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Geological Survey

Geology and ground-water resources of the Willcox Basin, Cochise and Graham Counties, Arizona

By

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With a section on quality of water

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Prepared in cooperation with
Arizona State Land Department
O. C. Williams, Commissioner

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INTRODUCTION

Purpose and cooperation

The Arizona State Legislature has recognized the increasing need in recent years for regulation of ground-water resources in Arizona. Because such regulation must be based upon adequate information as to the quantity, quality, and use, as well as the source and movement of the ground water, the Arizona State Legislature in 1945 appropriated funds for the investigation of the ground-water resources of the State. The investigation is being made by the Geological Survey, United States Department of the Interior, under a cooperative agreement with the Arizona State Land Department, O. C. Williams, Commissioner.

Field work in the Willcox Basin was started in 1945 and was done by M. B. Booher and R. L. Cushman, engineers, and by R. S. Jones, geologist, under the general direction of S. F. Turner, District Engineer (Ground Water) of the Geological Survey. Water analyses were made by J. D. Hem and R. T. Kiser, chemists, under the general direction of C. S. Howard, District Chemist of the Geological Survey.

Location and extent

The Willcox Basin is a part of a large valley in southeastern Arizona. The northern part of this valley is known as Aravaipa Valley; the central part is referred to in this report as the Willcox Basin; and the southern part is referred to in this report as the Douglas Basin. The Willcox and Douglas Basins are commonly known as Sulphur Springs Valley. The Willcox Basin extends from the drainage divide at the headwaters of Aravaipa Creek southward to the drainage divide among the buttes and ridges near the town of Pearce. Along the eastern side of the Willcox Basin are the Pinaleno, Dos Cabezas, and Chiricahua Mountains; and along the western side of the basin are the Galiuro, Winchester, Little Dragoon, and Dragoon Mountains. The Willcox Basin ranges from 10 to 25 miles in width and covers about 1,200 square miles. Although most of the basin is within Cochise County, approximately 250 square miles in the northern part of the basin is within Graham County.

Climatological data

Climatological data obtained at the U. S. Weather Bureau station near Willcox (elev. 4,200 ft.) are probably representative of climatic conditions in most of the basin. Table 1 contains a summary of precipitation, mean temperature, and evaporation at this station. Precipitation at the station in 1945 was 6.42 inches, and the annual mean temperature in 1945 was 58.8 degrees Fahrenheit. The last killing frost in the spring was on April 17, and the first killing frost in the fall was on October 25, so that there were 191 frost-free days during the 1945 growing season.

History of development

Ground water was first obtained in the Willcox Basin in 1872 from shallow dug wells for domestic and stock use. About 1905, parts of the basin were settled by homesteaders, who constructed wells from which ground water was pumped for irrigation. These wells consisted of open pits dug within a foot of the water table and a bored uncased hole extending down into the water-bearing strata. Centrifugal pumps in the pits were driven by internal combustion engines. Meinzer and Kelton[1/] reported about 60 pumping plants in operation in the Willcox Basin in 1910, and these pumping plants had discharges ranging from 20 to 1,500 gallons a minute. No figures are available for the cultivated acreage in 1910. It was reported that about 3,500 acres was cultivated in 1920, mostly irrigated with ground water. By 1926, the irrigated acreage had decreased to about 2,500 acres. During the following 14 years the amount of land cultivated varied from year to year. The United States Department of Agriculture[2/] estimated that, in 1940, 2,150 acres was irrigated with about 5,000 acre-feet of ground water pumped from approximately 55 wells. Practically all of these wells were the dug-pit type, with centrifugal pumps. The lowering water level, however, necessitated the deepening and casing of the holes in the bottom of the pits. Wells constructed since 1940 have been sunk and cased from the land surface and pumped with turbine pumps. The Rural Electrification Administration has distributed electric power in the Willcox Basin since 1940, and the internal combustion engines at the wells are gradually being replaced by electric motors. In 1946, 68 percent of the pumping plants were powered by electricity. Approximately 15,000 acre-feet of ground water was pumped from about 80 non-artesian wells to irrigate 4,800 acres in 1946 (see pl. 1). In addition, about 300 acre-feet of water was pumped from eight artesian wells, and about 200 acre-feet flowed from seven of these wells to irrigate about 200 acres.

Previous investigations

Earlier studies of the geology and the ground-water resources of the basin are described in the following reports:

1. Meinzer, O. E., and Kelton, F. C., Geology and water resources of Sulphur Spring Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 320, 1913.
2. Report on available ground-water supply and possible irrigation development near Willcox, Ariz.: Typewritten report submitted to Willcox Chamber of Commerce by Quinton, Code and Hill, consulting engineers, Dec. 3, 1928.
3. Water facilities area plan for Northern Sulphur Springs Valley area, Ariz.: U. S. Dept. Agr., Bur. Agr. Econ. (mimeographed), Oct. 1941.

1/ Meinzer, O. E., and Kelton, F. C., Geology and water resources of Sulphur Spring Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 320, p. 187, 1913.

2/ Water facilities area plan for Northern Sulphur Springs Valley area, Ariz.: U. S. Dept. Agr., Bur. Agr. Econ. (mimeographed), p. 39, Oct. 1941.

Water levels were measured in selected wells in the Willcox Basin from 1942 to 1945 by H. R. McDonald, J. F. Hostetter, and Theda P. Shelley of the Geological Survey. These water-level measurements have been released in mimeographed form and will be published in the following report:

Water levels and artesian pressure in observation wells in the United States, part 6, Southwestern States and Territory of Hawaii: Calendar year 1945: Water-Supply Paper (in preparation).

GEOLOGY AND ITS RELATION TO GROUND-WATER SUPPLIES

Maps and field work

About seven months of geologic reconnaissance of Sulphur Springs Valley was done by Robert S. Jones in 1946. The geology was mapped in the field on a scale of 1 mile to the inch on topographic maps of the Federal Geological Survey. Most of the field work was done in the Willcox Basin, although a limited amount of work was done along the east side of the Douglas Basin. Plate 1 shows the geology of the Willcox Basin.

Most of the geology of the Dragoon and Little Dragoon Mountains, shown on plate 1, was mapped by James Gilluly and John Cooper of the Geologic Branch of the Federal Geological Survey, who kindly permitted their work to be used in this report. Of necessity their work has been generalized on plate 1.

Land forms and drainage

Sulphur Springs Valley is a broad debris-filled valley which trends northwest and lies between two chains of maturely dissected fault-block mountain ranges. The mountains rise abruptly above the gently sloping valley, the mountains on the east side rising to higher elevations than those on the west side of the valley. The highest peak on the east side is Mount Graham, in the Pinaleno Mountains, which rises to a height of 10,713 feet above sea level. The highest peak on the west side is Riley Peak, in the Winchester Mountains, which rises to a height of 7,631 feet above sea level. Sulphur Springs Valley is separated into the Willcox and Douglas Basins by a series of low, partially buried hills that mark a drainage divide in the vicinity of Pearce.

The Willcox Basin has interior drainage into a large flat, known as the Willcox Playa, which occupies about 50 square miles south of the town of Willcox. The playa is mainly without vegetation and at times parts of its surface are incrusted with white salts. The winds have deposited sand dunes along the north and east sides of the playa. The altitude of the valley floor in the Willcox Basin ranges from 4,135 feet in the Willcox Playa to 4,500 feet at the lowest point of the drainage divide at the headwaters of Aravaipa Creek.

Geologic history

The oldest rocks exposed in the mountains about the Willcox Basin are pre-Cambrian low-grade schists. Sand grains and small pebbles can still be seen in a few places in these schists, indicating that the schists were formerly sedimentary rocks. The schists were intruded by a porphyritic granite batholith. During the intrusion of this pre-Cambrian granite, mountain-making movements may have occurred. The pre-Cambrian rocks were probably eroded to a surface of slight relief and gentle slopes, and later submerged beneath marine waters. During the Paleozoic era the submerged pre-Cambrian rocks were covered with a thick series of sandstones, shales, and limestones, predominantly calcareous and essentially conformable. Most of these sediments were deposited in late Paleozoic time during the Carboniferous and Permian periods. The maximum thickness of the Paleozoic sediments is more than 5,000 feet[3/].

Following the Paleozoic sedimentation, folding, faulting, and igneous intrusion occurred and the region was elevated above sea level[4/]. The region was subjected to erosion during and following the period of uplift. Volcanic rocks were extruded upon the tilted Paleozoic rocks. The region was again lowered beneath a sea and thick deposits of clastic sediments of Cretaceous age were laid upon the older rocks.

Following the Cretaceous sedimentation the rocks of the region were further deformed by folding and faulting and were intruded by magmas and covered by a great thickness of volcanic flow rocks and tuffs, and tuffaceous sediments. The greatest deformation in the region was probably post-volcanic, when compressional forces thrust older rocks over younger rocks. Felsite was intruded along some of the thrust planes, and granitic rocks were intruded in some parts of the region.

Following the deformation and intrusion, major faulting occurred along a northwest-southeast trend, causing the down-dropping of the valleys and the uplifting of the mountains of the region. The stratigraphic throw of these faults may have reached a maximum of several miles. In general, the amount of uplift increased from the Chiricahua Mountains northward to the Pinaleno Mountains where the more ancient crystalline rocks rise to heights of over 10,000 feet.

During and after the faulting the downfaulted or valley troughs received thick deposits of alluvium from the upfaulted masses. The earliest fill in the trough consisted almost entirely of volcanic debris, as erosion removed volcanic rocks from the upfaulted masses. Eventually non-volcanic rocks were exposed in some areas by erosion and, as erosion progressed, the trough received less volcanic debris and more non-volcanic debris.

3/ Ransome, F. L., The geology and ore deposits of the Bisbee Quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, p. 168, 1904.

4/ Wilson, Eldred D., Geology and ore deposits of the Courtland-Gleeson region, Ariz.: Univ. of Ariz., Ariz. Bur. Mines Geol. Ser. No. 5, Bull. 123, 1927.

One or more lakes occupied the Willcox Basin during the time that the upper parts of the fill were being deposited, and thick beds of clay were laid down within the lake or lakes. The shorelines fluctuated from time to time with the variations in climate, and thus sands and gravels interfinger with the lake clays. The shoreline of one ancient lake, called Lake Cochise by Meinzer and Kelton[5], is still partly preserved in the form of ancient beach ridges near the present-day playa. Lake Cochise covered an area greater than and including the present playa.

After the bulk of the fill had accumulated, probably by early Quaternary time, basaltic lavas were extruded near the base of the mountains. These lavas became interbedded with the fill or flowed upon its surface. After the extrusion of the basalt, a pediment surface was cut on both the basalt and the valley fill. In parts of the basin, pediment surfaces were also cut on older rocks. The pediments were later partially dissected by streams, soil-creep, sheet floods, and weathering. While the pediments were being cut and later dissected, the eroded materials were being deposited in the lower parts of the basin.

Aravaipa Creek, north of the Willcox Basin, began to remove the valley fill by headward erosion, probably after the pediments were formed. Thus was formed the inner and lower valley of Aravaipa Creek. South of Aravaipa Creek no inner valley occurs, but only the higher valley referred to as the Willcox Basin.

