United States

Department of the Interior

Geological Survey

Ground-water resources and problems of the Safford Basin, Arizona

by

S. F. Turner and others

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

46-38

Tucson, Arizona
December 9, 1946

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Purpose and cooperation

The need for State regulation of ground-water resources in Arizona has become increasingly apparent. Inasmuch as such control 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 principal ground-water basins in the state. The investigations are being made by the Geological Survey, United States Department of the Interior, in accordance with a cooperative agreement with the Arizona State Land Department, O. C. Williams, Commissioner.

A large part of the data contained herein were collected during an investigation of the water resources of the Safford Basin on the Gila River in 1939-1941 by the Federal Geological Survey, in cooperation with the State of Arizona, the United States Engineer Department, and the United States Bureau of Indian Affairs. Periodic measurements of water levels and an inventory of the pumpage have been made each year since 1941. The geology of the basin was mapped by R. B. Morrison, John D. Hem analyzed most of the water samples and prepared the quality of water section of this report. Field work during 1945 and 1946 was done by R. L. Cushman and H. B. Booher, engineers. L. C. Halpenny assisted in the preparation of the report. All of the work was done under the direct supervision of Samuel F. Turner, District Engineer (Ground Water), of the Geological Survey.

Location

The Safford Basin is a part of the structural trough that extends from the vicinity of Globe, Arizona, southeast to the vicinity of Rodeo, New Mexico (fig. 1). Southeast of the Safford Basin the trough is known as the San Simon Basin and northwest of the Safford Basin the trough is designated in this report as the Globe-San Carlos Basin. The Safford Basin is limited along the northeast side by the Gila Mountains and along the southwest side by the Santa Teresa and Pinaleno Mountains. The division between the Safford Basin and the San Simon Basin is arbitrarily designated in this report as the line between Ts. 7 and 8 S. This line passes through the Cactus Flat-Artesia area. The division between the Safford Basin and the Globe-San Carlos Basin is designated as a line perpendicular to the Gila River, passing through the stream-gaging station at Calva. The basin ranges in width from 15 to 20 miles and is about 65 miles long. It consists of two parts: the higher uncultivated land that slopes down from the mountains on either side; and the inner valley, which is half a mile to $3\frac{1}{2}$ miles in width and contains nearly all the irrigated land.

The extensive agricultural development in the Safford Basin lies southeast of the San Carlos Indian Reservation and therefore this report deals chiefly with the portion of the basin southeast of the reservation line. However, the data collected in 1941 were collected within limits imposed by the existing stream-gaging stations, and therefore these data apply to the basin from the gaging station on the Gila River at Calva upstream to the now-abandoned gaging station on the Gila River below Bonita Creek. Figure 1 shows the relations among the San Carlos Indian Reservation line, the stream-gaging stations, and the Safford Basin.

Climatological data

The climatological data for the Thatcher Weather Bureau station may be considered typical of conditions throughout the inner valley of the Safford Basin, as the elevation at Thatcher is 2,850 feet, which lies within the range of elevation of the inner valley. The elevation of the inner valley of the Safford Basin ranges from about 2,300 feet above sea level at Coolidge Dam to about 3,100 feet above sea level at the mouth of Bonita Creek. The average precipitation is 9.5 inches a year at Thatcher (elevation 2,850 feet), according to a 54-year record of the U. S. Weather Bureau. The mean annual temperature at Thatcher is 62.5 degrees Fahrenheit. The highest recorded temperature at Thatcher for the 55-year period ending in 1930 was 116° Fahrenheit, and the lowest recorded temperature was 7°. The frost-free season at Thatcher lasts about 6 months.

History of development

The Safford Basin was first settled by Mexican farmers at San Jose, near Solomonsville, about the end of the Civil War. Mormon farmers settled at Solomonsville in 1870 and later at Safford. Eventually most of the cultivable land along the Gila River was occupied from Bonita Creek to the boundary of the San Carlos Indian Reservation. The amount of land irrigated with surface water was 32 acres in 1872, 498 acres in 1880, 16,224 acres in 1890, 21,664 acres in 1900, 29,252 acres in 1910, and 32,512 acres in 1920[1/]. There has been no increase in land farmed by surface-water irrigation since 1920.

Originally the farmers used only water diverted from the Gila River to irrigate their lands. However, the river supply was inadequate, especially in dry years, and beginning about 1930 the river supply was supplemented by ground water. In 1940 about 150 irrigation wells were in operation. The number of wells in operation increased to about 260 in 1944 and 325 in August 1946. An additional 50 irrigation wells were not in use in August 1946 and further drilling was in progress. Table 1 presents records of typical domestic and irrigation wells in the inner valley. Plate 1 shows the locations of all irrigation wells and all wells in which water levels are measured periodically.

Agriculture is the main industry in the Safford Basin. The principal crops are alfalfa, cotton, grain, and vegetables. In recent years seed for sugar beets has been raised. The 1940 census lists the population of Graham County as 12,115, of which probably 95 percent reside in the Safford Basin.

1/ Firth, C. A., Distribution of waters of the Gila River: 8th Ann. Rept. of the Gila Water Commissioner, pl. 44, 1945.

Previous investigations

Earlier studies by the Geological Survey are described in the following reports:

Surface-water resources:

1. U. S. Geol. Survey 21st Ann. Rept., pp. 339-49, 1900.
2. Lippincott, J. B., Storage of water on Gila River, Ariz.: U. S. Geol. Survey Water-Supply Paper 33, 1900.
3. Surface-water supply of the Colorado River Basin, U. S. Geol. Survey water-supply papers for each year beginning with 1899.
4. Collins, W. D., Howard, C. S., and Love, S. K., Quality of surface waters of the United States:
   Water year 1941, Water-Supply Paper 942, pp. 62-64, 1943.
   Water year 1942, Water-Supply Paper 950, pp. 46-47, 1944.
   Water year 1943, Water-Supply Paper 970, pp. 117-119, 1945.
   Water year 1944, Water-Supply Paper 1022, in preparation.
   Water year 1945, water-supply paper in preparation.

Geology and ground-water resources:

1. Schwennesen, A. T., Geology and ground-water resources of the Gila and San Carlos Valleys in the San Carlos Indian Reservation, Ariz.: U. S. Geol. Survey Water Supply Paper 450-A, 1921.
2. Knechtel, M. M., Hydrology, Indian Hot Springs, Graham County, Ariz.: Washington Acad. Sci. Jour., vol. 25, no. 9, Sept. 15, 1935.
3. Knechtel, M. M., Geologic relations of the Gila conglomerate in southeast Ariz.: Am. Jour. Sci., 5th ser., vol. 31, pp. 80-92, Feb. 1936.
4. Knechtel, M. M., Geology and ground-water resources of the valley of Gila River and San Simon Creek, Ariz.: U. S. Geol. Survey Water-Supply Paper 796-F, 1938.
5. Turner, S. F., and others, Water resources of Safford and Duncan-Virden Valleys, Ariz. and N. Mex.: U. S. Geol. Survey (mimeographed), 1941.
6. Water levels and artesian pressure in observation wells in the United States, part 6, Southwestern States and Territory of Hawaii:
   Calendar year 1940, Water-Supply Paper 911, pp. 8-62, 1941.
   Calendar year 1941, Water-Supply Paper 941, pp. 8-43, 1943.
   Calendar year 1942, Water Supply Paper 949, pp. 8-23, 1944.
   Calendar year 1943, Water-Supply Paper 991, pp. 8-43, 1945.
   Calendar year 1944, water-supply paper in preparation.
   Calendar year 1945, water-supply paper in preparation.
7. Morrison, R. B., McDonald, H. R., and Stuart, W. T., Records of wells and springs, well logs, water analyses and map showing locations of wells and springs in Safford Valley, Ariz., mimeographed by Arizona State Water Commissioner, 1942.
8. Gatewood, J. S., and others, Use of water by river-bottom vegetation in lower Safford Valley, Ariz., U. S. Geol. Survey, unpublished manuscript, 1945.
9. Turner, S. F., and others, Geology and ground-water resources of Safford Valley, Ariz.: U. S. Geol. Survey water-supply paper in preparation.

10. Hem, J. D., Quality of water in the Gila River Basin above Coolidge Dam, Ariz.: U. S. Geol. Survey water-supply paper in preparation.

Other reports that refer to water resources and related subjects in the Safford Basin are:

1. Olmstead, Frank H., Gila River flood control, Report to Secretary of the Interior: Sen. Doc. 436, 65th Congress, 3rd session, 1919.
2. Poulson, E. N., and Young, F. O., Soil survey of the Upper Gila Valley area, Ariz.: U. S. Dept. Agric., Bureau of Chemistry and Soils, ser. 1935, No. 15, 1938.
3. Technical Committee, Upper Gila River Basin report: National Resources Planning Board, Water Resources Committee, 1940.
4. Firth, C. A., Distribution of waters of the Gila River: Annual reports of the Gila Water Commissioner for the years 1937-1945, inclusive.
5. Putnam, Rufus W., Interim report on survey flood control, Gila River and tributaries above Salt River, Ariz. and N. Mex., confidential report to Chief of Engineers, United States Army, 1945.

GEOLOGY OF THE SAFFORD BASIN AND ITS RELATION TO GROUND-WATER SUPPLIES

Character of basin

The Safford Basin is a deep trough that lies between mountain blocks of older rocks (pl. 2). These rocks are mostly volcanic lava and ash deposits on the northeast side of the basin and gneiss on the southwest side of the basin. The older rocks that comprise the mountain blocks are hard and resistant and for the most part impermeable, although they carry some water that issues as springs from cracks, fissures, and weathered zones along the sides of the mountains. The mountain blocks perform two major functions with respect to ground water in the basin: (1) because of their higher elevations they have greater annual rainfall and thus contribute a large share of the water that enters the basin; (2) because they are composed of relatively impermeable rocks they tend to confine the ground water within the basin.

The deep trough of the Safford Basin is partly filled with more or less unconsolidated deposits of gravel, sand, silt, and clay. The ground water occurs principally within these deposits.

Older alluvial fill

The larger part of the more or less unconsolidated deposits in the Safford Basin is termed "older alluvial fill" in this report (see pl. 2 and fig. 2). These deposits were derived from the hard rocks of the mountain blocks and were washed into the basin by streams and by sheet runoff. The alluvial fill was deposited in an enclosed basin and a shallow lake of the playa or semi-playa type was formed along the axis of the basin. The thickness of the older alluvial fill is at least 3,767 feet at one place, based upon the log of the Mary S. Mack oil test (well 301, pl. 1). Several deep water-bearing beds were encountered in this well. A well drilled at Safford for the Southern Pacific Railroad did not reach bedrock at 1,820 feet. An oil test drilled near Ashurst (SW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 30, T. 5 S., R. 24 E.) was abandoned in older alluvial fill at 2,645 feet.

