-feet per year of ground water from the Santa Cruz channel moved toward the east end of the Sacaton Mountains and joined the flow system in the alluvium from the north end of the Picacho Mountains to the Gila River. The amount of underflow in this reach is unknown. If the transmissibility of the aquifer is similar to that of the section between the Sawtooth and Picacho Mountains (100,000 gpd per foot), the underflow into the Casa Grande-Florence area from the east would be about 22,000 acre-feet per year. This includes 2,000 to 3,000 acre-feet per year of underflow derived principally from runoff in the Picacho Mountains that drained into McClellan Wash. Adequate information is not available to determine the geohydrologic characteristics of the aquifer between Florence and the Picacho Mountains, but data from a few wells indicate that the aquifer here may have a low transmissibility, in which instance underflow would be less than the calculated figure.

Regardless of the total amount of subsurface flow into the vicinity of Coolidge, only about 4,000 acre-feet per year of underflow could move through the Gila River channel at the narrow constriction between the Sacaton Mountains and the Malpais Hills. This figure is based on a transmissibility of 130,000 (estimated from specific-capacity data), a ground-water gradient of 10 feet per mile, and a width of 3 miles at the constriction. The rest of the underflow moved toward the land surface and was lost to the atmosphere as evapotranspiration or became surface flow in the Gila River. All the water loss has been shown at the 1,360-foot contour line, although the loss is distributed along the river in the phreatophyte zone (fig. 12). Turner and others (1943) estimated evapotranspiration in the reach of the Gila River from near Coolidge to the Salt River ranged from 100,000 to 150,000 acre-feet per year.

The water-level contours and flow lines indicate that in the reach from the Ashurst-Hayden Dam to Florence, the Gila River may recharge the aquifer only in a strip a few miles wide along the channel. The flexures of the contours in this reach are not symmetrical around the Gila River because flow in the river is extremely variable. Only during times of high flow does water go down the Gila River past the Ashurst-Hayden Dam.

The flow lines southeast of Magma indicate that the Gila River can be a source of recharge and that ground-water movement is toward a ground-water trough trending along the north side of the Goldmine and Santan Mountains to Chandler and east of the Salt River Mountains to the Salt River. This trough suggests the possibility of a buried channel, which may have been the valley of the ancestral Gila River. Cursory study of yields from a few wells also indicates the possibility of permeable channel deposits. The flow lines between the Santan and Salt River Mountains indicate that probably no ground water moves from the Salt River to the Gila River and that most of the flow is from the area south of the Queen Creek drainage.

Effects of Withdrawal of Ground Water

Whenever water is withdrawn from an aquifer, the water level is lowered near the discharging well. Water is removed from storage concurrently with the lowering of the water level; thus, a cone of depression is formed in the water table. Expansion of the cone and removal of water from storage must continue until recharge is increased, natural discharge decreased, or a combination of both by an amount equal to the rate of withdrawal. The overlapping influence of many pumping wells causes a regional lowering of the water level; the cone of depression is deepest in the center of heaviest pumping. The effect of ground-water withdrawal in western Pinal County at the present time is a widespread regional lowering of the water level.

History of Water Development

The lower Santa Cruz basin of western Pinal County and the area adjacent to the Gila River have been cultivated by Indians since prehistoric times. Floodwater from the Santa Cruz and Gila Rivers was used by American settlers for irrigating crops beginning in about 1850. In the 1860's canals were constructed to divert Gila River water to the lands south of the river. In 1890, Picacho Reservoir was constructed and floodwater from the Gila River was diverted into it by a canal for use near Casa Grande and Coolidge. In 1890, about 7,000 acres was irrigated, and by 1910, 25,000 acres was being irrigated in Pinal County, mostly with water from floodflow and shallow dug wells.

The first large irrigation wells were drilled in the lower Santa Cruz basin near Toltec in about 1914, and by 1930, about 40,000 acres was being irrigated in Pinal County. At the beginning of World War II, there was a large increase in the irrigated acreage caused by the demand for agricultural products. In 1942, about 170,000 acres was irrigated in Pinal County, resulting in increased pumping of water from the ground-water reservoir, and water levels began to decline at a rapid rate. In 1948, a ground-water code was enacted to restrict irrigation in critical areas. The code stated that after an area was declared critical, no additional land could be irrigated, and no new wells could be drilled except as replacements. The Eloy area was declared critical in 1949 and the Casa Grande-Florence and Stanfield-Maricopa areas in 1951. Additions to these areas and most of the Gila River area were declared critical in 1954.

In 1956, there were about 1,500 irrigation wells in western Pinal County—not all active—and about 275,000 acres was irrigated (fig. 2). Since that time, the number of wells has not increased greatly, although some new wells have been drilled as replacements.

The amount of ground water pumped from the lower Santa Cruz basin and the Gila River area from 1890 through 1963 is estimated to be about 26.7 million acre-feet. Slightly more than 80 percent of this total, or nearly 22 million acre-feet, was pumped from 1940 through 1963. The amount of ground water pumped is related directly to agricultural development, as only a minor amount of ground water is used for other purposes. In 1963 municipal water use in Casa Grande, Florence, Coolidge, and Eloy was only about 5,000 acre-feet; whereas, agricultural use of ground water was about 1 million acre-feet. Table 4 shows the amount of ground water pumped and the total irrigated acreage by years. The estimates of ground-water pumpage represent the total rather than the net withdrawal of ground water from the reservoir. The total withdrawal is all the water that is pumped to the land surface; whereas, the net withdrawal is total pumpage less that returned to the ground-water reservoir.

Prior to 1940, the amount of ground water pumped was estimated by assuming a water use of 3 acre-feet per acre of irrigated land; the total acreage irrigated was small, and a minor error in water duty would not materially change the total pumpage figure.

Table 4.--Irrigated land and ground-water pumpage, western Pinal County, 1889-1963

Year	Irrigated land (acres)	Ground-water pumpage, irrigation use (acre-feet)	Ground-water pumpage, municipal use (gallons)			
			Casa Grande	Florence	Coolidge	Eloy[1]
1889	6,919	[2] 21,000	-----	-----	-----	-----
1899	11,297	[2] 34,000	-----	-----	-----	-----
1909	25,431	[2] 76,000	-----	-----	-----	-----
1919	28,647	[2] 86,000	-----	-----	-----	-----
1929	37,044	[2] 111,000	-----	-----	-----	-----
1939	117,556	[2] 352,000	-----	-----	-----	-----
1949	280,000	1,100,000	-----	-----	-----	-----
1959	293,283	1,200,000	831,177,100	179,023,600	451,334,000	172,644,700
1960	285,900	1,100,000	860,915,700	168,601,300	425,126,000	151,020,800
1961	271,755	1,150,000	806,960,900	172,494,000	406,037,000	166,282,000
1962	258,095	1,050,000	875,755,600	187,240,900	436,190,000	[3] 150,724,000
1963	253,540	1,000,000	852,856,900	195,902,500	416,562,000	175,919,000

1/ Fiscal year, ending June 30.

2/ Computed on the basis of a water duty of 3 acre-feet per acre. From 1889-1909, figure includes some water from floodflow; E, estimated.

3/ Pumpage low, sand in meters.

From 1890 to 1939, less than 5 million acre-feet of ground water was pumped in western Pinal County. Subsequent to 1940, estimates of ground-water pumpage in western Pinal County have been based on the total power used for irrigation and the average amount of energy required to pump an acre-foot of water. An average energy factor—kilowatts of electric power per acre-foot or cubic feet of natural gas per acre-foot—is computed by measuring the amount of power used to pump an acre-foot of water at a representative 10 percent of the irrigation wells in the area in the summer irrigation season. Average energy factors and total pumpage were computed separately for the Eloy, Casa Grande-Florence, and Stanfield-Maricopa areas; data for the Gila River area have been included with those for the Casa Grande-Florence and Stanfield-Maricopa areas.

Comparison of average energy factors for 1953 through 1960 shows that each succeeding year more power is required to pump the same amount of water because of increased pumping lift caused by the decline in water levels (fig. 13). In this 8-year period, the amount of energy required to pump an acre-foot of water increased from 490 to 600 kilowatt hours of electric power and from 7,000 to 10,000 cubic feet of gas in the Casa Grande-Florence area; from 500 to 850 kilowatt hours and from 8,500 to 11,700 cubic feet of gas in the Stanfield-Maricopa area; and from 690 to 770 kilowatt hours and from 10,000 to 13,000 cubic feet of gas in the Eloy area.

Water-Level Fluctuations

Water-level fluctuations fall generally into two categories—short-term or seasonal and long-term—and each may be indicative of different hydrologic changes. Short-term or seasonal fluctuations may reflect changes in individual pumping rates and pressure adjustments caused by differential loading from barometric pressure, earth tides, and earthquakes, or they may be caused by climatic changes, seasonal changes in the amount of recharge to the ground-water reservoir, and changes in the amount of ground water pumped. Long-term fluctuations indicate the regional trend of the water level resulting from changes in ground-water storage.

Four continuous recording gages were installed in western Pinal County in April 1959 to record the short-term or seasonal fluctuations; the four continuous recording gages are on wells (D-9-8)17cdd, 8 miles south of Eloy; (D-6-5)25ccc, 2 miles southwest of Casa Grande; (D-4-2)13bcc, 4 miles northwest of Maricopa; and (D-5-8)16dda, at Coolidge. The recorder on well (D-9-8)17cdd is in the center of a heavily pumped area, and any short-term fluctuations are masked by the effects of pumping. The other gages are located away from the pumped area and reflect short-term fluctuations.

Water levels are measured in 300 to 500 wells each spring during the nonpumping season to determine the long-term fluctuations.

The ground-water regimen in western Pinal County was controlled entirely by climatic and geologic factors before it was disturbed by man's activities. Abnormal changes in stream runoff could cause local short-term fluctuations in the water table, but long-term changes were small because of the large storage capacity of the basin reservoir and the slow movement of ground water. When man began pumping ground water for irrigation the balanced water regimen was disturbed. Water is being withdrawn at a rate greatly in excess of natural recharge and inflow, resulting in the depletion or mining of ground water and declining water levels.

Short-term or seasonal fluctuations

In western Pinal County, water levels usually are highest in the winter and early spring when ground-water pumping is at a minimum. From February to October, the continuous withdrawal of ground water causes a lowering of water levels; the greatest decline is at the center of the cone of depression that develops in the area of pumping. When the pumps are turned off, the water levels recover and adjust to the regional level, which is usually lower than before pumping began because most of the water pumped comes from storage. Near-static conditions prevail in the aquifer until the following spring when the pumping cycle is repeated.

The effects of seasonal pumping on the water table are shown by the hydrograph of the water level for well (D-9-8)17cdd (fig. 14)—an unused well in the center of a heavily pumped area. The differences in the highest and lowest water levels each year for the period of record ranged from 30 to 60 feet. The progressive decline of the high water level in the well is an indication of the regional lowering of the water table, which is the result of the depletion of ground-water storage in the area.

The fluctuations of the water level in well (D-6-5)25ccc (fig. 14), adjacent to a canal on the Casa Grande Ridge, are related directly to the presence of surface water in the canal. In the summer growing season, the canal generally is full of water, some of which recharges the aquifer and causes a rise in water level in the well.

The fluctuations of the water level in well (D-4-2)13bcc, at the northern edge of the irrigated fields in the Stanfield-Maricopa area, are out of phase with those in most heavily pumped areas. The water level is highest in October at the end of the irrigation season and lowest in June during the peak of the pumping season (fig. 14). The trend of the water level is upward from June to October and then downward until the following June. The observation well is relatively shallow, and most of the nearby wells pump from a lower zone in the alluvium. It is possible that a part of the irrigation water applied to the adjacent fields recharges this shallow aquifer.

Long-term fluctuations

Long-term changes or trends of the water table show net changes in ground-water storage. In western Pinal County, the long-term trend of the water level is downward, indicating aquifer depletion. Long-term trends of the water level can be studied by preparing maps showing contours of equal change in water levels for different time intervals.

Maps showing the net change in ground-water levels in western Pinal County were constructed for the periods 1923-42, when there was only a small amount of agricultural development and ground-water pumpage, and for 1923-61.