At present, the wind is depositing sand in the form of dunes on the north and east sides of the playa and near some of the small buttes northwest of the main mass of the Swisshelm Mountains. The processes of erosion are continuing, and rock waste is being brought from higher elevations and deposited at lower elevations.

Rocks of the Willcox Basin

Schist and granite (pre-Cambrian)

The pre-Cambrian rocks that occur in the mountains surrounding the Willcox Basin include schists and granites.

The rocks mapped as schists consist of low-grade schist and hornfels, and are probably the oldest rocks in the basin. The schists usually occur near granitic rocks, although they are not as extensive as the granitic rocks. Schists have been noted in the Pinaleno, Dos Cabezas, Dragoon, and Little Dragoon Mountains, and in the northern part of the Chiricahua Mountains.

Only small quantities of water occur in the schists, along fractures and joint planes. Several domestic and stock wells derive water from these rocks in the basin.

A large part of the granitic rocks in the basin are probably pre-Cambrian in age, although granitic intrusions of later age occur in the Dos Cabezas and Dragoon Mountains. As the granites are principally of pre-Cambrian age, all of them will be discussed in this section.

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[5] Meinzer, O. E., and Kelton, F. C., Geology and water resources of Sulphur Spring Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 320, p. 34, 1913.

The rocks described as granitic rocks include granites, granodiorites, diorites, syenites, and aplite and pegmatite dikes. The granitic rocks are fine to coarse-grained and are porphyritic in many places. These rocks usually have a grayish color along a fresh fracture, but they weather to shades of brown. The main constituents are the feldspars, which generally form grains interlocking with those of quartz and various dark-colored minerals.

Granitic rocks occur in the mountains or buttes or at the foot of mountains, underlying pediments. Large masses of these rocks crop out in the Pinaleno, Dos Cabezas, Dragoon, and Little Dragoon Mountains and in the northern part of the Chiricahua Mountains.

The water-bearing characteristics of the granitic rocks are dependent upon two main properties, weathering and jointing. Both decrease in extent with depth, the weathered rocks mantling the jointed rocks. Generally, granitic rocks subjected to weathering processes disintegrate as a result of hydration and temperature changes and the separated particles become smaller through chemical decomposition. Feldspars decompose to clay but quartz is relatively unaffected. The clay may be carried downward along joints and fractures by percolating water, or may be carried away by surface waters. This removal of clay may increase the number and size of pore spaces among relatively unaffected grains in the rocks, but clay may also fill joints and decrease the water-bearing capacity of the joints. A spring in Taylor Canyon in the Pinaleno Mountains (no. 2300, pl. 1) is probably due to clay, derived from decomposition of feldspar, that has filled the lower joints and prevents the ground water from percolating downward. Small amounts of water from jointed granitic rocks have been obtained from wells in the village of Dos Cabezas.

Older sedimentary rocks (Paleozoic and Mesozoic)

Conglomerates, quartzites, sandstones, shales, and limestones of Paleozoic and Mesozoic age constitute the older sedimentary rocks of the basin. They are mapped as a unit (see pl. 1). The Paleozoic rocks are a conformable sequence, more than 5,000 feet in maximum thickness, consisting mainly of calcareous sediments. The younger overlying Mesozoic rocks are more than 3,000 feet in maximum thickness and consist mainly of clastic sediments.

The older sedimentary rocks constitute less than 5 percent of the total outcrop area of the mountains, dip at all angles and in many directions, and are greatly fractured and faulted. Consequently the prospects are poor for obtaining artesian water in the Willcox Basin from the older sedimentary rocks.

Water has been encountered in caves and in mine adits, drifts, and shafts in the older sediments. Springs occur in the older sediments in some localities.

Volcanic rocks (Tertiary and Cretaceous?)

The areas shown on plate 1 as "volcanic rocks" contain mostly rocks of Tertiary and Cretaceous? age, although a few basalts of Quaternary age are included, principally because time did not permit differentiation between the Tertiary and Cretaceous? and the Quaternary volcanic rocks in all parts of the basin. Although volcanic eruptions occurred prior to the Cretaceous period, no volcanic rocks of pre-Cretaceous age are known in the area mapped except as fragments in the clastic sediments of Cretaceous age.

A large variety of volcanic rocks of Tertiary and Cretaceous? age occur in the area mapped. Tuffaceous sediments are commonly interbedded with the volcanic rocks. Both pyroclastic rocks (explosively extruded materials) and lava flows are represented. The pyroclastic rocks may be more abundant than the lava flows. Andesitic and rhyolitic tuffs and breccias are the principal pyroclastic rocks of the basin. Some of the tuffs and breccias have been welded by their own heat, so that they resemble flow rocks. Their pyroclastic nature is revealed under the microscope. The flow rocks range from basalts to rhyolites although the basalts constitute only a minor part. The volcanic rocks are broadly warped in places and are, to some extent, broken into fault blocks.

Small amounts of water occur in the vesicles, interstices among the pyroclastic fragments, joint planes, fractures, and solution openings in the volcanic rocks. The older, non-basaltic flow rocks contain few vesicles and columnar jointing is rare, although other joints are common and may be a source of ground water. Solution cavities along fractures in the pyroclastic rocks may yield sufficient water for domestic and livestock purposes. Several springs issue from the pyroclastic rocks in the basin and supply sufficient water for stock use.

Older fill (Tertiary? and Quaternary)

The trough of the Willcox Basin contains large thicknesses of alluvial fill, termed "older fill" in this report. The older fill that is exposed at the surface is principally Quaternary in age. The age of the fill increases progressively with depth, and the age of the deepest parts of the fill is uncertain, although it is probably Tertiary.

The older fill was deposited after the trough was formed, although some of the tuffaceous sediments that may have been deposited before the trough was formed are included on the geologic map (pl. 1) with the older fill. These tuffaceous sediments that have been mapped with the older fill lie in a few small areas at the base of the mountains.

The older fill was derived from the rocks comprising the adjoining mountain masses. The deposits of the older fill are interbedded lenses of clay, silt, sand, sandstone, gravel, and conglomerate, carried into the basin from the surrounding mountains by streams and by sheet runoff. As the slope lessened and the carrying power of the water diminished, the boulders were dropped first, followed by gravel, sand, silt, and clay. Therefore, the deposits grade in texture from the large boulders on the higher slopes near the mountains to smaller particles at lower elevations. Each succeeding rain, with its accompanying runoff, did not occur in exactly the same area, or with the same force or duration. Because of these naturally fluctuating conditions, the water deposited, for example, sand or silt over areas where gravel had been dropped before. During the larger floods, lenses of coarse gravel were deposited along stream channels, and the channels shifted from time to time as deposition continued. The deposits of different texture therefore interfinger. The materials deposited on the steeper slopes, near the mountains, were mainly boulders, gravels, and sands. Those deposited on the more moderate slopes, away from the mountains, were mainly sands and silts. However, channel deposits of gravel are scattered throughout the basin, although they are naturally more abundant near the mountains.

During the past, the Willcox Basin has been without exterior drainage, as at present, and lakes occupied the lower parts of the basin. Clays and silts were deposited in these lakes, although exceptionally large floods deposited some gravel and sand lenses. The alternation of beds of gravel, sand, silt, and clay is shown in driller's logs of wells (table 3). With respect to the clays, Meinzer and Kelton[6] state:

> "A well sunk some years ago on the present premises of C. T. McGlone, near the southeast margin of the village of Willcox, is reported to have reached a depth of 480 feet and to have penetrated a bed of clay that does not seem to be a stream deposit. In the upper 280 feet the section appears from the reports to consist of ordinary stream deposits, including several layers of coarse water-bearing gravel. From 280 to 480 feet, however, the drill passed through a homogeneous stiff clay, called talc by the driller, presumably because it was so fine grained and so entirely wanting in grit that, like true talc, it was smooth to the touch. This clay was dark blue at top and jet black farther down, but when exposed to the air it turned yellow. It is also reported to have had a strong odor. The black color is probably due to impregnation of the formation with sulphides, which become rapidly oxidized when they are brought into contact with the air, and the odor is probably due to the presence of hydrogen sulphide. Throughout the 200 feet that was penetrated the formation is reported to have yielded no water whatever. When the hole was abandoned the drill was working in this clay and there is no means of estimating to what depth it may extend."

A well in the NE¼ sec. 14, T. 14 S., R. 24 E., was reported to have been drilled in clay from about 150 feet to 720 feet. The well was abandoned at 720 feet without penetrating the full thickness of clay. Ground water under artesian pressure has been encountered in a few wells that have penetrated sand and gravel lenses in the clay layers, particularly southeast of the Willcox Playa. Some of these wells flow, with a maximum flow of about 80 gallons a minute.

Water from areas of limestone and volcanic rocks usually carries calcium and bicarbonate in solution. Some of these dissolved salts have been incorporated in the clay in the form of small, well-formed calcite crystals. These were found in samples of clay from the 720-foot well described. Some of the dissolved salts were deposited among the particles of sand and gravel, forming caliche. Layers of relatively impermeable caliche were formed near the surface in a part of the outcrop area of the "gravel zone" near the edges of the fill. Streams have cut channels through the caliche, enabling water from rain and from stream-flow to enter the fill along the stream channels.

The sand and gravel lenses of the older fill are the principal aquifers in the Willcox Basin. Ground water has been obtained from both shallow and deep wells, in quantities ranging from a few gallons a minute to about 1,200 gallons a minute.

6/ Meinzer, O. E., and Kelton, F. C., Geology and water resources of Sulphur Spring Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 320, pp. 57-58, 1913.

Basalt (Quaternary)

Basaltic rocks occurring in Arizona are of both Tertiary and Quaternary age. Darton[7] states:

> "The Tertiary and early Quaternary volcanic rocks are largely rhyolites, dacites, andesites, and latites, but there were also outflows of basalt at various times. Most of the latest outflows of Quaternary time are basalts and some of these are are so fresh in appearance as to suggest that they were erupted only a few centuries ago."

Basalts occurring in the mountains have not been mapped separately from the older volcanic rocks shown on plate 1. However, outcrops of basalts occurring at lower elevations have been mapped separately. It was not possible, during the time available, to determine everywhere the age of the basalts. In some parts of the basin, basalts intrude or overlie the upper part of the older fill, indicating that the basalts are of Quaternary age.

The basalts are of such limited extent that they are of relatively minor importance for the storage and transmission of ground water. No wells or springs were noted in the basalts examined.

Younger fill (Recent)

The washes that enter the Willcox Basin from the mountains contain deposits of sand and gravel of Recent age along their channels. Many of these deposits are so small that they could not be shown on the geologic map (pl. 1). Domestic and stock wells are relatively common in the Recent fill along stream channels in the mountains.

Possible avenues of leakage of ground water from the basin

The mountains and hills that partially surround the Willcox Basin are composed of rocks that are relatively impermeable, and thus tend to confine ground water within the basin. The levels of the land surface and of the water table in the Willcox Basin are higher in altitude than the levels in the basins which adjoin on all sides, and therefore only movement of ground water out of the Willcox Basin need be considered. Possible avenues where ground water may escape from the basin through alluvial fill are: (1) northward to the valley of Aravaipa Creek; (2) eastward to the San Simon Basin; and (3) southward to the Douglas Basin.