Near the mountains on both sides of the basin the older alluvial fill consists of boulders, gravel, and conglomerate with small amounts of sand and silt, and is termed the "gravel zone" in this report. The width of the gravel zone is from 1 to 2 miles on each side of the basin (see pl. 2 and fig. 2). The gravel zone of the older alluvial fill is partly consolidated and moderately permeable. Layers of relatively impermeable caliche lie near the surface in most of the outcrop area of the gravel zone. Streams have cut channels through these layers, enabling water from rain and from streamflow to enter the fill along the stream channels.

The materials that comprise the older alluvial fill gradually become finer-grained toward the interior of the basin, grading first to interbedded sand and silt with some gravel, then to silt with some sand, and, finally, along the axis of the basin in the playa or "lake-bed zone", to silt and clay with local stringers of sand. The silts and clays of the lake-bed zone are relatively impermeable and contain salt and gypsum.

Alluvial fill of inner valley and tributary washes

The alluvial fill of the inner valley and tributary washes was deposited after the Gila River entered the Safford Basin. When the river first entered the basin it started a cycle of erosion that included development of gorges through the mountain barriers and rapid cutting of the fill in the interior of the basin. After the first rapid cutting the erosion slackened and an erosion surface was developed on the softer areas of the older alluvial fill (fig. 2). This surface is about 50 to 100 feet below the original depositional level, and it slopes gently toward the Gila River. It is covered with a thin mantle of gravel and is the main "mesa" level above the river plain near Safford. Subsequently the rate of erosion by the river was accelerated and an inner, narrower valley, about 150 feet deep, was cut within the larger one. This valley is partly filled, to a depth of 50 to 100 feet, with silt, sand, and gravel deposited by the river and its tributary washes. The part of the basin underlain by these younger deposits is called the inner valley and includes nearly all the irrigated lands (see fig. 3 and well logs in table 2).

The alluvial fill of the inner valley and tributary washes consists of irregular and discontinuous beds, and adjacent wells may encounter water-bearing sand or gravel beds at entirely different depths. The layers of silt are not continuous and water from the surface percolates downward, often by circuitous routes, to recharge the underlying ground-water reservoir.

GROUND-WATER RESOURCES

Older alluvial fill

Occurrence of ground water

Ground water is found along the sides of the Safford Basin in the beds of sand and gravel that occur in the "gravel zone" of the older alluvial fill. The lake-beds of the older alluvial fill near the center of the basin are largely silt and clay, but they include fingers of sand and gravel that represent extensions of the gravel zone. These fingers of sand and gravel contain water under artesian pressure. Flowing wells have been drilled along Cottonwood Wash, Ash Creek, and near Artesia, south of Safford. Water-bearing beds are encountered in these areas at depths ranging from 100 to 1,200 feet.

Source of ground water

Recharge to the older fill is from rainfall and from seepage of streams on the outcrops of the gravel zone near the mountains. The direct recharge from rainfall is probably small because relatively impermeable caliche at and near the land surface in the older alluvial fill is a partial barrier except where it has been cut through along stream channels. A large part of the water in these streams usually sinks into the alluvium lining the channels and moves downstream as underflow. A part of this underflow is fed into permeable beds of the underlying older alluvial fill. The water is unconfined in the gravel zone but as it moves toward the center of the basin it enters the fingers of sand and gravel that extend into the lake beds and is generally confined under artesian pressure.

Discharge of ground water

A part of the water in the permeable beds in the older fill reaches the surface through flowing wells and through artesian springs that rise along faults. Not all the faults in the older alluvial fill will transmit water, as some of them are sealed with clay. A part of the water of the older fill moves upward as diffused seepage through the most permeable parts of the lake-bed zone and enters the alluvial fill of the inner valley. The water in the lake-bed zone of the older alluvial fill has a higher mineral content than the water in the alluvial fill of the inner valley, and some places where the more saline water rises have been detected by chemical analysis of water samples.

The Mary S. Mack well (301) is the largest flowing well in the Safford Basin, and it produces about 1,500 gallons a minute. The Indian Hot Springs are the largest group of springs in the Safford Basin, and they produce a total of 520 gallons a minute. About 11,700 acre-feet of water was discharged from the older fill during the 12 months ending October 1, 1940[2/]. About 2,900 acre-feet of this was discharged through flowing wells and about 8,800 acre-feet was discharged through artesian springs and seeps.

Alluvial fill of inner valley and tributary washes

Occurrence of ground water

Ground water occurs at shallow depths in the sand and gravel beds of the alluvial fill of the inner valley of the Gila River. These beds are the source of water for nearly all the irrigation wells in the basin. Ground water also occurs at shallow depths in the alluvial fill of many of the tributary washes. Irrigation wells have been developed in the alluvial fill of the larger washes and domestic and stock wells have been developed in the fill of many of the smaller washes. In a few of the washes, however, the alluvial fill is only a few feet in thickness and cannot supply water for wells.

The fact should be emphasized that the individual water-bearing beds are not continuous in the alluvial fill of the inner valley of the Gila River. A bed of gravel may be 10 feet thick at one point, but at a distance of 100 feet it may be only 2 feet thick or may have pinched out entirely.

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

Source of ground water

Ground water in the alluvial fill of the inner valley is derived primarily from four sources: (1) Water from the older alluvial fill in the form of spring flow and diffused upward seepage; (2) underflow along the Gila River and tributary washes; (3) recharge from the Gila River when the water table is lowered below the level of the river; (4) water from rainfall and from infiltration of irrigation water. All figures given for recharge are from a previous report by Turner and others.[3]

The total recharge to the alluvial fill of the inner valley of the Safford Basin during 12 months beginning October 1, 1939, and ending October 1, 1940, was about 82,000 acre-feet.

Recharge from older alluvial fill. - The recharge to the alluvial of the inner valley from the older alluvial fill, in the form of spring flow and diffused upward seepage, was about 8,800 acre-feet of water during the 12-month period selected.

Recharge from underflow. - Underflow of the Gila River through the alluvial fill of the inner valley near the mouth of Bonita Creek was calculated to be about 2 cubic feet per second or about 1,500 acre-feet a year. This amount was calculated from the slope of the water table at this place, the cross-sectional area of saturated water-bearing materials, and the permeability of the water-bearing materials.

Underflow into the inner valley from tributary washes was calculated to be 12 cubic feet per second during 1939, a dray year, and 16 cubic feet per second during 1941, a wet year. The total ground-water recharge to the inner valley from underflow of tributary washes between October 1, 1939, and October 1, 1940, was about 9,200 acre-feet.

Recharge from the Gila River. - Recharge from the river occurs when the water table at the edge of the river is drawn down below river level by pumping or by evaporation and transpiration; or when the river rises above the adjacent water table during floods. It is not possible to estimate the amount of this recharge. A part of the water recharged from the river returns to the river.

Recharge from rainfall and from infiltration of irrigation water. - The recharge to the inner valley from rainfall was estimated to be between 2,500 and 5,000 acre-feet during the same period. The recharge to the alluvial fill of the inner valley from infiltration of irrigation water was about 60,000 acre-feet during the period October 1, 1939 to October 1, 1940. According to the 1941 report, approximately one-third of all water passing through canals and about one-fourth of all water applied to the fields for irrigation percolates downward to the ground-water reservoir. This means that one-half of all the surface water diverted and one-fourth of all the water pumped enters the ground-water reservoir.

Discharge of ground water

Water is discharged from the ground-water reservoir in the alluvial fill of the inner valley by pumping and by natural means. Natural discharge occurs through transpiration and evaporation in the area occupied by phreatophytes, or plants whose roots draw moisture directly from the ground-water reservoir; as evaporation from bare, wet land surfaces in the river bottoms; as underflow out of the basin along the Gila River, and as seepage from the ground-water reservoir into the river.

3/ Turner, S. F., and others, Water resources of Safford and Duncan-Virden Valleys, Ariz. and N. Mex.: U. S. Geol. Survey (mimeographed), pp. 38-45, 1941.

Discharge by pumping. - The Geological Survey has kept a record of the water pumped in the Safford Valley since January 1, 1940. The quantity pumped each year since that date is given below:

Year	1940	1941	1942	1943	1944	1945
Volume pumped, acre-feet	24,600	8,700	18,900	35,000	52,000	35,200

Figure 4 is a graph showing the quantity of water pumped, rainfall at Safford, and fluctuations of the water level in wells.

Most of the irrigation wells in the Safford Basin are used to supplement surface-water diversions. Table 1 lists records of typical irrigation wells and plate 1 shows the locations of all the irrigation wells as of August 1, 1946. These wells range in discharge from 100 to 4,600 gallons a minute, in depth from 15 to 100 feet, in pumping lift from 12 to 116 feet, and in diameter from 6 to 96 inches.

Natural discharge. - The amount of water used by phreatophytes in the inner valley during the period October 1, 1939, to October 1, 1940, was about 70,000 acre-feet, according to tests made at that time[4]. Later investigations[5] in 1943 and 1944 gave slightly lower results, indicating that in the lower half of the inner valley, from Thatcher to Calva, the amount of water used by phreatophytes was between 28,000 and 29,000 acre-feet a year. The results of the 1943-44 experiments were in substantial agreement with the results of the 1940-41 experiments, in terms of acre-feet of water used by each type of plant per acre per year. However, the 1940-41 reconnaissance survey indicated a density of growth greater than that shown by the detailed surveys of 1943-44, and thus indicated a greater use of water.

The natural discharge of ground water by evaporation from wetted lands amounted to about 6,000 acre-feet during the period October 1, 1939, to October 1, 1940.

Underflow out of the inner valley at the gaging station near Calva amounted to about 2 cubic feet per second, or about 1,500 acre-feet, during the 12-month period ending October 1, 1940. The underflow entering the inner valley near Bonita Creek and that leaving the inner valley at the gaging station near Calva are about equal. The amounts of underflow probably change very little from year to year, because the slope of the water table and the cross-sectional area of saturated water-bearing materials at these places do not change materially unless the river ceases to flow. The permeability of the water-bearing materials is a constant value. Therefore, the underflows of the Gila River entering and leaving the valley do not materially affect the amount of available ground water in the inner valley.

The natural discharge into the river from the ground-water reservoir represents the amount by which the recharge from all sources exceeds the discharge by pumping, evaporation, phreatophyte use, and underflow out of the basin, assuming no net gain or loss in ground-water storage. The

4/ Turner, S. F., and others, Water resources of Safford and Duncan-Virden Valleys, Ariz. and N. Mex.: U. S. Geol. Survey (mimeographed), pp. 40-41, 1941.