Changes in ground-water levels, spring 1923 to spring 1942.--The ground-water reservoir in western Pinal County was virtually undisturbed prior to 1923. The 19-year period from spring 1923 to spring 1942 covers the initial development of the basin, during which the amount of land irrigated increased from 30,000 to 130,000 acres and annual pumping of ground water increased from 95,000 to

351,000 acre-feet. Ground-water withdrawal in this period was about 3,600,000 acre-feet.

Changes in ground-water levels from spring 1923 to spring 1942 ranged from rises of as much as 20 feet west of Casa Grande to declines of as much as 30 feet in the Eloy area (fig. 15). Near Florence and Coolidge water-level declines ranged from 10 to 20 feet. The map (fig. 15) shows a long narrow trough in the water table trending north-south in the Eloy and Casa Grande-Florence areas. The decline is greatest in the center of pumping near Eloy and less toward the edges of the pumped area. The trough narrows near the Florence-Casa Grande Canal due to recharge from the Picacho Reservoir and less pumping of ground water where surface water is available. Recharge from Picacho Reservoir is indicated by the bending of the contours around the western margin of the reservoir.

The rise in water levels near Casa Grande may be attributed partly to recharge of the shallow water table from surface flow in the Florence-Casa Grande Canal, from irrigation water applied to the land, and from floodflow in the Santa Cruz River and its tributaries. Water may be rising from depth along fractures or faults in the hydrologic bedrock unit of the buried ridge and recharging the upper sand and gravel unit. Geologic evidence indicates the possibility of a fault zone on or along the impermeable Casa Grande Ridge, particularly near Santa Rosa Wash. Water quality generally is poor on the ridge—an indication that the water may be coming from depth, as water quality is excellent in the adjacent areas. These phenomena were noted by Cushman (1952).

There was no regional decline of the water table in the Stanfield-Maricopa area from spring 1923 to spring 1942 because agricultural development was minor.

Nearly 4,400,000 acre-feet of sediments was dewatered in the area of decline from 1923 to 1942. Assuming a specific yield of 10 to 20 percent, this volume of dewatered sediments would produce about 440,000 to 880,000 acre-feet of water or only about 15 to 25 percent of the total amount of ground water pumped; the remainder was supplied by ground-water inflow into the area. Ground-water inflow is analyzed in more detail in a later section of this report.

Changes in ground-water levels, spring 1923 to spring 1961.--The amount of water withdrawn from the ground-water reservoir in western Pinal County from 1923 to 1961 was about 21.5 million acre-feet. Recharge to the area in this period was substantially less than the amount pumped, resulting in a general decline in water level. The net change in water level for the 38-year period ranged from 0 in a small area west of Casa Grande to a decline of 275 feet in the southwestern part of the Stanfield-Maricopa area (fig. 16).

The pattern of the long-term water-level fluctuations in western Pinal County was influenced predominantly by the withdrawal of ground water. Other influences include differences in permeability and porosity of the unconsolidated alluvial aquifer, the amount and distribution of recharge, and the configuration of the hydrologic bedrock surface.

There was essentially no decline in water levels from 1923 to 1961 on a part of the Casa Grande Ridge, as very little water was pumped from the relatively thin section of saturated alluvium overlying the ridge. Because water-level declines are large on either side of the ridge, it essentially divides the basin into two areas of large-scale pumping and decline in water levels.

East of the ridge, water-level declines ranged from 25 to 175 feet (fig. 16). The greatest declines were in the center of the cultivated area near Eloy and southward.

West of the ridge, the water-level decline was 275 feet near the southwest boundary of the Stanfield-Maricopa area and about 200 feet near the southwest corner of the Sacaton Mountains. In these two regions, the adjacent mountains are a barrier to ground-water movement, and water is pumped at a greater rate than in the center of the area. Water-level changes increased from 0 along the top of the Casa Grande Ridge to 200 feet in sec. 6, T. 7 S., R. 5 E.—a distance of about 4 miles. Near Santa Rosa Wash about 3 miles southeast of Stanfield, water-level declines were only 125 feet, probably due to recharge from the wash. Water-level declines decreased from Stanfield northward toward Maricopa. Along the Gila River from Coolidge to Sacaton, water-level declines were less than 75 feet.

Relation of net changes in average water levels to pumpage

The method for studying the relation between the annual net change in water levels and pumpage consisted, first, of determining average depth to water and total pumpage for 1940. These values were then assumed as a zero base, and subsequent annual changes in average water levels or annual pumpage were added accumulatively through 1963. Computations were made separately for each of the three areas—Eloy, Stanfield-Maricopa, and Casa Grande-Florence. Data for the Gila River area were included with that for the latter two areas.

Ground-water pumpage in western Pinal County from 1940 through 1963 was nearly 22 million acre-feet. The decline in water levels for the period averaged 5.3 feet per year.

Ground-water pumpage in the Eloy area from 1940 through

1963 was about 7.2 million acre-feet. The net decline in water levels averaged about 6.0 feet per year, and the total decline for the 24-year period was nearly 143 feet (fig. 17). Ground-water pumpage in the Stanfield-Maricopa area was nearly 7.6 million acre-feet from 1940 through 1963. The net decline in water levels averaged about 6.4 feet per year, and the total decline for the 24-year period was about 154 feet (fig. 18). Ground-water pumpage in the Casa Grande-Florence area from 1940 through 1963 was about 7.1 million acre-feet. The net change in water levels averaged about 3.9 feet per year, and the total decline for the 24-year period was about 93 feet (fig. 19).

Changes in Ground-Water Movement

Prior to the development of ground water in western Pinal County, the rate and direction of ground-water movement was controlled by the porosity and permeability of the sediments and by the topography and structure of the basin. After pumping began ground-water flow patterns in the alluvial reservoir were altered in such a manner that the flow was toward the areas of intensive withdrawal. These changes in the direction of ground-water movement can be studied by constructing a series of water-level-contour maps—maps showing lines of equal altitude of the water level—for periods before and during development of ground water in the area.

Water-level-contour maps were prepared for western Pinal County based on water-level measurements for the following dates: spring 1923, before intensive development of ground water; spring 1949, in the early stages of intensive pumping; spring 1959 and summer 1959, to show the differences in the configuration of the water table in nonpumping and pumping seasons; and spring 1964, after nearly 25 years of intensive ground-water development.

Spring 1923

In the spring of 1923, when the ground-water reservoir in western Pinal County essentially was under natural hydrologic conditions, ground water entered the basin as underflow between Picacho Peak and the Silver Bell Mountains near Red Rock at a gradient of about 15 feet per mile (fig. 20). Movement continued north and northwestward through Eloy toward the southeast corner of the Sacaton Mountains—a distance of about 30 miles—at a gradient of 8 to 10 feet per mile. Because the Sacaton Mountains are a barrier to ground-water movement, part of the underflow moved west toward Casa Grande, Maricopa, and the Gila River, and part moved toward Coolidge and thence to the Gila River.

From Casa Grande westward for about 5 miles, the water table sloped westward at a gradient of about 20 feet per mile because the volume of permeable alluvium was reduced due to the Casa Grande Ridge. The configuration of the water-level contours in the Stanfield-Maricopa area indicates that there probably is some recharge from Santa Rosa and Vekol Washes. From Stanfield to Maricopa the ground-water gradient was about 5 feet per mile. That part of the underflow that moved from the southeast corner of the Sacaton Mountains north past Coolidge was joined by ground water moving westward from the east edge of the area between the Gila River and the Picacho Mountains, and, thence, moved toward the Gila River. All the underflow could not move through the narrow alluvial channel between Santan Mountain and the Sacaton Mountains; water was forced to the land surface near Blackwater, and water loss by evapotranspiration was high.

In general, the movement of ground water in the Gila River area was parallel to the river, and the gradient along the channel from Florence to Coolidge and downstream to Sacaton was about 10 feet per mile. The only control of streamflow in the Gila River in 1923 was low-flow diversion at Ashurst-Hayden Dam. Therefore, runoff in the river and, consequently, ground-water recharge along the river probably was at a maximum before the completion of Coolidge Dam in 1929. Underflow from the Stanfield-Maricopa area north of Maricopa joined that from the Gila River channel and moved westward out of the study area between the Sierra Estrella and Salt River Mountains (west of map area).

Spring 1949

The water-level contours for spring 1949 show definite changes in the configuration of the water table caused by pumping of ground water (fig. 21). The ground-water gradient between the Silver Bell Mountains and Picacho Peak from Red Rock into the Eloy area was about 20 feet per mile in spring 1949—an increase of 5 feet per mile from spring 1923. A trough had formed in the water table from about 5 miles southeast of Eloy to the Casa Grande and Florence-Casa Grande Canals, and ground water flowed into this trough from the west side of the Picacho Mountains. Between the Silver Bell and Sawtooth Mountains some ground water flowed toward this trough, some continued to flow northwestward between the Casa Grande and Sawtooth Mountains toward Casa Grande and Stanfield, and some flowed southwestward toward a depression in the water table southeast of the Sawtooth Mountains.

About 5 miles east of Casa Grande, a ground-water divide had developed, and ground water flowed eastward toward Coolidge and westward toward Stanfield. West of Casa Grande, the ground-water gradient across the Casa Grande Ridge was about 25 feet per mile—an increase of 5 feet per mile since spring 1923. The increased ground-water gradient on the ridge is attributed primarily to a large water-level decline west of the ridge near Stanfield. Pumping between Stanfield and Maricopa flattened the slope of the water surface to about 3 feet per mile in 1949, as compared to 5 feet per mile in 1923, resulting in a decrease in the amount of underflow leaving the area.

Along the Gila River channel from Ashurst-Hayden Dam to Sacaton, the water-table gradient was about the same as in spring 1923, although recharge in the Gila River area was much less in 1949 than in 1923 because Coolidge Dam (built in 1929) controlled flow in the river.

Comparison of spring and summer 1959

Comparison of the maps showing water-level contours for spring and summer 1959 (figs. 22 and 23) will indicate the difference in the configuration of the water table resulting from the seasonal pumping of wells in the area. The configuration of the water table and the direction and rate of ground-water movement in spring 1959, when conditions in the aquifer were relatively stable, are the accumulative results of long-term withdrawal of ground water. Measurement of the water level in nonpumping wells in the summer irrigation season and preparation of water-level contours based on these measurements will show the additional effects of the pumping season on the configuration of the water table.

For the most part, the configuration of the water table is similar for the two periods, but in summer 1959 depressions are deeper, mounds are more pronounced, and gradients are steeper than in spring 1959. In addition, new depressions are evident in summer 1959, and a few of the ground-water mounds apparent in spring 1959 have flattened out or are not present in summer 1959. These phenomena probably are the result of different rates of withdrawal of ground water in the area.

Spring 1964

The water-table contours for spring 1964 (fig. 24) reflect the configuration of the water table and the rate and direction of ground-water movement resulting from nearly 25 years of intensive ground-water withdrawal. The depressions in the water table and the steep gradients that were apparent in 1949 after a few years of intensive pumping are much more pronounced in the spring 1964 contours. The gradient of the water surface between the Silver Bell Mountains and Picacho Peak from Red Rock into western Pinal County was more than 30 feet per mile in spring 1964—an increase of more than 10 feet per mile since spring 1949 and more than twice the gradient in 1923 under equilibrium conditions. The ground-water gradient across the Casa Grande Ridge toward Stanfield was more than 70 feet per mile in spring 1964. Deep depressions are numerous in the Stanfield-Maricopa area; a notable depression is at the southeast edge of the Palo Verde Mountains where the mountains are a barrier to the movement of ground water into the area and ground water is withdrawn in large quantities. In the Gila River area the withdrawal of ground water is not extensive, and the ground-water reservoir receives some recharge from flow in the river; thus, the configuration of the water table is not greatly changed.

VOLUME OF RECOVERABLE GROUND WATER IN STORAGE

Natural recharge to the ground-water reservoir in western Pinal County is small compared to the amount of ground water withdrawn, and natural discharge from the aquifer that could be converted to man's use is negligible; most of the water pumped in the area comes from storage in the unconsolidated alluvial aquifer. Thus, it is important to ascertain the amount of stored water that can be extracted from the aquifer.