Northward to the valley of Aravaipa Creek

The width of alluvial fill at the divide at the north end of the Willcox Basin is about 7 miles. The thickness of the fill is not known, although it is at least several hundred feet, and ground water probably moves northward through this fill.

Eastward to the San Simon Basin

The most likely avenue of ground-water movement into the San Simon Basin lies between the Circle I Hills and the Pinaleno Mountains. The alluvial fill in this locality is about 2 miles wide and is probably several hundred feet thick. It is likely that bedrock extends northwestward from the Dos Cabezas Mountains to the Circle I Hills at relatively shallow depths, and therefore ground water probably does not move eastward through this section.

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[7] Darton, N. H., A resume of Arizona geology: Univ. of Ariz., Ariz. Bur. Mines Geol. Ser. No. 3, Bull. 119, p. 165, 1925.

Southward to the Douglas Basin

The Swisshelm Mountains are maturely dissected fault-block mountains that trend northwest and consist largely of a single ridge of northeast-dipping older sedimentary rocks. The broadest part of these mountains is the northern part, where older volcanic rocks occur on the northeast side. The Swisshelm Mountains do not end abruptly in their northern part but have bedrock projections into the alluvium. Buttes and ridges that rise above the alluvium lie along the continuation of the northwest trend of the Swisshelm Mountains. These buttes and ridges are composed of volcanic rocks and older sedimentary rocks. The northernmost outcrop of older sedimentary rocks in the series occurs about 2 miles north of Township Butte. The strike of the older sedimentary rocks in these buttes and ridges is roughly northwest and the dip is northeast. The strikes approximate the trend of the buttes. Thus, the attitude of the older sedimentary rocks in the isolated buttes and ridges is similar to that in the Swisshelm Mountains. Because of the similar trends and because of the similar attitudes of the older sedimentary rocks, it is probable that these isolated buttes and ridges are the structural continuation of the Swisshelm Mountains into Sulphur Springs Valley.

These isolated buttes and ridges extend northwestward from the Swisshelm Mountains about 20 miles to the Three Sister Buttes. The larger buttes and ridges encountered, starting from the Swisshelm Mountains, are: Whitehead Ridge, Squaretop Hills, Ash Creek Ridge, Township Butte, Turkey Creek Ridge, Sulphur Hills, and the Three Sister Buttes. Near Township Butte a salient of buttes and ridges of volcanic rocks extends westward to Pearce. Near Pearce the larger buttes are called Pearce Hill and Sixmile Hill. In the westward salient, the ridge trends are approximately parallel to the trends in the other buttes and ridges and in the Swisshelm Mountains.

Fault zones are prominent in many of the buttes and ridges and some of the fault zones are silicified. These fault zones have been shown on the geologic map (pl. 1) as single faults to indicate their trend. Most of the observed faults trend in a northwest direction. It is therefore probable that northwest-striking, parallel faulting is the predominant process by which the buttes and ridges assumed their present position. However, cross-faulting may have been partly responsible for minor variations in the size and shape of the buttes and ridges.

The thickness of fill among the buttes and ridges is an important factor with respect to the movement of ground water. A few outcrops of bedrock appear above the fill among the buttes and ridges. These outcrops are the tops of almost-buried hills connected beneath the alluvium with the buttes and ridges nearby. The thickness of fill between these small outcrops and the nearby buttes and ridges may be a function of the distance between adjacent bedrock exposures, as well as an expression of rock structure. The thickness of fill between adjacent bedrock masses in some parts of the chain may be sufficient to provide avenues through which ground water can move out of the Willcox Basin.

Probably the greatest thickness of fill occurs in the following localities: (1) Between Turkey Creek Ridge and Ash Creek Ridge, because of the distance between these ridges and the change from sedimentary rock in Ash Creek Ridge to volcanic rock in Turkey Creek Ridge, perhaps due to faulting; (2) between Turkey Creek Ridge and the ridge east of Township Butte. This avenue parallels the general northwest-trending structure, and more or less cuts across the junction of the west-trending salient of buttes with the northwest-trending buttes.

It is possible that the fill may also be thick in other localities among these buttes and ridges. More detailed geologic work will be needed, supplemented with geophysical probes and test drilling, to determine conclusively the possibilities of movement of ground water from the Willcox Basin into the Douglas Basin.

GROUND-WATER RESOURCES

The principal aquifer in the Willcox Basin is the older fill. All the ground water that is pumped for irrigation and most of the ground water that is pumped for domestic and stock use is derived from the older fill. The Recent fill is a source of water for some domestic and stock wells but is not sufficiently extensive in the basin to be an important source of ground water for irrigation. In general, the Recent fill and the hard rocks are relatively unimportant as aquifers and will not be discussed further in this report. Their water-bearing properties are shown in the explanation on plate 1.

Occurrence of ground water

The aquifers in the older fill in the Willcox Basin are permeable lenses of sand and gravel. These permeable lenses are discontinuous but interconnected, and they are interbedded with relatively impermeable layers of clay, silt, sandstone, and conglomerate.

Aquifers occurring at depths of less than 150 feet are the source of ground water for most of the irrigation wells in the Willcox Basin (see table 3). The shallow aquifers are heavily pumped northwest of the town of Willcox, and most of the irrigation occurs in this heavily pumped area. Generally, water in the shallow aquifers is not under artesian pressure. Ground water occurs at or within a few feet of the land surface in the Willcox Playa, but the depth to water increases away from the playa. The maximum depth at which water-bearing beds occur in the older fill is not known. Water in gravel was encountered at a depth of 3,215 feet below the land surface in well 1903 (see table 3), drilled for an oil test. However, the age of this gravel may be greater than that of the older fill.

In some localities the impermeable materials interbedded with the more permeable aquifers are sufficiently extensive to create areas of perched or semiperched water. For example, a thick layer of impermeable clay separates an aquifer at shallow depth from aquifers at greater depths near the drainage divide at the northern end of the Willcox Basin. The log of well 2604 (see table 3) indicates that this clay layer is at least 100 feet thick. The water table above the clay, in this vicinity, ranges from less than a foot to more than 10 feet below the land surface but the water level in well 2604 is 155 feet below the land surface and 14 feet above the bottom of the clay layer.

The lake beds of the older fill near the Willcox Playa are largely clay and silt, but they include fingers of sand and gravel containing water under artesian pressure. The most successful artesian wells have been found within 7 miles of the playa, although attempts have been made to obtain artesian water elsewhere in the basin. The artesian aquifers near the eastern side of the playa are the source of water for the most productive flowing wells in the basin.

Source and movement of ground water

Water recharges the ground-water reservoir of the older fill by seepage from: (1) stream flow and sheet runoff on the coarse materials near the mountains; (2) irrigation water applied to the land; and (3) precipitation.

Most of the recharge from seepage of water into the coarse materials near the mountains probably occurs on the eastern side of the basin. These mountains are higher and receive more rainfall and snow than the mountains on the western side of the basin. Streams, fed by water from winter rains and melting snow, issue from the loftier mountains and flow about 5 months each year. Generally, these streams do not flow more than 3 or 4 miles into the basin before all the water seeps into the ground. Some of the runoff from the mountains, especially that from torrential rains, does not follow the stream channels but spreads in sheets across the coarse materials near the mountains, thus exposing a large water surface to contact with the ground. Much of this water sinks into the ground. The data are insufficient to estimate the annual recharge to the ground-water reservoir that occurs as seepage into the coarse materials near the mountains.

A part of the irrigation water applied to the land seeps downward to the water table. Although the infiltration of irrigation water into the soils of the Willcox Basin was not studied, the subsurface materials inspected in walls of uncased dug wells were similar to those observed in wells in the Safford Basin. Turner and others[8] found that in the Safford Basin about 25 percent of the irrigation water applied to the land passes downward to the water table. This indicates that about 3,900 acre-feet of water reached the water table as downward seepage from the 15,500 acre-feet of irrigation water applied to the land in the Willcox Basin during 1946.

Precipitation on the valley floor does not leave the basin through surface drainage, but evaporates or seeps into the ground. The valley floor slopes gently from the foot of the mountains to the Willcox Playa and has no well-developed stream channels. Therefore, the runoff from precipitation generally moves in sheet form or in small rivulets, thus exposing a large water surface to evaporation and to seepage into the ground. A part of the water that seeps into the ground percolates downward to the water table. The amount of water reaching the water table annually from this source was not determined.

8/ Turner, S. F., and others, Ground-water resources of Safford and Duncan-Virden Valleys, Ariz. and N. Mex.: U S. Geol. Survey (mimeographed), pp. 23 and 36, 1941.

The movement of ground water is down the slope of the water table, from areas of recharge to areas of discharge. The water table slopes generally from the mountains toward the Willcox Playa. Pumping of ground water for irrigation causes the water table to be depressed in the pumped areas. Thus the natural slope of the water table in the vicinity of the pumped areas is changed, and ground water moves into these areas to fill the depressions. These depressions in the water table may become sufficiently deep that ground water will move from the vicinity of the playa to the pumped areas.

Discharge of ground water

Ground water is discharged from the older fill of the Willcox Basin by natural and artificial means. Natural discharge occurs through evaporation, springs, use by phreatophytes, and underflow from the basin. Ground water is artificially discharged from artesian and non-artesian aquifers through flowing and pumped wells.

Natural discharge

Evaporation of ground water

Evaporation from the water table occurs in areas where the depth to water is small. The largest tract underlain by shallow ground water is in the vicinity of the Willcox Playa, where approximately 32,000 acres of barren land overlies a water table that is about 5 feet below land surface. Concerning the playa, Meinzer and Kelton[9/] state:

> "The moist condition of the clay near the surface in all parts of the flat indicates that even in the interior the ground water is within reach of evaporation. But the alkali flat is so large and yet so nearly level that the water table beneath it can have only a very slight gradient. Both the slight gradient and the fact that the clay in the interior is very fine indicate that the ground water is disposed of but slowly in the interior, and that the movement of ground water from the margin of the barren flat toward the interior is sluggish. The largest quantities of water are probably lost near the margin, where the sediments are somewhat coarser."

White[10/] determined that the rate of evaporation from a water table 5 feet below a bare land surface is 5 percent of the rate of evaporation from a free-water surface. The rate of evaporation from a free-water surface at Willcox averaged 85.86 inches annually during the period 1917-35 (see table 1). Assuming that the soils in the Willcox Playa are similar to the soils used in White's experiments, the evaporation of ground water from the playa is estimated to be 11,400 acre-feet a year. The rate of evaporation from a water table 4 feet below a bare land surface in a tank containing fine-grained silt in the nearby Safford Basin was determined to be about 1.3 feet a year[11/].

9/ Meinzer, O. E., and Kelton, F. C., Geology and water resources of Sulphur Spring Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 320, p. 100, 1913.

