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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE UNDERGROUND WATERS OF GILA VALLEY, ARIZONA

BY

WILLIS T. LEE

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., January 8, 1904.

SIR: I transmit herewith a report by Mr. Willis T. Lee on the underground waters of the Gila Valley, and recommend that it be published in the series of Water-Supply and Irrigation Papers.

In this report there is presented all of the available information regarding the geology of the superficial formations in Gila Valley between The Buttes, 12 miles east of Florence, and the junction of Gila and Salt rivers, a district which lies mostly within the Pima Indian Reservation. This investigation has been made for the purpose of ascertaining the amount of water available for pumping, for irrigation by the Indians, and the area in which such waters may be had; and it is believed that the results will prove interesting and important.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

UNDERGROUND WATERS OF GILA VALLEY, ARIZONA.

By Willis T. Lee.

INTRODUCTION.

Gila Valley, as limited in this paper, extends from The Buttes, about 12 miles east of Florence, to the junction of Gila and Salt rivers, a distance of about 75 miles. The greater part of the valley is occupied by the Pima Indian Reservation, which is said to contain about 7,870 Indians. In the upper part of the valley, in the vicinity of Florence, are a few white settlers, but owing to scarcity of water comparatively little land is under cultivation. The greater part of the irrigable land in Gila Valley has been owned from time immemorial by the Indians, who are intelligent and industrious, and until 1890 were prosperous. Up to that time their irrigation canals were supplied by water diverted from the Gila, but since that year the diversion of the Gila waters above the reservation has caused a shortage of water. The Indians have been deprived of the water which is theirs by right of priority. The only water left for them is the seepage water and such small amounts as can be saved from passing floods. On account of the scarcity of water the area of lands cultivated by the Indians has decreased from about 14,000 to about 7,000 acres.

The purpose of the present investigation is to gather data concerning the underground waters of the Gila Valley and to determine as far as possible the volume of these waters and the probable cost of rendering them available for irrigation by the Indians.

REVIEW OF PREVIOUS INVESTIGATIONS.

In 1891 Mr. F. H. Newell published a paper on the hydrography of the arid regions[a] in which he sums up what was then known regarding the water resources of Gila Valley.

In 1897 a report by Arthur P. Davis, entitled "Irrigation investigation for the benefit of the Pima and other Indians on the Gila River Indian Reservation, Arizona," was published.[b] In this document Mr. Davis gives much information concerning underground waters. The

[a] Newell, F. H., Hydrography of the arid regions of the United States: Twelfth Ann. Rept. U. S. Geol. Survey, pt. 2, 1891, pp. 213-361.

[b] Senate Document No. 27, Fifty-fourth Congress, second session, 1897.

principal part of the paper, however, is devoted to a consideration of reservoirs to impound the flood waters of the Gila.

In 1897, also, Mr. Davis published a paper entitled "Irrigation near Phœnix, Arizona,"[a] in which 30 pages are devoted to Gila Valley. He discusses the topographic features of the Gila Basin and the atmospheric conditions affecting rainfall. Tables of precipitation at various points and the rate of discharge of the Gila and its tributaries are given. The canals of the Gila Valley are described and the amount of water diverted by them is stated. The subject of underground waters is touched upon, and records of some wells in Gila Valley are given.

In 1900 J. B. Lippincott published a paper entitled "Storage of water on Gila River, Arizona."[b] This paper is devoted entirely to questions relating to irrigation in the Gila Valley. The greater part of the paper is devoted to a discussion of the storage and distribution of surface waters.

AREA EXAMINED.

This investigation was intended primarily to ascertain the amount of water available for the lands of the Indians, but in order to obtain data concerning the underground water on the reservation the inves-

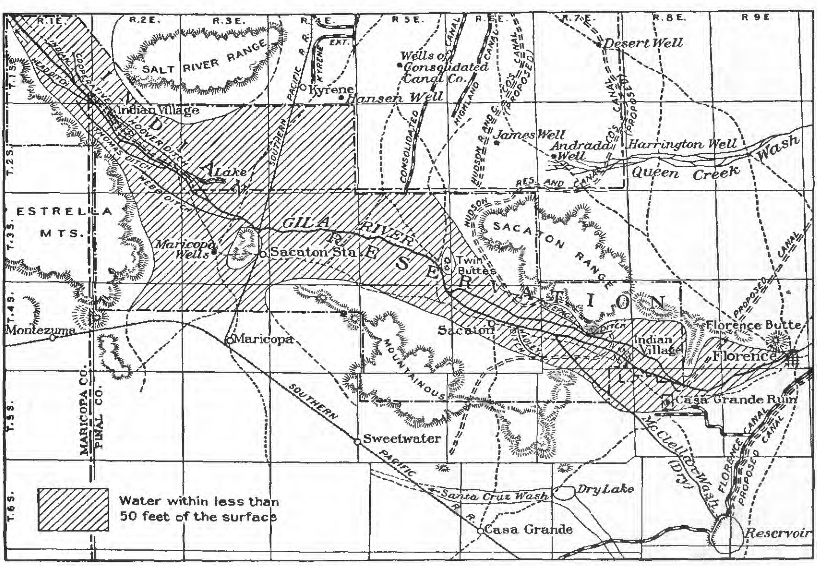
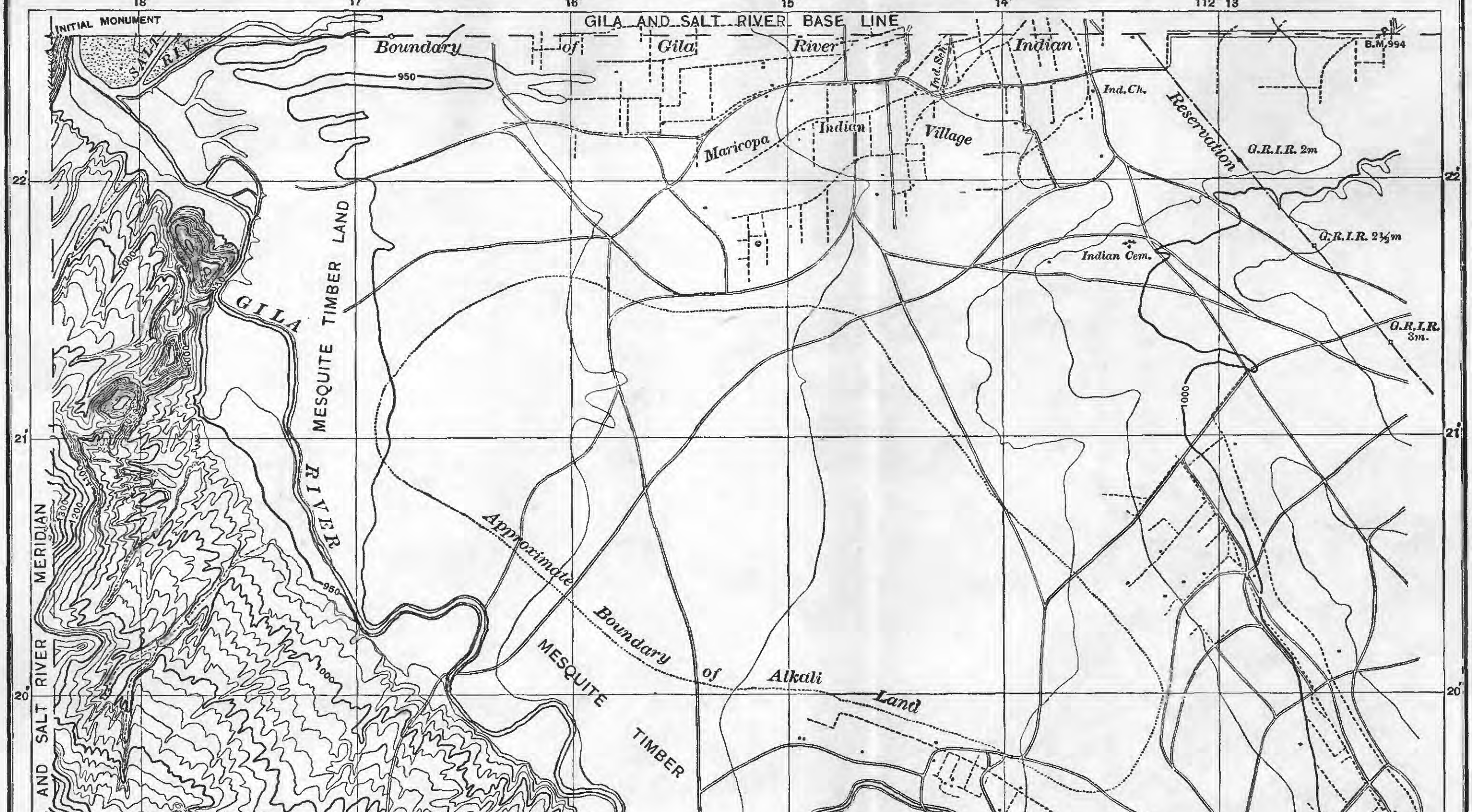


FIG. 1.—Map of Pima Indian Reservation.

tigation was extended beyond its borders. The area covered is limited on the south and east by the Southern Pacific Railroad and the Florence

[a] Water-Supply and Irrigation Papers, U. S. Geol. Survey, No. 2, 1897.
[b] Lippincott, J. B., Water-Supply and Irrigation Papers, U. S. Geol. Survey, No. 33, 1900.



F.H.Newell, chief engineer
A.P.Davis, supervising engineer
R.W.Hawley, assistant engineer in charge
Topography by I.S.Voorhees
Surveyed in 1903

MAP OF A PART OF GILA VALLEY NORTH OF THE ESTRELLA MOUNTAINS

ILLUSTRATING THE RELATION OF MOUNTAIN SLOPE TO VALLEY FLOOR.

Irrigation laterals ------
Wells •

Scale

0 ¼ ½ ¾ 1 2 miles

Contour interval 10 feet

Datum is mean sea level

Canal and on the north by the Salt River Valley, in which studies of the same nature have been carried on for some time. The accompanying map (fig. 1) shows the area under investigation.

GEOGRAPHIC FEATURES.

MOUNTAINS.

Gila Valley is separated in part from the extensive prairie lands and Salt River Valley to the north by a series of hills, the most massive of which is known as the Sacaton Range. The hills form more or less of a continuous chain from Twin Buttes eastward to beyond Florence. They are composed of a coarse-grained granite core, flanked in places by dark lavas and volcanic ash. Toward the east the massive granites give place to basalt, ash, glass, and perlite. In the southern part of the Sacaton Mountains proper are numerous sheets of fine porphyritic basalt, interbedded with scoria. North of the Indian village of Blackwater the massive granitic mountains cease, and thence eastward the chain is made up of numerous low peaks, somewhat isolated. It is probable that beneath the valley fill the ridge is continuous and connects the Sacaton Mountains with the mountains to the east. In other words, the Sacaton Mountains and their more or less isolated outliers probably mark the location of a mountain ridge which was formerly the northern border of the Gila Valley. The flanks and saddles of this ridge have been buried by the valley fill. A similar range of granite hills occurs south of the Gila, but has no obvious connection with the mountains to the east, although a buried ridge may connect it with the mountains south and east of Florence.

There are two mountain groups south of the Gila, separated by a low pass through which runs the road from Sacaton to Casa Grande. Directly south of Sacaton is the group composed of the highest and most rugged peaks, and southwest of Sacaton is a less rugged and more scattered group. Toward the southwest the peaks become progressively lower and finally disappear. It is probable that the small buttes west of Sacaton station denote the westward continuation of this ridge.

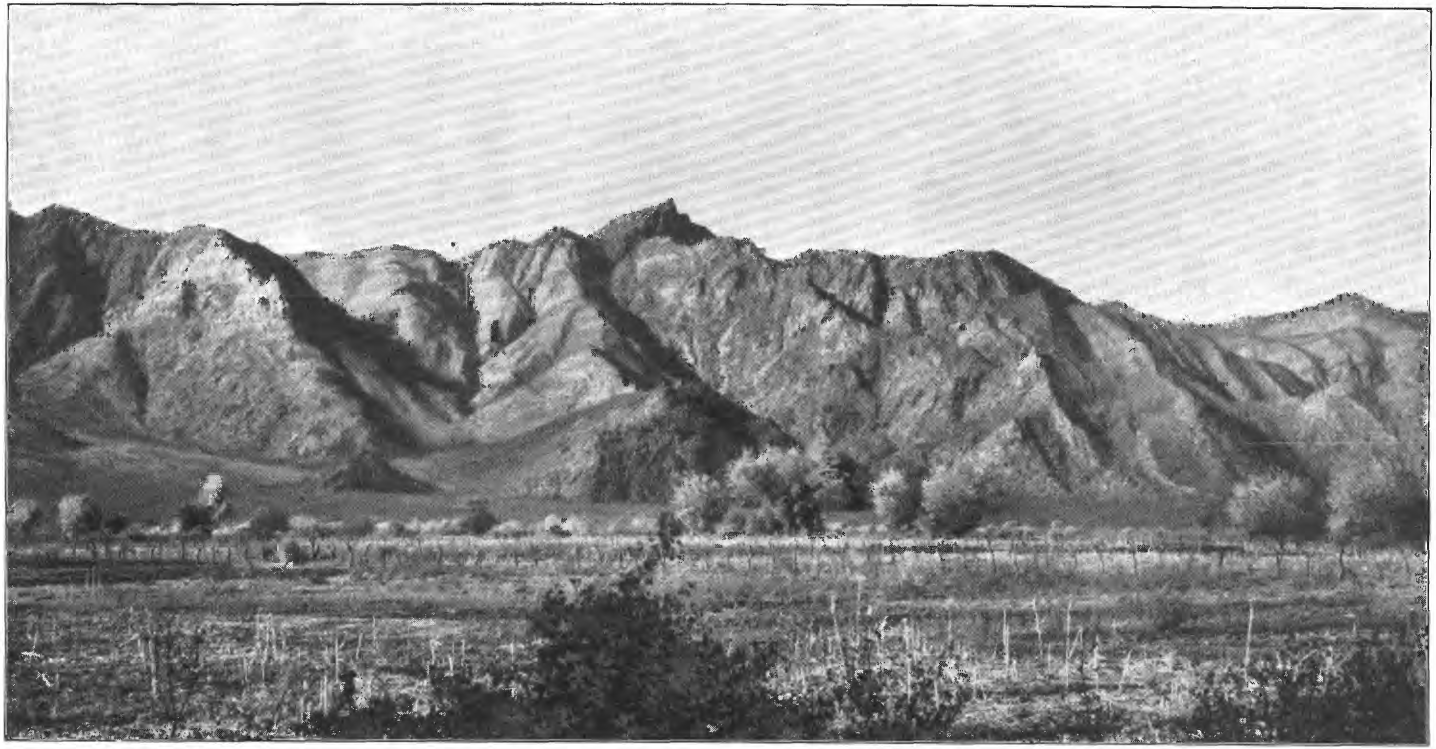
Between the eastern end of the mountains south of Sacaton and the nearest mountains to the east lies a broad sloping plain connecting Gila and Santa Cruz valleys. There is a popular belief that one of the arms of the Santa Cruz enters the Gila in this region. Whether this be true or whether a subterranean ridge divides the waters of the Santa Cruz from those of the Gila is at present a matter of conjecture. It is fairly certain, however, that the mountain groups and isolated peaks from a point 6 miles northeast of Casa Grande to Sacaton station are remnants of a continuous ridge which was formerly the southern border of Gila Valley.