5/ Manuscript report in files of U. S. Geol. Survey, Tucson, Ariz.

discharge of ground water into the river varies greatly because pumping and the use of water by phreatophytes are seasonal. In times of heavy ground-water use there may be very little natural discharge into the river, and the direction of ground-water movement may even be reversed at some places, the river feeding the ground-water reservoir. The measurements made during the 1940-41 investigation showed that the ground-water discharge from the inner valley into the river ranged from 16 to 115 cubic feet per second.

Fluctuations of the water table

The level of the water table in the ground-water reservoir of the inner valley is affected by the following factors: (1) Rainfall; (2) use of water by phreatophytes; (3) flow in canals and irrigation of fields; (4) pumping of irrigation wells; (5) stage of the Gila River.

The effects of rainfall upon the level of the water table are as follows: (1) Rainfall on the cropped area reduces the irrigation requirements so that less pumped water is required, and rainfall on the river-bottom area reduces the amount of ground water used by phreatophytes; (2) some of the rainfall percolates directly to the ground-water reservoir. The reduction in use and the addition of water are both factors that tend to raise the water level.

The use of water by phreatophytes affects the level of the ground-water reservoir. This use is greatest during July and August, and in these months water-level recorders have often measured a decline of 3 inches a day in the level of the water table in areas of phreatophyte growth. Some of the plants of this type in the Safford Basin use as much as 8 acre-feet of water a year per acre of growth of maximum density.

Recharge from flow in canals and irrigation of fields raises the level of the water table. Cross-sections of the water table beneath canals show pronounced ridges. Tests in a field near Safford showed that the water table rose more than 1.5 feet after one application of irrigation water[6].

The pumping of irrigation wells lowers the level of the water table. Each well develops a cone of depression in the water table, and as pumping continues the cone deepens and expands and eventually merges with the cones of nearby pumping wells, thus tending to lower the general water level.

The stage of the Gila River affects the level of the water table near the river. A rise in the river stage during a flood causes a corresponding rise in water level in nearby wells. This effect is usually of short duration and the water table falls as the river stage declines after a flood.

The graphs in figure 4 show fluctuations of water level in five typical wells in the Safford Basin, for the period 1940-46.

Well 76 is an unused well near Geronimo. Very little ground water is pumped in this area. The well is near an extensive stand of mesquite, and the use of ground water by the mesquite causes the water level to decline during the summer months. Recharge from underflow of Goodwin Wash replenishes the ground water and causes a rise in water level as the use by the mesquite declines.

6/ Turner, S. F., and others, Water resources of Safford and Duncan-Virden Valleys, Ariz. and N. Mex.: U. S. Geol. Survey (mimeographed), p. 15, 1941.

Well 282 is located 1 mile northwest of Pima, near a canal. The water level in this well is raised by recharge from the canal each spring, at the beginning of the irrigation season, and is gradually lowered during the summer, as a result of regional pumping.

Well 616 is located 1½ miles south of Safford, near an irrigation canal. The water level in this well is raised by recharge from the canal and by recharge from the older alluvial fill. The graph of this well clearly shows the effect of delayed recharge from the heavy rains that fell in the winter of 1940-41 and in September 1941. This delayed recharge to the ground-water reservoir of the inner valley resulted when water from the mountain streams recharged the gravel at the base of the mountains and thence moved slowly to the inner valley.

Well 597 is 2 miles west of Solomonsville, near a canal. The water level in this well is raised by recharge from the canal in the spring, and is lowered rapidly during the summer months as a result of heavy local pumping. The rise during the early winter months is caused by water that moves in from the sides of the basin to fill the cones of depression caused by pumping.

Well 662 is an unused dug well near the eastern, or upper, end of the basin. Until 1946 the water level in this well showed a slight decline during summer months and a slight rise during winter months. These fluctuations were caused by seasonal changes in the stage of the Gila River and by natural discharge of ground water by nearby mesquite trees. The spring of 1946 was a season of exceptionally low precipitation, with deficient stream flow in the Gila River and heavy pumping in the Safford Basin. During the summer of 1946 the water level in well 662 declined to the lowest level during the period of record.

SAFE YIELD

The "safe yield" of a ground-water reservoir is "the practicable rate of withdrawing water from it perennially for human use"[7]. Obviously, the safe yield depends on the number, location, and yield of the wells drawing on the reservoir and on the intermittency of their pumping. Moreover, in an irrigated area, such as the Safford Valley, where losses through evaporation and transpiration are large, the use to which the water is put and the area of application greatly influence the safe yield. The picture is further complicated by the presence of a through-flowing stream (the Gila River) which is intimately related to the ground-water reservoir. Thus the determination of the safe yield of ground water in the basin involves an appraisal of both surface and underground-water resources. Until the details of diversion and application of water from all sources within the basin are fixed through regulation all estimates of safe yield must be provisional and based on present or assumed future conditions.

The relations between the ground-water reservoir of a basin and a through-flowing river may range from one extreme, where the ground-water reservoir feeds the river, to the other extreme, where the river feeds the ground-water reservoir. The relation in the Safford Basin is predominantly of the first type, that is, the water table slopes toward

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7/ Meinzer, O. E., Outline of methods for estimating ground-water supplies: U. S. Geol. Survey Water-Supply Paper 638-C, p. 99, 1931.

the Gila River and the ground-water body feeds the river. In this type of ground-water reservoir, the part of the pumped water that is evaporated and transpired, and thus does not return to the ground-water reservoir, represents an eventual loss in the flow of the river because it is water that would otherwise have reached the river. However, during the season of heavy pumping, the relation in part of the Safford Basin is of the second type, that is, the ground-water reservoir is fed by the surface stream. Under these conditions, pumping will increase the slope of the water table away from the river and thus increase the rate of loss of water from the river. Under either condition, large-scale ground-water withdrawals tend to reduce the flow of the stream, and before the safe yield can be estimated it is necessary to determine the extent to which this is permissible.

QUALITY OF WATER

The chemical character of ground water and surface water in the Safford Basin was investigated in detail from 1940 to 1945. During this time nearly 4,000 water samples were collected and analyzed. Most of the analyses are being prepared for publication in a water-supply paper that will contain a detailed interpretation of quality-of-water conditions in the basin. The following brief discussion is based mainly on the forthcoming detailed report.

Chemical character of the ground water

Older alluvial fill

Water in the sand and gravel lenses of the older alluvial fill is usually warm and rather highly mineralized. The analysis of a sample from the Mary S. Mack flowing well near Pima (well 501, table 3) is typical of the deeper water from the older fill. The total dissolved mineral content of this water is about 3,500 parts per million, consisting mainly of sodium, chloride, and sulfate. In some parts of the basin, where the older alluvial fill is comparatively free from beds of easily soluble material, water from the older fill may contain less than 1,000 parts per million of dissolved solids. In contrast, the Knowles flowing well at Geronimo, which is drilled into the older fill, yields water containing more than 14,000 parts per million of dissolved solids. The principal constituents in the water from the older alluvial fill are sodium and chloride, although large amounts of sulfate are found in many places. The water also contains appreciable amounts of fluoride and borate.

Alluvial fill of inner valley

Ground water from the alluvial fill of the inner valley has a wide range in total dissolved mineral content. Ground waters from the inner valley contain less than 500 parts per million of dissolved solids in a few places, principally near the eastern end and near the mouths of Cottonwood, Black Rock, and Goodwin Washes. In most areas of the valley the total dissolved mineral content of ground water ranges from 1,000 to 3,000 parts per million or more. Between Glenbar and Fort Thomas a total dissolved mineral content of 10,000 parts per million or more is common. These differences in total dissolved mineral content of the ground water are best shown by the quality-of-water map, plate 3. This map was prepared from analyses made in 1940 and 1941.

Table 3 contains analyses for samples from 29 typical wells in the basin. All the wells except well 301 obtain water from the alluvial fill of the inner valley. There are points of similarity in the chemical character of most of the waters from the alluvial fill of the inner valley, although there is a wide range in total dissolved mineral content of the ground waters. Ground waters from the inner valley are generally hard. The waters of lower dissolved mineral content contain mostly calcium and bicarbonate. The waters of higher dissolved mineral content contain chiefly sodium and chloride, in many places with large amounts of sulfate. In some parts of the valley, particularly near Thatcher and Pima, the ground waters contain large amounts of bicarbonate, and in some areas the ground waters contain large amounts of nitrate, fluoride, and borate. All waters except those of lowest dissolved mineral content contain more than 60 percent of sodium, expressed as a percentage of the sum of the calcium, magnesium, and sodium contents.

Chemical character of the surface water

Many analyses of the surface waters of the valley are contained in the water-supply papers of the Geological Survey listed in this report, in the section on previous investigations. These analyses show that at the gaging station near Solomonsville (pl. 3) the water of the Gila River usually contains moderate amounts of dissolved matter. Calcium and bicarbonate usually predominate at high stages of the river and sodium and chloride at low stages. After the Gila River enters the Safford Valley the quality of the water changes only slightly until it reaches Safford. Below this point a very marked increase occurs in the concentration of the dissolved matter, chiefly in the sodium and chloride. This salt is contributed in part by return flow from irrigation and probably in part by seepage of saline water from the lake beds. A progressive rise in concentration occurs as far downstream as Geronimo, below which there is not much change in the salinity of the stream.

No perennial streams enter the river in the valley, but occasionally flood flows from washes in the basin may affect the concentration of dissolved matter in the river water. With the exception of flood flows from San Simon Creek and Mathewsville Wash, flood waters in the basin contain small amounts of dissolved matter. Flood waters from San Simon Creek and those originating in badland areas along Mathewsville Wash may contain moderate amounts of sodium, bicarbonate, chloride, and sulfate, and they usually carry much finely-divided sediment.

Analyses in table 4 show the weighted average concentration of dissolved solids in the river water at the gaging station above Solomonsville and at the lower end of the valley, at Bylas, for the 12 months ending Sept. 30, 1944. These averages are based on daily samples and show that the river water more than doubled in concentration of dissolved solids between these two stations.

Relation of quality of water to its use

Irrigation

The main supply of water for irrigation in Safford Valley has always come from the Gila River, but in recent years the ground water of the valley has been drawn upon for a large and increasing portion of the supply. Evaluated according to the standards for irrigation water stated by Wilcox and Magistad[8], the water from the river at the upper end of the valley is of "excellent to good" quality except at times of low flow. Water diverted from the river below Safford may be in the "good to injurious" or "injurious to unsatisfactory" class at times of low flow.