10/ White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil, results of investigation in Escalante Valley, Utah: U. S. Geol. Survey Water-Supply Paper 659-A, p. 80, 1932.

11/ Unpublished data in files of the U. S. Geol. Survey.

The rate of evaporation from a water table 2 feet below an alkali land surface in a tank containing river-bottom silt in the nearby Safford Basin was determined to be about 1.2 feet a year. Using the rates obtained in the Safford experiments as a basis for computing the evaporation from the water table in the Willcox Playa, the maximum annual evaporation of ground water from the playa is estimated to be about 1.0 foot or 32,000 acre-feet. The evaporation of ground water from the playa is therefore not less than 11,000 acre-feet a year and may be as much as 32,000 acre-feet a year.

Some ground water is evaporated from the shallow water tract in the northern part of the basin near well 2604, but the depth to water is generally greater than 10 feet in this tract and therefore the loss by evaporation is probably small.

Springs

The principal area where springs occur is along the margin of the playa. Although a few of the springs in the basin are probably caused by artesian leakage, several springs issue at places where the water table intersects the land surface. It is probable that Croton and Sulphur Springs (see pl. 1) are of the latter type. Springs also occur in the shallow water tract in the northern part of the basin near well 2604. The total amount of ground water discharged by springs is estimated to be less than 200 acre-feet a year.

Use by phreatophytes

Some plants growing where the depth to ground water is shallow in the basin obtain a perennial supply of water by sending their roots down to the water table. These plants are principally grasses, salt bushes, and mesquite, growing near the playa. The U. S. Department of Agriculture[12/] estimated that approximately 20,000 acre-feet of ground water was used annually by the grasses and salt bushes growing near the playa. Meinzer and Kelton[13/] indicated that mesquite grew on about 90,000 acres of land in the Willcox Basin in 1910. Except in areas which have been cleared for cultivation, the mesquite acreage was about the same in 1946 as in 1910. About 5,000 acres of mesquite land was cleared for cultivation between 1910 and 1946, and therefore the present (1946) mesquite acreage is approximately 85,000 acres. On the basis of studies of the water used by mesquite in the Safford Basin[14/] it was estimated that the mesquite in the Willcox Basin used about 1 acre-foot of water from the ground-water reservoir per year per acre. The amount of ground water used by the 85,000 acres of mesquite in the Willcox Basin may therefore be as much as 85,000 acre-feet a year.

12/ Water facilities area plan for Northern Sulphur Springs Valley area, Ariz.: U. S. Dept. Agr., Bur. Agr. Econ., p. 43, Oct. 1941.

13/ Meinzer, O. E., and Kelton, F. C., Geology and water resources of Sulphur Spring Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 320, pl. 1, 1913.

14/ Turner, S. F., and others, Water resources of Safford and Duncan-Virden Valleys, Ariz. and N. Mex.: U. S. Geol. Survey (mimeographed), p. 11, 1941.

Underflow from the basin

Possible avenues where ground water may move from the Willcox Basin through alluvial fill are: (1) northward to the valley of Aravaipa Creek; (2) eastward to the San Simon Basin; and (3) southward to the Douglas Basin among the buttes and ridges near Pearce.

The elevations of water levels in wells in the vicinity of the surface drainage divide at the northern boundary of the Willcox Basin indicate that the perched or semiperched ground water moves in the same direction as the surface drainage but that the ground-water divide in the main water table is south of the surface drainage divide. Exact elevations of the water levels in wells in the vicinity must be obtained before this ground-water divide can be accurately delineated. In the main ground-water reservoir, water north of the ground-water divide moves northward into the valley of Aravaipa Creek, and water south of the ground-water divide moves southward toward the Willcox Playa.

The elevations of water levels in wells in the vicinity of the surface drainage divide between the Willcox Basin and the San Simon Basin indicate that ground-water moving toward the Willcox Basin from the southern end of the Pinaleno Mountains is divided, part of the water moving eastward into the San Simon Basin, and the remainder moving westward into the Willcox Basin. The ground-water divide apparently is west of the surface drainage divide (see pl. 1). Water levels in wells northeast of the pass between the Circle I Hills and the Dos Cabezas Mountains are more than 100 feet higher in elevation than water levels in wells southeast of this pass. This difference in water-level elevations indicates the presence of a ground-water barrier between the Circle I Hills and the Dos Cabezas Mountains. This barrier impedes or prevents the movement of ground water through this pass, and maintains the ground water northeast of the pass at an altitude sufficiently great to cause the movement of the ground water eastward to the San Simon Basin. Exact elevations of water levels in wells must be obtained before the ground-water divide can be accurately delineated.

Reconnaissance studies indicate that ground water probably moves from the Willcox Basin to the Douglas Basin through the alluvial fill among the buttes and ridges near Pearce. Possible avenues through which ground water moves, as indicated by water levels in wells, are between Ash Creek Ridge and Turkey Creek Ridge, and between Turkey Creek Ridge and the ridge east of Township Butte. The preliminary data indicate that the water table between Turkey Creek Ridge and Ash Creek Ridge slopes toward the southwest at a rate of about 20 feet per mile. The data also indicate that the water table between Turkey Creek Ridge and the Sulphur Hills slopes toward the southwest, and that this slope may continue southward between Turkey Creek Ridge and the ridge east of Township Butte. It is likely, however, that a ground-water divide exists north of the surface drainage divide. Additional data must be obtained concerning the elevation of water levels in wells in this area before definite conclusions can be made.

Artificial discharge

In 1946, about 500 acre-feet of water was discharged from the artesian aquifers through flowing and pumped wells, and about 15,000 acre-feet was discharged from non-artesian aquifers through pumped wells. Most of the water obtained from the non-artesian aquifers was pumped during the summer months for irrigation.

There were approximately 90 irrigation wells in the Willcox Basin in December 1946. Eight of these wells obtained water from artesian aquifers. These artesian wells ranged from 380 to 700 feet in depth and from 4 to 16 inches in diameter. Seven of the eight artesian wells were flowing wells, and they ranged in rate of flow from 10 to 80 gallons a minute. The artesian well that did not flow and two of the flowing wells were equipped with pumps, and they ranged in rate of pumped discharge from 150 to 500 gallons a minute. The pressure in flowing well 1952 was sufficient to raise a column of water 23 feet above the land surface when the well was completed. The pressures in the other artesian wells were reported to have been less than 23 feet.

The non-artesian irrigation wells ranged from 50 to 240 feet in depth and were generally between 12 and 16 inches in diameter. Prior to 1940, most of the wells were dug within a foot of the water table and a hole was augered into the water-bearing strata. Wells drilled since 1940 have been 12 to 16 inches in diameter, cased from the land surface, and the casing perforated opposite the water-bearing beds. These pumped irrigation wells range in rate of discharge from 250 to 1,200 gallons a minute. The specific capacities of 24 wells ranged from 20 to 87 gallons a minute for each foot of drawdown.

Table 2 shows records of typical wells in the basin.

Fluctuations of the water level

Meinzer and Kelton[15] state that the water levels in two wells were reported to have declined 7 feet during the 35 years prior to 1910. Both wells were located east of the playa. A comparison of the depth to water in 1910 with that in 1946 shows that the water table has declined in most of the Willcox Basin; however, the amount of decline has not been the same in all parts of the basin. In the vicinity of the playa the altitude of the water table in 1946 was from a fraction of a foot to 5 feet below the level in 1910, and in areas where ground water was pumped for irrigation the water table in 1946 was as much as 25 feet below the 1910 level. The Geological Survey has been measuring water levels periodically in selected wells in the basin since May 1942. Water-level fluctuations in four typical wells are graphed on figure 1 for the period 1942 to 1946, inclusive.

Well 1953 is 14 miles southeast of Willcox, in an area where the annual pumpage of ground water has been moderate to light. The water table declined about 3 feet in the vicinity of this well between 1910 and 1942, and declined 1.5 feet more between 1942 and 1946. The water level in this well fluctuated through a range of 1.7 feet in 1946, owing principally to the operation of three nearby irrigation wells.

15/ Meinzer, O. E., and Kelton, F. C., Geology and water resources of Sulphur Spring Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 320, p. 102, 1913.

Well 1700 is 8 miles southwest of Willcox, in an area where no ground water is pumped for irrigation. The water table declined about 6 feet in the vicinity of this well between 1910 and 1942, and 4.0 feet more between 1942 and 1946. The water level in this well fluctuated through a range of 1.7 feet in 1946. During the early summer months of 1946 the increased use of ground water by mesquite in the vicinity of the well and the increased evaporation of ground water from the playa lowered the water level. The summer rains reduced the draft upon the ground-water reservoir, and the water level partially recovered.

Well 1585 is 1 mile northwest of Willcox, between the playa and an area where ground water is pumped for irrigation (see pl. 1). The irrigation pumping has reduced the slope of the water table toward the playa and has lowered the water level in the vicinity of well 1585. The water table declined about 18 feet in the vicinity of this well between 1910 and 1942, and 2 feet more between 1942 and 1946.

Well 1582 is an unused well 5 miles northwest of Willcox and about 1½ miles south of a heavily pumped area (see pl. 1). This well was drilled as a test to determine the possibilities of obtaining artesian water. The log of this well (table 2) does not indicate that the casing was perforated from the land surface to 375 feet; the casing below this level was removed soon after the well was completed. Probably the well casing has no perforations, because the graph of water-level fluctuations in the well (see fig. 1) does not show the seasonal effects of nearby pumping for irrigation. However, the trend of the water level in well 1582 has been downward, indicating that the shallow, heavily pumped aquifers in the vicinity may be connected with the deeper aquifers tapped by this well. The water table declined 6 feet in the vicinity of well 1582 between 1910 and 1942, and 2 feet more between 1942 and 1946.

Well 1527 is 9 miles northwest of Willcox in a heavily pumped area. The water table declined 13 feet in the vicinity of this well between 1910 and 1942, and 8 feet more between 1942 and 1946. Pumping of ground water for irrigation causes the water table to be depressed in the pumped area during the pumping season. A cone of influence or depression develops in the water table as the water is withdrawn. After the pumping season, the deeper part of the depression is filled with ground water that moves in from outside the pumped area. This is the reason that water levels in wells within the depression decline throughout the pumping season, and then gradually recover after the pumping season. Records of water-level measurements show that the depression of the water table in the vicinity of well 1527 is not completely filled each year before the next pumping season begins.

Safe yield of the ground-water reservoir

The most vital concern of farmers in the Willcox Basin is the determination of the quantity of water that can be pumped annually from the ground-water reservoir without depleting the supply available for continued economical pumping. The annual safe yield is affected by many factors that cannot be evaluated with existing data and, therefore, no estimate of the annual safe yield is given in this report. Before the safe yield can be determined, more accurate data are needed for the discharge of ground water from the basin by evaporation, by transpiration through mesquite and other phreatophytes, and by movement into other basins. In addition, longer records are needed of the fluctuations of water levels in wells and of the discharge of ground water by pumped and flowing wells. However, none of the existing data indicate that the annual safe yield of the Willcox Basin has been exceeded.