The storage capacity of the aquifer is defined as the volume of space available to contain water; i.e., the volume of saturated sediments multiplied by their porosity. The porosity, expressed as a percentage, is that part of the total volume of saturated sediments filled with water. However, because a large part of this stored water will be held in the aquifer by molecular attraction and other forces of retention, the amount that can be extracted is less than the total storage capacity. The volume of saturated sediments multiplied by the average specific yield of the sediments determines the amount of stored water that can be recovered by pumping from wells.

The volume of water that can be withdrawn from storage in western Pinal County was determined by the following steps: (1) delineation of the storage area; (2) selection of depth zones; (3) grouping of materials described in the well logs into several categories; (4) assignment of specific-yield values to the several categories of material; (5) computation of weighted average specific yield; and (6) multiplication of the total volume of saturated sediments by the average specific yield.

Calculations of ground water in storage were made for a storage area of about 1,100 square miles (700,000 acres), divided into townships. The depth zones selected were from the average static water level in the township as of spring 1960 to 400 feet, 400 to 600 feet, and 600 to 800 feet below the land surface. The upper limit was determined by the position of the water table, the 800-foot depth was selected as the lower limit because of insufficient data at greater depths, and the intermediate depths were chosen for flexibility of computation.

Data from drillers' logs were correlated with well cuttings collected and analyzed by the U. S. Geological Survey and were used in evaluating the water-bearing characteristics of the sediments in the area. The materials described in well logs were grouped into five categories and subdivided by the depth zones for each township. Only those logs reporting half or more of a depth zone were used for that zone. For each depth zone, the footage in each of the categories of material was determined, and the percentage of the total footage contained in each category was calculated (table 5). The amount of saturated material analyzed from 925 logs was about 337,000 feet or more than 63 miles of drilling. The specific yield (table 6) assigned to each category of material was based largely on earlier work done in California (Davis and others, 1959, p. 209), which resulted from test drilling and laboratory analysis.

The weighted average specific yield was computed for each depth zone (by township) by multiplying the percent of the total footage contained in each category of material by the assigned specific yield. The total volume of saturated sediments (area multiplied by saturated thickness of depth zone) was multiplied by the average specific yield to determine the volume of recoverable water for each depth zone. The volume in the three depth zones was added to obtain the total recoverable water for each area and for the entire study area. Where the hydrologic bedrock unit occurred above the 800-foot depth, the volume of saturated sediments and the amount of ground water in storage were reduced accordingly.

The total volume of recoverable water from the water level as of spring 1960 to a depth of 800 feet below the land surface was calculated to be about 44 million acre-feet; the average specific yield was about 15 percent for the Casa Grande-Florence, Eloy, and Stanfield-Maricopa areas (table 7). The amount of recoverable water in storage

Table 6.--Specific yields used to estimate ground water in storage in part of western Pinal County

Material	Material category	Assigned specific yield (percent)
Gravel, related coarse gravelly deposits, and medium- to coarse-grained loose well-sorted sand	Sand and gravel	25
Primarily sand and gravel, and some fine sand, silt, and clay ..	Sand, gravel, and clay	20
Primarily fine sand, silt, and clay, and some sand and gravel.	Clay, sand, and gravel	15
Fine sand, silt, clay, and related fine-grained deposits ...	Silt and clay	10
Rock, cemented sand, and conglomerate; indurated deposits...	Rock	3

below a depth of 800 feet was not determined because well data were insufficient for analysis; however, there probably is more water in storage below 800 feet than above.

The amount of recoverable ground water in storage was about 17 million acre-feet in the shallow zone (static water level as of spring 1960 to 400 feet below land surface), 15 million acre-feet in the intermediate zone (400 to 600 feet), and 12 million acre-feet in the deep zone (600 to 800 feet). The computed average specific yield was 15.0 percent for the shallow zone, 14.2 percent for the intermediate zone, and 14.0 percent for the deep zone.

In the Casa Grande-Florence area (about 260 square miles), the recoverable ground water in storage to a depth of 800 feet is about 12 million acre-feet, and the average specific yield is about 13 percent (table 7). The amount of water in storage per unit area decreases with depth due to a decrease in volume of saturated sediments, as more bedrock is exposed above the water table, and to a decrease in specific yield. The hydrologic bedrock unit is at a shallow depth near Coolidge and between the Casa Grande and Sacaton Mountains, and the less permeable silt and clay unit is present in the central part of the area. In T. 6 S., Rs. 6 and 9 E., the specific yield of the lower depth zone was higher due to the presence of highly permeable material in the lower sand and gravel unit—a potential aquifer that is largely undeveloped.

In the Eloy area (about 440 square miles), the recoverable ground water in storage is nearly 17 million acre-feet, and the average specific yield is about 14 percent (table 7). The hydrologic bedrock unit is present in the lower depth zones between the Casa Grande and Sawtooth Mountains and between Picacho Peak and the Silver Bell Mountains. The average specific yield decreased from 15.0 percent in the shallow zone to 13.3 percent in the 600- to 800-foot zone, primarily because of the presence of the thick silt and clay unit. The occurrence of a high average specific yield for the 600- to 800-foot zone in T. 8 S., R. 6 E., is an indication of the yield characteristics of the lower sand and gravel unit. However, for the most part, this unit is below the 800-foot level in the Eloy area.

In the Stanfield-Maricopa area (about 400 square miles), the recoverable ground water in storage to a depth of 800 feet is about 15 million acre-feet, and the average specific yield is about 16 percent (table 7). There is more ground water in storage in the intermediate (400 to 600 feet) zone than in either the shallow or the deep zone, and the specific yield is higher. The hydrologic bedrock unit is present in the deep zone along the sides of the mountains that border the area and at the Casa Grande Ridge. In the shallow zone water-level declines caused by long-term pumping have resulted in a smaller volume of saturated sediments. In T. 7 S., R. 5 E., the specific yield of the lower depth zone was the highest for any single township in the area, due to the occurrence of the local gravel unit. In the central part of the area between Stanfield and Maricopa, the specific yields are slightly lower than in the surrounding part of the area due to the presence of the thick silt and clay unit. However, the average specific yield of the silt and clay unit is higher here than in the Eloy and Casa Grande-Florence areas, which indicates the presence of more permeable material—such as sand and gravel—within the silt and clay unit.

SUMMARY

This report is the result of a study begun in 1958 by the Geological Survey in cooperation with the Arizona State Land Department. The purpose of the project was to make a comprehensive analysis of the basic geohydrologic data for western Pinal County in order to provide a better understanding of the ground-water supply in relation to the present and potential water use in this area of extensive ground-water development. The overall objectives of the project were: (1) to analyze the characteristics and extent of the subsurface materials in the basin, i.e., to describe the geohydrologic system; (2) to study the occurrence, movement, and discharge of ground water under varying patterns of stress on the system; (3) to determine the amount of ground water available from storage in the basin; and (4) to relate geology and long-term pumping to the quality and change in quality of pumped ground water (Kister and Hardt, 1965). The basic geohydrologic data on which the studies and interpretations were based have been published as Arizona State Land Department Water-Resources Report 18.

The arid climate of western Pinal County—combining high temperatures and low humidity—causes most of the precipitation to

be returned to the atmosphere by evapotranspiration, which leaves only a very small part for recharge to the ground-water reservoir. The computed potential evapotranspiration—44.97 inches—is five times greater than the average precipitation. Thus, it is unlikely that any significant amount of precipitation falling in the area is recharged to the aquifer.

In general, the subsurface materials in western Pinal County are unconsolidated alluvial deposits underlain by consolidated alluvium and crystalline rocks and bounded by mountains consisting of crystalline and minor sedimentary rocks. The crystalline and sedimentary rocks of the mountains are not known to be water bearing in western Pinal County. However, where faults or fractures have increased the porosity and permeability of these rocks, they may yield a small amount of water to wells. The impermeable rocks underlying the basin are called the hydrologic bedrock unit. Although the unit may consist of several different rock types, the distinction between them is relatively unimportant in this study because none of them yield appreciable amounts of water. The lower Santa Cruz basin in western Pinal County is divided into two sections by a buried ridge of the hydrologic bedrock unit, referred to in this report as the Casa Grande Ridge. The ridge trends in a north-south direction from the Sacaton to the Silver Reef Mountains and is about 200 feet below the land surface in places.

The unconsolidated alluvial deposits constitute the main storage reservoir for ground water in western Pinal County. These unconsolidated deposits are divided into four units—the local gravel unit, the lower sand and gravel unit, the silt and clay unit, and the upper sand and gravel unit—all of which are major water-yielding units except the silt and clay unit. However, the silt and clay unit stores a large amount of ground water because the saturated part of the unit is of great areal extent and is extremely thick.

The local gravel unit, which is present only in the western section of the lower Santa Cruz basin, ranges in thickness from 0 to nearly 1,000 feet and is generally a productive aquifer. The deposit is primarily sand and gravel with minor amounts of clay and locally is firmly cemented.

The lower sand and gravel unit, which is a heterogeneous mixture of sand, gravel, and clay, ranges in thickness from 0 to about 500 feet. The depth to the top of the unit ranges from about 300 to nearly 2,000 feet below the land surface. Where the lower sand and gravel unit is overlain by the silt and clay unit, it generally contains water under artesian conditions; where it is not overlain by the silt and clay unit, it is indistinguishable from the upper sand and gravel unit, and the water is under water-table conditions. This essentially untapped aquifer potentially can yield 1,000 to 2,000 gpm of fair- to good-quality water to wells, although, locally, it may be very firmly cemented or contain fine-grained material of low water-yielding potential.

The silt and clay unit, which is a fluviatile and lacustrine deposit composed of fine sand, silt, and clay, ranges in thickness from 0 to about 2,000 feet. It is the least permeable deposit of the unconsolidated alluvium, although it yields moderate amounts of water from numerous thin stringers and lenses of highly permeable sand and gravel.

The upper sand and gravel unit is at the land surface in most of the area; it ranges in thickness from less than 50 to about 600 feet. The unit is similar in lithology to the lower sand and gravel unit, but it is not as firmly cemented and is areally more extensive. The upper sand and gravel unit has the highest average permeability of all the unconsolidated alluvial units; however, the permeability of the unit varies vertically and laterally, which results in a wide range of well yields. As of 1964, the static water levels in most wells in the basin were still in the upper sand and gravel unit. However, the unit is being dewatered in most of the basin, and water levels in some areas have declined nearly to the bottom of the unit.

Under natural conditions, prior to significant ground-water development, movement of ground water was controlled mainly by the differences in the altitude of the water surface at the extremities of the area; the regional ground-water movement was northwestward from Red Rock and westward along the Gila River. North of Maricopa, the ground water left the area through the narrow Gila River channel between the Sierra Estrella and the Salt River Mountains.

In order to fully understand the hydrologic system of the area, it is necessary to determine the hydrologic characteristics of the aquifer that control the occurrence, movement, recharge, and discharge of ground water and to study the cause and effect of the operation of the system. Data derived from well records or tests may be used in several ways to estimate the water-bearing characteristics of the aquifer. For the most part, methods for determining hydrologic characteristics from well data are based directly or indirectly on the specific capacity of wells—the relation of yield to drawdown. However, the specific capacity of a well is a function not only of the hydrologic characteristics of the aquifer but also of factors such as depth of penetration into the aquifer, well construction, duration of pumping, and well efficiency and, therefore, is not an exact measure of the characteristics of the aquifer. Within limitations, however, analysis of specific capacity provides an approximate value of transmissibility of the aquifer in a small area around a well; using many such determinations, the relative transmissibility values of the aquifer can be correlated. Specific capacities, computed from well-completion tests of 539 wells, ranged from 2 to more than 200 gpm per foot of drawdown. Transmissibility of the aquifer based on these specific-capacity data ranged from 5,000 to 30,000 gpd per foot.