Ground water from the older alluvial fill is high in total dissolved solids and in percentage of sodium, and most of this ground water is in the "injurious to unsatisfactory" class. It is used for irrigation in the valley to a small extent after mixing with less highly mineralized river water. Because of its poor quality there is little possibility of using water from the older fill for extensive irrigation. Ground water in a few places in the alluvial fill of the inner valley is in the "excellent to good" class. In most of the heavily-pumped areas of the inner valley the ground water is in the "good to injurious" class and in large areas it is in the "injurious to unsatisfactory" class.

The water of the Gila River in the Safford Basin is normally of suitable quality for irrigation. It is probable, therefore, that no serious problem exists regarding the quality of irrigation waters in the basin, as a large part of the water used for irrigation comes from the Gila River. Ground waters used for irrigation in the basin are generally more highly mineralized than water from the Gila River. If it becomes necessary to use ground water exclusively for irrigation, care would be required in its use to prevent damage to the soil, particularly in poorly-drained areas and in areas where the ground water contains a high percentage of sodium. It is possible to use more highly-mineralized waters for irrigation in the well-drained areas than in the poorly-drained areas.

Domestic use

Ground waters from the older fill are usually highly mineralized, although some of them may be considered suitable for drinking and other domestic use. These ground waters usually contain 2.0 parts per million or more of fluoride, some of them more than 10 parts per million. More than 15 parts per million of fluoride in water may cause permanent mottling of tooth enamel when used continuously by young children. Ground waters from the alluvial fill of the inner valley are generally hard, and in some areas they may be high in fluoride. The high concentration of dissolved mineral matter in many of the waters makes them unsuitable for domestic purposes.

The municipal water supply for Safford and the neighboring communities is taken from an infiltration gallery on Bonita Creek, and in emergencies supplies are derived from a well in Safford or from a reservoir on Frye Creek. Several tap samples have been analyzed, and these samples show that the water contains principally calcium, magnesium, and bicarbonate. The water is hard but has a total dissolved solids content of less than 300 parts per million.

Relation of quality of water to ground-water recharge

The recent alluvium is partly recharged by artesian water escaping from the underlying older fill. Areas where this recharge occurs may be detected by the similarity of chemical analyses of shallow ground waters to those of ground waters from the older fill. The presence of large amounts of fluoride and borate in shallow ground waters indicates a possibility of artesian leakage because waters from the older fill are often high in these constituents. In some areas the artesian inflow to the alluvial fill of the inner valley is sufficiently large in volume

[8] Wilcox, L. V., and Magistad, O. C., Interpretation of analyses of irrigation waters and the relative tolerance of crop plants: U. S. Dept. Agr., Bur. Plant Industry, Soil and Agr. Research Administration; Riverside, Calif. Mimeographed, 8 pp., May 1943.

to cause the shallow ground waters to have temperatures considerably above normal. The most striking example of concealed leakage from artesian sources is in the portion of the valley between Fort Thomas and Geronimo. Along the north side of the valley in this area wells 20 feet deep may yield water with temperatures of 80° to 100°F., compared with a normal temperature for shallow ground waters in the valley of about 65°F. Waters from these wells are similar in chemical character to waters from the Indian Hot Springs near Eden, which are known to issue from the older fill.

Using available data on quality of water, it was estimated that the recharge from artesian leakage along the Gila River in the 3.9 mile stretch immediately downstream from Fort Thomas was about 5 cubic feet per second in the winter of 1943-44. It is probable that no other stretch of similar length in the valley receives as large an amount of artesian leakage. Analyses of ground waters in the valley indicate that artesian leakage probably occurs between Pima and Eden, and possibly in other parts of the valley. The analyses also indicate a large amount of recharge of water of low total mineral content from the underflows of Goodwin and Black Rock Washes.

Source of dissolved matter in ground water

The dissolved matter present in ground waters of the basin is principally derived from soluble minerals deposited in the older fill. Common salt (sodium chloride) and gypsum (calcium sulfate) were included in some of these older fill deposits when they were laid down, and ground waters coming in contact with these minerals take them into solution. Thus, ground water in the older fill is usually highly mineralized. Water seeping from the older fill into the alluvial fill of the inner valley is an important source of dissolved salts in the shallow ground waters. Another important source of dissolved salts in the shallow ground waters 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. Recharge of the ground-water reservoir by the river and its tributaries contributes some dissolved matter.

Discharge of dissolved solids from basin

The Gila River carried about 105,000 tons of dissolved mineral matter past the gaging station at Calva in the 12 months ending September 30, 1944. These salts were derived from four main sources: Surface flow and underflow of the Gila River entering the basin, surface flow and underflow of tributary washes, artesian leakage from the older alluvial fill, and leaching of salts from the alluvial fill of the inner valley. The Gila River brought about 64,000 tons of dissolved mineral matter into the basin past the gaging station above Solomonsville. A comparatively small amount of dissolved mineral matter was derived from the surface flow and underflow of the washes within the basin. A large but unknown amount was contributed by the artesian leakage from the older fill. The alluvial fill of the inner valley probably contributed little, if any, dissolved mineral matter during this period.

SUMMARY AND CONCLUSIONS

The older alluvial fill of the Safford Basin contains ground water in the "gravel zone" near the sides of the basin. Ground water is also found in sand and gravel fingers that extend from the gravel zone into the silts and clays of the "lake-bed zone". The water in the fill is derived from recharge by rainfall and by seepage from streams crossing the gravel zone. The total discharge of ground water from the older alluvial fill through flowing wells, springs, and diffused upward seepage was about 11,700 acre-feet during the 12 months ending October 1, 1940.

The principal ground-water reservoir of the Safford Basin is the sand and gravel fill of the inner valley along the Gila River. The water in this reservoir is derived primarily from four sources: (1) Water from the older alluvial fill in the form of spring flow and diffused upward seepage; (2) water from underflow of the Gila River and its tributary washes; (3) water from the Gila River; (4) water from rainfall and from infiltration of irrigation water. The total recharge to the inner valley of the Safford Basin was about 82,000 acre-feet during the 12 months ending October 1, 1940.

The development of irrigation wells to supplement surface water diversions has been steadily increasing in the Safford Basin during recent years. Nearly all the irrigation wells derive their water from the sand and gravel fill of the inner valley along the Gila River, but a few irrigation wells obtain their water from the fill of the major tributary washes. The amount of water pumped for irrigation has been measured each year, beginning in 1940. The minimum amount pumped was 8,700 acre-feet in 1941 and the maximum was 52,000 acre-feet in 1944.

The natural discharge from the ground-water reservoir of the inner valley is by evaporation and transpiration in the river-bottom area, underflow out of the basin, and seepage into the Gila River. It is estimated that during the 12 months ending October 1, 1940, a maximum of 76,000 acre-feet of water was evaporated and transpired in the river-bottom area, and about 1,500 acre-feet of water moved out of the basin as underflow. The amount of seepage into the river was not estimated, as this could not be done without extremely detailed work.

Analyses of many water samples show that water from the older fill is generally highly mineralized and contains large amounts of sodium, chloride, and sulfate. Water from the alluvial fill of the inner valley has a wide range in total dissolved mineral content. Much of it is highly mineralized and contains large amounts of sodium and chloride. Waters of the Gila River increase in mineral concentration as they pass through the valley because of inflows of highly mineralized ground waters, derived from the older fill, irrigation drainage, and other sources.

Most of the ground waters of the basin are classified as "good to injurious" or "injurious to unsatisfactory" for irrigation because of their dissolved matter. If waters of these classifications are used for irrigation they should be used with caution, to avoid damage to soils and crops. Many ground waters of the basin are unsatisfactory for domestic use because of high concentrations of dissolved matter and excessive amounts of fluoride.

The Gila River carried about 105,000 tons of dissolved salts past the gaging station at Calva in the 12 months ending September 30, 1944.

These salts were derived from four main sources, surface flow and underflow of the Gila River entering the basin, surface flow and underflow of tributary washes, artesian leakage from the older alluvial fill, and leaching of salts from the alluvial fill of the inner valley.

Because of the intimate relation between the water in the ground in this basin and the water flowing in the Gila River, the regulation of withdrawal of ground water will be affected by the legal rights to the use of the river waters. Therefore, in arriving at a determination of the principles that are to serve as a basis for regulation of ground-water withdrawals, careful consideration must be given to the interrelation of water from the two sources. To illustrate the intricacy of the problems involved, waters of the following four types or sources are cited:

1. Ground water derived by recharge from appropriated surface water, such as seepage from canals and from the irrigated lands. If this ground water is not intercepted by pumping, a part of it will be lost by evaporation and transpiration, but the remainder will eventually re-enter the river downstream and there become available for diversion. However, in many places it might be practicable to intercept this water partially by means of wells or to reduce the losses by lining the canals, thus in effect cutting off the source of some of the flow in the river channel downstream.

2. Ground water derived from recharge by tributary-wash inflow and from natural recharge on outcrop areas. If this ground water is intercepted before it reaches the river, the flow of the river will thereby be decreased even though such interception would tend to reduce losses by evaporation and transpiration. Diversion of such ground water might be made by wells near the source.

3. Ground water saved by destruction of natural river-bottom growth or by reduction of evaporation and transpiration through a lowering of the water table caused by pumping. Except for that in areas covered with river-bottom growth, there is only a small amount of additional cultivable land. The ground water saved by clearing such land would be available for use either by additional water-well developments on the land or by allowing it to return to the river for later diversion. Some ground water which would otherwise be lost by evaporation and transpiration could doubtless be saved through lowering the water table by pumping from wells.

4. Surface water that must now be allowed to move downstream in the Gila River to meet prior claims. Much of this water is used en route by phreatophytes or lost through evaporation. Removal of river-bottom growth would save some of this water for beneficial use.

Table 1. Records of typical wells in Safford Basin, Graham County, Arizona.
(All wells are drilled except wells 76, 282, and 662.)
(Table 4 lists analyses of water from all wells except 76, 455, 597, 616, and 663.)

No.	Location	Owner	Driller	Date com-ple-ted	Altitude above sea level (feet)	Depth of well (feet)	Diam-eter of well (in.)
24	About 0.5 mile north of Bylas Post Office	U. S. Indian Service	-	1937	-	100	20
	T. 4 S., R. 22 E.						
51	NW¼SE¼ sec. 13	Bert Hinton	L. W. Farrington	1938	2641.45	76	16
	T. 4 S., R. 25 E.						
76	NE¼NW¼ sec. 18	E. [illegible]. Black	-	-	2659.99	26	72
78	SW¼SE¼ sec. 18	do	-	-	-	72	10
87	SE¼NE¼ sec. 27	Herman Uhli	-	-	2870.71	65	24
	T. 5 S., R. 25 E.						
156	SW¼SE¼ sec. 1	Roy Layton	L. W. Farrington	1939	2705.78	66	12

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

b/ T, turbine; B, bucket; C, cylinder; O, diesel oil; G, gasoline or natural gas engine; H, hand; W, windmill.