QUALITY OF WATER

By

J. D. Hem

Chemical character of the ground water

During the study of the Willcox Basin in 1946, 92 samples of ground water from the basin were analyzed. Table 4 lists analyses of typical ground waters in the basin. The analyses indicate that most of the waters of the basin contain moderate amounts of dissolved matter, ranging in dissolved solids content from 150 to 300 parts per million. These waters contain mostly calcium, sodium, and bicarbonate. In most parts of the basin, waters from different aquifers in the fill generally are similar in chemical character.

Ground waters around the Willcox Playa are rather highly mineralized, containing mostly sodium, sulfate, and chloride. Water from Croton Spring (see analysis 1829, table 4), about 3 miles north of Cochise, had 2,940 parts per million of dissolved solids, mostly sodium and sulfate. This was the most highly mineralized water found in the basin in 1946. Waters containing less than 100 parts per million of dissolved solids occur in a few places, mainly in areas near the higher mountains at the north end of the basin.

Relation of quality of water to use

Irrigation

Most of the ground water being used for irrigation in the basin is "excellent to good" for this purpose, according to the standards of Wilcox and Magistad[16/]. None of the waters tested for borate contained sufficient amounts to be harmful to crops grown in the basin. A few samples from the basin were sufficiently highly mineralized to be considered "good to injurious" or "injurious to unsatisfactory" for irrigation. One reason that few highly mineralized samples were collected is that the soils are not satisfactory for farming in most of the areas where the ground waters are highly mineralized; consequently there are few wells in these areas.

Domestic use

Most of the ground waters of the basin are rather hard but only a few waters contain enough dissolved matter to have a noticeable taste. Ground waters in the vicinity of the Willcox Playa are too highly mineralized to be satisfactory for domestic use.

The main problem in obtaining satisfactory domestic water supplies in the basin, especially south of Willcox, is to find a water that is low in fluoride. On the basis of the analyses, it is apparent that many ground waters in the basin contain too much fluoride to be used for drinking by young children without risking mottling of their tooth enamel.

16/ Wilcox, L. V., and Magistad, C. C., Interpretation of analyses of irrigation waters and the relative tolerance of plant crops: U. S. Dept. Agr., Bur. Plant Industry, Soil and Agr. Research Administration; Riverside, Calif. Mimeographed, 8 pp. May 1943.

According to the U. S. Public Health Service[17] a satisfactory drinking water should contain no more than 1.5 parts per million of fluoride. Ground waters north of Willcox generally contain less than 1.5 parts per million of fluoride. Ground waters near the Willcox Playa are high in fluoride, the maximum content occurring in the water from Croton Springs. A sample of this water contained 16 parts per million of fluoride (analysis 1828, table 4) and some of the other spring waters in the vicinity had nearly as much. South of the playa ground waters generally contain from 2.0 to 6.0 parts per million. Along the southern edge of the basin, east of Pearce, fluoride concentrations generally are less than 2.0 parts per million and some of the waters in this area contain less than 1.0 part per million. Near the mountains on both sides of the basin the fluoride content of ground water generally is less than 1.0 part per million.

Relation of quality of water to recharge and source of dissolved matter in ground water

The most dilute ground waters of the Willcox Basin occur in the principal recharge areas. Areas of dilute water are located in the north end of the basin and along the edges of the older fill, near the mountains. The effect of recharge on the quality of ground water in the basin is less noticeable in areas near low mountains than in areas near the high Pinaleno Mountains to the north and the Chiricahua Mountains to the east.

Ground waters moving through the fill away from recharge areas increase gradually in concentration, although the low dissolved solids content of most of the ground water in the basin is an indication that a large proportion of the valley fill material contains little soluble matter. The ground water is most highly mineralized in the vicinity of the Willcox Playa. Ground water has been discharged by evaporation and transpiration in the vicinity of the playa, leaving soluble material behind. In addition, soluble matter has accumulated in the playa from evaporation of surface water. These processes have concentrated the dissolved matter in the fill and in the ground water in this area.

The waters from Croton Springs and other springs west of the playa are more highly mineralized than waters from the shallow wells in the neighborhood, and the spring waters are proportionately higher in sodium sulfate and chloride. Consideration of the analyses above indicates the possibility that the springs may be supplied by deep-seated artesian aquifers. However, as the waters are not thermal, it is more likely that the waters of the springs became highly mineralized by leaching playa deposits in the fill.

17/ Public Health Service drinking water standards, 1946: Reprint no. 2697, Public Health Reports vol. 61, no. 11, pp. 371-384, March 15, 1946.

Discharge of dissolved solids from the basin

With regard to disposal of dissolved salts the Willcox Basin is essentially undrained, although small amounts of dissolved matter are contained in the ground water that moves from the basin into the Aravaipa Valley, the San Simon Basin, and the Douglas Basin. Dissolved matter is accumulating in the ground water and valley fill at the lowest part of the basin, in the vicinity of the Willcox Playa. The accumulation has been slow because the amounts of dissolved matter entering the basin in surface runoff are probably small. If the water table in the heavily pumped areas were lowered sufficiently some of the highly mineralized water near the playa might move toward the areas where the water table had been lowered. This movement would probably bring more highly mineralized ground waters into the heavily pumped areas and cause some wells in these areas to yield progressively saltier water.

A source of dissolved salts in the ground water is the drainage from irrigated lands. This drainage water seeps downward, carrying with it some of the soluble salts that were formerly contained in water evaporated or used by the plants. As the ground waters are generally dilute, this effect is likely to be so slow as to be almost unnoticeable for the period since irrigation began in the basin. This effect will contribute to the accumulation of dissolved matter in the ground-water reservoir.

A comparison of the analyses made during 1946 with those made in 1910[18] indicates in a general way the changes in quality of water that have taken place in the 36-year period. In most of the basin these changes have been slight. A few wells in the areas of dilute water show slight decreases in concentration, due probably to movement of ground water from areas of recharge toward pumped areas. The area of highly mineralized ground water surrounding the Willcox Playa has apparently expanded toward the southeast during the period. Water from several wells in T. 16 S., R. 25 E., increased considerably in concentration from 1910 to 1946.

SUMMARY AND CONCLUSIONS

The Willcox Basin is part of a broad debris-filled northwest-trending valley that lies between two chains of mountains in southeastern Arizona. The mountains rise abruptly above the gently sloping valley, the mountains on the east side rising to higher elevations than those on the west side of the valley. The basin does not have drainage to the outside, but instead has interior drainage into a large flat, known as the Willcox Playa.

The basin was formed by great northwest-trending faults which caused the down-dropping of the valley and the uplifting of the mountains of the region. During and after the faulting, the downfaulted or valley trough received great thicknesses of alluvium from the upfaulted masses. The earliest fill in the trough consisted almost entirely of volcanic debris, and as erosion of the mountain masses progressed the trough received less volcanic material and more non-volcanic material. One or

[18] Meinzer, O. E., and Kelton, F. C., Geology and water resources of Sulphur Spring Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 320, p. 154-158, 1913.

more lakes occupied the Willcox Basin during the time that the upper parts of the fill were being deposited. Thick beds of clay were deposited within the lake or lakes.

Generally, the hard rocks of the mountains do not yield water readily to wells. The Recent fill of the stream channels in the mountains is not sufficiently extensive to be an important aquifer. The principal aquifers in the basin are the permeable lenses of sand and gravel in the older fill. Water in shallow aquifers in the older fill generally is not under artesian pressure, and is pumped for irrigation use. The lake beds of the older fill near the Willcox Playa are largely clay and silt, but they include fingers of sand and gravel containing water under artesian pressure.

Water recharges the ground-water reservoir of the older fill by seepage from: (1) stream flow and sheet runoff on the coarse materials near the mountains; (2) irrigation water applied to the land; and (3) precipitation.

Ground water is discharged from the older fill by evaporation, use by phreatophytes, through wells and springs, and underground movement out of the basin. Approximately 125,000 acre-feet of ground water is evaporated or used by grasses, salt bush, and mesquite in the vicinity of the playa annually. The amount of ground water moving out of the basin is probably small. Ground water has been obtained from wells for irrigation since about 1905. In 1946, 15,500 acre-feet of ground water was obtained from about 90 wells to irrigate 5,000 acres.

A comparison of the depth to water in 1910 with that in 1946 shows that the water table has declined as much as 10 feet in the areas away from pumping for irrigation, and has declined as much as 25 feet in the heavily pumped areas. The greatest amount of lowering occurred in the pumped area northwest of Willcox.

The annual safe yield could not be evaluated with the existing data, although none of these data indicate that the annual safe yield has been exceeded. The amounts of ground water discharged annually by evaporation, phreatophytes, and movement from this basin into adjoining basins, together with a longer period of record of the annual discharge from pumped and flowing wells and of the water levels, must be obtained before the annual safe yield can be accurately determined.

Water analyses indicate that most of the waters in the basin, except those in the vicinity of the playa, contain moderate amounts of dissolved matter. Ground waters pumped for irrigation generally are suitable for the crops grown in the basin. Most of the waters in the basins are hard. Waters north of Willcox do not contain fluoride in concentrations that would be harmful to the teeth of growing children. However, most of the waters in the other parts of the basin contain fluoride in objectionable amounts.

Table 1. Summary of climatological data, Willcox, Cochise County, Arizona
(From records of U. S. Weather Bureau)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
a/Average precipitation, in.	0.83	0.99	0.76	0.20	0.26	0.30	2.32	2.58	1.18	0.64	0.71	0.94	11.71
a/Mean temperature, °F.	41.6	45.3	50.8	57.7	65.6	74.8	79.4	76.8	71.0	60.6	49.8	42.4	59.6
b/Average evaporation, in.	3.82	4.64	7.12	9.82	10.51	11.14	9.70	8.10	7.28	5.96	4.51	3.26	85.86

a/ Records for period 1880-1945.

b/ Records for period 1917-1935.

Table 2. Records of typical wells and springs in Willcox Basin, Cochise and Graham Counties, Arizona.
(All wells are drilled. Wells are in Cochise County unless otherwise noted in "Remarks" column).

No.	Location	Owner	Driller	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
	T. 8 S., R. 23 E.						
2300	NE¼SW¼ sec. 32	76 Ranch	-	-	-	-	-
	T. 11 S., R. 23 E.						
2604	NE¼NW¼ sec. 6	Sierra Bonita Ranch	-	-	-	1,985	-
	T. 12 S., R. 24 E.						
1527	NW¼NW¼ sec. 28	Unknown	-	1942	-	-	6
d/ 1530	SE¼SW¼ sec. 29	Clifton Tuck	-	-	-	94	16
d/ 1539	NW¼SE¼ sec. 28	C. A. Church	-	-	-	132	-
d/ 1542	SE¼SE¼ sec. 32	Ben White	-	-	-	124	-
1547	SE¼SW¼ sec. 34	S. E. Evans	-	1940	-	107	16
	T. 13 S., R. 24 E.						
1582	NW¼NW¼ sec. 16	State of Ariz.	State of Ariz.	1932	-	1,356	16
d/ 1584	NW¼NW¼ sec. 23	J. J. Meyer	-	1920	-	50	8
1585	SW¼SW¼ sec. 25	W. A. Hines	-	-	-	-	12

a/Measuring point was usually top of casing, top of pump base, or top of well curb.

b/C, cylinder; T, turbine; W, windmill; D, diesel; E, electric; G, gasoline; number indicates horsepower.