The Salt River and Estrella mountains are more compact, especially the Estrella group. On the northeastern side, the only portion I have examined, these mountains rise abruptly from the nearly level valley floor. (See Pls. I and II; Pl. I gives in contour the same territory shown in photograph in Pl. II.) There are no outlying spurs or peaks on the side toward the Gila until the western end of the reservation is reached. The valley fill is built directly against the abrupt mountain slope. The approach to the Salt River Range is more gradual, but the group is compact in the sense that there are few isolated outliers.

PLAINS.

The Gila Valley, as well as other valleys in the region, is properly a part of the general plain forming the desert surface of southwestern Arizona. This plain is of great extent and is not definitely divided into valleys. The streams, except the largest ones, disappear shortly after emerging from the hills, their waters sinking into the loose material of the plain's surface. Gila Valley merges into this general plain in three directions. First, it connects with that part of it known as Salt River Valley to the north between the Salt River and Sacaton mountains; second, it opens into the extensive stretch of plain to the south at Maricopa, and, third, it opens into that part of the plain known as the Casa Grande Valley through the area in which is situated the reservoir of the Florence canal.

The few deep wells in and near the Gila Valley indicate that in former ages it was excavated to a great though unknown depth and later filled with débris from the hills. A more careful study of physiographic changes was made in the Salt River Valley, where there are better opportunities for such an investigation. The known facts point to the conclusion that the conditions are similar in the two valleys. It seems evident that this part of Arizona was a deeply dissected granitic region in which the rivers changed from degrading to aggrading streams. The valleys were then filled with silt, sand, and gravel brought down by the streams and with "wash" from the surrounding hills. The result is an accumulation of "fill" in the valleys many hundreds of feet in depth and composed of alternating beds of silt, sand, gravel, clay, and cement, or "caliche." These beds are irregular, and grade into one another both laterally and vertically. The fill of the valley is probably not the result of one continuous period of aggradation; there is ample evidence in neighboring regions that the streams repeatedly changed from an aggrading to a degrading condition, and vice versa, but that, on the whole, aggradation predominated. From the surface of the débris the crystalline rocks rise abruptly from the plain as partly submerged peaks. (See Pls. III and IV.) Well records in Salt River Valley



ESTRELLA MOUNTAINS FROM GILA CROSSING, ARIZONA.

An example of the sharp division between mountain and plain.

indicate that the lower peaks have been entirely submerged in some cases.

It thus appears that with the exception of the probable connection with Salt River Valley on the north, which I have previously referred to, and a similar connection with the Santa Cruz Valley to the south, the Gila Valley from The Buttes to the junction of the Gila and Salt

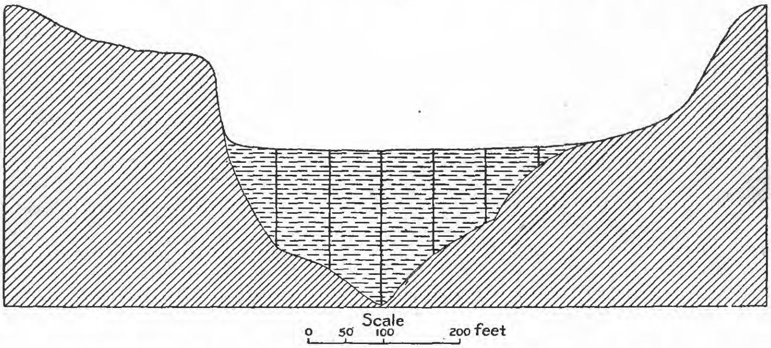


FIG. 2.—Cross section of Gila Valley at The Buttes dam site, Arizona.

River is a comparatively regular valley, 5 to 10 miles wide and 75 miles long. The material deposited in the valley is for the most part unconsolidated and admits water with the greatest freedom. Unfortunately no wells have been drilled which would give even approximately a cross section of the valley fill. A suggestion, however, of the conditions may be obtained from the borings at The Buttes dam site east of Florence. The accompanying figure (fig. 2) shows the

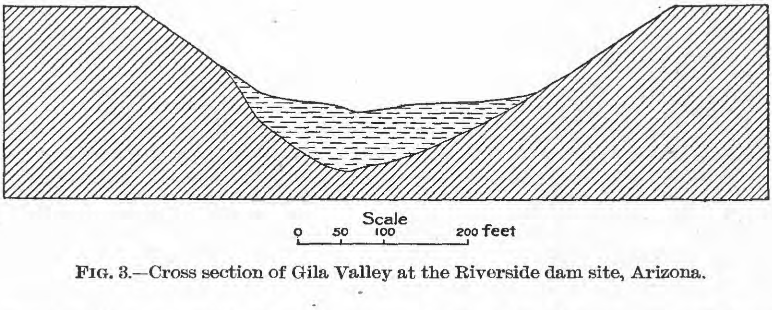


FIG. 3.—Cross section of Gila Valley at the Riverside dam site, Arizona.

ancient valley now filled with river drift. In the survey of the reservoir site at this place 25 holes were bored in a search for a firm foundation for a dam. Bed rock was found at a maximum depth of 122.5 feet. The section of the canyon thus shown is typical for the whole valley. A similar illustration is found in the cross section of the Riverside dam site, although this is of less value in this investigation, since it is farther from the area described (see fig. 3).

WELLS.

There are only two important wells or series of wells on the Pima Reservation and few to the east and south of it.

SACATON.

At the Pima Agency and training school at Sacaton there is a dug well which supplies water for the school and its surroundings, and 5 drilled wells which will be used for irrigation when completed. The dug well is 11 feet in diameter and 26.5 feet deep and contains about 8.5 feet of water. This well furnished 450 gallons per minute in 1896,[a] but at present it is capable of yielding a continuous supply of only 250 gallons per minute.

When the irrigation plant is complete there will be five 12-inch, double steel-cased drilled wells 200 feet deep in line 15 feet apart. The water will be raised by a 12-inch centrifugal pump operated by steam, and will be used to irrigate the lands at the agency. Water-bearing gravels giving promise of abundant supply were struck at a depth of 32 feet. The sands near the surface are also water bearing, but the water moves less readily through them than through the more open gravels beneath. The water rises to within 15 feet of the surface. One of the notable features of these wells is the granitic material penetrated. At a depth of 112 feet the drill entered granitic débris similar to the coarse, angular, granitic sand of the present mountain slopes. Beneath this were 12 feet of very hard rock which the driller insists was solid granite. The drill penetrated it with difficulty and the material when lifted from the well did not seem to be decomposed like the material above. Beneath this "granite" the water-bearing gravels and bowlders were again encountered. It is possible that the "granite" is an ancient wash derived from the granitic hills which rise on either side of Sacaton and firmly cemented by caliche. On the other hand, it is entirely possible that the drill penetrated a granite bowlder which had been buried long ago by the accumulating débris. Granite bowlders 8 and 10 feet in diameter have been observed in similar deposits in several places in Arizona.

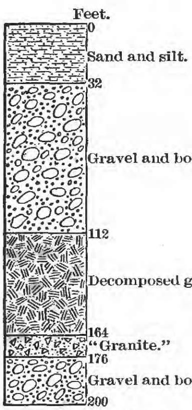


FIG. 4.—Log of the deep well at Sacaton, Ariz.

Of the 200 feet of material penetrated at Sacaton 32 feet are of sand and silt and do not yield water with as much freedom as the underlying gravels. A thickness of 52 feet is made up of granitic

[a] See Senate Doc. No. 27, Fifty-fourth Congress, second session, 1897, p. 21.

TWIN BUTTE FROM THE SOUTH.

A granite peak partly submerged in the valley fill.

débris, but this probably yields some water, and 12 feet may be considered nonwater-bearing. The remaining 104 feet are of gravel and bowlders and yield water readily. As the five wells are 12 inches in diameter and 200 feet deep, they would have a percolating area of 3,142 square feet if perforated throughout their depth. As 96 feet are not of first-class water-bearing material, this area should be reduced, for fair comparison, by something like one-half of the percolating surface represented by this 96 feet, which would leave a total percolating area of about 2,300 square feet. Since this plant is incomplete, no pumping tests have been made. A similar plant in Salt River Valley—No. 3 of the Consolidated Canal Company—may be compared with it. Two drilled wells 15 inches in diameter and 266 feet deep penetrate 126 feet of water-bearing gravels. The percolating area is 983 square feet. These wells furnish 202 inches of water, or 2,275 gallons, per minute. The percolating area therefore yields an average of about 2.3 gallons per square foot per minute. At this rate the battery of wells at Sacaton, with a percolating area of 2,300 feet, should furnish 5,290 gallons per minute. On the other hand Davis determined in the experiment described that a shallow well yielded only 0.28 gallon per minute per square foot. At this rate the Sacaton wells would yield only 644 gallons per minute. There are too many variables, however, entering into the problem to make such comparisons of more than illustrative value.

Analyses of water from wells at Sacaton, Ariz.[a]

[Parts in 100,000.]

Quantitative:	Shallow well.	Deep well.
Total soluble solids at 110° C	132.6	68.0
Chlorine in terms of NaCl (common salt)	66.8	28.8
Hardness in terms of $CaSO_4$ (calcium sulphate)	29.4	0.0
Alkalinity in terms of Na_2CO_3 (black alkali)	0.0	2.97
Nitrogen in the form of nitrates	.083	.08
Nitrogen in the form of nitrites	.031	Trace.

Qualitative:

Shallow well, sulphates and lime very strong, magnesia strong; deep well, sulphates distinct, magnesia and lime very strong.

SACATON TO FLORENCE.

Many shallow Indian wells were measured on both sides of the river between Sacaton and Florence. Near the river to a point about 5 miles west of Florence the water rises in the wells practically to the level of the river bed. Three miles east of Blackwater village A. J. Hansen has recently purchased a ranch and established a temporary

[a] The chemical analyses in this paper were made at the Arizona experiment station at Tucson by Prof. R. H. Forbes and W. W. Skinner.

pumping plant. The well is 25 feet deep and contains 3 feet of water. A temporary pumping plant has been established and furnishes a continuous stream of 15 inches. Mr. Hansen proposes putting down a series of steel-cased wells similar to those at Sacaton.

Eugene Pearson, 5 miles west of Florence, has a well from which he irrigates a few acres of land. His well is 13 by 18 feet and 24 feet deep. The water is raised by a small centrifugal pump and traction engine. The pump has been in operation for two years and the height of the water is found to fluctuate about 3 feet, according to the season, rising and falling in general with the river. The well is badly filled with sand at the present time, but still furnishes about 20 inches of water.

A few years ago, at Mr. Beasley's ranch, A. P. Davis[a] made an experiment to ascertain the supply of water available for pumping. A well was sunk, striking water at a depth of 11 feet, and a crib 6 feet square sunk 2 feet into the water-bearing gravels. A 10-horsepower engine and centrifugal pump were employed in the test. It was found that the rate of percolation was "a little over 53 cubic feet per day for each square foot of percolating surface." Since this experiment throws much light upon the subject in hand, the description, as given by Mr. Davis, is here transcribed:

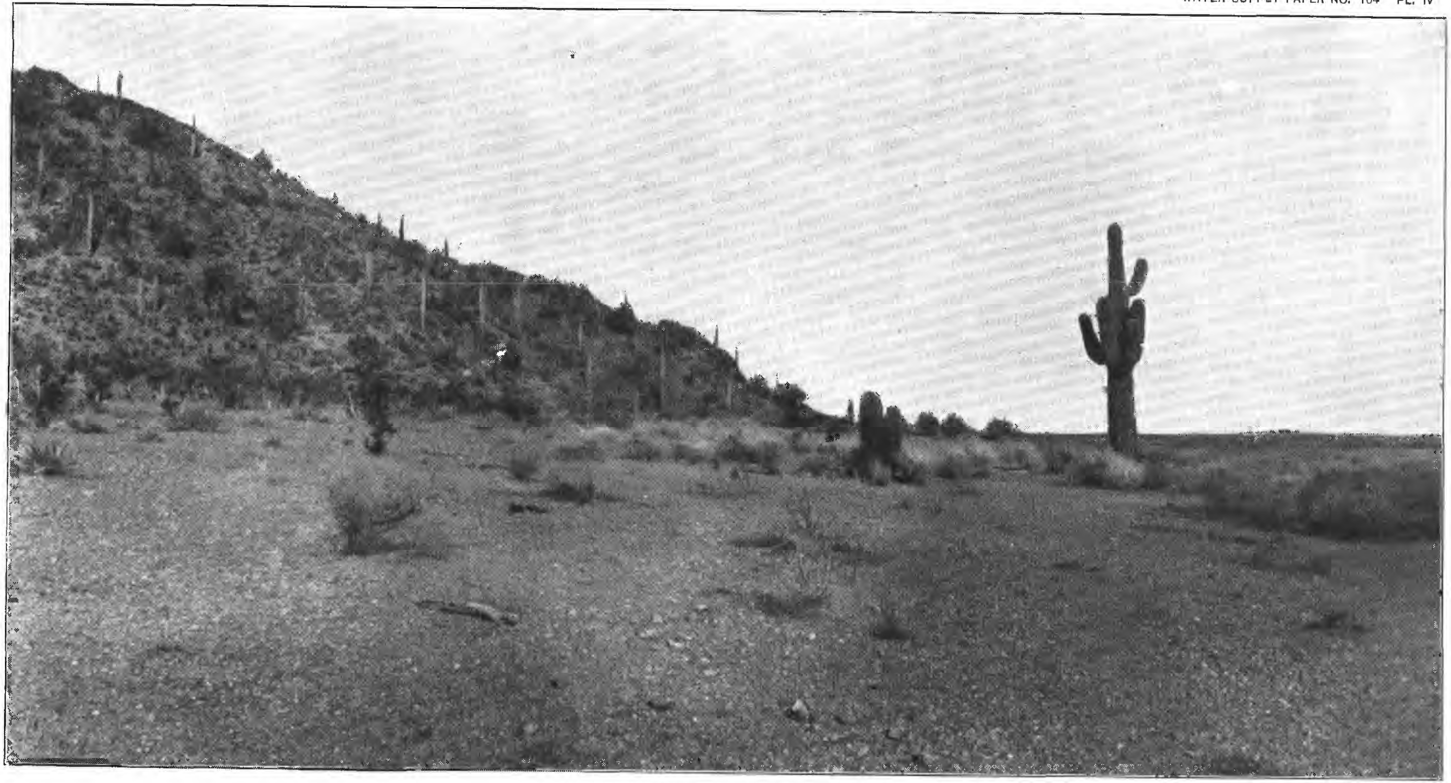
For the purpose of testing the possibility of obtaining the requisite quantity of water from wells, it was determined to make some pumping tests of wells to be made or already existing on the reservation. These operations were not inaugurated until the month of May, because it was desirable to test the wells in the dry season, when they could not be fed by subterranean connection with the Gila River. This stream was dry at Florence in February and remained so until July, so that these tests may be considered applicable to the dry season.