Well records obtained by R. B. Morrison, H. R. McDonald, and W. T. Stuart

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
24	23 d/	Nov. 18, 1941	T,C	D,I	66	"Bylas #1." Discharge 1,025 gallons a minute, measured July 7, 1941; drawdown reported as 13 feet.
51	18.4 19.8	Nov. 29, 1939 Jan. 19, 1946	T,G	I	68	Drawdown reported 25 feet when pumping 2,000 gallons a minute.
76	24.5 25.8	Oct. 19, 1939 Jan. 19, 1946	-	N	-	Dug shaft 5 by 7 feet, lined with concrete. Formerly used for irrigation but now abandoned. See graph, figure 4.
78	30 d/	Feb. 20, 1940	T,G	I	-	Discharge 1,370 gallons a minute, June 5, 1941; 952 gallons a minute, May 3, 1943. Reported drilled through 28 feet of hardpan and then through 42 feet of water-bearing gravels.
87	-	-	T,G	I	-	Discharge 1,750 gallons a minute, measured May 9, 1941; 18 feet of drawdown after continued pumping.
156	12.5 13.7	Nov. 29, 1939 May 22, 1946	T,G	I	-	Drawdown 10 feet after 10 hours pumping. Discharge 1,054 gallons a minute, July 23, 1940; 1,150 gallons a minute, June 15, 1944. See log.

c/ D, domestic; I, irrigation; S, stock; N, none.

d/ Water level reported.

Table 1. Records of typical wells in Safford Basin, Graham County, Arizona-Cont.

No.	Location	Owner	Driller	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
	T. 5 S., R. 24 E.						
199	NE¼NW¼ sec. 20	L. C. Hooper & E. L. Trejo	- Smithson	-	-	72	16
209	SE¼SE¼ sec. 31	Eldon Palmer	L. W. Farrington	1941	-	76	16
	T. 6 S., R. 24 E.						
266	SE¼NE¼ sec. 4	Curtis Canal Co.	E. G. Rogers	1938	-	52	16
282	SW¼NE¼ sec. 13	Guy Anderson	-	-	2814.59	25	36
284	SE¼SE¼ sec. 13	do.	E. G. Rogers	-	-	-	16
301	NE¼NE¼ sec. 13	Dodge-Nevada Canal Co.	Gila Oil Syndicate	-	-	3767	24
	T. 6 S., R. 25 E.						
313	NW¼NE¼ sec. 7	Jack Bryce	E. G. Rogers	1940	-	105	16
318	NE¼NE¼ sec. 17	Vance Marshall	do.	-	-	42	16
339	NE¼NW¼ sec. 22	Jessie Gomez	-	1940	-	73	16
341	SW¼SW¼ sec. 23	Ed Howard	E. G. Rogers	1939	2877.76	90	16
560	SE¼SW¼ sec. 29	Verne Pace Estate	J. A. Watts	-	-	-	16

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
199	41.3	Jan. 24, 1945	T,G	I	69	Discharge 330 gallons a minute, measured July 18, 1940; 753 gallons a minute, 1942.
209	50.7	Jan. 8, 1942	T,G	I	-	Discharge 850 gallons a minute, measured June 12, 1941; 1,250 gallons a minute, March 17, 1944.
266	-	-	T,G	I	-	Discharge 557 gallons a minute, measured June 21, 1940. See log.
282	24.7	Oct. 26, 1939				Dug well; brick lining. See graph, figure 4.
	20.8	Jan. 19, 1946	B,H	D	63	
284	-	-	T,G	I	-	Water-bearing gravels 41 to 45 feet and 46 to 48 feet. Discharge 765 gallons a minute, June 20, 1940; 644 gallons a minute, June 23, 1945.
301	Flows	-	-	I	138	"Mary S. Mack" oil test. Discharge 1,550 gallons a minute, measured Feb. 20, 1940; 1,350 gallons a minute April 20, 1942.
313	61.7	Aug. 28, 1940	T,G	I	69	Discharge 830 gallons a minute, measured 1942. See log.
	60.0	Jan. 17, 1946				
318	22.0	Feb. 17, 1940	T,G	I	68	Discharge 730 gallons a minute, measured June 19, 1940; 830 gallons a minute, March 16, 1944. See log.
	21.1	Jan. 17, 1946				
339	52.6	June 5, 1940	T,G	I	61	Discharge 920 gallons a minute, measured August 15, 1941; 719 gallons a minute, April 1943. See log.
341	41.6	Jan. 12, 1940	T,G	I	69	Discharge 1,375 gallons a minute, measured July 12, 1941. See log.
360	28.4	Mar. 28, 1940	T,G	I	-	Powered by tractor motor. Discharge 500 gallons a minute, June 22, 1940. See log.

Table 1. Records of typical wells in Safford Basin, Graham County, Arizona - Cont.

No.	Location	Owner	Driller	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
	T. 6 S., R. 26 E.						
413	SW¼SW¼ sec. 31	F. M. Skinner	E. G. Rogers	1937	2881.19	41	16
	T. 6 S., R. 28 E.						
453	NE¼SE¼ sec. 31	S. A. Clonts	do.	-	-	52	16
454	NE¼NE¼ sec. 31	Brown Canal Co.	-	-	-	57	16
	T. 7 S., R. 25 E.						
505	SE¼NW¼ sec. 2	Young, Hoopes, Moody, Porter	J. A. Watts	-	-	90	20
513	SW¼NE¼ sec. 4	Ted Ferguson	L. W. Farrington	1940	-	70	20
527	SE¼SE¼ sec. 12	R. G. Layton	-	-	2922.44	100	16
	T. 7 S., R. 26 E.						
554	SW¼SE¼ sec. 5	Graham Canal Co.	E. G. Rogers	1938	2901.08	59	16
593	SE¼SW¼ sec. 13	E. M. Claridge	do.	-	2963.88	90	20
597	NE¼SE¼ sec. 15	Charles Pursley	do.	-	-	-	16
601	SW¼NW¼ sec. 15	Union Canal Co.	-	-	2938.30	-	20
604	SE¼SW¼ sec. 16	Lawrence Fuller	E. G. Rogers	-	-	106	20
616	NW¼SE¼ sec. 20	S. Kimball - Greenhalgh	-	-	2964.32	51	6

No.	Water level: Depth below measuring point (feet) a/	Date of measurement	Pump and power b/	Use of water c/	Temp. °F.	Remarks
413	13.8	Jan. 15, 1940	T,G	I	-	Discharge 930 gallons a minute, measured July 12, 1941; 865 gallons a minute, measured 1942. See log.
453	-	-	T,G	I	-	Estimated discharge 900 gallons a minute, 1940; 822 gallons a minute, measured 1942.
454	21.3	Jan. 23, 1940	T,G	I	67	Discharge 300 gallons a minute, 1940.
	22.1	Jan. 17, 1946				
505	-	-	T,G	I	66	Discharge 1,500 gallons a minute, measured July 10, 1941; 1,835 gallons a minute, measured March 21, 1944.
513	-	-	T,G	I	66	Discharge 490 gallons a minute, measured July 11, 1941. See log.
527	34.4	Jan. 11, 1940	T,G	I	62	Discharge 2,130 gallons a minute, measured Aug. 1, 1940.
554	12.4	Nov. 24, 1939	T,E	I	-	Discharge 1,460 gallons a minute, measured June 27, 1941; 1,060 gallons a minute, measured Feb. 29, 1944. See log.
593	22.2	Nov. 29, 1939	T,G	I	66	Discharge 1,740 gallons a minute, measured July 1, 1941; 1,500 gallons a minute, Mar. 30, 1944.
	20.6	Jan. 17, 1946				
597	16.4	Nov. 2, 1939	C,W	S	-	See graph, figure 4.
	15.9	Jan. 17, 1946				
601	-	Nov. 8, 1939	T,G	I	66	Discharge 4,650 gallons a minute, measured June 25, 1941.
604	-	-	T,G	I	64	Discharge 970 gallons a minute, June 19, 1940; 1,250 gallons a minute, measured 1942.
616	48.0	Oct. 28, 1939	C,H	N	-	See graph, figure 4.
	48.3	Jan. 19, 1946				

Table 1. Records of typical wells in Safford Basin, Graham County, Arizona - Cont

No.	Location	Owner	Driller	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
	T. 7 S., R. 27 E.						
662	NE¼NE¼ sec. 2	Mrs. Jose Somora	U. S. Geological Survey	1940	3053.93	19	36
663	NW¼SE¼ sec. 2	"Big Five" Irrigation Co.	E. G. Rogers	-	-	110	20
674	NE¼SE¼ sec. 9	Zelma Clonts, F. W. Butler	do.	1938	-	81	16
678	SE¼SE¼ sec. 7	Mrs. E. L. Tidwell	-	-	-	-	-
707	NE¼NE¼ sec. 20	Clyde Kempton	-	-	-	81	16

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

b/ T, turbine; B, bucket; C, cylinder; O, diesel oil; G, gasoline or natural gas engine; H, hand; W, windmill.

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
662	17.9	June 6, 1940	-	-	-	Dug well for water-level observations. See log. See graph, figure 4.
663	-	-	T,G	I	-	Discharge 1,520 gallons a minute, measured June 20, 1940. See log.
674	15.8 16.1	Jan. 11, 1940 Jan. 17, 1946	T,G	I	68	Discharge 980 gallons a minute, measured June 20, 1940. 768 gallons a minute, measured 1942.
678	-	-	T,G	I	65	Discharge 1,200 gallons a minute, measured June 20, 1940; 1,280 gallons a minute, measured 1942.
707	-	-	T,G	I	69	Discharge 380 gallons a minute, measured July 12, 1940; 1,060 gallons a minute, Mar. 30, 1944. See log.

c/ D, domestic; I, irrigation; S, stock; N, none.

d/ Water level reported.

Table 2. Logs of typical wells in Safford Basin, Graham County, Arizona

Log of well 156
Roy Layton, owner.
SW¼SE¼ sec. 1, T. 5 S., R. 23 E.

	Thickness (feet)	Depth (feet)
Fill	18	18
Water gravel	36	54
Clay	12	66
TOTAL DEPTH		66

Log of well 266
Curtis Canal Co., owner.
SE¼NE¼ sec. 4, T. 6 S., R. 24 E.