Well records by R. L. Cushman and M. B. Booher

No.	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Temp. °F.	Remarks
2300	-	-	-	-	-	Spring in Taylor Canyon. Estimated discharge 2 gallons a minute Oct. 2, 1946.
2604	-	-	-	-	-	Well is in Graham County. See log.
1527	55.9 64.4	May 13, 1942 Dec. 11, 1946	C,W	S	66	See graph, figure 1.
1530	-	-	T,D, 25	I	-	Measured discharge 600 gallons a minute June 11, 1946.
1539	-	-	T,E, 20	I	66	Cased to 120 feet. Measured discharge 610 gallons a minute April 5, 1946. See log.
1542	-	-	T,E, 25	I	66	Measured discharge 460 gallons a minute April 5, 1946. See log.
1547	47e/	-	T,E	-	-	Reported discharge 800 gallons a minute. See log.
1582	29.2 32.1	May 13, 1942 Dec. 11, 1946	None	N	-	Test well drilled for artesian water. See log. See graph, figure 1.
1584	34.6 39.8	May 13, 1942 Dec. 12, 1946	C,W	D	68	-
1585	22.8 25.7	May 13, 1942 Dec. 12, 1946	C,W	S	64	See graph, figure 1.

c/ S, stock; I, irrigation; D, domestic; N, not used.
d/ See table 4 for analysis of water.
e/ Water level reported.

Table 2. Records of typical wells and springs in Willcox Basin, Cochise and Graham Counties, Arizona-Cont.

No.	Location	Owner	Driller	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
d/ 1588	NE¼SW¼ sec. 35	P. H. Pregenzer	-	1938	-	54	6
1592	NW¼NW¼ sec. 3	C. C. Bowen	Ira Spenser	1946	-	96	16
1616	NW¼NW¼ sec. 5	L. L. Church	-	-	-	110	8
	T. 13 S., R. 25 E.						
d/ 1675	SW¼SE¼ sec. 3	Mark A. Cook	-	-	4,300	118	6
	T. 14 S., R. 23 E.						
1700	NE¼NW¼ sec. 36	Foy Proctor	-	-	4,210	50	6
	T. 14 S., R. 25 E.						
1784	SW¼SE¼ sec. 9	Willcox Oil and Gas Synd.	-	-	-	2,360	-
	T. 15 S., R. 24 E.						
d/ 1828	SW¼NE¼ sec. 6	Unknown	-	-	4,150	-	-
d/ 1829	SE¼SE¼ sec. 31	do.	-	-	4,138	-	-
	T. 15 S., R. 26 E.						
1903	NW¼SE¼ sec. 19	Arzberger well #1	-	-	-	3,285	-
	T. 16 S., R. 25 E.						
d/ 1952	NE¼NW¼ sec. 9	George M. Anderson	Kyle	1933	-	380	6
1953	NE¼NE¼ sec. 11	B. B. Gibbons	-	-	4,217	-	6

No.	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Temp. °F.	Remarks
1588	21.4 24.3	May 12, 1942 Dec. 12, 1946	C,W	D,S	64	-
1592	44	Sept. 1946	T,G, 46	I	66	Measured discharge 840 gallons a minute June 11, 1946. See log.
1616	-	-	T,E, 15	I	66	Measured discharge 420 gallons a minute April 11, 1946. See log.
1675	105.9	Feb. 20, 1946	C,W	S	69	-
1700	36.6 40.2	May 13, 1942 Dec. 11, 1946	C,W	D,S	-	See graph, figure 1.
1784	-	-	-	-	-	See log.
1828	-	-	-	S	-	Croton Springs. Estimated discharge 1 gallon a minute Feb. 14, 1946. Seepage from spring mound at margin of Willcox Playa.
1829	-	-	-	S	-	Do.
1903	-	-	None	N	-	Oil test. See log.
1952	Flows	1933	None	I	78	Estimated flow 85 gallons a minute May 1942. See log.
1953	42.6 44.2	May 14, 1942 Dec. 12, 1946	C,W	S	-	See graph, figure 1.

Table 2. Records of typical wells and springs in Willcox Basin, Cochise and Graham Counties, Arizona-Cont.

No.	Location	Owner	Driller	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
d/ 1956	SE¼NE¼ sec. 16	School land	-	-	4,190	-	6
1963	SE¼NE¼ sec. 23	Sherman C. Ingle	-	-	4,225	108	16
1976	SE¼SW¼ sec. 1	Byron Forsyth	-	-	-	136	-
1978	SE¼SE¼ sec. 10	Fred Ackey	Ralph H. Parker	-	-	236	16
	T. 17 S., R. 25 E.						
d/ 2175	SW¼SE¼ sec. 19	Unknown	-	-	4,350	190	-
2190	SW¼NW¼ sec. 9	Jack Crews	Ralph H. Parker	-	-	130	12

a/Measuring point was usually top of casing, top of pump base, or top of well curb.

b/C, cylinder; T, turbine; W, windmill; D, diesel; E, electric; G, gasoline; number indicates horsepower.

No.	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Temp. °F.	Remarks
1956	37.9	May 28, 1942				
	36.2	Dec. 12, 1946	C,W	S	66	-
1963	41.1	May 21, 1946	-	I	-	See log.
1976	-	-	T,G	I	-	Do.
1978	38e/	Sept. 1946	T,D, 39	I	-	Reported drawdown 50 feet pumping 550 gallons a minute. See log.
2175	161.6	Feb. 28, 1946	C,W	S	71	-
2190	36e/	Oct. 1946	T,G	I	-	Cased to 130 feet; perforated 55-130 feet. See log.

c/ S, stock; I, irrigation; D, domestic; N, not used.
d/ See table 4 for analysis of water.
e/ Water level reported.

Table 3. Logs of typical wells in Willcox Basin, Arizona

	Thickness (feet)	Depth (feet)
Log of well 2604, Graham County		
Sierra Bonita Ranch, owner		
NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 6, T. 11 S., R. 23 E.		
Soil and clay - - - - -	40	40
Water gravel - - - - -	20	60
Red clay - - - - - - -	100	160
Water gravel - - - - -	20	180
Red clay - - - - - - -	60	240
Water gravel - - - - -	20	260
Red mud - - - - - - -	30	290
Sand and gravel - - - -	10	300
Red mud - - - - - - - -	30	330
Water gravel - - - - -	90	420
Red clay with some water	180	600
Quick sand		
(160 ft. to water) - -	30	630
Red rock - - - - - - -	20	650
Cavey sand - - - - - -	15	665
Red rock - - - - - - -	10	675
Cavey sand - - - - - -	15	690
Red rock - - - - - - -	320	1,010
Yellow clay - - - - - -	80	1,080
Red rock - - - - - - -	10	1,100
Yellow clay - - - - - -	20	1,120
Red rock - - - - - - -	60	1,180
Yellow clay - - - - - -	20	1,200
Red rock - - - - - - -	85	1,285
Brown sand - - - - - -	50	1,335
Gray sandy shale and clay	45	1,380
Red sand - - - - - - -	40	1,420
Hard red rock - - - - -	50	1,470
Sand yellow clay - - -	20	1,490
Gray shale - - - - - -	20	1,510
Brown sandy shale - - -	100	1,610
Brown sand - - - - - -	375	1,985
TOTAL DEPTH - - - - - -		1,985

	Thickness (feet)	Depth (feet)
Log of well 1539		
C. A. Church, owner		
NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 28, T. 12 S., R. 24 E.		
Top soil - - - - - - - -	2	2
Caliche - - - - - - - -	1	3
Sand and clay - - - - -	6	9
Clay - - - - - - - - - -	49	58
Gravel and fine sand - -	6	64
Gravel - - - - - - - - -	4	68
Clay - - - - - - - - - -	4	72
Gravel - - - - - - - - -	4	76
Clay - - - - - - - - - -	4	80
Gravel - - - - - - - - -	4	84
Clay - - - - - - - - - -	4	88
Gravel - - - - - - - - -	4	92
Clay - - - - - - - - - -	4	96
Gravel - - - - - - - - -	4	100
Clay - - - - - - - - - -	16	116
Fine sand - - - - - - -	4	120
Clay - - - - - - - - - -	12	132
TOTAL DEPTH - - - - - -		132
Log of well 1542		
Ben White, owner		
SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 32, T. 12 S., R. 24 E.		
Clay - - - - - - - - - -	10	10
Sand - - - - - - - - - -	10	20
Clay - - - - - - - - - -	15	35
Sand - - - - - - - - - -	21	56
Clay - - - - - - - - - -	19	75
Sand - - - - - - - - - -	4	79
Clay - - - - - - - - - -	3	82
Sand - - - - - - - - - -	4	86
Clay and sand - - - - -	38	124
TOTAL DEPTH - - - - - -		124
Log of well 1547		
S. F. Evans, owner		
SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 34, T. 12 S., R. 24 E.		
Sand and clay - - - - -	10	10
Sand and gravel - - - -	6	16
Clay - - - - - - - - - -	36	52
Sand, water - - - - - -	5	57
Gray sandy clay - - - -	12	69
Sand and gravel - - - -	9	78
Clay, yellow - - - - - -	11	89
Sand and gravel, water -	8	97
Clay, yellow - - - - - -	10	107
TOTAL DEPTH - - - - - -		107

Table 3. Logs of typical wells in Willcox Basin, Arizona-Cont.