At Beasley's ranch, about a mile above the eastern end of the Indian reservation, the water rises in the dry bed of the Gila River and flows throughout the dry season a stream of about a cubic foot per second. The wells and vegetation in this vicinity were also of an encouraging nature, and the Indians have built a canal, heading near this point, intended to take water from the river. The location is considered the most promising for a water supply near the upper end of the reservation, as well as a desirable point to have such a supply.

By permission of Mr. Beasley an excavation was made in the lower edge of his field, about 1,000 feet south of the river. High water sometimes overflows this spot. For a short distance below the surface the ground was hard and required plowing, but below this the sand was removed by slip scrapers without plowing. At a depth of about 11 feet water was reached, and a hole 6 feet square and protected by cribwork was sunk about 2 feet into the water stratum.

A vertical gage was placed in the well, reading to feet and tenths and estimated to hundredths. A 10-horsepower engine and centrifugal pump were employed to test the well. To measure the discharge, a box was provided about 3 by 6 feet and 2 feet deep, with a measuring weir 2 feet long and 7 inches deep The box was divided into three compartments by means of two half partitions,

[a] Davis, Arthur P., The Pima and other Indians on the Gila Indian Reservation, Ariz.: Senate Doc. No. 27, Fifty-fourth Congress, second session, 1897, pp. 18-20.



EAST SLOPE OF TWIN BUTTE.

The valley fill is built against the granite slope.

one open at the bottom and one at the top, to quiet the waves and pulsations in the water before it reached the weir. The method of test adopted was to pump the well as nearly dry as practicable, measuring the discharge over the weir, taking a reading of the gage in the well at the beginning and end of the pumping, and noting the time required for the well to refill to a certain height somewhat below its maximum. This test was repeated nine times. The rate of inflow was, by these tests, in cubic feet per second, 0.058, 0.056, 0.053, 0.052, 0.050, 0.047, 0.044, 0.043, and 0.043.

The diminution in rate of inflow was doubtless due to the drainage of small subterranean cavities in the material near the well, which absorbed a part of the inflow. The observations were continued, however, until the result was practically constant, giving an inflow of about 0.043 feet per second, which the well could doubtless furnish to a constant draft of that amount. The area exposed to percolation was approximately 70 square feet. This gives a rate of percolation of a little over 53 cubic feet per day for each square foot of percolating surface.

The question then arises whether by increasing the size of the well and thereby the percolating surface, a proportionate increase in the supply of water could be obtained. Without the actual construction of a large and expensive well, with the necessary timbering, etc., this question could be determined only by judgment based on a careful examination of the conditions.

Two influences operate somewhat against the supply being proportionate to the area furnishing it:

1. Radial lines drawn from the center of any well through each linear unit of its circumference are more divergent in a small than in a large well. The rate of flow through the particles immediately adjacent to the well is higher than through those at some distance, on account of the pressure of the more distant particles. This increased rate of flow can diminish more rapidly with a small than with a large well on account of the greater diversion of the radial lines above referred to, and the small well has consequently a somewhat greater available head, or, what is the same thing, its bed of supply is somewhat nearer.

2. The small well tested may be, and probably is, to some extent drawing on small cavities or reservoirs, which would, under a constant draft, soon be exhausted.

On the other hand, there are two influences which operate strongly in favor of the supply increasing faster than the exposed area:

(1) The larger well would be made deeper and the entire area of the bottom and a part of the sides would furnish water under a greater head than the exposed area of the small well.

(2) In many cases, and the one under consideration is one of them, the character of material becomes coarser and more pervious with increased depth.

The two tendencies to increased supply are, under the circumstances of this case and the plans proposed, much more potent than the two opposing tendencies. It is considered, therefore, amply conservative to consider the supply as increasing within the limits proposed in direct proportion to the increase of the percolating surface.

Successful irrigation requires a certain volume of water in order to flow readily over cultivated ground and lend itself to the manipulation necessary to economical control by the irrigator. This "irrigating head," as it is called, varies somewhat with the slope of the land irrigated and the character of the soil. Ground with considerable slope can be irrigated with a smaller stream of water than similar ground on a gentler slope, and light pervious soil requires a larger stream than a soil relatively heavy and impervious. For the purposes of these estimates it is assumed that a stream flowing 1,000 gallons per minute would be ample to meet the conditions presented, and to furnish this amount a well of that capacity should be provided, or sufficient storage should be furnished, so that by accumulating the water as pumped an irrigating head could be obtained for a shorter time. Such storage would materially increase the relative cost of the plant and is somewhat wasteful of water. For irrigation on a large scale, it is far preferable to provide a plant that can furnish a constant irrigating head, and on that basis these estimates are made.

A well to be depended upon for this duty should have a capacity of about 200,000 cubic feet per day. Allowing 50 cubic feet per day from each square foot of percolating area, a well would require an available area of 4,000 square feet.

According to the figures given by Davis, the average yield of the percolating area is about 0.28 gallon per minute for each square foot. The average yield per square foot in the deep well just cited is 2.3 gallons per minute. In comparing these figures it should be noted that the percolating area experimented on by Davis was similar to the upper portion of the section shown in the log of the Sacaton well, which has the double disadvantage of low head, since it is near the surface, and comparatively fine texture, preventing a free flow.

At Florence the water surface is 60 to 70 feet deep at present, although it is said to vary greatly in different years. During the past few years the wells have been repeatedly lowered. The records given by Davis for 1897[a] show the depth to water at that time to have been about 40 feet where now it is 60 to 75 feet. From Florence westward the water comes gradually nearer the surface in proportion as the land surface lowers to a point where the hills encroach on the valley from the north. Near this constriction of the valley, water is found near the surface. Between this point and Sacaton a large number of Indian wells were visited and the water was found everywhere at practically the level of the river bed.

SACATON TO THE JUNCTION OF THE GILA AND SALT RIVERS.

Only shallow wells are found in this region, most of them near the river. A few, however, are found several miles from the river—sufficient to indicate that there is a general water table and that the differences in depth laterally are due to the differences in the surface elevation of the land. There is a comparatively uniform inclination of this water table downstream, corresponding in general with the gradient of the river. This part of the valley, especially between Sacaton and Sacaton station, is somewhat thickly settled by Indians, and shallow wells are numerous. A few miles north of the reservation, near Kyrene, is situated one of the largest pumping plants of the region, that of A. J. Hansen. While this plant should properly be included among the wells of Salt River Valley, it is near enough

[a]Davis, A. P., Irrigation near Phoenix, Arizona: Water-Sup. and Irr. Paper No. 2, U. S. Geol. Survey, 1897, p. 88.

to the reservation to throw light upon the conditions to be expected in the Gila Valley, a few miles to the south.

A. J. Hansen's well, sec. 35, T. 1 S., R. 4 E.—Mr. Hansen's pumping plant is located about 10 miles south of Tempe. There are four 12-inch drilled wells, double steel cased, 30 feet apart, and sunk to a depth of 200 feet. A central shaft containing a 12-inch horizontal centrifugal pump is sunk to water level. From this shaft tunnels communicate with the wells, which are connected by a horizontal suction pipe. The pump is operated by a steam engine at the surface, the connection being made by a belt extending downward to the pump. The fuel used will be crude oil until such time as electric power can be furnished at a low rate of cost.

No satisfactory tests have been made on the capacity of the plant. Mr. Hansen estimates, from some rough measurements, that the plant will yield something over 5,000 gallons of water per minute. He is preparing to irrigate in this way his entire tract of land of something over 1,100 acres. When the pump is run at full speed, drawing from the four wells alike, the water level in the wells is lowered 9 feet 3 inches, making the total lift 26 feet 3 inches. When the water is drawn entirely from an end well, the others being shut off, the water level in that well is said to fall 18 feet, while in the well 90 feet distant it is lowered 5 feet. The effect on the intervening wells was not determined.

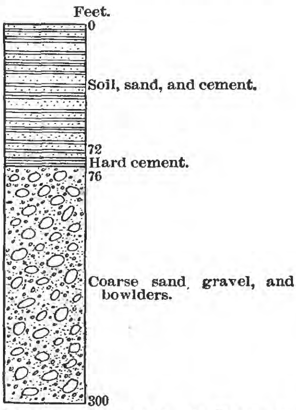


FIG. 5.—Log of A. J. Hansen's well, 10 miles south of Tempe, Ariz.

In drilling the wells very little surface water was encountered. At a depth of 76 feet water-bearing gravels and bowlders were struck, and the water rose 59 feet; i. e., to within 17 feet of the surface.

In drilling these wells two circumstances indicated the looseness of the water-bearing gravels. While the last well was being drilled it was noted that the water in the first one, 90 feet away, moved in unison with the plunge of the sand pump. As the sand bucket, with its massive attachments, descended, the water surface in the first well was agitated and moved slightly upward; as the sand bucket was withdrawn the water surface was lowered and there was a slight churning motion in unison with the movement of the drill. The second circumstance was noted in connection with the sinking of the casing. The casing is forced downward into the hole made by the sand bucket by means of hydraulic pressure. Ordinarily it takes considerable pressure to force the casing. In Mr. Hansen's wells the gravels were so loose that the casing settled into them of its own weight, and had to be held back to prevent it from settling faster than desired.

Analysis of water from A. J. Hansen's well, south of Tempe, Ariz.

Quantitative:	Parts in 100,000.
Total soluble solids at 110° C	446.8
Chloride in terms of NaCl (common salt)	307.0
Hardness in terms of $CaSO_4$ (calcium sulphate)	135.4
Alkalinity in terms of Na_2CO_3 (black alkali)	0.0
Nitrogen in the form of nitrates	Faint.
Nitrogen in the form of nitrites	Faint.

Qualitative:

Sulphates, magnesia, and lime, very strong.

MARICOPA.

Several wells were visited in the vicinity of Maricopa. At Maricopa station a well 9 feet in diameter and 50 feet deep was dug in 1890. At present there is 7 feet of water in it. The pump when running discharges 67 gallons per minute, and lowers the water in the well 4.5 feet. One mile and a half west of Maricopa the Southern Pacific Railroad Company has a well, dug in 1883. It is 9 feet in diameter and 40 feet deep, with 8 feet of water. The pump discharges 134 gallons per minute continuously, and lowers the water in the well 5 feet.

Analysis of the Southern Pacific Railroad Company's well 1.5 miles west of Maricopa, Ariz.

Quantitative:	Parts in 100,000.
Total soluble solids at 110° C	39.8
Chlorides in terms of NaCl (common salt)	6.4
Hardness in terms of $CaSO_4$ (calcium sulphate)	5.41
Alkalinity in terms of Na_2CO_3 (black alkali)	0.0
Nitrogen in the form of nitrates	0.104
Nitrogen in the form of nitrites	Very faint.

Qualitative:

Sulphates and magnesia, strong; lime, faint.

Analysis of water from P. M. Williams's well, Maricopa station, Ariz.

Quantitative:	Parts in 100,000.
Total soluble solids at 110° C	160.0
Chlorides in terms of NaCl (common salt)	50.0
Hardness in terms of $CaSO_4$ (calcium sulphate)	24.48
Alkalinity in terms of Na_2CO_3 (black alkali)	0.0
Nitrogen in the form of nitrates	.20
Nitrogen in the form of nitrites	0.0

Qualitative:

Sulphates and magnesia, very strong; lime, strong.

About fifteen years ago the Arizona Vineyard Company dug a well 12 by 20 feet near Maricopa and established an extensive pumping plant for irrigation. A large quantity of water was obtained, but for financial reasons the plant was never completed.

About the same time a well was drilled near Maricopa. At a depth of 90 feet a water-bearing bowlder bed was entered, but the drilling machinery was not adequate to drive through the bowlders and the well was abandoned.

These wells, as well as several private wells which I visited, indicate that a large quantity of water is here available within reasonable pumping distance of the surface and that a bowlder stratum exists here similar to that encountered at Sacaton and in the Salt River Valley.

CASA GRANDE.

Until two years ago the railroad company obtained water at Casa Grande from a dug well 10 feet square and 54 feet deep. It had 12 feet of water. A continual discharge by the pump of 200 gallons per minute lowered the water only 2 feet. This water was so strongly alkaline, however, that it was thought best to drill deep wells in the hope of obtaining water of better quality. In 1901 two 10-inch wells were put down to a depth of 625 and 635 feet. The beds yielding alkali water extend to a depth of 190 feet. Water was encountered again at a depth of 475 feet and rose to within 49 feet of the surface. Additional depth did not increase the amount of water, and the drilling was discontinued. The wells yield 167 gallons per minute and the water is soft and free from obnoxious salts. The material passed through was sand, clay, etc., to a depth of 195 feet, when shale and red sandstone were encountered, as indicated in the accompanying log (fig. 6).

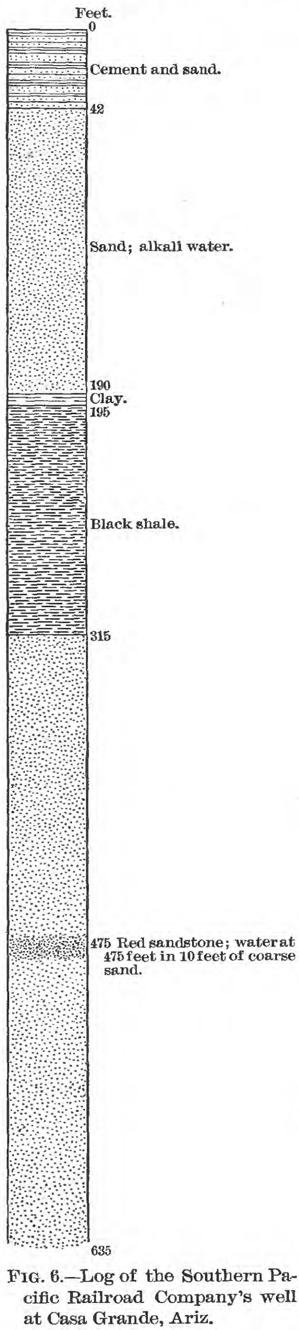


FIG. 6.—Log of the Southern Pacific Railroad Company's well at Casa Grande, Ariz.