A flow net is a two-dimensional portrayal of the ground-water flow pattern, which can help to evaluate the hydrologic system of an alluvial basin. A flow-net analysis of the area shows that the regional ground-water movement is controlled by the major drainages and is toward the confluence of the Gila and Salt Rivers. Transmissibility, based on the flow net, ranged from about 45,000 gpd per foot on the Casa Grande Ridge to about 270,000 in the area between the Palo Verde and Sacaton Mountains.

Some ground water was pumped in western Pinal County as early as 1890, although the first large irrigation wells were drilled in 1914. The amount of ground water pumped from 1890 through 1963 is estimated to be about 26.7 million acre-feet. Slightly more than 80 percent of this total, or nearly 22 million acre-feet, was pumped from 1940 through 1963. The amount of ground water pumped is related directly to agricultural development, as only a minor amount of ground water is used for other purposes. At the present time (1964), slightly more than 250,000 acres of land is under cultivation in Pinal County, and about 1 million acre-feet of ground water is pumped each year. The effect of the withdrawal of ground water in the area is a regional lowering of the water level. From 1923 to 1961, the net change in water level ranged from 0 in a small area west of Casa Grande to a decline of 275 feet in the southwestern part of the Stanfield-Maricopa area. The average water-level decline from 1940 through 1963 was nearly 143 feet in the Eloy area, about 154 feet in the Stanfield-Maricopa area, and about 93 feet in the Casa Grande-Florence area.

The pumping of ground water has altered the ground-water flow patterns in the alluvial reservoir in western Pinal County in such a manner that ground water moves into areas of intensive withdrawal. These areas are indicated as depressions in the water table and are discernible on maps showing contours of the water level.

Natural recharge to the ground-water reservoir in western Pinal County is small compared to the amount of ground water withdrawn, and natural discharge from the aquifer that could be converted to man's use is negligible; most of the water pumped in the area comes from storage in the unconsolidated alluvial aquifer. Calculations of ground water in storage were made for a storage area of about 1,100 square miles and a saturated thickness from the static water level measured in spring 1960 to 800 feet below the land surface. On this basis the volume of recoverable ground water in storage was calculated to be about 44 million acre-feet, based on an estimated average specific yield of the sediments of about 15 percent.

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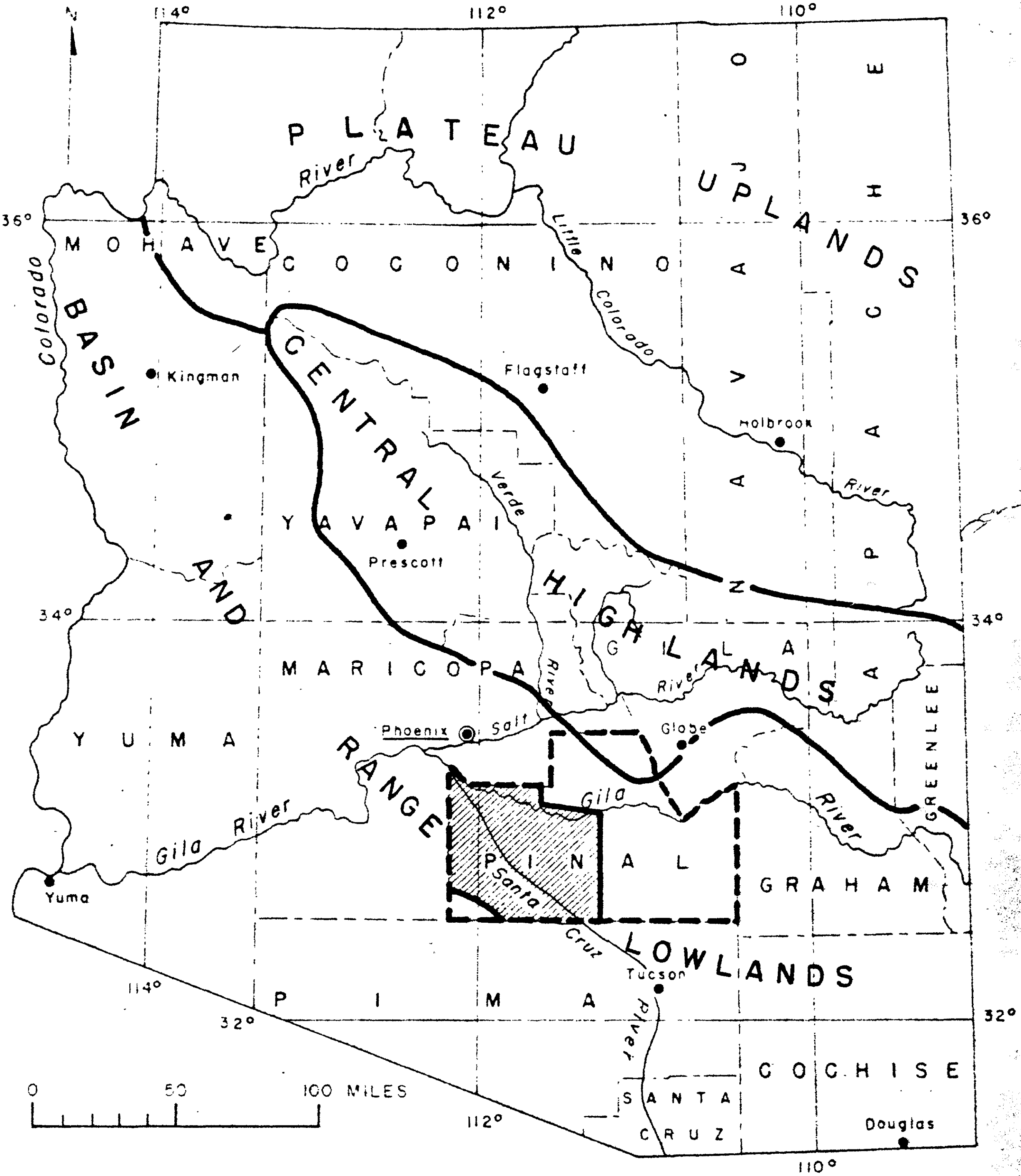
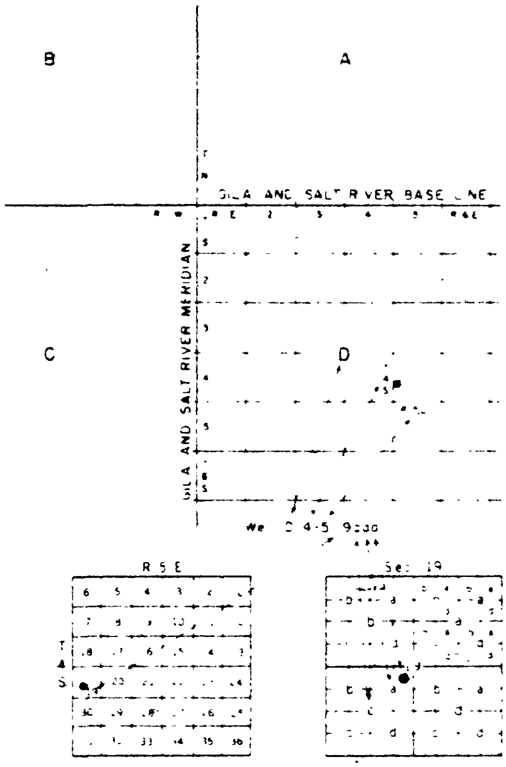


Figure 1.--Map of Arizona, showing the three water provinces and area of study in western Pinal County.



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.

Where a section is more than a mile long in either direction, the designation S-1/2, N-1/2, E-1/2, or W-1/2 is added to indicate the part of the section in which the well is located.

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

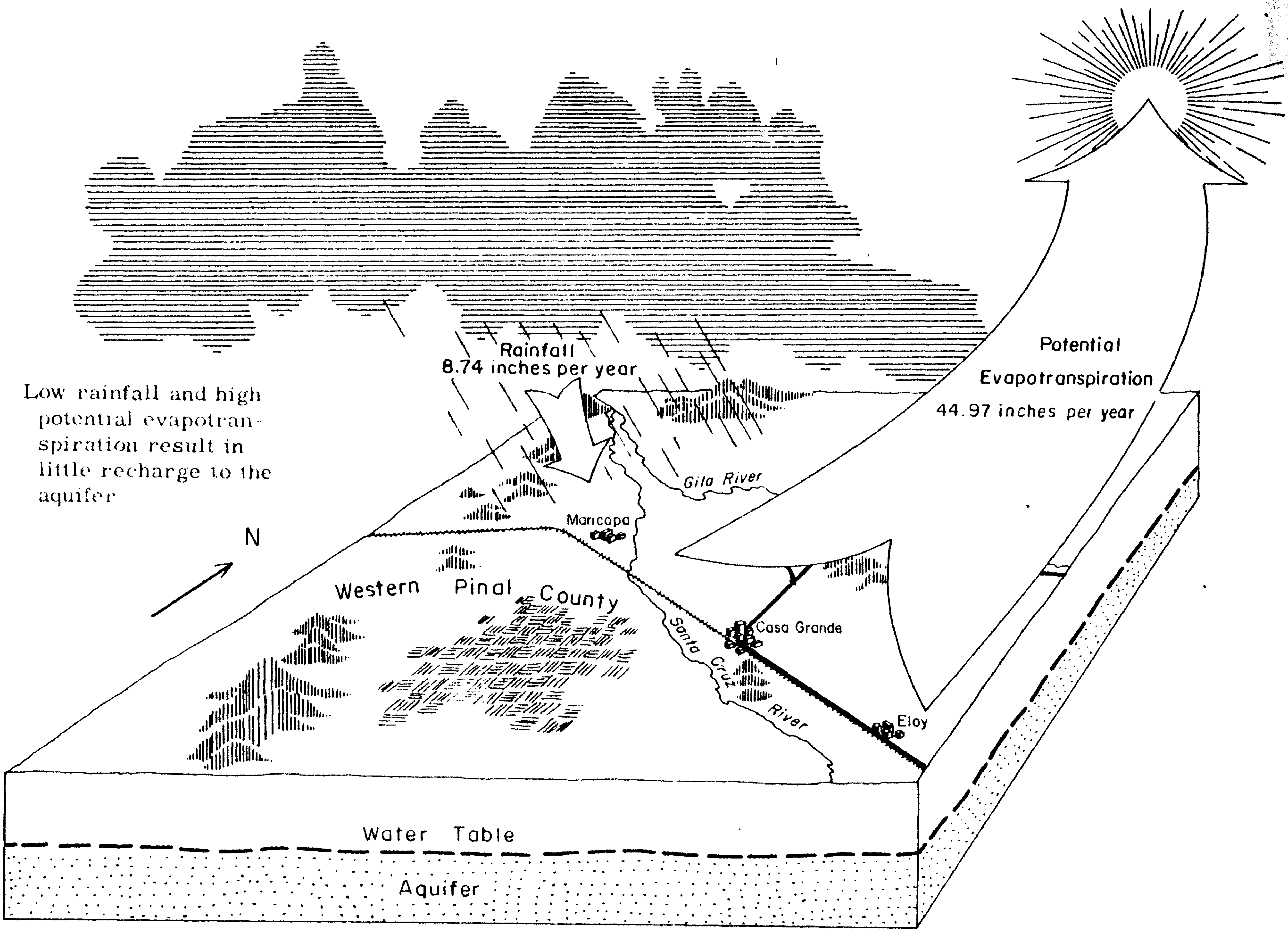


Figure 4. --The water-resources dilemma in arid lands.