	Thickness (feet)	Depth (feet)
To water	20	20
Water gravel	19	39
Hard clay	13	52
TOTAL DEPTH		52

Log of well 313
Jack Bryce, owner.
NW¼NE¼ sec. 7, T. 6 S., R. 25 E.

	Thickness (feet)	Depth (feet)
Topsoil and boulders to water	60	60
Water-bearing sands	2	62
Sand and clay	1	63
Water-bearing gravels	30	93
Clay	7	100
TOTAL DEPTH		100

Log of well 318
Vance Marshall, owner.
NE¼NE¼ sec. 17, T. 6 S., R. 25 E.

	Thickness (feet)	Depth (feet)
Top fill to water	30	30
Gravel	10	40
Clay	2	42
TOTAL DEPTH		42

Log of well 339
Wallace and Palmer, owners.
NE¼NW¼ sec. 22, T. 6 S., R. 25 E.

	Thickness (feet)	Depth (feet)
Top fill to water	59	59
Clean gravel	16	75
Clay	5	80
TOTAL DEPTH		80

Log of well 341
Ed. Howard, owner.
SW¼SW¼ sec. 23, T. 6 S., R. 25 E.
Thatcher

	Thickness (feet)	Depth (feet)
Rock fill (many boulders)	30	30
Clay	20	50
Water gravel	6	56
Clay	2	58
Water sand	20	78
Clay	12	90
TOTAL DEPTH		90

Log of well 360
Verne Pace, owner.
SE¼SW¼ sec. 29, T. 6 S., R. 25 E.

	Thickness (feet)	Depth (feet)
Topsoil	29	29
Gravel	6	35
Clay	5	40
TOTAL DEPTH		40

Log of well 413
F. M. Skinner, owner.
SW¼SW¼ sec. 31, T. 6 S., R. 26 E.

	Thickness (feet)	Depth (feet)
Fill	10	10
Water gravel	31	41
TOTAL DEPTH		41

Log of well 513
Ted Ferguson, owner.
SW¼NE¼ sec. 4, T. 7 S., R. 25 E.

	Thickness (feet)	Depth (feet)
Topsoil	44	44
Clay	17	61
Gravel	10	71
Clay	9	80
TOTAL DEPTH		80

Log of well 554
Graham Canal Co., owner.
SW¼SE¼ sec. 5, T. 7 S., R. 26 E.

	Thickness (feet)	Depth (feet)
Top fill	14	14
Water gravel	31	45
"Big clay"	14	59
TOTAL DEPTH		59

Table 2. Logs of typical wells in Safford Basin, Graham County, Arizona - continued

	Thickness (feet)	Depth (feet)
Log of well 662		
Mrs. Jose Somoro, owner.		
NE¼NE¼ sec. 2, T. 7 S., R. 27 E.		
Fine sandy loam consisting mostly of silt and very fine sand with rare 3/4-inch pebbles	1½	1½
Similar to above but with smaller pebbles	1	2½
Poorly-sorted medium gravel containing some silt and fine sand with some 2 inch cobbles	3½	6
Well-sorted medium gravel containing some sand and 2½ inch cobbles	9	15
TOTAL DEPTH		15
Driller's log of well 663		
Big Five Irrigation Co., owner.		
NW¼SE¼ sec. 2, T. 7 S., R. 27 E.		
Top fill	7	7
Water gravel	40	47
Silt (or very fine sand-gritty)	19	66
Water gravel	6	72
Silty clay	38	110
TOTAL DEPTH		110
Driller's log of well 707		
Clyde Kempton, owner.		
NE¼NW¼ sec. 20, T. 7 S., R. 27 E.		
Fill	26	26
Water gravel	52	78
Clay	3	81
TOTAL DEPTH		81

Table 3. Analyses of water from typical wells in Safford Basin, Graham County, 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 number	Date of collection	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 $CaCO_3$	Per cent sodium
24	Aug. 6, 1941	105	325	178	45	473	313	306	765	0.8	2.5	1924	630	62
51	May 12, 1940	76	80	-	-	-	212	-	112	-	-	-	248	-
78	July 23, 1940	72	65	-	-	-	144	-	73	-	-	-	90	-
67	June 19, 1940	65	540	-	-	-	371	-	1388	-	-	-	930	-
156	July 23, 1940	64	800	-	-	-	468	-	2225	-	-	-	1,050	-
199	July 16, 1940	66	410	-	-	-	522	-	883	.1	-	-	690	-
209	Aug. 7, 1941	76	564	224	73	1144	609	652	1520	2.1	23	3940	859	74
266	May 28, 1940	52	540	-	-	-	460	-	1090	-	-	-	450	-
282	Mar. 28, 1940	251	171	-	-	-	248	-	335	.2	27	-	158	-
284	June 20, 1940	-	190	-	-	-	444	-	350	-	-	-	270	-
301	Oct. 30, 1940	3767	592	74	8.7	1220	101	416	1660	6.0	-	3530	220	92
313	Aug. 23, 1940	103	680	92	49	1508	798	1201	1280	-	-	4520	431	88
318	June 19, 1940	-	430	-	-	-	676	-	738	-	-	-	81	-
339	Aug. 13, 1941	73	423	91	34	830	581	481	825	3.0	28	2580	367	83
341	July 13, 1940	90	339	-	-	-	524	-	675	-	-	-	255	-
360	June 22, 1940	-	237	-	-	-	500	-	440	-	-	-	285	-
413	July 29, 1940	41	290	-	-	-	434	-	570	-	-	-	525	-
454	July 29, 1941	57	83.0	58	15	98	247	44	118	1.3	.8	457	206	51
505	July 15, 1941	-	223	105	38	340	506	166	390	.5	22	1311	418	64
513	July 23, 1940	-	310	-	-	-	574	-	615	-	-	-	360	-
527	Aug. 1, 1940	100	216	-	-	-	484	-	380	-	-	-	480	-
554	June 18, 1940	59	270	-	-	-	396	-	560	-	-	-	472	-
593	do.	90	190	-	-	-	423	-	312	-	-	-	195	-
601	July 19, 1941	-	343	108	29	633	548	385	630	3.6	21	2080	389	78
604	June 19, 1940	-	270	-	-	-	251	-	530	-	-	-	338	-
662	June 6, 1940	18	300	46	9.2	622	422	428	505	-	-	1818	153	90
674	June 20, 1940	81	151	-	-	-	335	-	270	-	-	-	232	-
678	do.	-	128	-	-	-	278	-	240	-	-	-	248	-
707	July 12, 1940	81	175	-	-	-	392	150	280	-	-	-	120	-

Table 4. Weighted average analyses for Gila River at two points in Safford Basin, Graham County, Arizona, for year ending September 30, 1944.

Analyses by Geological Survey. (Parts per million except specific conductance.)

	1	2
Date of collection	1943-44	1943-44
Silica (SiO_2)	39	36
Iron (Fe)	.17	.22
Calcium (Ca)	51	69
Magnesium (Mg)	12	21
Sodium (Na)	87	246
Potassium (K)	6.0	
Bicarbonate (HCO_3)	204	212
Sulfate (SO_4)	39	161
Chloride (Cl)	117	316
Fluoride (F)	1.3	1.2
Nitrate (NO_3)	1.1	2.2
Borate (BO_3)	.4	1.6
Dissolved solids:		
Sum-parts per million	454	957
-tons per acre-foot	.62	1.30
Hardness as $CaCO_3$:		
Total	177	258
Noncarbonate	10	85
Specific conductance ($K \times 10^5$ at 25° C.)	74.3	157
Percent sodium	51	67