Well records in and near Gila Valley.

Owner.	Location. T.[a]	Location. R.[b]	Location. Sec.	Year completed.	Diameter. Ft.	Diameter. In.	Depth of well.	Depth of water.	Depth to water.
							Feet.	Feet.	Feet.
FLORENCE.									
Whitney	5	9	10	1891	4	0	70	2	68
T. F. Marquand	5	7	13	1895	12	0	23	7.5	15
L. E. Graham	5	8	24	1891	6	0	56	6	50
J. M. Hurley	5	9	32	1891	4	0	102	31	71
James F. Pry	5	8	27	1896	3	8	40	2	38
Wm. H. Graham	5	8	28	1893	4	0	32	4	28
Daniel Bringham	5	8	26		4	0	51	2	49
Shields & Price	5	8	24		3	0	66	5	61
W. J. La Baron	5	8	25	1892	4	0	65	5.5	59.5
B. A. La Baron	5	9			4	0	95	2	93
Florence hotel	4	9	36				61	13	48
West of Florence	4	9	36		4	0	75	1	74
Do	4	9	36		4	0	70	2	68
MARICOPA.									
	4	3	17	1885	20	0			
	4	3		1887	0	10	90	(?)	(?)
P. M. Williams	4	3	17	1896	6	0	48	10	38
Southern Pacific Railroad Company				1890	9	0	50	7	43
Southern Pacific Railroad Company, 1.25 miles west				1883	9	0	40	8	32
CASA GRANDE.									
Southern Pacific Railroad Company	6	6		1901	0	10	635	586	49
Do	6	6		1880	10	0	54	12	42
SACATON.									
Indian school	4	6			11	0	26.5	8.5	18
Do	4	6		1904	0	12	200	185	15
Casa Grande ruins					4	0	47	1	46
Casa Grande ruins, 1.5 miles north	5	8	9						30
Casa Grande ruins, 1.5 miles southeast					4	0	39	3	36
Ballu	5	8			8	0	31	3	28
A. J. Hansen	5	8	6		4	0	25	3	22
Eugene Pearson	5	8	1	1901	13 by 18		26	2	24
Adrian Pearson	4	9	31		4	0	23	1	22

[a] South. [b] East.

Well records in and near Gila Valley—Continued.

Owner.	Location.			Year completed.	Diameter.		Depth of well.	Depth of water.	Depth to water.
	T.[a]	R.[b]	Sec.						
SACATON—continued.					*Ft.*	*In.*	*Feet.*	*Feet.*	*Feet.*
	5	8	11				29	2	27
Indian	3	6	(?)33		4	0	53	1	52
Do	4	6	(?) 4		4	0	37	1	36
Do	4	5			4	0	29	1	28
Do	3	4			4	0	28	2	26
Railroad crossing	3	3			4	0	15	1	14
Indian	2	2			4	0	23	2	21
A. J. Hansen	1	4	35		0	12	200	183	17
Indian	3	6	(?)18		4	0	66	4	62
Store	2	5	(?)34		4	0	44	4	40

[a] South. [b] East.

RETURN WATERS.

EAST OF SACATON.

About 10 miles east of Sacaton, and east of the point where the hills encroach upon the valley, the underground water reaches the surface and returns in considerable amount to the river bed, forming a surface stream of several hundred inches, the amount of water varying with the season. This stream continues on the surface for a few miles and again either disappears into the sands of the river bed or is diverted for irrigation. On either side of the river in this vicinity are swamps and sloughs containing water throughout the year.

North of the river the underground water surface is several feet above the level of the river bed and the water occurs in quantities sufficient to justify some expenditure for its development. A seepage ditch has recently been constructed at this point. The ditch has been run 1,000 feet into the water-saturated sands and gravels. It has a maximum depth of 11 feet, reaching 18 inches below the level of the river bed. It is 4.5 feet wide at the bottom with a 1 to 1 slope of the sides. When the ditch was first constructed the water stood 4 feet above the level of the river bed. The ground near the ditch was soon drained, however, and at the present time water is obtained from only the lower 18 inches. J. R. Meskimons, the engineer in charge of the construction of this ditch, reports that it is furnishing 75 to 125 inches of water, the amount varying with the season. For a distance of 4 miles in this vicinity test wells were sunk as guides in running the seepage ditch. Water was found from 1 to 11 feet below the surface.

The water table is practically a plane surface, the difference in depth being due to the contour of the land. To test the quantity of water a well point was driven to various depths down to 35 feet and the available quantity tested by pumping at intervals of 3 feet. The pipe was only 1.25 inches in diameter, yet a hand pump is said to have drawn 50 gallons per minute from it without difficulty at each depth tested.

A small seepage ditch—the Hadley ditch—was constructed some years ago south of the river, near the mouth of McClellan Wash. At the time of my visit water was standing in the ditch, but no amount worthy of mention was being obtained, and the ditch is reported a failure.

GILA CROSSING.

A much more important area of return water is the western third of the reservation, extending from the railroad to the mouth of Salt River. Within this distance of about 20 miles six irrigation ditches have been constructed by the Indians, each of which in turn diverts all the water in the river except in time of flood.

In the course of his investigations for the development of water near Gila Crossing, Mr. Meskimons measured the discharge at various places on June 1, 1903, with the following results:

Discharge measurements of seepage water near Gila Crossing, Ariz.

	Inches.
Webb ditch	200
Thomas ditch	600
Hoover ditch	300
Cooperative ditch	150
Head ditch	150
Walker ditch	50
Water unappropriated in river	600
Total available amount	2,050

This water is entirely derived by seepage from the underflow, no account being taken of flood water.

About 5 miles west of the railroad and a little north of the channel of the Gila lies a small body of water known as "The Lake." It is surrounded by marshy ground, but the body of water itself is about 4,000 feet long. From its shape it appears to be an abandoned river channel. The water is about 6 feet deep, with a much greater depth of soft mud at the bottom. There is a constant discharge of water from this lake through the swampy slough connecting it with the river channel. The water is now partially diverted by the Hoover ditch. Efforts are being put forth to conserve this supply and, if possible, to develop a greater supply.

J. R. Meskimons, one of the engineers in the Indian Service, has recently made investigations and surveys looking to the development of this water for the benefit of the Indians, and is convinced that a notable quantity of water may be obtained at a reasonable cost.

Water occurs near the surface over a large part of the lowlands of the western third of the reservation. Bogs and sloughs are of frequent occurrence. At the edge of one of these sloughs, near the Indian village at Gila Crossing, large springs were noted boiling up from the sands below. One spring had a discharge of about 25 gallons per minute. These springs, together with the large quantities of water always present in the sloughs and the lake, show how readily the water moves in the underflow.

The importance of the perpetual water supply in the lake and the sloughs near Gila Crossing can not be too much emphasized. Such water bodies in a region where rainfall is abundant or where streams are perpetual would be of little consequence. These bodies of water, however, exist in the midst of a desert, where the rainfall is not only not enough to be seriously considered as a source of supply, but is only a small fraction of the amount actually lost by evaporation. The annual rainfall is about 7 inches, while the annual evaporation is about 91 inches. Furthermore, for a distance of about 50 miles upstream from "The Lake" the Gila channel is dry except in times of flood, and it is very seldom that the floods are of sufficient volume when they reach Gila Crossing to directly affect the quantity of water in the lake and the sloughs. This water is wholly due to a return to the surface of water that entered the valley fill many miles from Gila Crossing.

In the hope that a chemical analysis of this water would throw some light upon the source of this underflow, analyses were made, which resulted as follows:

Analyses of water from the underflow near Gila Crossing, Arizona.

Location.	Quantitative: Parts in 100,000.				Qualitative.			
	Total soluble solids at 110° C.	Chlorine, NaCl (common salt).	Hardness, $CaSO_4$ (calcium sulphate).	Alkalinity, Na_2CO_3 (black alkali).	Sulphates.	Magnesia.	Lime.	Bicarbonates.
Gila River at Gila Crossing.	127	76.4	12.5	0.0	Very strong	Strong	Strong	Pronounced.
Cooperative Company's ditch, Gila Crossing.	106	62.8	13.1	0.0	Strong	do	do	Strong.
Lake at head of Hoover's ditch.	107	61.2	2.72	0.0	Very strong	do	do	Do.
Well at Presbyterian Mission, Gila Crossing.	160	110.8	28.4	0.0	do	do	do	Do.

UNDERFLOW.

GILA RIVER.

As already indicated, the Gila Valley in this region consists of a long and comparatively narrow depression filled with débris from the mountains. This débris is generally uncemented and allows water to pass readily. No impervious clay or cement layer of importance was encountered in sinking the well at Sacaton, the only deep well in that region. If this one example is typical of the valley, there is nothing to prevent the surface waters from quickly sinking into the loose sands and gravels of the valley fill. It is a matter of comment among those familiar with the Gila that when floods descend the river the velocity of the water is much greater than the velocity of the advancing front. The water of the smaller floods sinks and is lost completely in the loose sands and gravels before it has traveled any great distance in the parched channel. With the larger floods the phenomena are different. A large part of the water in the advancing front of the flood is taken by the thirsty sands of the broad, dry river bed, and it is only after the surface sands have been saturated that the flood passes over them. Only the largest floods find their way above ground to the mouth of the river. In the upper portions of the valley large quantities of water sink into the valley fill, and at the constriction of the valley east of Sacaton, and again near Gila Crossing, the underground water again reaches the surface. In addition to this, wells throughout the valley dug to no great depth yield an abundance of water, though the amount has been measured in but few places. The rainfall in the valley is inadequate to account for more than a small portion of this underground water, and it must enter the valley fill from an outside source. In the upper part of the valley the only obvious source is Gila River, together with occasional floods from the hills north and south of the valley. It follows, therefore, that these waters find their way through the valley fill, and, working slowly down the valley, constitute what is known as the underflow.

SALT RIVER UNDERFLOW.

There are reasons for believing that the underground waters of Salt River Valley find their way, to some extent at least, by underground passages between Salt River Mountains and Sacaton Mountains, joining the Gila underflow west of where the railroad crosses the Gila. This subject will be discussed in the report of Salt River Valley, and need not be repeated in this connection. It may be said, however, that the abundance of seepage or return water near Gila Crossing is in part due to the Salt River underflow. With this underflow may be included that of Queen Creek, entering from north of the Sacaton

Mountains, although the amount of water yielded by the creek is thought to be very small compared with that from Salt River.

SANTA CRUZ UNDERFLOW.

The waters of the Santa Cruz ordinarily sink beneath the surface long before they reach the region shown in the accompanying map (Pl. I.) The floods of the Santa Cruz, however, are said to find their way over the plain near Casa Grande and Maricopa and finally reach the Gila north of Estrella Mountains.

Certain more or less isolated depressions in the plain have probably been formed by these floods and may be taken to indicate roughly the course which the Santa Cruz would follow should that stream continue above ground until it joined the Gila. It would seem from these indications that the ancient valley of the Santa Cruz joined the Gila in the vicinity of Maricopa. This hypothesis is strengthened by the fact that wide stretches of graded plain occur about Maricopa, and the material composing the surface of this plain to a depth of at least 90 feet is river wash filled with water. This hypothesis is also in accord with the abundance of seepage water in the lowlands near Gila Crossing. It is probable that the large amount of underground water evident in this region, an amount sufficient to saturate the valley fill and still give an overflow of more than 2,000 inches, is due to the junction of the three underflows—Gila, Salt River, and Santa Cruz.

In this region it is generally believed that the rise of the underground water east of Sacaton and again near Gila Crossing is due to the existence of natural subterranean dams or reefs of rock across the valley over which the water must pass, thus causing a rise of the water surface back of the dams. My observations point to the conclusion that the valleys are valleys of erosion, although modified to some extent by subsequent movement, and later filled with débris brought down by the streams and washes. If this view be correct, a subterranean dam could not exist across the valley unless made by some accident subsequent to its excavation, such as faulting and tilting of a crust block or by volcanic outburst. No evidence has thus far been noted of any accidents which would tend to form such subterranean dams. It seems more rational and more in accord with the natural course of events to explain the phenomena as due to the known decrease in width of the valley rather than to a hypothetical decrease in depth due to a subterranean dam. As the underflow approaches a narrow place in the valley the water surface must of necessity rise in order that the water may be forced through the constricted passage, just as a flood in a broad valley with a constricted outlet will be higher in proportion as the outlet is narrow.

AMOUNT OF UNDERFLOW.

The quantity of water in the underflow depends upon at least three factors:

(1) The rainfall in the valley contributes to the underflow. In the vicinity of Phoenix the annual rainfall based on an average of 16 years is 7.35 inches. Much of the water soon evaporates from the surface, but some no doubt finds its way into the underflow. This is especially true when the precipitation occurs, as is likely to be the case, in short heavy showers or "cloudbursts." There seems to be no impervious layer of clay or cement to prevent surface waters from joining the underflow of the Gila, as in Salt River Valley. At Sacaton the deep well indicates that pervious material is practically continuous from the top downward.

(2) Springs from the hillsides now buried by the valley fill may send their waters through the gravels to join the underflow. It is probable, however, that such waters are too limited in volume to be considered.

(3) By far the most important sources of the water of the underflow are the various streams entering the valley from the hills, the principal one being the Gila itself. These streams, with the exception of the Gila, are dry for the greater part of the year. The occasional floods entering the valley sink into the loose material of the valley fill, in which the water is held as in a sponge and slowly works its way through this material down the valley.

The data at hand are inadequate to give more than the roughest estimate of the quantity of the underflow. Mr. Lippincott[a] states that "in the Gila Narrows, below the Sanchez ditch, there was, on April 15, 1899, 237 second-feet of water. Within a distance of 40.7 miles below this point there was diverted in ditches 429.8 second-feet of water. A small amount of water is wasted back into the river from these ditches, but the actual amount used for irrigation is 64 per cent in excess of the amount available for that purpose at the highest point of diversion." Other places along the Gila where no measurements have been made would probably show a similar return of the underground waters to the surface. As I have previously stated, there are two such places in this region where partial measurements have been made.

To obtain even the roughest quantitative estimate of the underflow it would be necessary to determine the volume of water entering the valley. This would necessitate the measurement of the rainfall, the measurement of all surface streams entering the valley, and the measurement of the underflow of Gila River, Salt River, Santa Cruz Wash,

[a] Lippincott, J. B., Storage of water on the Gila River, Arizona: Water-Sup. and Irr. Paper No. 33, U. S. Geol. Survey, 1900, p. 24.

and others. It would also require a measurement of the actual as distinct from the theoretical loss by evaporation, as well as of the amount of the flood waters of Gila River which pass out of the valley. The only factors which have been measured are the rainfall, the theoretical evaporation—that is, evaporation from a continually exposed water surface—and the surface flow of Gila River at The Buttes. Measurements have been made at other points higher up the Gila, but these do not have any direct bearing on the problem in hand. Records have also been kept of the rainfall at a number of points in this vicinity. Such records as apply directly to this part of the Gila Valley are given below.