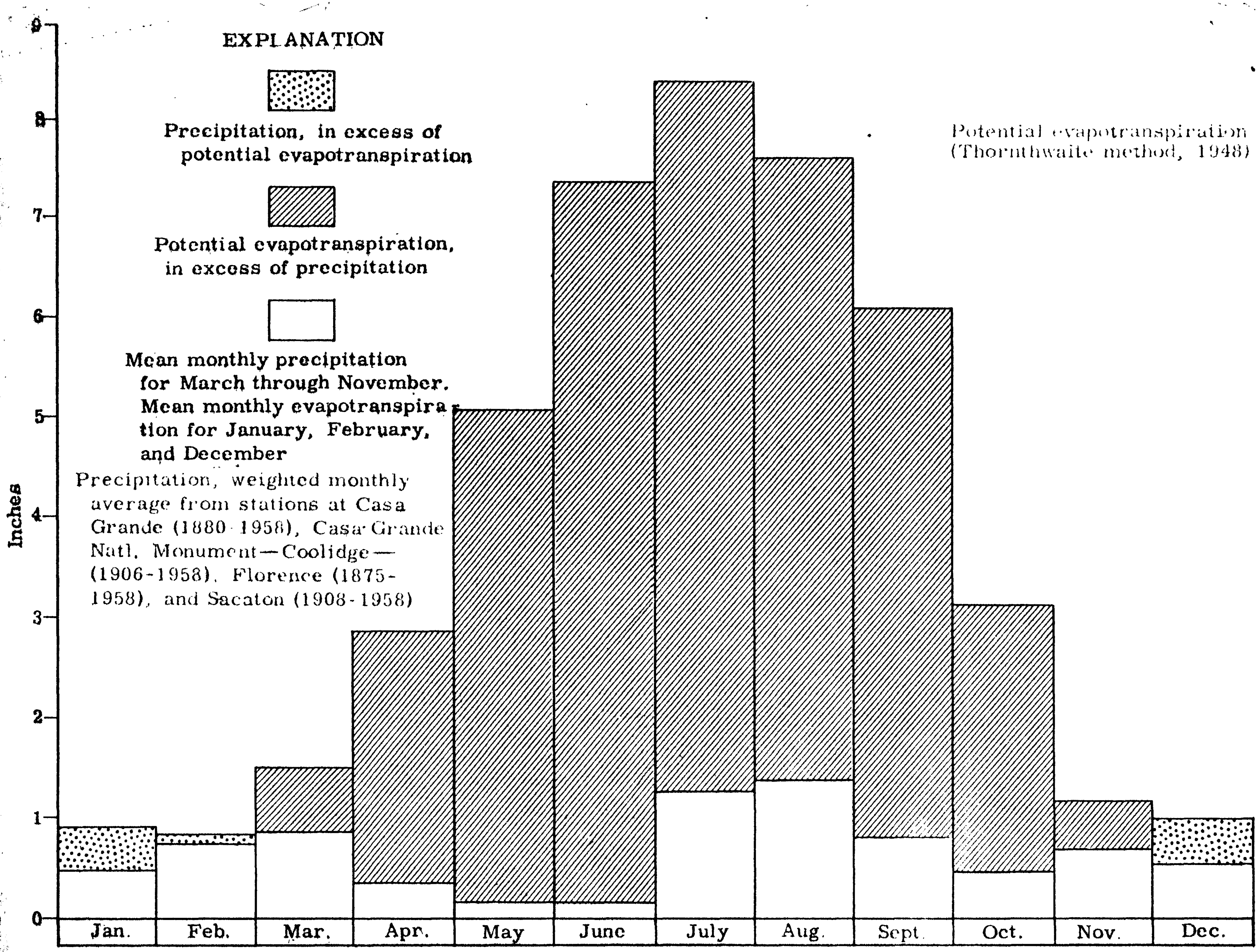


Figure 5. --Precipitation and potential evapotranspiration, western Pinal County.

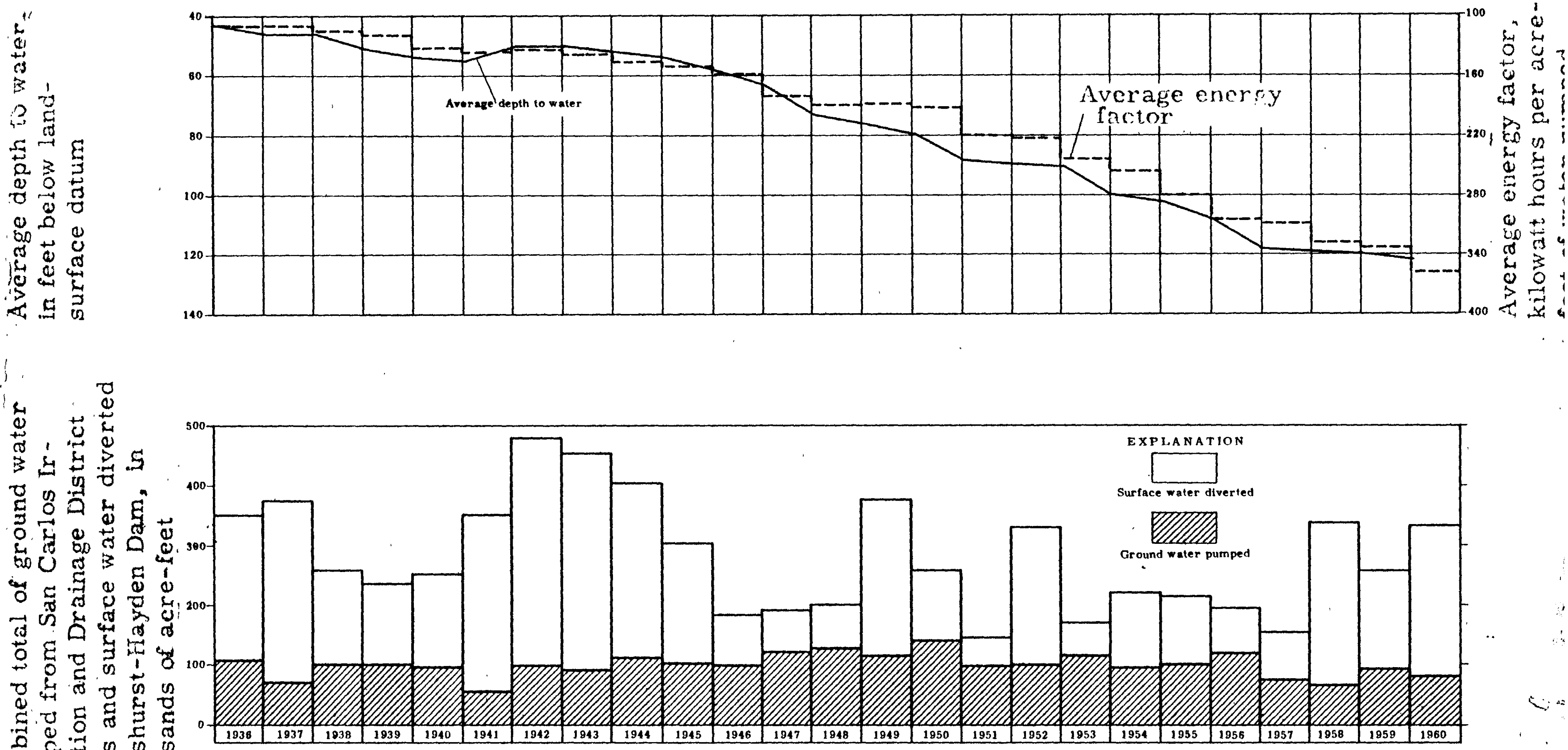


Figure 13. --Pumpage, water levels, and power consumption, San Carlos Irrigation and Drainage District, 1936-60.