	Thickness (feet)	Depth (feet)
Log of well 1582		
State of Arizona, owner		
NW¼NW¼ sec. 16, T. 13 S., R. 24 E.		
Top soil - - - - - - - - -	3	3
Caliche - - - - - - - - -	2	5
Yellow clay - - - - - - -	13	18
Red clay - - - - - - - - -	17	35
Sand and gravel, water -	5	40
Sandy clay - - - - - - - -	40	80
Clay - - - - - - - - - - -	3	83
Sandy clay - - - - - - - -	35	118
Sand, water - - - - - - -	3	121
Packed sand - - - - - - -	13	134
Sticky yellow clay - - -	6	140
Sand, gravel, and clay, water - - - - - - - - - -	4	144
Fine gravel and sand - -	6	150
Yellow clay - - - - - - -	2	152
Sandy clay - - - - - - - -	15	167
Sticky blue clay - - - -	13	180
Brown clay with sand - -	8	188
Sticky blue clay - - - -	24	212
Brown sandy clay - - - -	6	218
Sand and gravel, water -	4	222
Sandy clay - - - - - - - -	21	243
Sticky yellow clay - - -	18	261
Sand, water - - - - - - -	4	265
Gray shale - - - - - - - -	2	267
Brown sandy clay - - - -	5	272
Sand and gravel, water -	7	279
Blue sandy clay - - - -	23	302
Fine gravel, water - - -	8	310
Blue sandy clay - - - -	6	316
Large gravel, water - -	3	319
Fine sand and clay, water	1	320
Gravel, water - - - - - -	4	324
Blue sandy clay - - - -	8	332
Sand, water - - - - - - -	1	333
Blue sandy clay - - - -	7	340
Sand with little clay, water	3	343
Dark brown sandy clay -	7	350
Fine sandy gravel, water	11	361
Blue sandy shale - - - -	10	371
Blue shale, hard - - - -	21	392
Gray shale - - - - - - - -	6	398
Light gray shale - - - -	5	403
Gray shale - - - - - - - -	9	412
Blue shale - - - - - - - -	10	422
Gray shale - - - - - - - -	20	442
Log of well 1582-Cont.		
Blue shale, sticky - - -	18	460
Gray sandstone, hard - -	6	466
Gray shale - - - - - - - -	14	480
Blue clay - - - - - - - -	50	530
Brown clay - - - - - - - -	65	595
Hard gray sand - - - - - -	3	598
Brown clay - - - - - - - -	138	736
Gypsum - - - - - - - - - -	3	739
Brown clay - - - - - - - -	156	895
Brown clay and gypsum -	23	918
Gray clay - - - - - - - -	2	920
Brown clay and gypsum -	2	922
Dark brown clay - - - -	228	1,150
Brown clay and crystallized gypsum - -	4	1,154
Brown clay - - - - - - - -	126	1,280
Sandy brown clay - - - -	10	1,290
Brown clay - - - - - - - -	20	1,310
Dark brown clay - - - -	46	1,356
TOTAL DEPTH - - - - - - -		1,356
Log of well 1592		
C. C. Bowen, owner		
NW¼NW¼ sec. 3, T. 13 S., R. 24 E.		
Clay and caliche - - - -	44	44
Gravel and sand, some clots of clay - - - -	16	60
Clay, heavy - - - - - - -	2	62
Creek gravel and sand -	14	76
Small gravel and water sand	12	88
Heavy clay - - - - - - - -	8"	88' 8"
Small gravel and water sand	7'4"	96
TOTAL DEPTH - - - - - - -		96
Log of well 1616		
L. L. Church, owner		
NW¼NW¼ sec. 5, T. 13 S., R. 24 E.		
Top soil - - - - - - - - -	4	4
Clay - - - - - - - - - - -	20	24
Gravel and sand, dry - -	15	39
Clay - - - - - - - - - - -	15	54
Fine sand - - - - - - - -	10	64
Coarse gravel - - - - - -	20	84
Clay - - - - - - - - - - -	20	104
Sand and gravel - - - -	6	110
TOTAL DEPTH - - - - - - -		110

Table 3. Logs of typical wells in Willcox Basin, Arizona-Cont.

	Thickness (feet)	Depth (feet)
Log of well 1784		
Willcox Oil and Gas Syndicate, owner		
SE¼SE¼ sec. 9, T. 14 S., R. 25 E.		
Yellow clay and sand	55	55
Salt water sand	13	68
Yellow clay	17	85
Water sand	5	90
Blue clay	260	350
Sticky shale	100	450
Lime shell	4	454
Sticky shale	31	485
Conglomerate	25	510
Yellow shale	5	515
Lime shell	4	519
Red bed and gravel	41	560
Sandy lime	8	568
Red mud	8	576
Lime shell	4	580
Red bed	33	613
Sandy shale	5	618
Lime shell	3	621
Sandy shale	9	630
Hard sand	5	635
Red bed and gravel	10	645
Conglomerate	100	745
Fresh water sand	15	760
Cemented gravel	100	860
Red bed	10	870
Cemented gravel	26	896
Red bed	10	906
Sandy gravel	10	916
Conglomerate	109	1,025
Red chalk	37	1,062
Sand and gravel	53	1,115
Water sand	10	1,125
Lime shell	5	1,130
Sandstone	15	1,145
Conglomerate	55	1,200
Yellow clay	10	1,210
Sandstone	10	1,220
Sandy lime	11	1,231
Sandstone	7	1,238
Conglomerate	35	1,273
Sandstone	9	1,282
Sandy lime	8	1,290
Sandstone	5	1,295
Water sand	15	1,310
Conglomerate	25	1,335
Yellow clay and gravel	5	1,340
Log of well 1784-Cont.		
Lime shell	10	1,350
Yellow clay and gravel	10	1,360
Red sandstone and clay	30	1,390
Hard coarse sand	20	1,410
Conglomerate	35	1,445
Quicksand and gravel, flowing hot water	15	1,460
Brown sand rock	15	1,475
Yellow clay and gravel	45	1,520
Hard, sharp sandstone	10	1,530
Yellow clay and gravel	30	1,560
Hard brown sand	15	1,575
Yellow conglomerate	55	1,630
Pink sand	15	1,645
Yellow clay and gravel	5	1,650
Hard red sand	10	1,660
Yellow clay and gravel	5	1,665
Pink sandstone	15	1,680
Red sand rock	105	1,785
Brown shale and sand	25	1,810
Red sand	20	1,830
Blue and brown shale	10	1,840
Blood-red sandstone	45	1,885
Red water sand	20	1,905
Brown sand	105	2,010
Yellow sand	55	2,065
Red sand	5	2,070
Brown sandstone	100	2,170
Water seepage	3	2,173
Brown sandstone	62	2,235
Sand and gravel, water	15	2,250
Red and brown sandstone	50	2,300
Sand and shale	40	2,340
Red sand and gravel	20	2,360
TOTAL DEPTH		2,360

Table 3. Logs of typical wells in Willcox Basin, Arizona-Cont.

	Thickness (feet)	Depth (feet)
Log of well 1903		
Arzberger well #1		
NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 19, T. 15 S., R. 26 E		
Yellow clay - - - - - - - -	40	40
White shale - - - - - - - -	43	83
Water sand - - - - - - - -	20	103
Yellow clay - - - - - - - -	2	105
Clay - - - - - - - - - - -	5	110
Gravel - - - - - - - - - -	15	125
White and yellow clay - -	25	150
Red shale, sandy - - - -	15	165
Soft red shale - - - - - -	15	180
Red shale and gypsum - -	70	250
Red shale - - - - - - - -	5	255
Hard shells - - - - - - - -	5	260
Red shale - - - - - - - - -	5	265
Hard shells and gypsum -	18	283
Red shale - - - - - - - - -	4	287
Gypsum - - - - - - - - - -	8	295
Red shale and sand - - -	10	305
Gypsum shells and red shale	50	355
Gravel (water) - - - - - -	5	360
Red sand and gravel (water)	38	398
Gravel (water) - - - - - -	2	400
Red sand and gravel (water)	8	408
Hard shell, very sharp (water) - - - - - - - -	4	412
Gravel and boulders - - -	7	419
Sand and gravel, very hard	166	585
Sandy shale, very sticky	5	590
Pink sandy shale - - - -	25	615
Red sandy shale - - - - -	20	635
Pink sandy shale and gravel	30	665
Red and pink sandy shale with streaks of gravel -	30	695
Pink sandy shale and gravel	5	700
Sandy gravel with pink shale bricks - - - - - - - - -	15	715
Pink shale and sandy gravel	40	755
Pink shale and gravel - -	50	805
Pink shale very sticky -	35	840
Pink shale - - - - - - - -	16	856
Pink shale, sand and gravel, soft - - - - - -	24	880
Pink shale and sand - - -	60	940
Pink shale - - - - - - - -	15	955
Pink shale, very sticky -	60	1,015
Pink shale - - - - - - - -	30	1,045
Pink shale, sticky - - -	20	1,065
Pink shale, sandy - - - -	35	1,100
Red sand - - - - - - - - -	25	1,125
Log of well 1903-Cont.		
Very hard brown gravel -	15	1,140
Brown sand and gravel - -	90	1,230
Shale, sand and gravel -	15	1,245
Hard brown gravel - - - -	5	1,250
Sand and gravel - - - - -	10	1,260
Brown sand and gravel - -	40	1,300
Brown sand, water - - - -	10	1,310
Brown sand - - - - - - - -	15	1,325
Brown sand, hard - - - -	15	1,340
Brown sand with hard shells	25	1,365
Brown sand and shale - -	20	1,385
Sand, gravel, and shale -	10	1,395
Shale, red - - - - - - - -	13	1,408
Sticky red shale - - - -	2	1,410
Red shale - - - - - - - - -	5	1,415
Sand and shale - - - - - -	15	1,430
Red shale - - - - - - - - -	5	1,435
Gypsum - - - - - - - - - -	25	1,460
Red shale - - - - - - - - -	5	1,465
Gypsum - - - - - - - - - -	75	1,540
Gypsum with gray shale -	48	1,588
Quicksand, dark brown, water - - - - - - - - - -	4	1,592
Gypsum and gray shale - -	6	1,598
Red sand - - - - - - - - -	22	1,620
White shale - - - - - - - -	60	1,680
Conglomerate - - - - - - -	10	1,690
Yellow conglomerate - - -	60	1,750
Red conglomerate - - - -	25	1,775
Gray conglomerate, sandy	13	1,788
Red conglomerate - - - -	10	1,798
Gray conglomerate, hard -	45	1,843
Dark gray water sand - -	32	1,875
Dark gray grit with small particles of bentonite -	30	1,905
Gray grit with gray shale streaks - - - - - - - - -	70	1,975
Gray sand, hole full of water - - - - - - - - - -	5	1,980
Gray shale with streaks of sand - - - - - - - - - -	15	1,995
Dark gray sand - - - - - -	5	2,000
Gray sand - - - - - - - - -	10	2,010
Gray shale with sand - -	8	2,018
Gray sand - - - - - - - - -	42	2,060
Sand, water - - - - - - - -	20	2,080
Gray sand, very fine - -	20	2,100
Water sand gray, hard and very fine - - - - - - - -	15	2,115
Gray sand, soft - - - - - -	35	2,150

Table 3. Logs of typical wells in Willcox Basin, Arizona-Cont.