SOURCE OF UNDERFLOW.

PRECIPITATION.

The following account of the rainfall is given by Mr. J. B. Lippincott:[a]

Rainfall observations have been taken at 31 different points in the basin of Gila River above The Buttes, * * * the earliest record beginning at Fort Bayard, N. Mex., in 1867. Undoubtedly the greatest precipitation of the basin occurs in the higher mountains, in its northeastern portion. The records for these mountain districts are rare, most of them being taken in the valleys where settlements and agriculture occur. It is probable, therefore, that the actual rainfall for the basin is greater than that indicated by the tables and diagrams. For the purpose of this report the rainfall observations in the basin of Gila River above The Buttes have been grouped in three classes in the following table. First, the Gila Basin proper, exclusive of the basin of the San Pedro; second, the basin of the San Pedro, and, third, a series of observations at three stations in the vicinity of Florence, five stations in the basin of Santa Cruz River, which stream enters the Gila below the mouth of the Salt, and three sets of observations in the vicinity of Phoenix. The segregation of the records into the groups named is for the purpose of comparing the relative amount of water available for storage purposes at the reservoir site at San Carlos and at The Buttes.

[a] Lippincott, J. B., Storage of water on the Gila River, Arizona: Water-Sup. and Irr. Paper No 33, U. S. Geol. Survey, 1900, pp. 18-20.

Annual rainfall, in inches, in basin of Gila River above San Carlos, Ariz.

Year.	Fort Bayard.	Gila.	Alma.	Oro.	San Simon.	Willcox.	Fort Grant.	Cedar Springs.	Fort Thomas.	San Carlos.	Fort Apache.	Mean above San Carlos.
Elevation (feet)	6,022	......	5,500	3,610	3,611	4,164	4,860	4,900	2,700	2,450	5,050	......
1867	13.87	......	......	......	......	......	......	......	......	......	......	......
1868	15.23	......	......	......	......	......	......	......	......	......	......	......
1869	12.84	......	......	......	......	......	......	......	......	......	......	......
1870	10.07	......	......	......	......	......	......	......	......	......	......	......
1871	5.79	......	......	......	......	......	......	......	......	......	......	......
1872	13.61	......	......	......	......	......	......	......	......	......	......	......
1873	22.18	......	......	......	......	......	17.99	......	......	......	......	......
1874	20.38	......	......	......	......	......	17.81	......	......	......	......	......
1875	19.66	......	......	......	......	......	20.91	......	......	......	......	......
1876	18.94	......	......	......	......	......	......	......	......	......	19.74	......
1877	13.12	......	......	......	......	......	10.13	......	......	......	12.50	......
1878	......	......	......	......	......	......	16.46	......	......	......	28.61	......
1879	......	......	......	......	......	......	12.82	......	......	......	18.58	......
1880	......	......	......	......	......	......	15.74	......	......	......	14.77	......
1881	......	......	......	......	......	12.11	18.96	......	11.41	......	31.12	18.40
1882	......	......	......	......	6.50	8.58	15.42	......	8.66	15.27	27.62	13.69
1883	......	......	......	......	7.15	8.73	15.48	......	10.85	12.21	21.65	12.68
1884	......	......	......	......	10.37	14.38	25.67	......	18.16	20.41	29.47	19.74
1885	......	......	......	......	2.39	8.51	9.21	......	8.70	8.19	15.58	8.76
1886	......	......	......	......	2.02	9.37	......	......	10.86	10.44	21.06	10.75
1887	13.59	......	......	......	.99	16.49	24.32	......	16.35	8.68	17.84	14.04
1888	13.42	......	......	......	4.55	11.93	14.20	......	13.34	13.04	18.89	12.77
1889	7.21	......	......	......	......	13.68	13.32	16.44	10.89	13.40	17.10	12.60
1890	......	......	......	15.94	8.43	......	15.88	......	13.93	17.86	26.72	16.46
1891	10.30	......	......	10.90	4.04	7.36	12.21	......	......	11.00	13.36	9.88
1892	8.80	......	......	......	2.57	8.01	7.90	......	......	12.05	12.70	8.67
1893	......	......	......	......	5.65	3.95	13.85	......	......	12.53	15.08	10.21
1894	8.67	......	......	......	3.24	5.88	13.53	......	......	10.15	17.42	9.81
1895	14.45	12.41	16.51	......	2.78	8.04	13.22	......	......	14.41	18.03	12.48
1896	19.98	17.87	15.09	12.99	4.36	9.22	15.99	......	......	13.88	16.09	13.84
1897	17.00	14.44	15.68	10.69	......	5.66	13.87	......	......	7.90	14.93	12.52
1898	16.21	15.22	17.26	16.14	......	8.16	14.26	......	......	7.79	20.55	14.45
1899	......	......	......	......	......	......	......	......	......	......	......	......
Mean	14.06	14.98	16.13	13.33	4.65	9.42	15.34	......	12.32	12.31	19.54	12.87

Annual rainfall at stations in basin of Gila River, in the vicinity of Florence, Tucson, and Phoenix, Ariz.

Year.	Florence vicinity.				Santa Cruz Basin.				Phoenix vicinity.			
	Buttes.	Florence.	Casa Grande.	Tucson.	Pantano.	St. Helena ranch.	Calabasas.	Lochiel.	Phoenix.	Fort McDowell.	Pinal ranch.	Silver King.
Elevation (feet)	1,600	1,493	1,396	2,404	3,538		3,445	5,100	1,068	1,250	4,400	3,800
1867										15.26		
1868										15.22		
1869										7.69		
1870										5.45		
1871										4.94		
1872										20.01		
1873										8.13		
1874										16.84		
1875										4.97		
1876		9.33		14.02						7.73		
1877		5.35		12.77					5.17	9.38		
1878		13.49		16.66					8.52	11.92		
1879		12.02		12.01					6.40	8.34		
1880		5.35		6.61					6.82	6.61		
1881		12.14	1.73	14.92	15.65				8.91	7.24		
1882				15.59	15.73				6.94	9.10		
1883			3.01	7.78					7.40	9.89		
1884			9.71	15.03					12.83	20.95		
1885			2.02	5.26	8.96				3.77	8.30		
1886			5.12	8.59	10.36				5.78	8.08		
1887			7.71	12.95						10.32		
1888			4.30	10.60						11.91		
1889		8.90	4.25	18.37	15.50					12.78		
1890		12.70	10.70	14.16	18.71			26.90				
1891		8.24	3.62	7.30	9.87		9.65	15.10				
1892		9.95	8.75	9.61	10.79		11.83		5.50			
1893		9.63	4.92	13.12	3.35		10.28		7.68			
1894			5.82	7.29	18.84		10.29		5.50			
1895				11.07	11.40		15.14					
1896				11.39	14.58				10.48		20.38	
1897	7.59		3.03	10.77	10.73	18.21	10.83	16.14	9.87		23.23	
1898				12.72	12.16				5.95		19.84	
1899												
Mean		9.74	5.33	11.68	12.62		11.34	19.38	7.35	10.48	21.15	

The records in the vicinity of Florence and Phoenix apply to the districts where the water stored will probably be applied for irrigation and indicate the need of an artificial supply. In the case of the San Pedro Basin the greater portion of its water supply is furnished near the headwaters of that stream. The lower portion of the river, which constitutes the greater part of its area, being low in elevation, has a relatively higher rainfall, and, owing to the flat nature of the valleys, a low per cent of run-off. The observations of precipitation in the San Pedro Basin have, with one exception—those of Dudleyville—been made in this upper portion of the basin and at points of high elevation. They indicate, therefore, a water supply in excess of conditions as they really exist.

In connection with the study of the increase of rainfall with an increase in elevation, the following table is of interest:

Increase of rainfall with each 100 feet of rise in elevation, with Fort McDowell as a base.

Station.	Length of record.		Elevation.	Elevation above McDowell.	Measured rain.	Constant increase per 100 feet rise.
	Yrs.	*Mos.*	*Feet.*	*Feet.*	*Inches.*	*Inches.*
McDowell	23	10	1,250		10.38	Base.
Lowell	19	5	2,400	1,150	12.37	0.17
Breckenridge	6	10	3,800	2,550	17.03	.26
Fort Grant	17	2	4,860	3,610	16.85	.18
Fort Buchanan	3	11	5,330	4,080	21.58	.27
Fort Apache	18	10	5,050	3,800	21.04	.28
Verde	22	0	3,160	1,910	13.13	.15
Prescott	23	11	5,390	4,140	17.06	.16
Mean						.21

Comparing the stations given in this table with the record at Fort McDowell, which is a very old one, extending from 1867 to 1888, it is found that in eastern Arizona the rate of increase for each 100 feet of rise in elevation is 0.21 of an inch of rain. It is probable that notwithstanding the fact that the mean rainfall as measured above San Carlos for all stations is 12.87 inches, and that the mean for the San Pedro Basin is given as 14.13, the average rainfall of the basin of the Gila above San Carlos is greater than the average for the entire San Pedro Basin, and consequently the run-off per square mile of the San Pedro Basin, owing particularly to the flat valley lands through which the river flows in the greater portion of its course, is less than the run-off per square mile of the Gila above San Carlos. This is sustained by observations of flow of both streams during a period of five months.

FLOW OF GILA RIVER AT THE BUTTES, ARIZONA.

Lippincott gives the following description of the flow of Gila River:[a]

Gila River leaves the mountains and enters the plains at a point 15 miles above Florence, known as The Buttes. At this place the river is in a canyon, which is

[a]Lippincott, J. B., Storage of Water on Gila River, Ariz.; Water-Sup. and Irr. Paper No. 33, U. S. Geol. Survey, 1900, pp. 25-30.

approximately 450 feet wide, its bed being covered with sand and gravel to a maximum depth of 123 feet. Beyond this point, until it forms a junction with its principal tributary, Salt River, it loses in volume. A gaging station was established here, and the amount of water available from the basin was accurately determined by the Geological Survey from August 26, 1889, to August 31, 1890, but the work was stopped at the end of this time by lack of available funds. The results of these measurements are given in the Twelfth Annual Report, Part II, Irrigation, pages 306 to 309, and following tables. * * * A gap occurs in the record from August, 1890, to August, 1895. In the fall of 1895 measurements were begun by the reestablishment of a station at The Buttes, above Florence, at the same point at which observations were made during the years 1889 and 1890.

From August 1, 1895, to December 10, 1895, gage heights and depths were observed by W. Richins, and occasional estimates of velocity were made, and with these data and the measurements made subsequent to the middle of December the daily discharge for the months of August, September, and November, and the early part of December, 1895, has been ascertained. These results can be regarded only in the light of approximations and do not compare in value with those following December 10. Measurements were continued throughout the year 1896 by W. J. Brash, daily readings of the gage being taken and current-meter measurements made from one to three times a week. The data obtained for the period following December 10, 1895, and extending to October, 1896, are of a high degree of accuracy.

During the year 1897 measurements were continued at this station by W. J. Brash and Albert T. Colton, 49 measurements of discharge being taken, the last measurement being made on October 24, 1897. Mr. Brash, who was connected with this work in 1896 and 1897, died in the fall of 1897, and no other person residing in that immediate locality, it was not possible, with funds available, to have the gage rod read daily.

Measurements were made between March 7 and October 10, 1898, by Albert T. Colton, and subsequent to November 14 by Cyrus C. Babb and others connected with the present investigation. Sixteen meter measurements of discharge were thus made * * * prior to November 25, 1898. After this time a continuous record was maintained to the end of the year. In order to make the best possible use of the 16 observations made prior to November 25, 1898, the volumes as measured on those dates were platted in diagram, the vertical axis representing volumes measured in cubic feet per second and the horizontal axis representing intervals of one day's time each. The points thus determined were connected by straight lines, and from this diagram monthly estimates of discharge were made. Subsequent to November 25, 1898, daily observations of gage height and area were taken and frequent meter measurements of volume made. * * * As daily measurements of areas in square feet were made, the rating curve graphically shown on Pl. VI, *A* [Pl. V, *A*, of this paper] is in terms of are s of cross section and discharge.

During the year 1899, until October 20, measurements of area were made daily and frequent observations of velocity were taken with a meter. The results are shown graphically on Pl. VI, *B* [Pl. V, *B* of this paper]. The rating table, applying from November 25, 1898, to July 10, 1899, is used for the first portion of this year. The meter which was in service at The Buttes got out of order July 20, 1899, and until August 10 observations of gage height and area were taken daily. * * * The following table expresses numerically the values given in the rating curve:

Rating table for Gila River at The Buttes, Arizona, from July 11, 1899, to August 10, 1899.

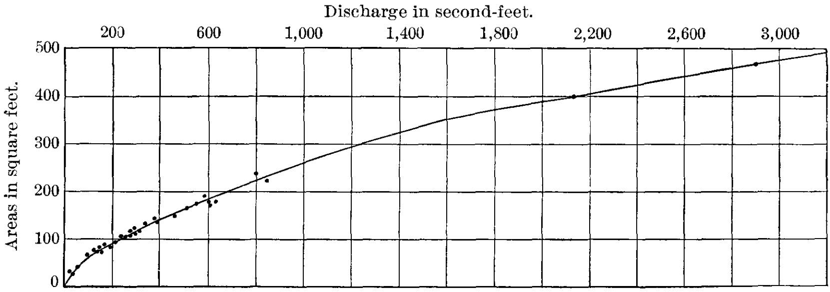
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Sec.-ft.		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*
1.5	....	2.7	250	3.9	1,445	5.1	3,364
1.6	0	2.8	320	4.0	1,550	5.2	3,548
1.7	1	2.9	410	4.1	1,670	5.3	3,732
1.8	5	3.0	500	4.2	1,800	5.4	3,916
1.9	9	3.1	605	4.3	1,950	5.5	4,100
2.0	15	3.2	710	4.4	2,100	6.0	5,020
2.1	25	3.3	815	4.5	2,260	6.5	5,940
2.2	40	3.4	920	4.6	2,440	7.0	6,860
2.3	60	3.5	1,025	4.7	2,625	7.5	7,780
2.4	90	3.6	1,130	4.8	2,810	8.0	8,700
2.5	130	3.7	1,235	4.9	2,995	8.5	9,620
2.6	180	3.8	1,340	5.0	3,180	9.0	10,540

From these daily measurements of area and frequent measurements of discharge, together with the rating tables mentioned above, the following table of volumes of discharge for Gila River at The Buttes from November 25, 1898, to September 30, 1899, has been prepared.