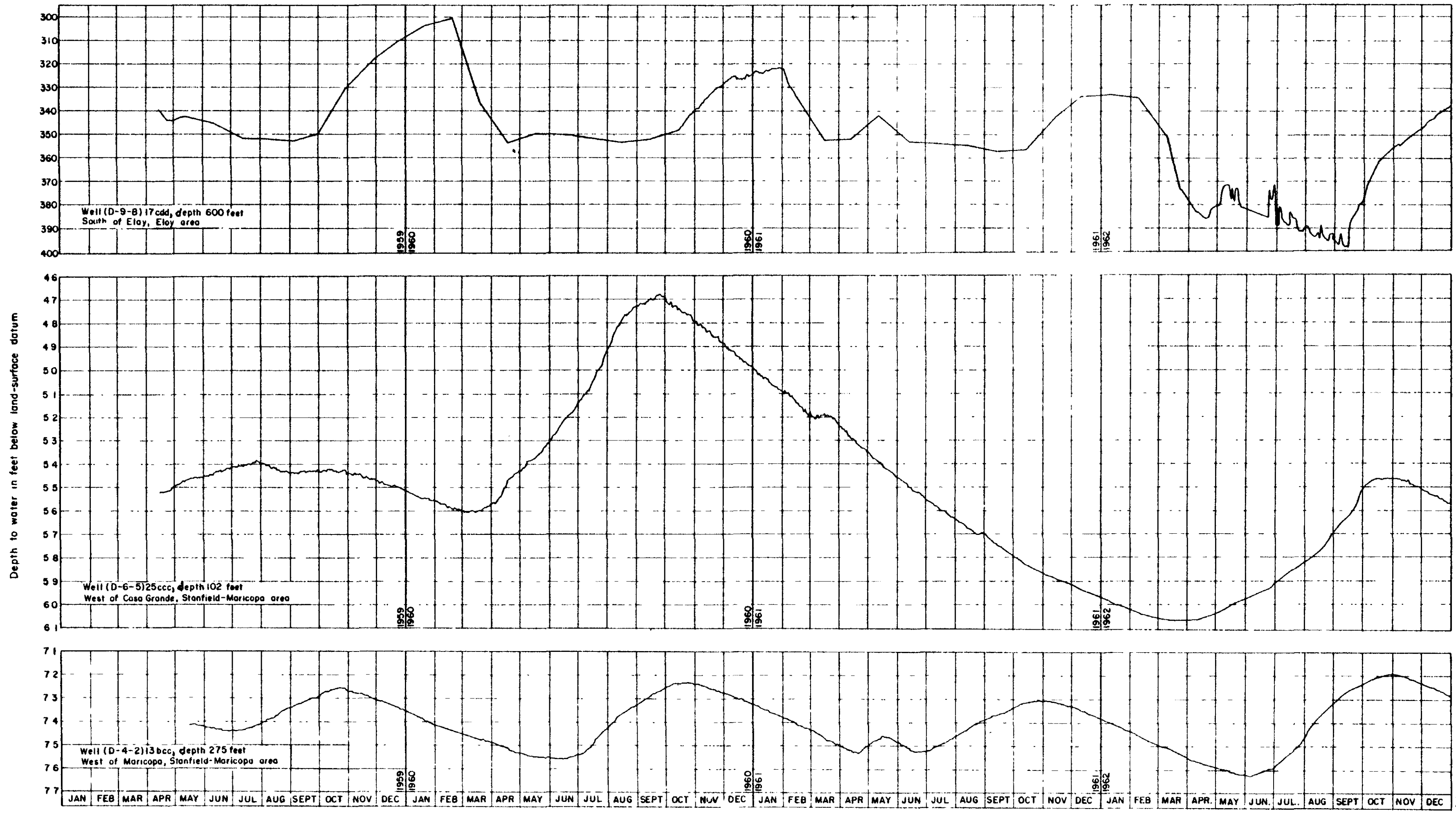
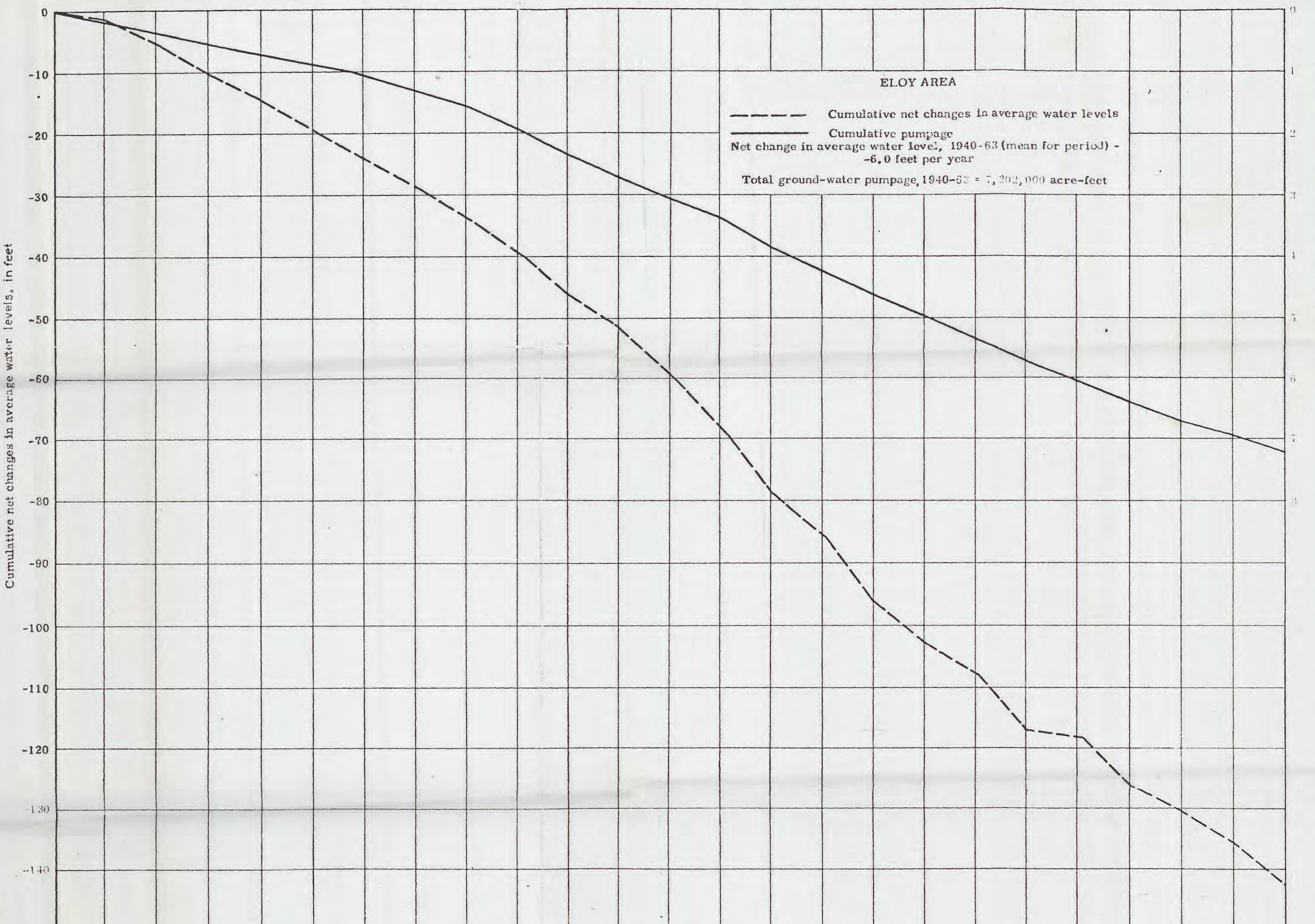
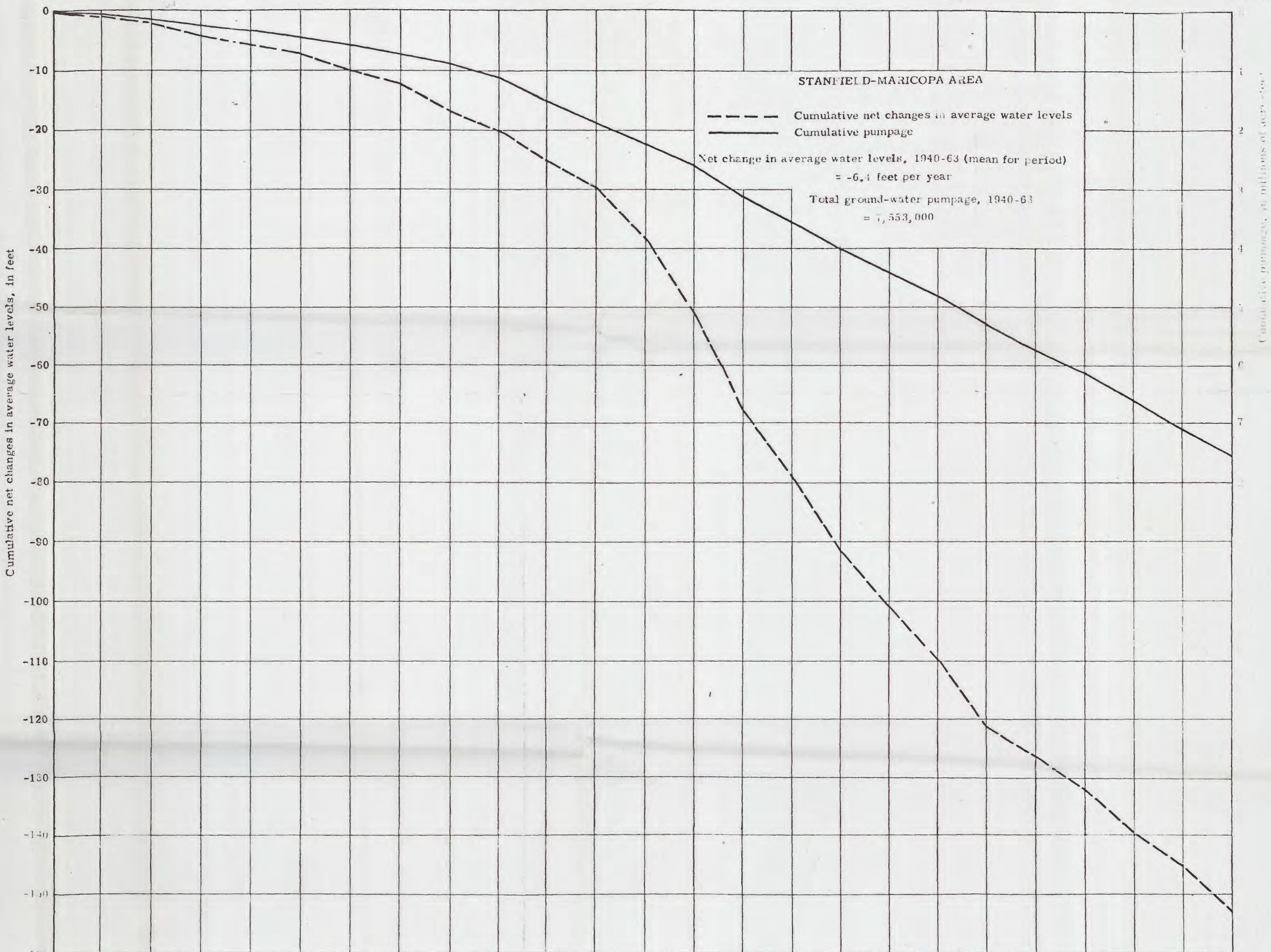


Figure 14.--Hydrographs showing seasonal water-level fluctuations in selected wells, western Pinal County.



Year	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
Net changes in average water levels, in feet	-1.3	-4.4	-4.5	-4.3	-4.8	-5.0	-4.3	-5.0	-5.4	-7.1	-5.7	-7.8	-9.2	-10.4	-6.7	-10.7	-6.5	-4.8	-9.5	-1.4	-8.1	-3.6	[illegible]	-6.8
Ground-water pumpage, in acre-feet	172,000	150,000	200,000	190,000	180,000	200,000	220,000	260,000	360,000	420,000	370,000	370,000	300,000	450,000	400,000	390,000	360,000	360,000	360,000	360,000	330,000	[illegible]	[illegible]	[illegible]

Figure 17.--Cumulative net changes in average water levels and total pumpage in the Eloy area, 1940-63.



1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
-1.0	-1.[illegible]	-1.9	-1.6	-1.5	-2.7	-2.4	-4.8	-3.0	-5.6	-4.3	-8.8	-12.2	-17.0	-11.1	-12.0	-10.0	-8.6	-11.7	-4.6	-6.8	[illegible]	[illegible]	[illegible]

Net changes in average water levels, in feet

70,000	74,000	100,000	110,000	11[illegible] 000	140,000	150,000	150,000	260,000	360,000	370,000	350,000	364,000	550,000	420,000	450,000	400,000	400,000	470,000	47[illegible],000	400,000	[illegible]	[illegible]	[illegible]

Ground-water pumpage, in acre-feet

Figure 1[illegible]. --Cumulative net changes in average water levels and total pumpage in the Stanfield-Maricopa area, 1940-63.

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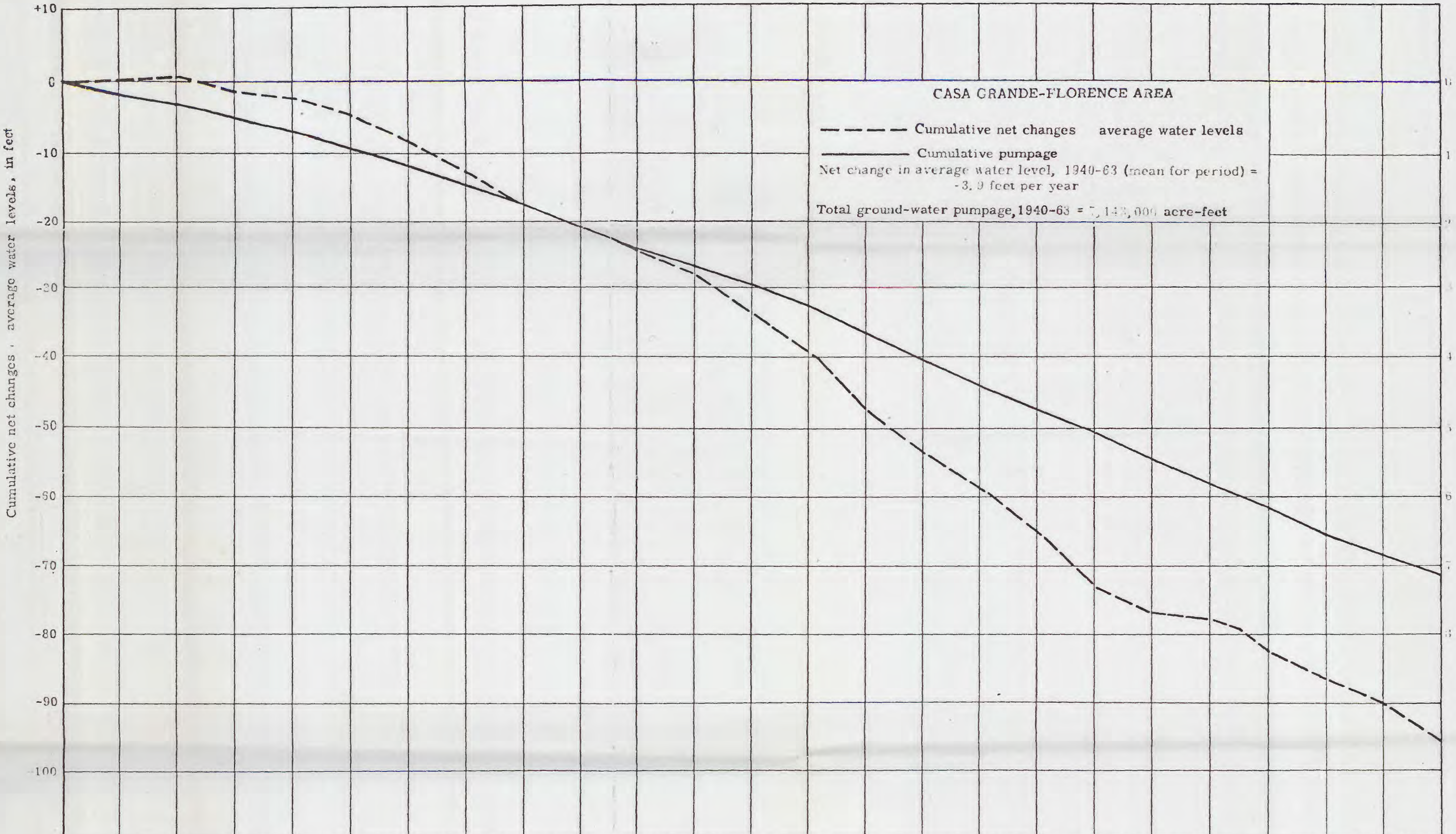

1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
+0.5	+0.6	-1.3	-1.2	-2.7	-3.9	-4.5	-4.8	-3.3	-3.9	-3.4	-5.6	-5.1	-8.4	-6.2	-5.8	-6.3	-8.0	-3.5	-1.1	-2.6	[illegible]	[illegible]	[illegible]

Net changes in average water levels, in feet

1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
130,000	127,000	200,000	215,000	235,000	270,000	290,000	290,000	330,000	320,000	260,000	310,000	286,000	400,000	380,000	360,000	340,000	340,000	370,000	370,000	370,000	[illegible]	310,000	[illegible]

Ground-water pumpage, in acre-feet

Figure 19. --Cumulative net changes in average water levels and total pumpage in the Casa Grande-Florence area, 1940-63.