1. Gila River near Solomonsville, Arizona.
2. Gila River at Bylas, Arizona.

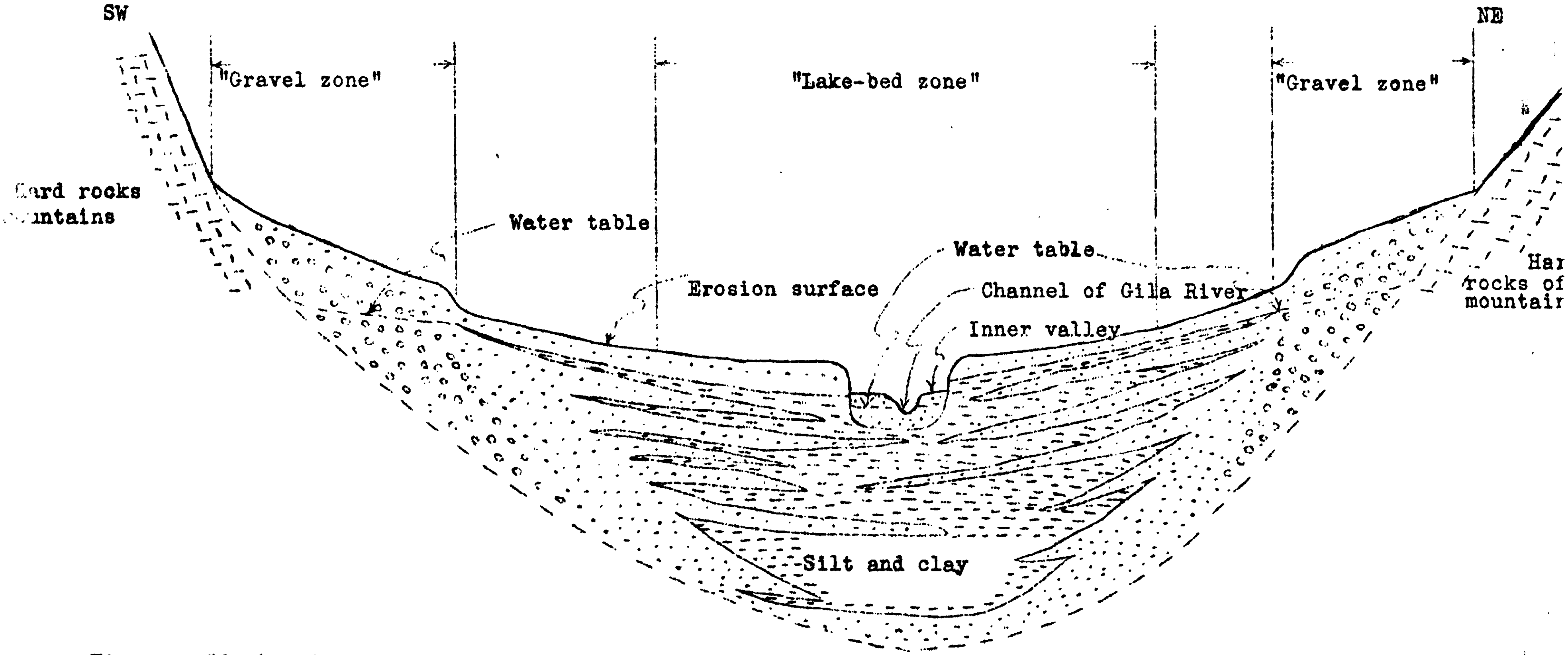
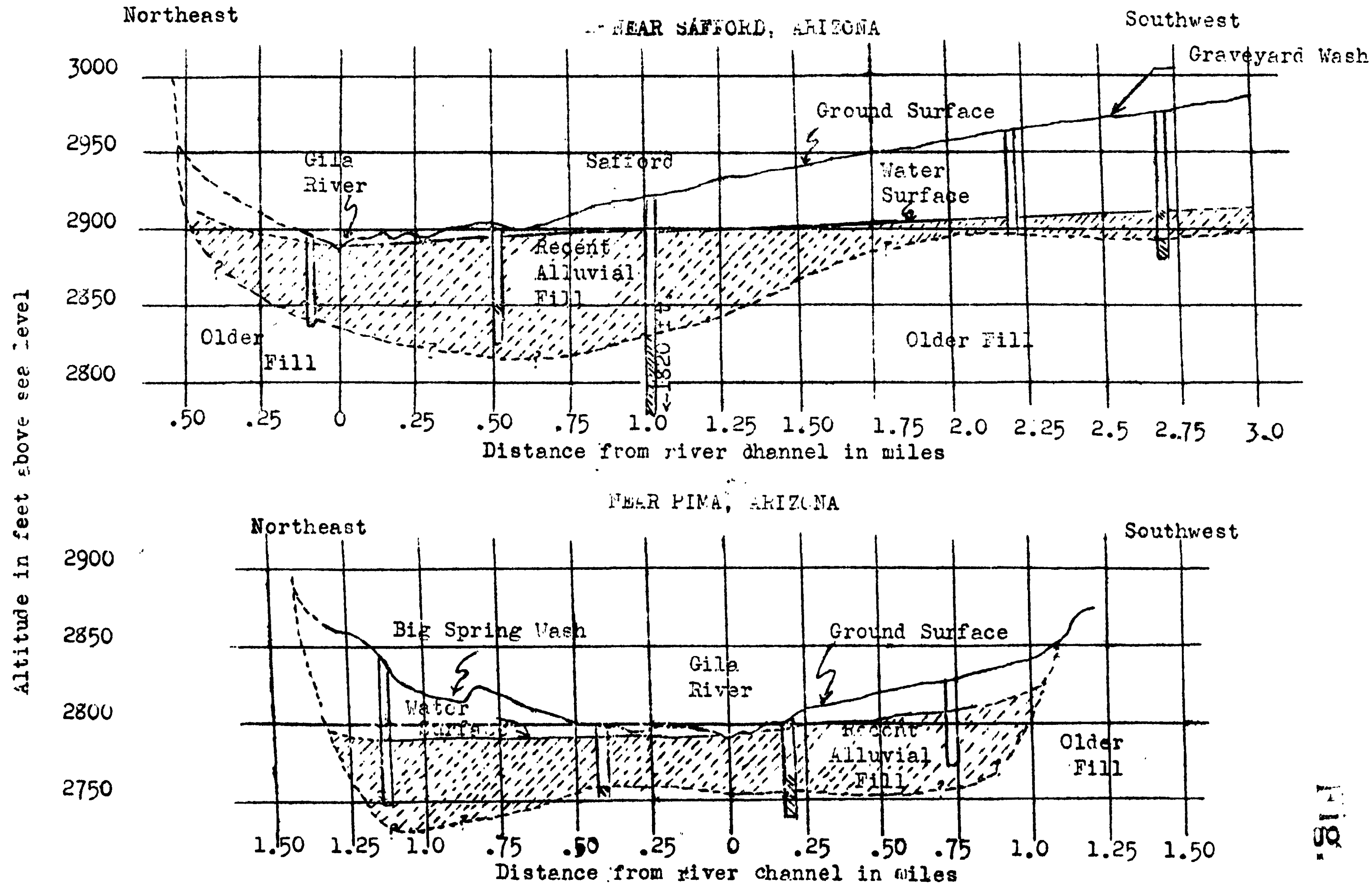


Fig. 2. Idealized cross-section of Safford Basin, Graham County, Arizona, showing relationship between materials comprising older alluvial fill

Fig. 2



CROSS SECTIONS THROUGH GILA RIVER FLOOD PLAIN
SAFFORD VALLEY

Fig. 3

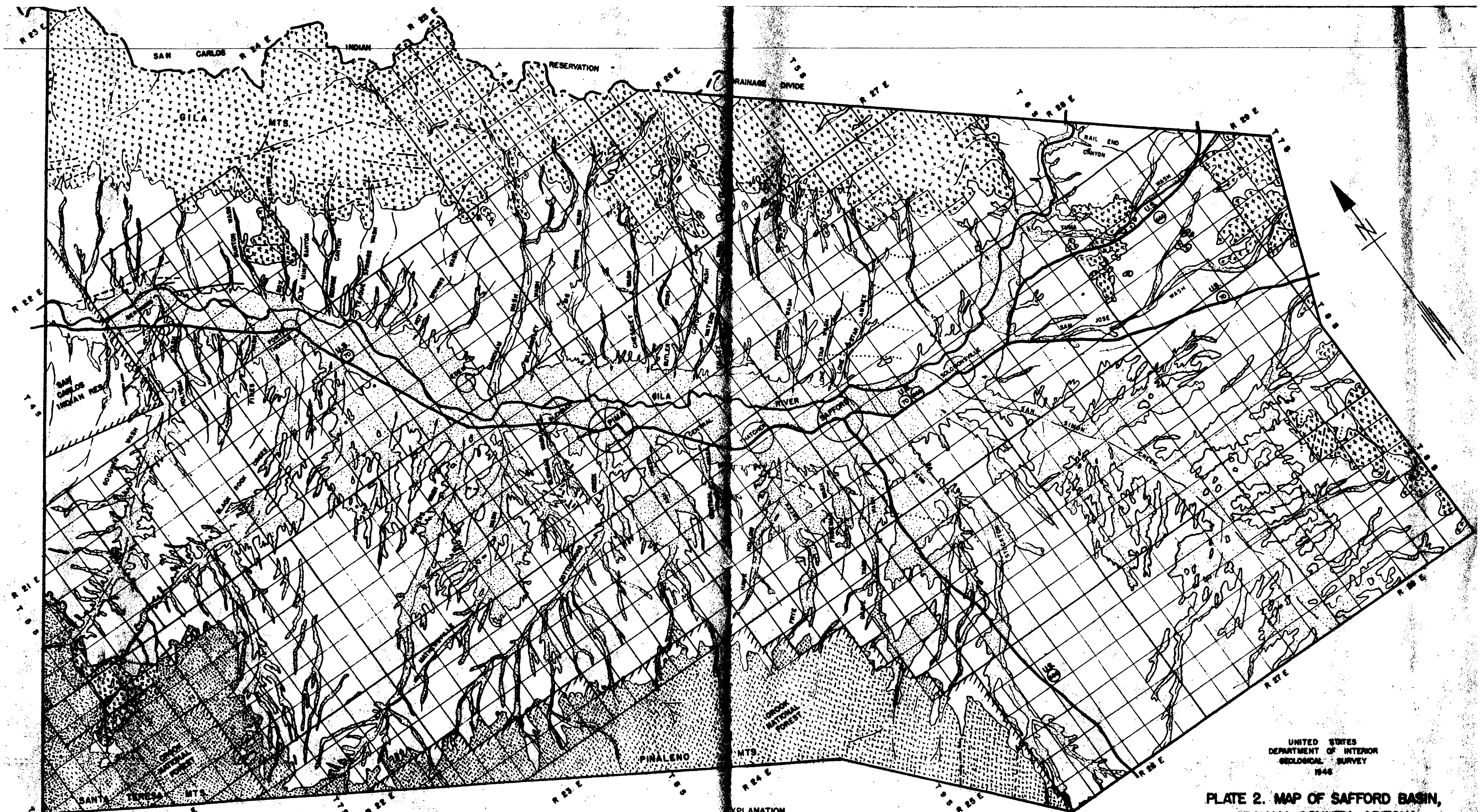


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PLATE 2. MAP OF SAFFORD BASIN, GRAHAM COUNTY, ARIZONA
SHOWING GENERALIZED GEOLOGY.

SCALE 0 1 2 3 4 5 MILES

EXPLANATION

- ALLUVIAL FILL OF INNER VALLEY
- OLDER ALLUVIAL FILL
- VOLCANIC ROCKS
- GNEISS

- KNOWN FAULT
- PROBABLE FAULT
- CONCEALED FAULT

ALLUVIAL FILL OF INNER VALLEY IS PRINCIPAL AQUIFER IN BASIN. OLDER ALLUVIAL FILL YIELDS MINERALIZED WATER FROM FLOWING WELLS AND FAULT ZONES. OTHER ROCKS ESSENTIALLY NON-WATER-BEARING IN BASIN.