Estimated monthly discharge of Gila River at The Buttes, Arizona.

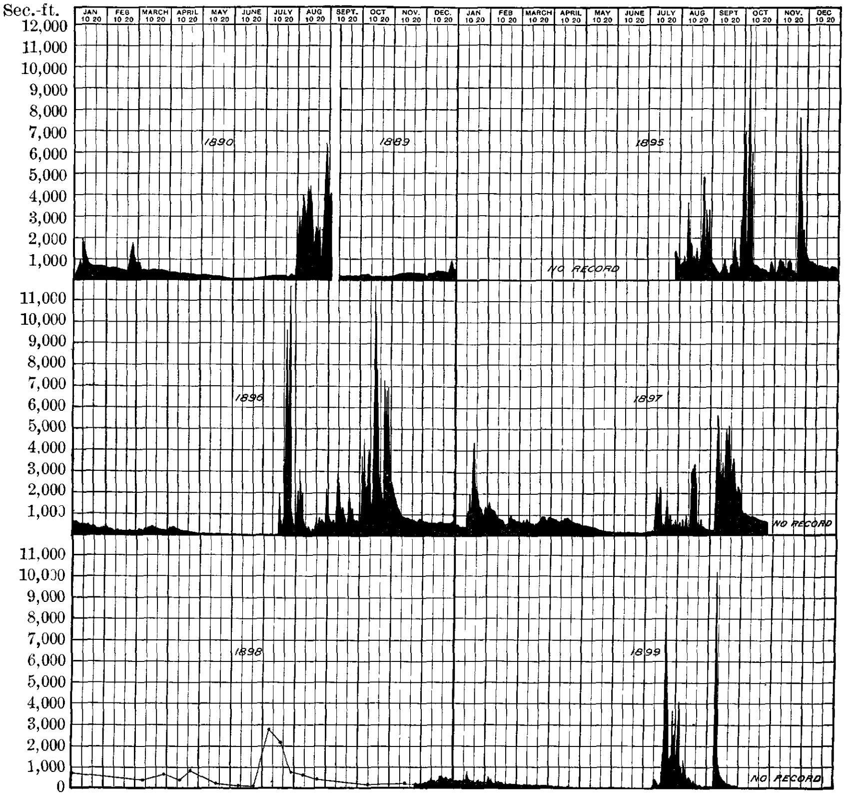
[Drainage area, 17,834 square miles.]

Month.	Discharge in second-feet.					Run-off.
	Maximum.	Minimum.	Mean.	Total for month in acre-feet.	Depth in inches.	Second-feet per square mile.
1889.						
September	210	90	128	7,616	0.010	0.009
October	210	140	157	9,655	.013	.011
November	250	156	212	12,614	.017	.015
December	890	124	275	16,909	.023	.020
1890.						
January	2,100	310	680	42,812	.056	.049
February	1,514	405	578	32,100	.043	.042
March	710	300	387	23,795	.032	.028
April	333	158	238	14,161	.019	.017
May	150	35	87	5,350	.207	.206
June	35	27	28	1,666	.002	.002
July	3,112	11	130	7,995	.010	.009
August	6,330	1,115	3,137	192,888	.263	.228
Total for season 1889–90	....	....	503	366,561	.447	....



A. RATING CURVE OF GILA RIVER AT THE BUTTES, ARIZONA.

Applied from November 25, 1898, to July 10, 1899.



B. DISCHARGE OF GILA RIVER AT THE BUTTES, ARIZONA, 1889–1899.

Estimated monthly discharge of Gila River at The Buttes, Arizona—Continued.

Month.	Discharge in second-feet.					Run-off.
	Maximum.	Minimum.	Mean.	Total for month in acre-feet.	Depth in inches.	Second-feet per square mile.
1895.						
August	3,910	536	1,583	97,336	0.133	0.115
September	2,880	300	812	48,317	.065	.059
October	12,000	400	1,577	96,966	.133	.115
November	7,500	300	1,103	65,633	.089	.080
December	1,150	518	751	46,177	.056	.055
Total				354,429		
1896.						
January	560	250	396	24,349	.032	.028
February	340	175	209	12,027	.016	.015
March	356	153	242	14,880	.021	.018
April	340	68	180	10,711	.014	.013
May	68	12	32	1,968	.002	.002
June	32	1	5	298	.000	.000
July	11,708	1	1,441	88,604	.121	.105
August	3,150	175	810	49,805	.068	.059
September	2,850	455	980	58,314	.079	.071
October	11,793	1,030	4,145	254,868	.347	.301
November	2,275	696	1,037	61,706	.083	.075
December	710	576	629	38,676	.053	.046
Per annum	11,793	1	842	616,206	.839	.062
1897.						
January	4,310	400	1,286	79,074	.108	.094
February	1,580	560	883	49,039	.066	.064
March	920	520	702	43,165	.059	.051
April	800	520	694	41,296	.056	.050
May	440	94	224	13,773	.018	.016
June	83	20	52	3,094	.004	.004
July	2,360	00	565	34,741	.047	.041
August	3,270	160	799	49,129	.067	.058
September	5,590	106	2,371	141,084	.192	.172
October			800	49,190	.067	.058
Total				503,585		

Estimated monthly discharge of Gila River at The Buttes, Arizona—Continued.

Month.	Discharge in second-feet.					Run-off.
	Maximum.	Minimum.	Mean.	Total for month in acre-feet.	Depth in inches.	Second-feet per square mile.
1898.						
January			640	39,352		
February			485	26,936		
March			473	29,083		
April			547	32,549		
May			292	17,954		
June			252	14,995		
July			2,022	124,328		
August			537	33,018		
September			270	16,066		
October			79	1,858		
November			101	6,010		
December	480	195	305	18,753		
Total				363,902		
1899.						
January	800	170	318	19,552	0.0209	0.0178
February	550	125	239	13,273	.0135	.0130
March	155	100	130.5	7,993	.0080	.0070
April	100	20	62.3	3,689	.0040	.0036
May	38	4	18.2	1,107	.0010	.0010
June	30	1	5.4	307	.0003	.0003
July	8,700	0.2	1,188.2	73,060	.0767	.0666
August	4,100	60	671.8	41,307	.0437	.0376
September	10,187	24	733.1	43,622	.0460	.0411
Total				203,910	.2141	

From the foregoing data the following tables of annual discharge of Gila River at The Buttes have been compiled:

Estimated annual discharge of Gila River at The Buttes, Arizona.

	Acre-feet.
Seasonal year 1889–90, Sept. 1 to Aug. 31	366,561
Fractional year 1895, Aug. 1 to Dec. 31	354,429
Year 1896	616,206
Fractional year 1897, Jan. 1 to Oct. 3	503,585
Year 1898, approximate	363,902
Fractional year 1899, Jan. 1 to Sept. 30	203,910

In order to get the greatest possible value from the records which have been compiled, and more particularly to make comparison with the annual rainfall records, the table given below has been prepared. In this statement every month in which measurements were taken is considered in the determination of an average monthly discharge for each month of the year. There are sixty months in all during which observations were made, there being five different years in which the flow was observed between January and September, inclusive, and four years in which November and December observations were made. From this table the mean monthly discharge is determined. and where a year has seven or more months of measured record, the remaining portion of it being deficient, the mean monthly discharge, as determined, is substituted for the months in which the record is defective. In this way a complete estimated record for five years is obtained, four months having been supplied for the year 1890, two for the year 1897, and three for the present year, 1899. A mean annual discharge is obtained by adding the mean monthly discharges actually measured. so that the mean annual discharge, which is 485,545 acre-feet, is determined only from actual measurements and includes all measurements that have been made. According to the census of 1890, there were but 6,619 acres irrigated from this great water supply, or less than 3 per cent of its possible utility. Practically the same area is irrigated at present as in 1890.

Estimated mean monthly, annual, and mean annual discharge, in acre-feet, of Gila River at The Buttes, Arizona.

[Drainage area, 17,834 square miles. Sixty months of observation.]

Year.	January.	February.	March.	April.	May.	June.
1890	41.812	32.100	23.795	14.161	5.350	1.666
1896	24.349	12.027	14.880	10.711	1.968	.298
1897	79.074	49.039	43.165	41.296	13.773	3.094
1898	39.352	26.936	29.083	32.549	17.954	14.995
1899	19.552	13.273	7.993	3.689	1.107	.307
Mean	40.828	26.675	23.783	20.481	8.030	4.072

Year.	July.	August.	September.	October.	November.	December.	Total.
1889			7.616	9.655	12.614	16.909	
1890	7.995	192.888	[a] 52.503	[a] 83.109	[a] 36.491	[a] 30.129	523.775
1895		97.336	48.317	96.966	65.633	46.177	
1896	88.604	49.805	58.314	254.868	61.706	38.676	616.206
1897	34.741	49.129	141.084	49.190	[a] 36.491	[a] 30.129	570.205
1898	124.328	33.018	16.066	4.858	6.010	18.753	363.902
1899	73.060	41.307	43.622	[a] 83.109	[a] 36.491	[a] 30.129	353.639
Mean	65.745	77.247	52.503	83.109	36.491	30.129	469.093

[a] Approximate.

For the purposes of the present study The Buttes may be considered as the upper end of Gila Valley, and the junction of Gila and Salt rivers the lower end. The quantity of water discharged at The Buttes is given in second-feet in the accompanying tables. Records at The Buttes for the forty-eight months indicate a small and comparatively regular flow and a few heavy floods. It is a well-known fact that the waters of the Gila below The Buttes, except in times of flood, sink beneath the surface and leave the river bed dry. It is not possible at present to state what portion of the total discharge at The Buttes thus enters the ground as underflow.

While exact computation is impossible, it may be useful to make an estimate based on assumptions that seem to be safely conservative. It is certainly on the side of conservatism to regard the underflow as equal to the minimum surface discharge of the river at The Buttes. It may be objected that this is a useless assumption, owing to the fact that in times of low water the Florence Canal diverts all the surface flow. Some of the water thus diverted and spread over the surface of the land evaporates, and some sinks into the ground and joins the underflow. It is probable, however, that the floods which pass the head-gates of the canal and sink from sight before reaching the lower Gila will more than counterbalance the loss due to diversion by this canal. The average daily minimum discharge for the forty-eight months that it was measured was 242 second-feet. It may safely be assumed that at least this amount joins the underground waters in the upper portion of the valley. At this rate the underflow would reach 175,200 acre-feet per year. By this volume of underflow is meant not the total volume of the underground waters, but the volume of water that will pass through a given cross section of the valley fill in one year. This estimate takes no account of a number of factors which combine to greatly increase the quantity of the underflow. Some of the more important of these factors are, first, the water flowing through the 105 feet of sand and gravel filling the old river bed beneath the river at The Buttes (see fig. 2); second, the greatly increased amount available during the times of flood; third, the occasional floods from the numerous tributary washes or dry creeks; fourth, the underflow from Santa Cruz and Salt rivers; fifth, the small amount contributed by springs and rainfall. It is possible that the total volume is much greater than 175,200 acre-feet.

A somewhat conspicuous example of the quantity of water that either evaporates or is contributed to the underflow occurred during the course of my investigations. During the early part of June, 1903, a flood occurred at Clifton, about 140 miles east of Sacaton, near the eastern border of the Territory. In the vicinity of Clifton the water is said to have risen about 30 feet and to have been very destructive to life and property. It was several days before the flood reached

Sacaton, and the waters had been so retarded and distributed in their course that the surface flow in the river at Sacaton lasted about four days. It should be said in this connection that much of the water was diverted by canals, but in the end this water must either evaporate or join the underflow, since it was diverted to lands within the valley. The water flowing in the channel at Sacaton was estimated to have had a maximum depth of 3 feet and width of 40 feet on a grade of 10 feet to the mile. Forty miles down the river from Sacaton the Buckeye canal diverts all the surface water ordinarily flowing in Gila River. Mr. William Apgar, the engineer in charge of the Buckeye canal, had made preparation for the protection of the canal at its head-gate when the flood, which was confidently expected to reach that point, should arrive. His water gage indicates that the flood never reached it. The increase in the amount of water was not enough to affect the reading. In other words, the flood waters had disappeared entirely from the surface and either evaporated or joined the underflow before reaching the Buckeye canal.

PRINCIPLES AND EXPERIMENTS.

For the establishment of extensive pumping plants the available quantity of underground water is a matter of prime importance. Unfortunately, it is impossible without extensive and costly investigations to obtain anything like an accurate measure of this water. While no strictly accurate computations can be made, owing to the lack of adequate data, estimates based upon available data and safe assumptions may be of value.

Mr. Arthur P. Davis, in his report on "The irrigation investigation for the benefit of the Pima and other Indians on the Gila River Indian Reservation, Arizona,"[a] describes an experiment performed for the purpose of ascertaining the rate of flow of water through the sand and gravel of the Gila River bed, where the gradient is 10 feet per mile. He arrives at the conclusion that the "percolation of water through sand and gravel indicates that the velocity of water through such material as constitutes the bed of the Gila River on the grade of 10 feet per mile * * * would not exceed 4 feet per day." At this rate the movement would be 1,460 feet per year. In the same paper he describes a pumping experiment, which I have already referred to, and concludes that the "rate of percolation is a little over 53 cubic feet per day for each square foot of percolating surface." The voids occupied by water in such cases are assumed to amount to one-third of the space. On this assumption the waters entering the well must have moved at an average rate of 159 feet per day, or about 11 miles per year. These figures are not, however, a true measure of the rate of the underflow at

[a] Senate Doc. No. 27, Fifty-fourth Congress, second session, 1897, pp. 12-18.

that point, since the conditions at the well are very different from those at places where the flow is uninterrupted. The figures are of value as indicating something of the freedom of movement of the underground water when obstructions are removed.

RATE AND VOLUME OF UNDERFLOW.

Mr. L. G. Carpenter has published a paper giving the results of his study on the rapidity of underflow.[a] In it he states that near Montrose, Colo., the velocity was found to be about 1 mile per year;[b] at Fort Morgan, Colo., it is 15 feet per day, or a little more than 1 mile per year in soil and sand;[c] and in the Hoover ditch it is 3.6 feet per day, or 314 feet per year in sand.[c]

Professor Slichter has recently published a paper[d] on underground waters, in which, after a discussion of principles relating to the movement of underground waters, he states these principles as follows:

> The formula which the writer has devised for determining the flow of water through a column of sand is as follows:
>
> $$q=0.2012\,\frac{pd^2s}{\mu hK}\text{ cubic feet per minute.} \qquad (3)$$
>
> In this formula q stands for the quantity of water transmitted by the column of sand in one minute; p is the difference in pressure at the ends of the columns, or the head under which the flow takes place, measured in feet of water; s is the area of the cross section of the sand column, measured in square feet; h is the length of the column in feet; d is the mean diameter of the soil grains, measured in millimeters, or the so-called "effective size;" μ is the number which takes account of the friction between the particles of water, and is known as the coefficient of viscosity (it is defined as the amount of force necessary to maintain unit difference in velocity between two layers of water unit distance apart; its value, which decreases rapidly with an increase in the temperature of water, for temperatures from 32° to 100°, is given in Table II, below); K is a constant which depends upon the porosity of the sand, and its value for porosities, varying from 26 to 47 per cent, has been computed and is given in Table III. * * *

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[a] Carpenter, L. G., Seepage or return waters from irrigation: Colorado Agr. Exp. Station Bull. No. 33, 1896.