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Table 1.--Selected climatic data for western Pinal County

(Data from publications of the U. S. Weather Bureau)

a/ Mean for period of record indicated.

b/ Computed by the Thornthwaite method (1948; also see fig. 5).

Station	Altitude (feet above mean sea level)	Item a/	Period of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Casa Grande 32°53' lat. 111°45' long	1,405	Precipitation, in inches	1880-1958	0.73	0.73	0.63	0.27	0.08	0.16	1.05	1.20	0.70	0.38	0.64	0.82	7.39
		Temperature, °F	1896-1958	50.5	54.9	60.7	68.6	77.1	86.6	91.8	89.7	84.4	72.1	60.0	52.2	70.7
Casa Grande Nat. Monument (Coolidge) 33°00' lat 111°32' long	1,419	Precipitation, in inches	1906-58	.96	.79	.75	.37	.13	.19	1.22	1.26	.83	.59	.76	1.05	8.90
		Temperature, °F	1926-58	49.7	53.3	58.9	66.4	74.1	83.3	89.8	88.3	83.0	69.8	57.7	50.8	68.8
Florence 33°02' lat 111°23' long	1,500	Precipitation, in inches	1875-1958	1.05	.93	.96	.41	.18	.11	1.34	1.52	.86	.55	.75	1.19	9.85
		Temperature, °F	1905-58	50.7	54.7	59.5	67.1	74.7	83.7	90.1	87.8	82.8	71.1	58.9	52.1	69.4
Sacaton 33°04' lat 111°45' long	1,285	Precipitation, in inches	1908-58	.89	.78	.82	.38	.18	.13	1.50	1.53	.89	.43	.70	1.01	9.24
		Temperature, °F	1908-58	49.3	53.8	59.0	66.3	74.4	83.2	88.7	86.9	81.9	70.0	57.6	50.4	68.5
Weighted average of the four stations		Precipitation, in inches		.90	.81	.78	.35	.15	.14	1.26	1.37	.81	.47	.70	1.00	8.74
		Temperature, °F		50.1	54.3	59.6	67.3	75.3	84.4	90.2	88.2	83.1	70.9	58.7	51.5	69.5
		Potential evapotranspiration (inches) b/		.45	.74	1.50	2.83	5.06	7.37	8.36	7.65	6.12	3.17	1.18	.54	44.97

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Table 5. --Percent of total footage in each material category for each of the three depth zones by townships

Township	Depth zone 1/ (feet)	Number of logs analyzed	Category of materials: Sand, gravel		Sand, gravel, clay		Clay, sand, gravel		Silt, clay		Rock		Total for depth zone	
			Total footage	Percent of total footage	Total footage	Percent of total footage	Total footage	Percent of total footage	Total footage	Percent of total footage	Total footage	Percent of total footage	Total footage	Percent of total footage
CASA GRANDE--FLORENCE AREA														
T. 5 S., R. 6 E. 2/	178-400	7	160	10.5	450	29.6	572	37.7	75	4.9	265	17.3	1,522	100
	400-600	---	-----	----	-----	----	-----	----	-----	----	-----	----	------	---
	600-800	---	-----	----	-----	----	-----	----	-----	----	-----	----	------	---
T. 5 S., R. 7 E. 2/	140-400	38	776	12.2	568	8.9	1,737	27.3	3,156	49.6	125	2.0	6,362	100
	400-600	7	0	0	0	0	223	18.2	1,002	81.8	0	0	1,225	100
	600-800	---	-----	----	-----	----	-----	----	-----	----	-----	----	------	---
T. 5 S., R. 8 E.	130-400	56	326	2.7	682	5.7	6,289	53.0	4,524	38.1	60	.5	11,881	100
	400-600	16	0	0	0	0	310	10.8	2,558	89.2	0	0	2,868	100
	600-800	7	20	1.6	0	0	130	10.3	908	71.8	207	16.3	1,265	100
T. 5 S., R. 9 E.	173-400	30	250	4.0	2,539	40.8	2,452	39.6	968	15.6	0	0	6,209	100
	400-600	15	79	3.3	1,198	49.6	739	30.6	361	15.0	36	1.5	2,413	100
	600-800	---	-----	----	-----	----	-----	----	-----	----	-----	----	-----	---
T. 6 S., R. 6 E.	93-400	45	586	5.1	1,617	14.1	5,317	46.3	3,070	26.8	881	7.7	11,471	100
	400-600	27	40	.8	859	16.8	1,515	29.8	1,498	29.4	1,180	23.2	5,092	100
	600-800	12	50	2.4	610	29.4	833	40.1	455	21.9	128	6.2	2,076	100
T. 6 S., R. 7 E.	164-400	53	279	2.3	1,531	12.8	5,494	45.8	4,687	39.1	0	0	11,991	100
	400-600	31	0	0	21	.4	1,159	20.2	4,547	79.4	0	0	5,727	100
	600-800	16	30	1.1	202	7.0	452	15.7	2,166	75.1	32	1.1	2,882	100
T. 6 S., R. 8 E.	155-400	58	52	.4	1,620	11.8	8,879	64.6	3,190	23.2	0	0	13,741	100
	400-600	31	0	0	222	4.4	518	10.3	4,293	85.3	0	0	5,033	100
	600-800	12	0	0	0	0	10	.5	2,190	99.5	0	0	2,200	100
T. 6 S., R. 9 E. 2/	174-400	6	0	0	100	7.4	830	61.7	416	30.9	0	0	1,346	100
	400-600	5	80	8.4	0	0	320	33.7	550	57.9	0	0	950	100
	600-800	4	10	1.2	200	25.0	300	37.5	290	36.3	0	0	800	100
Total or average for area			2,738	2.8	12,419	12.8	38,079	39.2	40,904	42.2	2,914	3.0	97,054	100
ELOY AREA														
T. 7 S., R. 6 E.	140-400	33	260	3.3	1,005	12.6	3,275	41.0	2,405	30.1	1,040	13.0	7,985	100
	400-600	13	130	5.0	270	10.4	310	11.9	1,055	40.6	835	32.1	2,600	100
	600-800	---	-----	----	-----	----	-----	----	-----	----	-----	----	------	---
T. 7 S., R. 7 E.	208-400	46	250	2.5	1,037	11.9	6,312	71.6	1,233	14.0	0	0	8,832	100
	400-600	29	100	1.8	895	15.8	1,950	34.3	2,635	46.3	100	1.8	5,680	100
	600-800	14	0	0	400	12.8	350	11.2	2,376	76.0	0	0	3,126	100
T. 7 S., R. 8 E.	223-400	33	250	4.3	1,055	18.1	3,892	66.6	644	11.0	0	0	5,841	100
	400-600	24	0	0	505	11.8	2,457	58.0	1,280	30.2	0	0	4,242	100
	600-800	10	0	0	260	13.6	805	42.4	835	44.0	0	0	1,900	100
T. 8 S., R. 6 E.	165-400	26	205	3.5	825	14.0	2,242	38.3	1,835	31.3	760	12.9	5,867	100
	400-600	19	285	7.6	395	10.6	1,220	32.7	1,448	38.8	385	10.3	3,733	100
	600-800	13	350	14.7	570	23.9	905	37.9	400	16.8	160	6.7	2,385	100
T. 8 S., R. 7 E.	231-400	35	279	4.7	1,024	17.4	3,497	59.0	1,115	18.9	0	0	5,915	100
	400-600	35	90	1.3	965	13.8	2,815	40.2	3,130	44.7	0	0	7,000	100
	600-800	22	75	1.6	535	11.3	1,862	39.4	2,259	47.7	0	0	4,731	100
T. 8 S., R. 8 E.	289-400	29	393	11.8	505	15.2	1,354	40.7	1,078	32.3	0	0	3,330	100
	400-600	27	378	7.5	390	7.7	2,720	53.6	1,580	31.2	0	0	5,068	100
	600-800	19	100	2.7	235	6.3	1,395	37.4	2,005	53.6	0	0	3,735	100
T. 8 S., R. 9 E. 2/	250-400	4	0	0	240	40.0	270	45.0	90	15.0	0	0	600	100
	400-600	3	0	0	145	24.2	145	24.2	310	51.6	0	0	600	100
	600-800	3	0	0	80	13.3	300	50.0	220	36.7	0	0	600	100
T. 9 S., R. 7 E.	208-400	28	0	0	494	9.2	3,504	65.3	1,378	25.5	0	0	5,376	100
	400-600	26	0	0	310	6.2	2,501	50.0	2,191	43.8	0	0	5,002	100
	600-800	18	20	.5	410	11.4	1,010	28.1	2,160	60.0	0	0	3,600	100
T. 9 S., R. 8 E.	288-400	29	246	7.6	610	18.8	1,620	49.8	772	23.8	0	0	3,248	100
	400-600	27	70	1.3	830	15.7	2,130	40.4	2,250	42.6	0	0	5,280	100
	600-800	10	0	0	415	22.3	870	46.8	525	28.2	50	2.7	1,860	100

See footnotes at end of table.

Table 5. --Percent of total footage in each material category for each of the three depth zones by townships—Continued