	Thickness (feet)	Depth (feet)
Log of well 1903-Cont.		
Dark gray sand - - - - -	40	2,190
Gray sand - - - - - - - -	10	2,200
Pink shale and sand - -	15	2,215
Shale streaks in gray sand	10	2,225
Gray sand, hard - - - -	60	2,285
Hard gray sand, water -	5	2,290
Gray sand - - - - - - - -	30	2,320
Gray sand and red shale	5	2,325
Gray sand - - - - - - - -	23	2,348
Dark brown sand, very hard	12	2,360
Dark brown sand with brown shale streaks - - - - -	20	2,380
Dark brown sand, very hard	15	2,395
Brown sand - - - - - - - -	20	2,415
Red sandy lime - - - - -	10	2,425
Brown sandy lime, very hard at bottom - - - -	25	2,450
Brown sandy lime - - - -	25	2,475
Red volcanic mud and cinders - - - - - - - -	45	2,520
Red volcanic mud - - - -	25	2,545
Red sand and shale - - -	23	2,568
Gray sand with small showing of lime - - - -	52	2,620
Brown sand - - - - - - - -	20	2,640
Gray sand - - - - - - - -	15	2,655
Red shale with sand shells	25	2,680
Red sandy shale and shells	20	2,700
Red sandy lime, hard - -	20	2,720
Red sandy lime, very hard	15	2,735
Red sandy lime, hard - -	20	2,755
Brown shale and very hard shells - - - - - - - -	15	2,770
Red shale and shells - -	10	2,780
Red mud with very thin hard shells - - - - - - -	30	2,810
Red mud with brown hard shells - - - - - - - -	20	2,830
Red mud with thin hard shells - - - - - - - -	25	2,855
Red mud with hard brown shells - - - - - - - -	90	2,945
Water in brown grit - -	10	2,955
Brown grit - - - - - - - -	10	2,965
Brown sand and shells -	20	2,985
Brown shale and shells -	5	2,990
Brown sandy lime, hard shells - - - - - - - -	25	3,015
Brown shale - - - - - -	15	3,030
Log of well 1903-Cont.		
Hard brown sand - - - -	5	3,035
Brown shale - - - - - - -	10	3,045
Brown sandy lime - - -	30	3,075
Brown shale with thin hard shells - - - - - - - - -	25	3,100
Brown sandy lime - - -	25	3,125
Brown shale and thin hard shells - - - - - - - - -	25	3,150
Brown sandy lime - - -	15	3,165
Red limey shale - - - -	15	3,180
Red shale with lime-covered brown boulders - - - -	35	3,215
Red gravel, water 110°F.	15	3,230
Red shale - - - - - - - -	20	3,250
Red shale and gravel -	5	3,255
Red shale and gravel mixed with brown shale - - -	15	3,270
Red shale and gravel -	5	3,275
Red lime - - - - - - - -	10	3,285
TOTAL DEPTH - - - - - - -		3,285
Log of well 1952		
George M. Anderson, owner		
$NE\frac{1}{4}NW\frac{1}{4}$ sec. 9, T. 16 S., R. 25 E.		
Soil - - - - - - - - - -	5	5
White caliche - - - - - -	15	20
Brown clay - - - - - - -	45	65
Red sand - - - - - - - -	4	69
Brown clay, some gravel	34	103
Sand and gravel - - - -	6	109
Hard sand rock - - - -	1	110
Brown sticky clay, no sand or gravel - - - - - - -	8	118
Sand - - - - - - - - - -	3	121
Sticky brown clay - - -	14	135
Sand - - - - - - - - - -	6	141
Brown sticky clay - - -	75	216
Hard sand - - - - - - - -	4	220
Brown sticky clay - - -	18	238
Hard sandstone or shale	1	239
Brown clay - - - - - - -	19	258
White caliche, lots of gravel - - - - - - - - -	19	277
White and brown clay -	30	307
Sandy brown clay - - -	11	318
Gray sand, water rose to within 5' of ground surface	5	323
Red sand. Flowed 35 gpm 5 ft. hard brown clay, then water-bearing gray sand	27	350
----------------------	30	380
TOTAL DEPTH - - - - - - -		380

Table 3. Logs of typical wells in Willcox Basin, Arizona-Cont.

	Thickness (feet)	Depth (feet)
Log of well 1963		
Sherman C. Ingle, owner		
SE¼NE¼ sec. 23, T. 16 S., R. 25 E.		
Top soil - - - - - - - - -	4	4
Gravel - - - - - - - - -	8	12
Clay - - - - - - - - - - -	15	27
Clay, gravel - - - - - - -	10	37
Sand with little water -	3	40
Clay - - - - - - - - - - -	15	55
Gravel - - - - - - - - - -	4	59
Clay - - - - - - - - - - -	11	70
Gravel and sand - - - -	3	73
Clay - - - - - - - - - - -	35	108
TOTAL DEPTH - - - - - - -		108
Log of well 1976		
Byron Forsyth, owner		
SE¼SW¼ sec. 1, T. 16 S., R. 25 E.		
Soil - - - - - - - - - - -	3	3
Clay and caliche - - - -	11	14
Clay - - - - - - - - - - -	39	53
Sand - - - - - - - - - - -	0.5	53.5
Clay - - - - - - - - - - -	4.5	58
Gravel - - - - - - - - - -	6	64
Clay - - - - - - - - - - -	26	90
Conglomerate - - - - - - -	10	100
Clay - - - - - - - - - - -	33	133
Sand and gravel - - - -	3	136
TOTAL DEPTH - - - - - - -		136
Log of well 1978		
Fred Ackey, owner		
SE¼SE¼ sec. 10, T. 16 S., R. 25 E.		
Clay - - - - - - - - - - -	55	55
Fine sand - - - - - - - -	10	65
Clay - - - - - - - - - - -	3	68
Sand - - - - - - - - - - -	9	77
Clay - - - - - - - - - - -	25	102
Sand and gravel - - - -	4	106
Clay - - - - - - - - - - -	24	130
Clay and gravel mixture	10	140
Clay - - - - - - - - - - -	25	165
Sand - - - - - - - - - - -	4	169
Clay - - - - - - - - - - -	17	136
Sandy silt - - - - - - -	2	188
Clay - - - - - - - - - - -	38	226
Sand - - - - - - - - - - -	8	234
Clay - - - - - - - - - - -	2	236
TOTAL DEPTH - - - - - - -		236

	Thickness (feet)	Depth (feet)
Log of well 2190		
Jack Crews, owner		
SW¼NW¼ sec. 9, T. 17 S., R. 25 E.		
Clay - - - - - - - - - - -	54	54
Sand and gravel - - - -	26	80
Clay - - - - - - - - - - -	16	96
Sand - - - - - - - - - - -	2	98
Clay - - - - - - - - - - -	14	112
Sand - - - - - - - - - - -	3	115
Clay - - - - - - - - - - -	15	130
TOTAL DEPTH - - - - - - -		130

Table 4. Analyses of water from typical wells and springs in Willcox Basin, Arizona
Numbers correspond to numbers given in table 1 and shown on plate 1.
Analyses by Geological Survey. (Parts per million except specific conductance.)

Well No.	Date of collection (1946)	Depth (feet)	Specific conductance ($K \times 10^5$ at 25°C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
1530	June 11	94	36.2	42	6.9	17	112	7.0	46	0.4	5.8	180	134	22
1539	Apr. 5	132	21.2	24	4.0	19	120	6.2	6	0.8	2.2	121	76	35
1542	do.	124	31.9	34	8.0	25	136	15	24	0.4	13	186	118	32
1584	Mar. 27	50	47.6	47	6.4	48	204	31	30	0.8	4.8	268	144	42
1588	Feb. 28	54	89.7	44	10	144	274	63	117	2.2	3.7	519	151	67
1675	Feb. 20	118	47.0	37	14	42	190	18	28	0.6	32	265	150	38
1828	Feb. 14	-	255	12	3.7	553	367	251	455	16	1.6	1,510	45	96
1829	do.	-	426	66	38	904	378	1,250	460	9.3	1.8	2,940	320	86
1952	May 14	380	30.1	32	3.1	27	85	60	11	0.8	1.0	177	93	39
1956	May 21	-	66.7	-	-	-	264	-	20	2.7	-	-	-	-
2175	Feb. 28	190	41.5	53	8.0	27	198	22	23	0.6	4.8	236	165	26

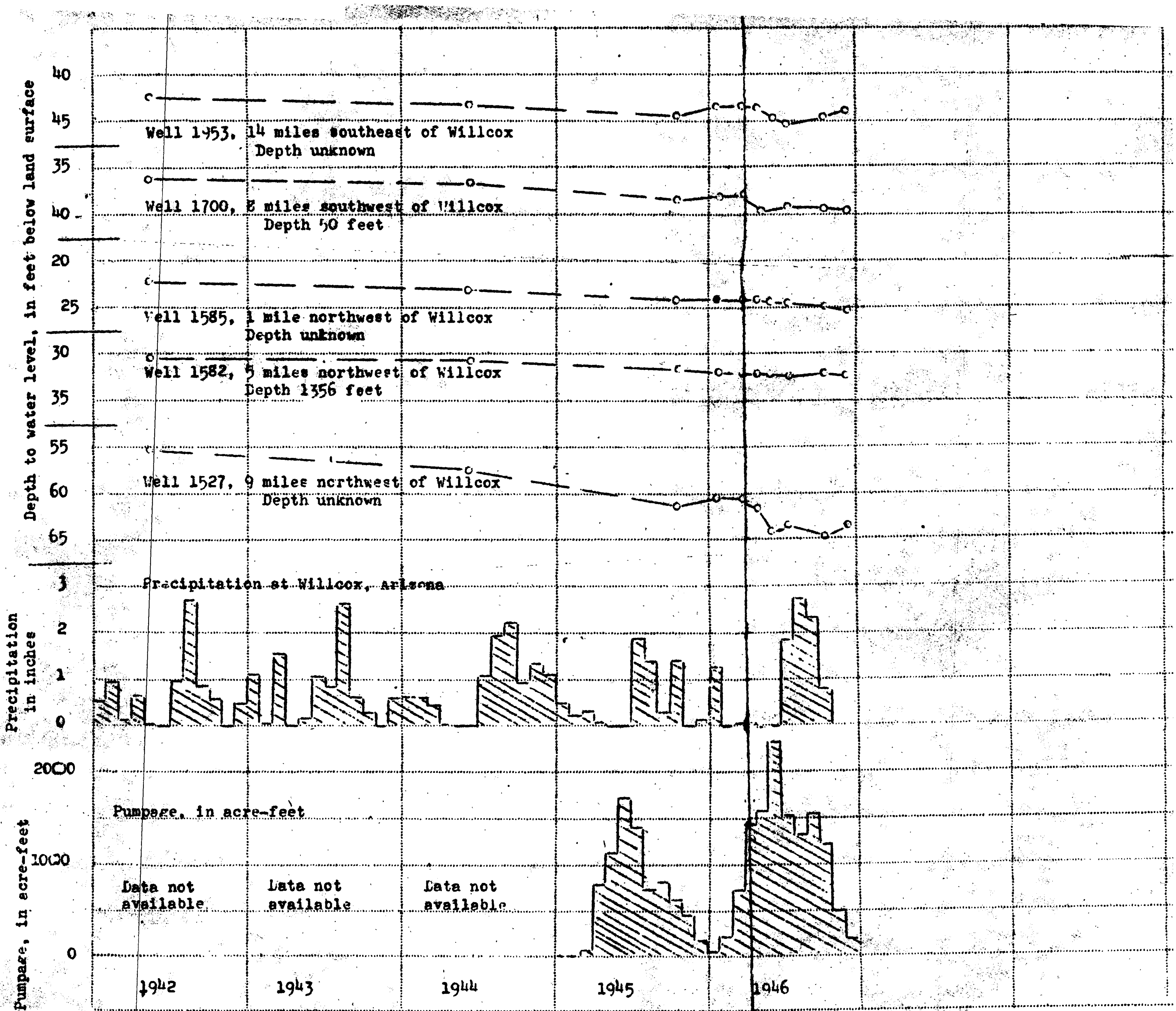

Figure 1.-Graphs showing fluctuations of water level in typical observation wells, precipitation at Willcox, and pumpage of ground water for irrigation in the Willcox Basin, Cochise County, Arizona.