[b] Ibid., p. 45.

[c] Ibid., p. 48.

[d] Slichter, C. S., The motions of underground waters: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, pp. 24–30.

TABLE II.—*Variations of the viscosity of water with temperature, and the relative flow of water of various temperatures through a soil, 50° F. being taken as the standard temperature.*

Temperature.	Coefficient of viscosity.	Relative flow.[a]	Temperature.	Coefficient of viscosity.	Relative flow.[a]
Deg. F.			*Deg. F.*		
32	0.0178	0.74	70	0.098	1.34
35	.0168	.78	75	.092	1.42
40	.0154	.85	80	.087	1.51
45	.0142	.92	85	.081	1.62
50	.0131	1.00	90	.077	1.70
55	.0121	1.08	95	.073	1.80
60	.0113	1.16	100	.069	1.90
65	.0105	1.25			

[a] "Relative flow" means flow at given temperature compared with flow at 50° F. It is expressed as a percentage.

TABLE III.—*Constants for various porosities of an ideal soil.*

Porosity m.	$\frac{1}{K}$	Log. K.	Diff.	Colog. K.
Per cent.				
0.26	[a]0.01187	1.9258	563	8.0742
.27	.01350	1.8695	504	8.1305
.28	.01517	1.8191	490	8.1809
.29	.01694	1.7701	502	8.2299
.30	.01905	1.7199	467	8.2801
.31	.02122	1.6732	455	8.3268
.32	.02356	1.6277	430	8.3723
.33	.02601	1.5847	438	8.4152
.34	.02878	1.5409	410	8.4591
.35	.03163	1.4999	407	8.5001
.36	.03473	1.4592	400	8.5408
.37	.03808	1.4193	377	8.5807
.38	.04154	1.3816	371	8.6184
.39	.04524	1.3445	367	8.6555
.40	.04922	1.3078	353	8.6922
.41	.05339	1.2725	351	8.7275
.42	.05789	1.2374	345	8.7626
.43	.06267	1.2029	339	8.7971
.44	.06776	1.1690	320	8.8310
.45	.07295	1.1370	312	8.8630
.46	.07838	1.1058	329	8.8942
.47	.08455	1.0729	----------	8.9271

[a] By a typographical error this column was printed incorrectly in Professor Slichter's paper. It is given correctly here.

If t stands for temperature of the water, Fahrenheit, the author's formula, in which the coefficient of viscosity has been replaced by an expression varying with the temperature similar to that given in the formula of Hazen, may be written as follows:

$$q=11.3\frac{pd^2s}{hK}\,[1+0.0187\,(t-32)] \text{ cubic feet per minute.} \tag{4}$$

It is seen from the above formula that the quantity of water transmitted by a column of sand not only depends upon the length of the column and the head of water as expressed by Darcy's law, but varies in a most remarkable way with the effective size of the soil grain, with the temperature of the water, and with the porosity. Since the flow varies as the square of the size of the soil grain this element in the formula has a most important effect, as doubling the size of the soil grain will quadruple the flow of water. Thus the flow through a sand whose effective size of grain is 1 mm. is 10,000 times the flow through a soil whose effective size of grain is 0.01 mm. The variation of flow with temperature is also important, as the flow at 70° F. is about double that at 32° F. The variation in porosity is quite as important as the variation in temperature.

From Table III it appears that if two samples of the same sand are packed, one sample so that its porosity is 26 per cent and the other sample so that its porosity is 47 per cent, the flow through the latter sample will be more than seven times the flow through the former sample. If the two samples of the same sand are packed so that their porosities are 30 per cent and 40 per cent, the flow through the latter sample will be about 2.6 times the flow through the former sample. These facts should make clear the enormous influence of porosity on flow and the inadequacy of a formula of flow which does not take it into account.

Part of the expression on the right side of formula (3) or (4) depends only upon the character of the soil through which the water is passing. Representing this by K, we have

$$K = 0.2012\,\frac{d^2}{\mu K} = Md^2, \tag{5}$$

and the formula for the flow becomes

$$q = k\frac{ps}{h}, \tag{6}$$

which is essentially Darcy's formula. The constant K is the quantity of water that is transmitted in unit time through a cylinder of the soil of unit length and unit cross section under unit difference in head at the ends. We shall frequently refer to k as the transmission constant or merely as the constant of a soil.

It should be especially noted that the velocity of flow through a soil for the pressure gradients and size of grain that commonly occur is exceedingly slow and much less than might at first be supposed. Darton states that the rate of flow in the sands of the Dakota formation, from which the remarkable artesian wells of South Dakota draw their supply, does not exceed a mile or two a year.[a] Mr. E. L. Rogers reported to the Denver society of civil engineers [b] that American estimates agree with careful and exhaustive studies of French engineers, which show the average velocity in sands to be about a mile a year, or about an eighth of an inch a minute. In Arizona the rate has been figured out as between one-fourth and one-third of an inch per minute, while on Arkansas River above Dodge, Kans., a ditch a mile long and 5 feet below the water table in the sand developed a flow of about three-eighths inch per minute.

[a] Darton, N. H., New developments in well boring and irrigation in eastern South Dakota: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1897, p. 609.

[b] Eng. Record, vol. 25, p. 4351.

TABLE IV.—*Velocity of water in sands of various effective sizes of soil grain and the maximum flow or transmission constant for each soil.*

[Porosity, 32 per cent; temperature, 50° F. Results for other porosities can be found by the use of Table V, and for other temperatures by the use of Table II.]

Diameter of soil grain.	Velocity pressure gradient 1:1.	Velocity pressure gradient 1:1.	Velocity pressure gradient 100 feet to 1 mile.	Maximum flow, or transmission constant, *k*.	Logarithm of numbers in column 5.	Kind of soil.
Mm.	*Ins. per min.*	*Miles per year.*	*Miles per year.*	*Cu. ft. per min.*		
0.01	0.0014	0.0113	0.00023	0.000036	5.5569	Silt.
.02	.0054	.0452	.00102	.000144	6.1590	
.03	.0122	.1016	.00230	.000324	6.5111	
.04	.0218	.1807	.00408	.000577	6.7610	
.05	.0340	.2823	.00638	.000901	6.9548	Very fine sand.
.06	.0490	.4065	.00918	.001298	7.1132	
.07	.0667	.5534	.01250	.001766	7.2471	
.08	.0871	.7228	.01633	.002308	7.3631	
.09	.1103	.9147	.02066	.002920	7.4654	
.10	.1361	1.129	.02551	.003605	7.5569	Fine sand.
.12	.1961	1.627	.03674	.005192	7.7153	
.14	.2668	2.213	.05011	.007065	7.8491	
.15	.3063	2.541	.05753	.008112	7.9091	
.16	.3485	2.892	.06382	.009228	7.9651	
.18	.4412	3.659	.08266	.01168	8.0675	
.20	.5446	4.518	.1021	.01442	8.1590	
.25	.8509	7.058	.1594	.02253	8.3528	Medium sand.
.30	1.225	10.16	.2296	.03244	8.5111	
.35	1.668	13.84	.3125	.04417	8.6451	
.40	2.178	18.07	.4081	.05768	8.7610	
.45	2.757	22.87	.5165	.07300	8.8633	
.50	3.403	28.23	.6377	.09012	8.9548	Coarse sand.
.55	4.119	34.17	.7718	.1090	9.0377	
.60	4.901	40.65	.9183	.1298	9.1132	
.65	5.751	47.81	1.077	.1523	9.1827	
.70	6.671	55.34	1.250	.1766	9.2471	
.75	7.660	63.53	1.435	.2028	9.3071	
.80	8.714	72.28	1.633	.2308	9.3631	
.85	9.835	81.57	1.843	.2604	9.4157	
.90	11.03	91.47	2.066	.2920	9.4654	
.95	12.28	101.9	2.302	.3253	9.5123	
1.00	13.61	112.9	2.551	.3605	9.5569	Fine gravel.
2.00	54.46	451.8	10.21	1.442	.1590	
3.00	122.5	1,016	22.96	3.244	.5111	
4.00	217.8	1,807	40.81	5.768	.7610	
5.00	340.3	2,823	63.77	9.012	.9548	

Table IV, above, gives the velocity of movement of water in sands of various grades for different pressure gradients. Column 1 gives the effective size of the soil grains in millimeters. As already stated, this size is such that if all grains were of that diameter, the soil would have the same transmission capacity that it actually has. Column 2 gives the velocity of flow, or the rate at which the water moves through the ground, in inches per minute under a pressure gradient of 1 foot difference in head to each foot of distance. Column 3 gives the velocity of flow reduced to miles per year, the pressure gradient being the same as in column 2. Column 4 gives the velocity of flow in miles per year under a pressure gradient of 100 feet to the mile. The velocity for a pressure gradient of 10 feet to the mile would be one-tenth of the numbers in this (fourth) column, and so on for other gradients. Column 5 gives the actual discharge in cubic feet per minute for each square foot of cross section if the pressure gradient be 1 foot difference in head in each foot of distance. For a pressure gradient of 1 foot difference in head for each 100 feet in distance the flow per square foot will be 0.01 of the tabulated numbers, and so on for other gradients. The numbers in this (fifth) column have also been called the "transmission constants" and have been represented in the formulas by k.

TABLE V.—*Relative flow of water through sands of same effective size grain, but packed so as to possess different porosities.*

Porosity, or per cent of voids.	Relative flow.[a]
30	0.81
32	1.00
34	1.22
36	1.47
38	1.76
40	2.09

[a] Relative flow means the flow for the given porosity compared with the flow for a porosity of 32 per cent as a standard.

Inasmuch as the flow of ground water is nearly always caused by a difference in head due to gravity only, the maximum flow that is possible is found in the case in which the ground water is free to move in a vertical direction, as in a perfectly underdrained sand-filter bed. The motion in this case is due to the weight of the water of saturation, and the flow is of course greater than would be the case if the water were obliged to flow in a direction inclined to the vertical, instead of in the vertical direction, as supposed. These facts are illustrated in fig. 7. The flow in the case of pressure gradient 1:1 forms a most convenient basis for calculation, and it is frequently called, as suggested by Hazen, the maximum flow. The flow for any other gradient is immediately calculable from the maximum flow—for a gradient 1:100 the flow being, of course, one one-hundredth of the maximum flow.

The appropriateness of the term "maximum flow" is illustrated by fig. 8, which shows the original water table and the depressed water table due to the construction of a drainage ditch. It is plain that the pressure gradient for all of the streams of flow marked by arrowheads is less than the gradient 1:1. If the wetted area of the ditch be multiplied by the maximum flow for the kind of material in which the ditch has been excavated the flow thus computed will in every case exceed the flow actually determined by measurements of the yield of the ditch.

There is not uniformity in the use of the term "velocity" as applied to the motion of ground waters. We use the term to express the rate (measured as so many feet a day, etc.) at which the water advances through the porous medium

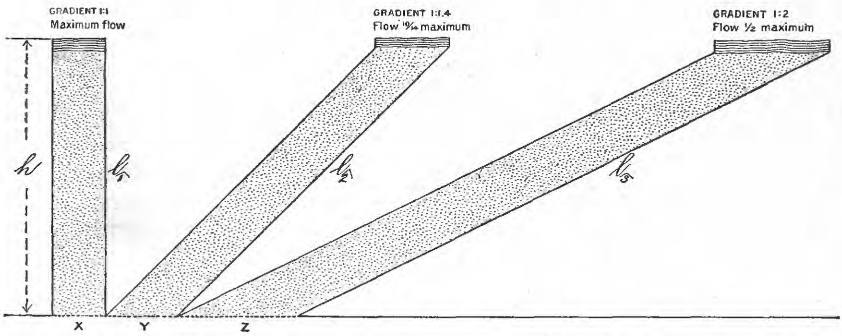

FIG. 7.—Diagram illustrating various pressure gradients and the maximum flow. In these three cases the upper portions of the soil columns are supposed to be supplied with water as fast as it can flow through the columns. The escape at X, Y, Z is supposed to be perfectly free. The head under which the flow takes place is h in each case, as shown at the left of the figure. The various lengths of the soil columns, l_1, l_2, and l_3, produce the pressure gradients $h/l_1 = 1$, $h/l_2 = \frac{1}{1.4}$, and $h/l_3 = \frac{1}{2}$, respectively, with the resulting flows in proportion if the material in the various columns be the same.

irrespective of the amount of water thus advancing. The amount of ground water (measured in cubic feet per minute, etc.) passing through a given cross section the writer has called the flow or the discharge. It is equal to the velocity multiplied by the porosity. Some measure velocity as a rate of motion in a solid column of same area as the cross section of the porous medium. This is the same magnitude which we have called flow.

In using Table IV one should use the numbers in columns 2, 3, or 4 if the

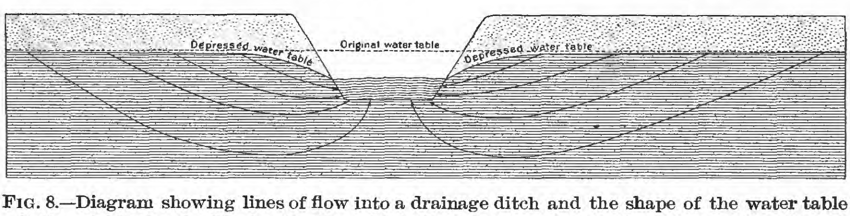

FIG. 8.—Diagram showing lines of flow into a drainage ditch and the shape of the water table in its neighborhood. The head under which the flow takes place is the difference in height of the original water table and the level of the surface of the water in the ditch. This is much less than the lengths of the curved lines of the flow into the ditch, hence the rate of flow must be much less than the so-called maximum flow.

velocity of ground water is wanted, but should pass to column 5 if the flow or yield is required. Thus, suppose it is desired to find the rate of motion of ground water through a bed of sand which slopes 10 feet to the mile. The results can be found for various materials and grades of material by dividing the numbers in column 4 by 10, since a slope of 10 feet to a mile will cause but one-tenth of the velocity existing for a slope of 100 feet to a mile. For materials of various grades we obtain the following results:

Velocity of ground water in materials of different grades, pressure gradient 10 feet per mile.