Township	Depth zone 1/ (feet)	Number of logs analyzed	Category of materials: Sand, gravel		Sand, gravel, clay		Clay, sand, gravel		Silt, clay		Rock		Total for depth zone	
			Total footage	Percent of total footage	Total footage	Percent of total footage	Total footage	Percent of total footage	Total footage	Percent of total footage	Total footage	Percent of total footage	Total footage	Percent of total footage
ELOY AREA—Continued														
T. 9 S., R. 9 E. 2/	200-400	4	0	0	420	52.5	200	25.0	180	22.5	0	0	800	100
	400-600	3	0	0	330	66.5	0	0	136	27.4	30	6.1	496	100
	600-800	----	------	-----	------	----	------	----	------	----	------	----	------	----
T. 10 S., Rs. 6 and 7 E. 2/	217-400	6	336	30.6	288	26.2	273	24.9	161	14.7	40	3.6	1,098	100
	400-600	5	116	12.9	330	36.7	349	38.7	105	11.7	0	0	900	100
	600-800	2	------	-----	------	----	------	----	------	----	------	----	------	----
T. 10 S., R. 8 E. 2/	283-400	7	27	3.3	235	28.9	425	52.2	127	15.6	0	0	814	100
	400-600	6	0	0	125	12.4	564	56.2	86	8.5	230	22.9	1,005	100
	600-800	---	------	-----	------	----	------	----	------	----	------	----	------	----
T. 10 S., R. 9 E. 2/	227-400	18	0	0	931	29.9	1,573	50.5	365	11.7	245	7.9	3,114	100
	400-600	8	75	6.2	122	10.0	593	48.8	353	29.1	72	5.9	1,215	100
	600-800	---	------	-----	------	----	------	----	------	----	------	----	------	----
Total or average for area			4,035	3.4	17,186	14.6	53,688	45.7	38,722	32.9	3,947	3.4	117,578	100
STANFIELD—MARICOPA AREA														
T. 4 S., R. 2 E. 2/	155-400	20	1,126	24.0	509	10.9	2,075	44.2	785	16.7	193	4.2	4,688	100
	400-600	8	255	18.2	211	15.1	454	32.5	70	5.0	408	29.2	1,398	100
	600-800	---	------	-----	------	----	------	----	------	----	------	----	------	----
T. 4 S., R. 3 E. 2/	108-400	15	242	6.1	348	8.6	2,086	52.3	1,321	33.0	0	0	3,997	100
	400-600	3	0	0	0	0	287	47.8	313	52.2	0	0	600	100
	600-800	3	0	0	0	0	435	72.5	165	27.5	0	0	600	100
T. 4 S., R. 4 E. 2/	134-400	27	303	4.3	817	11.7	4,492	63.9	1,398	19.9	15	.2	7,025	100
	400-600	18	471	14.0	884	26.4	772	23.0	1,134	33.9	87	2.7	3,348	100
	600-800	7	0	0	545	38.9	400	28.6	455	32.5	0	0	1,400	100
T. 5 S., R. 2 E. 2/	292-400	29	1,041	33.5	642	20.6	358	11.5	1,022	33.0	44	1.4	3,107	100
	400-600	26	1,854	40.2	690	15.0	524	11.3	1,107	24.0	440	9.5	4,615	100
	600-800	4	122	20.8	63	10.9	180	30.7	220	37.6	0	0	585	100
T. 5 S., R. 3 E.	229-400	38	1,155	18.3	461	7.3	2,231	35.3	2,472	39.1	0	0	6,319	100
	400-600	28	1,439	27.4	200	3.8	1,259	24.0	2,181	41.7	165	3.1	5,244	100
	600-800	11	295	13.6	284	13.1	495	22.8	1,074	49.4	26	1.1	2,174	100
T. 5 S., R. 4 E.	225-400	36	596	8.1	1,255	17.0	3,037	41.1	2,424	32.9	66	.9	7,378	100
	400-600	28	659	12.1	855	15.7	2,261	41.6	1,559	28.7	104	1.9	5,438	100
	600-800	11	336	8.9	815	21.5	1,474	38.8	870	23.0	295	7.8	3,790	100
T. 5 S., R. 5 E. 2/	200-400	5	0	0	320	32.0	550	55.0	60	6.0	70	7.0	1,000	100
	400-600	4	0	0	225	32.2	425	60.6	50	7.2	0	0	700	100
	600-800	---	------	-----	------	----	------	----	------	----	------	----	------	----
T. 6 S., R. 2 E. 2/	381-400	7	57	42.8	19	14.3	32	24.1	25	18.8	0	0	133	100
	400-600	7	365	42.6	133	15.5	200	23.4	116	13.5	43	5.0	857	100
	600-800	---	------	-----	------	----	------	----	------	----	------	----	------	----
T. 6 S., R. 3 E.	345-400	53	479	16.7	642	22.5	881	30.8	803	28.1	55	1.9	2,860	100
	400-600	53	2,461	27.3	2,667	29.7	2,700	30.0	1,164	12.9	10	.1	9,002	100
	600-800	24	1,093	25.0	1,291	29.4	1,036	23.6	961	22.0	2	0	4,383	100
T. 6 S., R. 4 E.	247-400	45	179	2.9	2,421	40.3	2,304	38.3	1,078	17.9	34	.6	6,016	100
	400-600	32	1,219	19.9	2,090	34.1	1,927	31.4	856	14.0	35	.6	6,127	100
	600-800	22	828	19.3	1,422	33.2	1,922	45.0	60	1.4	48	1.1	4,280	100
T. 6 S., R. 5 E.	133-400	30	332	5.9	1,277	22.7	2,947	52.4	670	11.9	400	7.1	5,626	100
	400-600	14	52	2.2	500	21.4	1,373	58.5	310	13.2	110	4.7	2,345	100
	600-800	5	0	0	200	20.0	600	60.0	200	20.0	0	0	1,000	100
T. 7 S., R. 4 E.	256-400	26	502	13.4	891	23.8	1,512	40.4	737	19.7	100	2.7	3,742	100
	400-600	24	600	14.1	1,449	34.2	1,305	30.8	636	15.0	255	5.9	4,245	100
	600-800	14	642	20.3	1,230	38.9	641	20.3	406	12.8	240	7.7	3,159	100
T. 7 S., R. 5 E.	299-400	17	242	13.7	509	28.9	799	45.3	213	12.1	0	0	1,763	100
	400-600	14	389	14.5	566	21.1	1,420	53.0	207	7.7	100	3.7	2,682	100
	600-800	4	220	29.8	217	29.3	293	39.6	10	1.3	0	0	740	100
Total or average for area			19,554	16.0	26,648	21.8	45,687	37.4	27,132	22.1	3,345	2.7	122,366	100
Grand total or average for all areas			26,327	7.8	56,253	16.7	137,454	40.8	106,758	31.6	10,206	3.1	336,998	100

1/ Initial depth zone, starts at average depth to water (spring 1960).

2/ Partial township.

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Table 7.--Average specific yield and volume of recoverable water in storage in part of western Pinal County

[E, estimated. In the depth zones of a few townships the specific yield was estimated at 10, 13, or 16 percent, based on data of adjacent townships. Only the computed specific yields have been included in the overall averages]

Township	Depth, in feet below land surface 1/										
	1960 depth to water—400 2/			400-600 2/			600-800 2/			All zones 2/	
	Specific yield (percent)	Saturated sediments (acre-feet)	Recoverable water in storage (acre-feet)	Specific yield (percent)	Saturated sediments (acre-feet)	Recoverable water in storage (acre-feet)	Specific yield (percent)	Saturated sediments (acre-feet)	Recoverable water in storage (acre-feet)	Specific yield (percent)	Recoverable water in storage (acre-feet)
CASA GRANDE-FLORENCE AREA											
T. 5 S., R. 6 E. 3/	15.2	658,400	100,000	10 E	300,000	30,000	-----	-----	-----	-----	130,000
T. 5 S., R. 7 E. 3/	14.0	4,524,000	633,000	10.9	2,890,000	315,000	10 E	2,690,000	269,000	-----	1,217,000
T. 5 S., R. 8 E.	13.6	5,836,000	800,000	10.5	3,360,000	353,000	9.6	2,660,000	255,000	11.2	1,408,000
T. 5 S., R. 9 E.	16.7	5,221,000	872,000	16.8	4,600,000	773,000	13 E	4,100,000	533,000	-----	2,178,000
T. 6 S., R. 6 E.	14.0	5,616,600	786,000	10.7	1,980,000	212,000	14.9	600,000	89,000	13.2	1,087,000
T. 6 S., R. 7 E.	13.9	5,428,000	754,000	11.1	4,350,000	483,000	11.6	4,060,000	471,000	12.2	1,708,000
T. 6 S., R. 8 E.	14.5	6,100,500	884,000	11.0	4,980,000	548,000	10.0	4,980,000	498,000	11.8	1,930,000
T. 6 S., R. 9 E. 3/	13.8	5,491,800	758,000	13.0	4,860,000	632,000	14.5	4,860,000	705,000	13.8	2,095,000
Average specific yield, total recoverable water in storage	14.4		5,587,000	12.3		3,346,000	11.8		2,820,000	13.1	11,753,000
ELOY AREA											
T. 7 S., R. 6 E.	12.9	3,630,000	476,000	10.1	1,550,000	157,000	10 E	400,000	40,000	-----	673,000
T. 7 S., R. 7 E.	15.1	4,377,600	661,000	13.4	4,190,000	561,000	11.8	3,700,000	437,000	13.4	1,659,000
T. 7 S., R. 8 E.	15.8	4,106,400	649,000	14.1	4,640,000	654,000	13.5	4,640,000	626,000	14.5	1,929,000
T. 8 S., R. 6 E.	12.9	4,055,000	523,000	13.1	2,040,000	267,000	16.0	1,090,000	174,000	14.0	964,000
T. 8 S., R. 7 E.	15.4	3,887,000	599,000	13.6	4,600,000	626,000	13.3	4,600,000	612,000	14.1	1,837,000
T. 8 S., R. 8 E.	15.3	2,553,000	391,000	14.6	4,600,000	672,000	12.9	4,600,000	593,000	14.3	1,656,000
T. 8 S., R. 9 E. 3/	16.2	1,500,000	243,000	13.6	2,000,000	272,000	13.8	2,000,000	276,000	14.5	791,000
T. 9 S., R. 7 E.	14.1	4,416,000	623,000	13.1	4,600,000	603,000	12.6	4,600,000	580,000	13.3	1,806,000
T. 9 S., R. 8 E.	15.5	2,576,000	399,000	13.8	4,600,000	635,000	14.4	4,600,000	662,000	14.6	1,696,000
T. 9 S., R. 9 E. 3/	16.5	1,905,000	314,000	16.2	2,540,000	411,000	13 E	2,180,000	283,000	-----	1,008,000
T. 10 S., Rs. 6 and 7 E. 3/	18.2	1,518,900	276,000	17.5	1,470,000	257,000	13 E	1,140,000	148,000	-----	681,000
T. 10 S., R. 8 E. 3/	16.0	900,900	144,000	12.4	720,000	89,000	10 E	290,000	29,000	-----	262,000
T. 10 S., R. 9 E. 3/	15.0	2,184,000	328,000	14.0	950,000	133,000	-----	-----	-----	-----	461,000
T. 7 S., R. 9 E. 3/	13 E	2,700,000	351,000	10 E	3,600,000	360,000	10 E	3,600,000	360,000	-----	1,071,000
T. 9 S., R. 6 E. 3/	13 E	1,600,000	208,000	10 E	800,000	80,000	10 E	300,000	30,000	-----	318,000
Average specific yield, total recoverable water in storage	15.0		6,185,000	13.9		5,777,000	13.3		4,850,000	14.1	16,812,000
STANFIELD-MARICOPA AREA											
T. 4 S., R. 2 E. 3/	16.6	1,529,500	254,000	13.8	570,000	79,000	13 E	190,000	25,000	-----	358,000
T. 4 S., R. 3 E. 3/	14.4	4,526,000	652,000	12.4	3,020,000	374,000	13.6	2,960,000	403,000	13.5	1,429,000
T. 4 S., R. 4 E. 3/	15.0	2,695,000	404,000	15.7	1,210,000	190,000	15.3	1,010,000	155,000	15.3	749,000
T. 5 S., R. 2 E. 3/	17.6	1,426,500	251,000	17.4	1,000,000	174,000	15.7	200,000	31,000	16.9	456,000
T. 5 S., R. 3 E.	15.2	3,950,100	600,000	15.5	4,620,000	716,000	14.4	4,470,000	644,000	15.0	1,960,000
T. 5 S., R. 4 E.	14.9	3,800,000	566,000	15.3	3,640,000	557,000	14.9	3,040,000	453,000	15.0	1,576,000
T. 5 S., R. 5 E. 3/	15.5	1,020,000	158,000	16.2	410,000	66,000	13 E	260,000	34,000	-----	258,000
T. 6 S., R. 2 E. 3/	19.1	323,000	62,000	18.8	1,370,000	258,000	16 E	170,000	27,000	-----	347,000
T. 6 S., R. 3 E.	16.2	1,292,500	209,000	18.5	3,690,000	683,000	17.9	3,150,000	564,000	17.5	1,456,000
T. 6 S., R. 4 E.	16.3	3,580,200	584,000	17.9	4,680,000	838,000	18.4	4,680,000	861,000	17.5	2,283,000
T. 6 S., R. 5 E.	15.3	3,963,900	606,000	15.1	1,970,000	297,000	15.0	1,250,000	188,000	15.1	1,091,000
T. 7 S., R. 4 E.	16.2	3,292,500	533,000	16.7	3,280,000	548,000	17.4	2,060,000	358,000	16.8	1,439,000
T. 7 S., R. 5 E.	17.2	2,312,900	398,000	16.7	3,640,000	608,000	19.4	2,450,000	475,000	17.8	1,481,000
T. 7 S., R. 3 E. 3/	-----	-----	-----	16 E	1,600,000	256,000	16 E	590,000	94,000	-----	350,000
Average specific yield, total recoverable water in storage	15.7		5,277,000	16.2		5,644,000	16.0		4,312,000	16.0	15,233,000
Average or total for Santa Cruz basin	15.0		17,049,000	14.2		14,767,000	14.0		11,982,000	14.5	43,798,000

1/ Data refers only to the unconsolidated alluvium. The hydrologic bedrock above 800 feet is not included in any of the calculations.

2/ Accuracy of specific yield to tenths, volume of saturated sediments to the nearest 100 acre-feet, or amount of recoverable water to the nearest 1,000 acre-feet is not implied.

3/ Partial township.