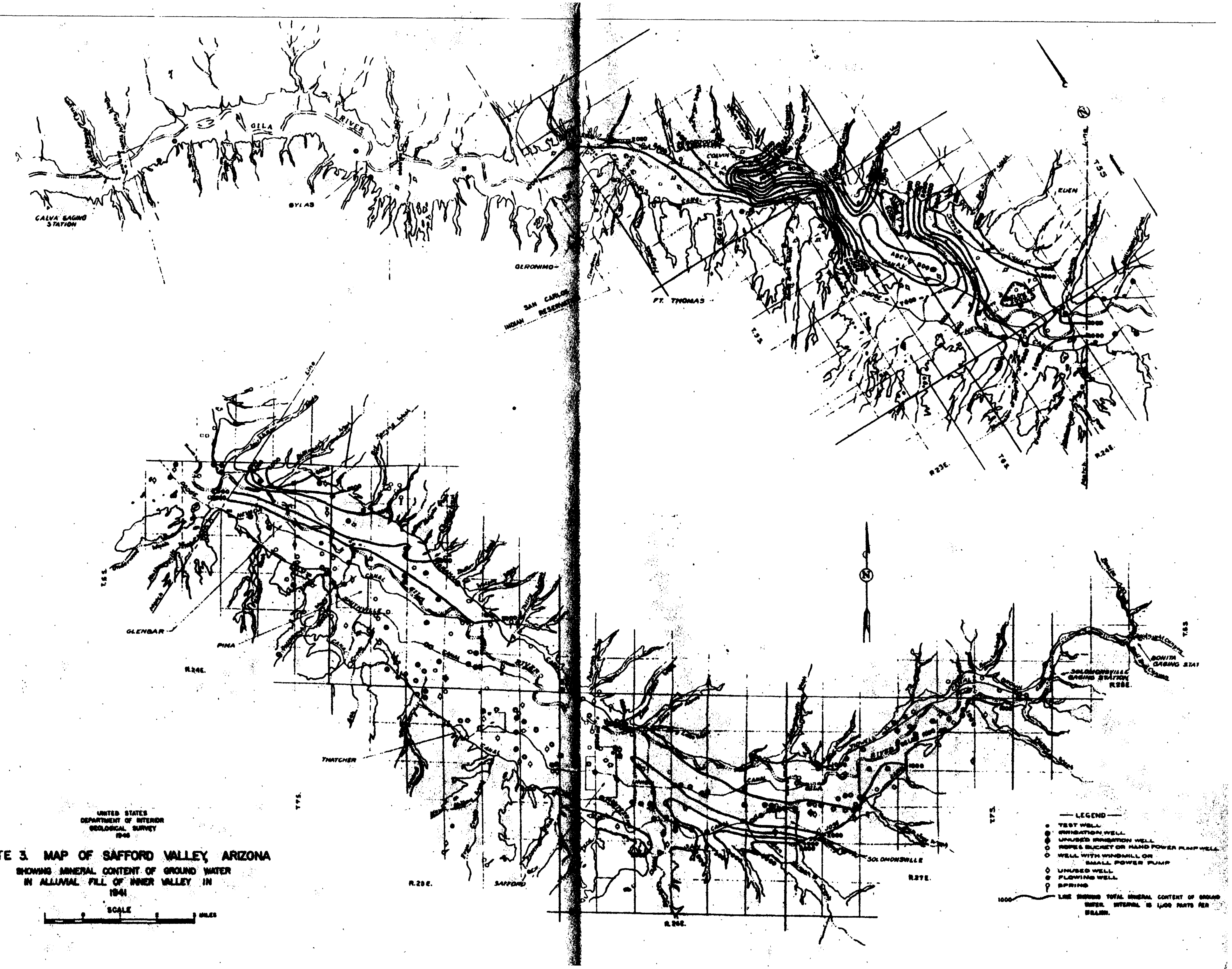

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PLATE 3. MAP OF SAFFORD VALLEY, ARIZONA
SHOWING MINERAL CONTENT OF GROUND WATER
IN ALLUVIAL FILL OF INNER VALLEY IN
1941

SCALE
0 1 2 3 MILES

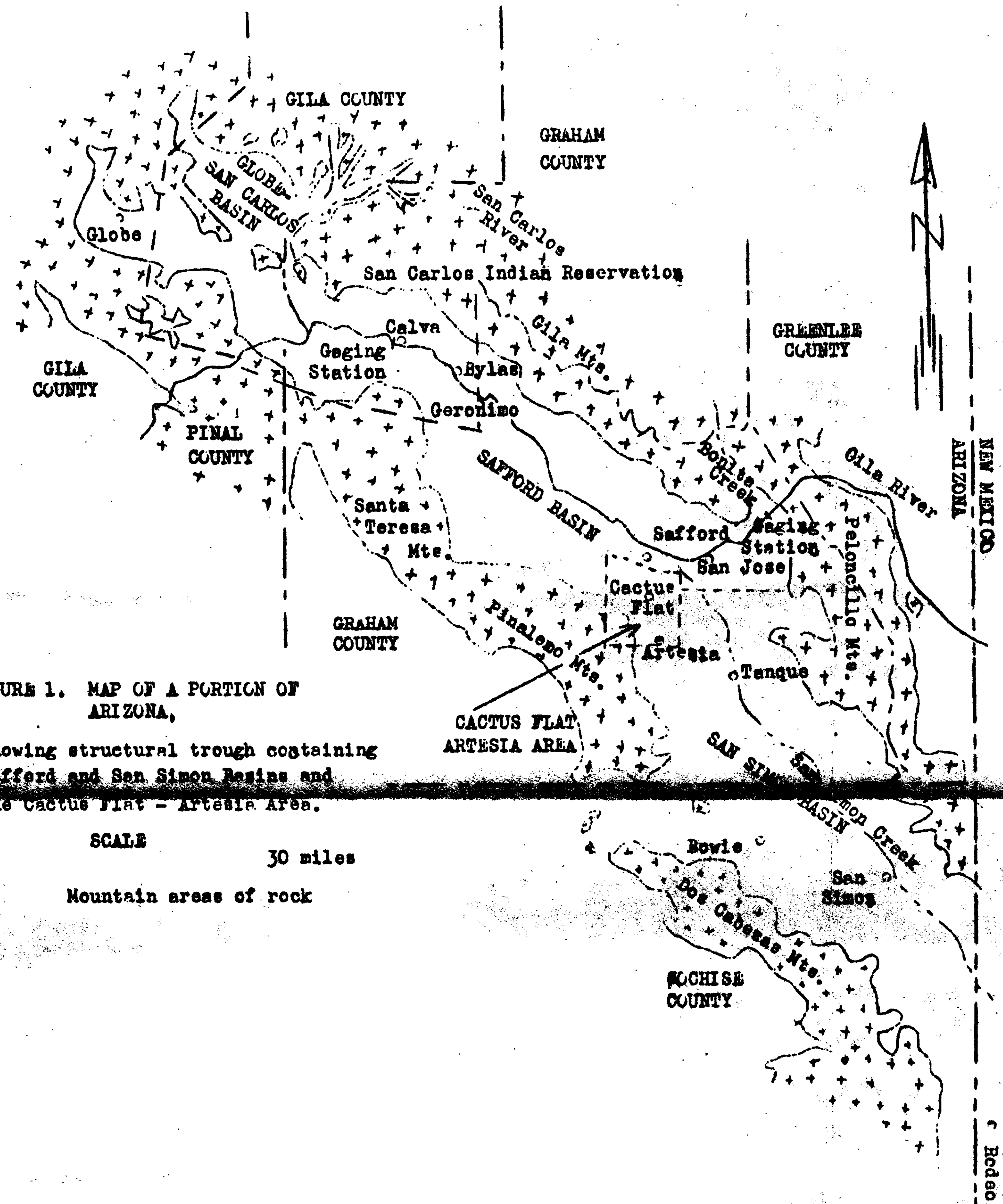

FIGURE 1. MAP OF A PORTION OF ARIZONA,

showing structural trough containing Safford and San Simon Basins and the Cactus Flat - Artesia Area.

SCALE

30 miles

Mountain areas of rock

Fig. 4

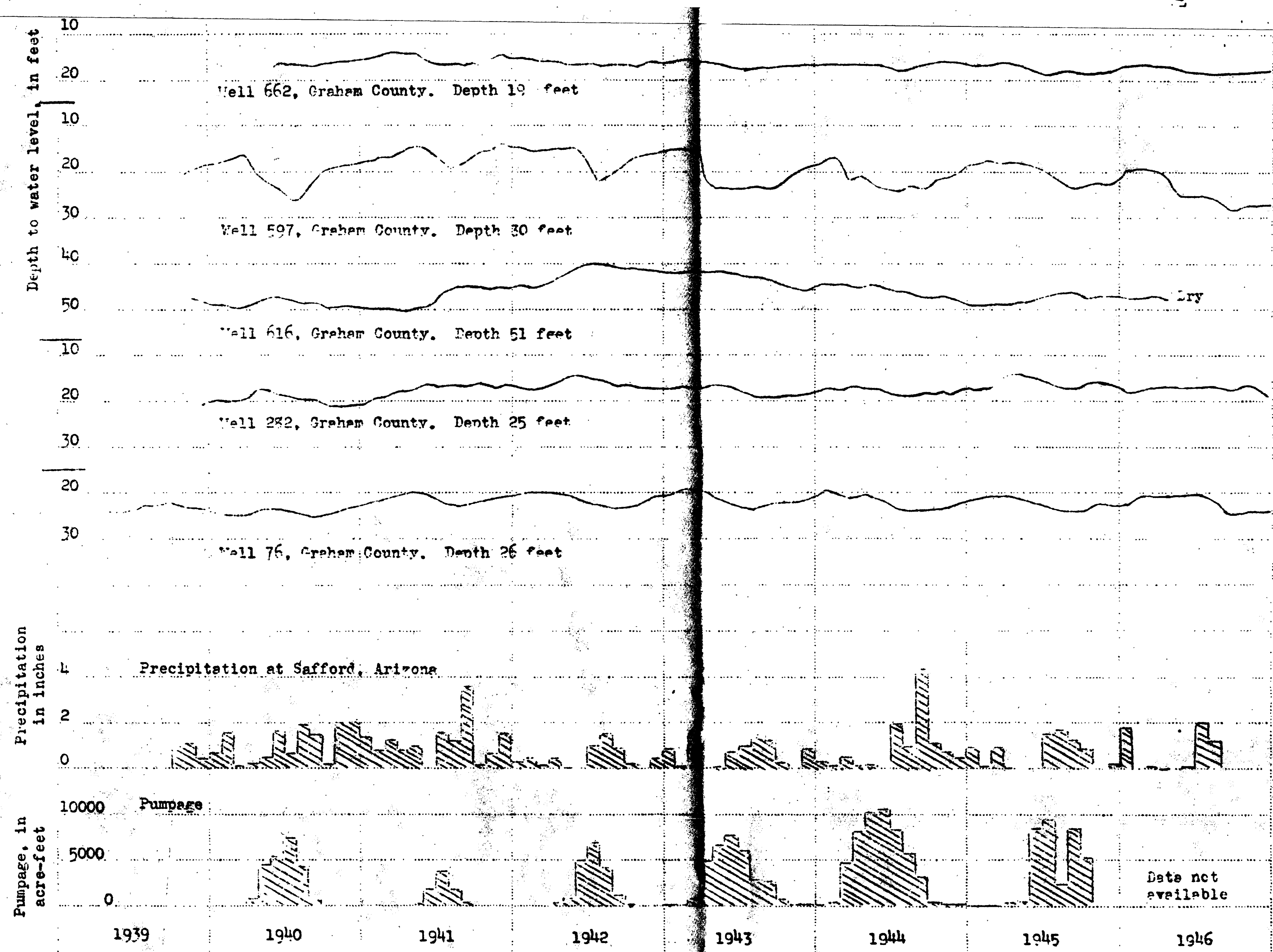

Figure .—Graphs showing fluctuations of water level in observation wells in the Safford Valley, Graham County, Arizona