Material.	Miles.	Feet per year.
Fine sand, 0.2 mm. diameter	0.010	52.8
Medium sand, 0.4 mm. diameter	.041	216.0
Coarse sand, 0.8 mm. diameter	.16	845.0
Fine gravel, 2 mm. diameter	1.02	5,368.0

Suppose that it is desired to ascertain the amount of water that will pass through a bed 200 feet deep and 1,000 feet wide, having the same slope as that just mentioned. This problem requires us to find the flow, and the numbers used in the computation should therefore be taken from column 5 of Table IV. The flow for 1 square foot of cross section of the bed will be $\frac{10}{5280}$ of the maximum flow given in that column for material of various grades, and the total flow is found by multiplying the maximum flow by $\frac{10}{5280} \times 200 \times 1{,}000$, which gives the following results for the same materials described in the preceding table:

Flow of ground water in materials of different grades through a bed of vertical cross section 200 by 1,000 feet, sloping 10 feet per mile.

	Cu. ft. per min.
Fine sand	5.5
Medium sand	22.0
Coarse sand	87.0
Fine gravel	546.0

The estimates in Table IV were based upon a porosity of 32 per cent. For other porosities the results must be changed by the percentages shown in Table V. Thus all of the results just found must be increased by about 37 per cent if the porosity of the material be 35 instead of 32 per cent.

In the same paper Professor Slichter gives rate of movement of underground water at various points as follows:[a] Weldon Valley canal, 1½ miles in five years, or 1,584 feet per year; Larimer County canal, 40 rods in five years, or 132 feet per year; near Greeley, 2½ miles in ten years, or 1,320 feet per year; King River, California, 4.8, 4.3, and 1.6 feet per day, or 1,792, 1,580, and 584 feet per year; Centerville canal, California, 16 feet per day, or 5,840 feet per year; Kingsbury canal, California, 52 feet per day, or 3.6 miles per year; Arkansas River, Kansas, 2½ feet per day, or 913 feet per year; near Garden, Kans., 12 feet per day, or 4,380 feet per year; Hondo and San Gabriel rivers, California, 3½, 4, 5½, and 7 feet per day, or 1,278, 1,460, 2,008, and 2,555 feet per year.

From the above it appears that the rate of movement of underflow, as measured in several localities, varies from a minimum of 132 feet

[a] Op. cit., pp. 42, 43.

to a maximum of 3.6 miles per year. Because of the application to follow, however, it should be noted here that the material through which the water passed at the above rates is for the most part soil or comparatively fine sand. In no case described is the material coarse sand, gravel, and bowlders, such as the beds penetrated, for example, at Sacaton; nor is there in Slichter's tables a diameter of grain to correspond with the gravels of Sacaton. These materials here vary from silt to bowlders several inches in diameter. The coarse and fine material is commingled in all proportions, from beds of pure sand to beds of large gravel and bowlders. Furthermore, the material is very loose, allowing water to pass through it readily.

PRACTICAL POROSITY.

In the foregoing statement concerning the proportion of voids it is assumed in each case that the size of the grain is much more uniform than in the heterogeneous material of the valley fill. Where coarse and fine materials are commingled it is obviously erroneous to make computations for any selected size or even for an average size. The finer material packs into the interstices between the coarser. It would be entirely possible to have such materials packed in such a manner that the porosity of the entire mass would, for all intents and purposes, equal the porosity of the smallest of the mixed material; no doubt such cases occur in the valley fill. There is also no doubt that places may be found where coarse material occurs apart from the fine, and also where, although coarse and fine exist together, they are loosely packed and allow a free passage of water. In order to arrive at an approximation of the water available in the mixed gravels of the valley, I made a series of measurements by filling a barrel with gravel and sand and measuring the water which could be poured into it, which I assumed would be a fair measure of the amount that would seep into a well from an equal bulk of ground and be available for pumping. In order to obtain representative material, the measurements were made east of Phoenix, where the material thrown from a well lies undisturbed. The barrel held 46⅝ gallons, measured by a standard graduate. The material first selected was sand, pebbles, and bowlders up to 8 inches in diameter, which seemed to be a fair average of the water-bearing materials as I have observed them throughout the valley. The sand was slightly moist from a shower which fell the day before the measurements were made. The material was carefully packed in the barrel in order to approximate as nearly as possible the natural conditions. Water was then poured in slowly until the barrel was full. It was found that the barrel would hold 10.5 gallons of water, representing 20.5 per cent of the total space. These gravels would probably be packed more closely in the ground than they were in the barrel, and the amount of water that could be pumped from them would be something less than 20 per cent of the total bulk. Since sands and gravel can never be pumped dry it is obvious that the porosity may be very much greater than the amount which can be drawn from them by pumping.

For a second experiment a place was selected where the material available was mostly coarse gravel and bowlders varying in size from half an inch to 8 inches in diameter. In addition to this material, the barrel held $16\frac{5}{8}$ gallons of water, being 35.8 per cent of the total space. In this case, as in the former one, the percentage of voids in nature would probably be something less, owing to the closer packing. Owing to the slight amount of water held in the material previous to the addition of water, and owing also to small air spaces which the water did not displace, the actual percentage of voids is probably considerably greater than given above.[a] The porosity, however, is not the essential thing in this case, as the sands and gravels could not be pumped dry. It is thought, however, that the material of the Gila Valley, as represented in the deep wells at Sacaton, will yield water equivalent to at least 20 per cent of its bulk, which is the practical available amount of water that can be obtained by pumping.

APPLICATION OF PRINCIPLES TO GILA UNDERFLOW.

The well records indicate that near Sacaton underground water is less than 50 feet beneath the land surface over a strip of land averaging at least 4 miles in width. The area of water-bearing gravels is wider than this—how much wider can not be stated, since they have not been penetrated by wells except near the river. The wells at Sacaton are 200 feet deep and penetrate 136 feet of water-saturated gravel and bowlders, and do not reach the bottom of these gravels. It would seem, therefore, that it is conservative to assume that a bed of gravel and bowlders at least 4 miles wide and 136 feet deep has water passing through it in the form of underflow in this part of the valley. Using these facts as a basis for the application of the principles just quoted, certain computations may be made which will illustrate the possibilities of obtaining water from the underflow of the Gila Valley. Adopting Slichter's formula (4) and substituting the values applicable to the Gila Valley, we have:

$p = 10$, the average gradient of the water-bearing gravels.

$d =$ various sizes from silt to gravel and bowlders. The "effective size" has not been determined, but probably does not differ materially from .72 mm., the effective size of the water-bearing material in Salt River Valley.

$s = 4$ miles wide and 136 feet deep, or 2,872,320 square feet.

$h = 1$ mile, or 5,280 feet. Any convenient length may be taken, but if $p = 10$, h must be 5,280.

$K =$ the variable, corresponding in this case to a porosity of 40 per cent, the porosity as determined for Salt River Valley.

[a] Professor Slichter has determined the porosity of similar gravels from Salt River Valley to be 40 per cent.

$t = 70°$ F. The temperature will vary somewhat, but will be found greater than 70° more often than less.

Applying local values, therefore, Slichter's formula becomes:

$$q=\frac{11.3\times10\times(72)^2\times2.872,320\times525.600}{5,280\times43,560\times20.318}[1+.0187(80-32)]=35,830 \text{ acre-feet per year.}$$

In order that the result may express acre-feet per year, I have placed above the line the number of minutes in one year, and beneath the line the number of cubic feet in one acre-foot of water. Solving this equation the quantity of underflow appears as 35,830 acre-feet per year. In other words, assuming that the estimates are correct, enough water enters the gravels of the Gila Valley to cover 35,830 acres of land one foot deep.

This indicates a velocity of movement of the underflow of Gila Valley of about 1,360 feet per year.

It is moderately certain that there are portions, at least, of the valley fill through which the movement is more rapid than 1,360 feet per year. It may be proper here, therefore, to compare the volume of water which may pass as underflow at certain assumed rates with the volume at the rate of 1,360 feet per year.

Velocity and volume of flow in materials of different grades.

[Pressure gradient, 10 feet per mile, and area of cross section (4 miles wide and 136 feet deep) 2,872,320 square feet; porosity = 40 per cent; temperature = 80° F.]

Velocity in feet per year.	Volume of flow in acre-feet per year.
1,360	35,830
[a] 2,640	69,564
[b] 5 280	139,128
[c] 10,560	278,256

[a] ½ mile. [b] 1 mile. [c] 2 miles.

It is assumed in the above table that water may be passing as underflow down the Gila Valley at a rate varying from 1,360 feet to 2 miles per year and in volume varying from 35,830 to 278,250 acre-feet per year. It may be well at this point to scrutinize the figures somewhat carefully and inquire which rate and volume are likely to most nearly represent the truth. The assumptions in the application of principles to Gila Valley are as follows:

1. The material is assumed to be similar in porosity and size to the water-bearing material in Salt River Valley.

2. The assumed depth of 136 feet is less than the actual thickness of the water-bearing stratum. The maximum depth is unknown.

3. The assumed width of 4 miles is below the average width of the water-bearing gravels. A glance at the map (fig. 1) will convince one that the average width is greater than 4 miles.

4. The assumed porosity of 40 per cent is based on determinations of similar gravels from Salt River.

5. The assumed temperature, 80° F., is the temperature indicated by deep-well observations near Phoenix.

It would seem from the above considerations that the lower rate of 1,360 feet of flow and the corresponding volume of 35,830 acre-feet per year is certainly moderate and that the higher rate of 2 miles and 278,256 acre-feet per year is not unreasonable. In other words, it is probable that from 100,000 to 600,000 acre-feet of water each year pass through the sands and gravels of the Gila Valley in the underflow.

It may also be of value to compute the probable amount of water which is available for pumping in the gravels of the Gila Valley at any particular time, irrespective of the flow into or out of these gravels. The area under which water occurs less than 50 feet beneath the surface of the Gila Valley is about 350 square miles. Under a considerable portion of this area the water is but a few feet beneath the surface, and could be lowered 40 feet or more and still be within pumping distance. In the higher portions of the valley the amount of lowering within practicable limits would be less. It is probable that an average of 25 feet for the whole area would represent the distance by which the water table might be lowered and still be within reach of the pumps, on the assumption that 60 feet is the maximum lift for profitable pumping.

On a previous page it was shown that Gila River discharges into the valley at The Buttes a quantity of water varying, in round numbers, from 175,200 to 600,000 acre-feet per year, and that a large part of this water enters the underflow. It was assumed that at least the minimum discharge of 175,200 acre-feet could reasonably be counted as joining the underflow.

Table showing the quantity of water available for pumping in the gravels of the Gila Valley at the porosities assumed.

Porosity.	Amount of permanent lowering of the water table.	Yield.	Depth of water if distributed over the entire area (350 square miles).
Per cent.	*Feet.*	*Acre-feet.*	*Feet.*
20	25	1,120,000	5
25	25	1,400,000	6.25
30	25	1,705,000	7.5
35	25	1,960,000	8.75

Computations from Slichter's formula indicate a capacity for underflow through the valley fill of 35,830 acre-feet per year, while an assumed rate of movement of 2 miles per year yields 278,256 acre-feet of water. This is the possible quantity of annual intake, while the probable quantity in the underground "reservoir" in reach of the pumps is 1,120,000 to 1,960,000 acre-feet. The valley fill is in a sense a large reservoir which is kept constantly filled by the inflow of the Gila at The Buttes and by less important lateral sources. From the above figures it will be readily seen that the underflow of the Gila Valley contains water in quantities sufficient to warrant the most careful consideration of ways and means for rendering it available. It has been estimated that 40,000 acre-feet of water per year would supply all the present needs of the Indians on the reservation. At this rate there is enough water, if the computations be correct, at present within pumping distance of the surface to supply the Indians for twenty-eight to forty-nine years. Or, again, if the minimum annual underflow, as stated above, be accepted, enough water is passing to supply the needs of Indians of the Pima Reservation; and if the maximum be passing, to leave a surplus of 238,000 acre-feet unappropriated.

It may be well to insert at this point a caution against taking computations and figures of this kind too literally. The problem deals with subterranean conditions of which very little at best can be known. The computations are based on assumptions which seem to be well founded, but must not be accepted for anything more weighty than assumption. The underground conditions may not be what they seem, and important elements may enter which have been wholly disregarded. The figures illustrate possibilities. The only safe method of procedure in developing the underground water is by actual experiment, and expansion as the experiments warrant. It would be much easier to increase the acreage of cultivated land as water is developed for it than to decrease an acreage which might prove to be too great.

METHODS OF SECURING THE WATER OF THE UNDERFLOW.

There seems to be little doubt that large quantities of water are present in the Gila underflow. The problem remains then to make this water available for irrigation. Two methods are being tried—seepage ditches and pumping plants.

SEEPAGE DITCHES.

Where seepage ditches have been tried the results are disappointing. In the ditch east of Sacaton the near-by water-bearing sands and gravels were soon drained to such an extent that the water table was depressed locally 4 feet. When the ditch was first constructed, the surface of the underground water stood at a maximum elevation of 5.5 feet above the bottom of the ditch. The water-bearing material in the immediate vicinity of the ditch was soon drained and a water gradient established for the lateral flow. At the present writing water actually enters the ditch from only the lower 18 inches of the side. In the case of the Jenkins ditch, near Phoenix, and the Richardson ditch, west of the Agua Fria, the quantity of water actually obtained falls far short of expectations. The cost of constructing and maintaining a deep ditch in the loose gravels and quicksands is large compared with the amount of water obtained. Seepage ditches can penetrate only a few feet at most into the water-bearing material and have to be carefully cribbed to keep out the sand and gravel. At best only the uppermost part of the underflow is penetrated—the part most readily affected by fluctuation in the water level.

The cost and trouble of maintaining a seepage ditch should also be considered, although this may balance the cost and trouble of operating a pumping plant. In spite of the cribbing required in the seepage ditches, the sand finds its way in with the water and has to be removed periodically. The mosses and algæ accumulate and have to be removed frequently. During dry cycles the water supply diminishes or fails. At best there are few places where the water is found near enough to the surface to be secured by seepage ditches, and under the best conditions the ditch must be long in order to penetrate the water-bearing materials and still have fall enough to conduct the water upon irrigable land.

As previously stated about 2,050 inches of seepage water is obtained in the Gila Valley, and this amount will probably be increased by developments now in progress. If the flow of 2,050 inches did not fluctuate it would amount to about 23,870 acre-feet per year. Mr. M. M. Murphy, who has charge of the distribution of water in the western part of the reservation, states that the minimum flow is about half the maximum flow. The quantity given—2,050 inches—is probably somewhere near the maximum. At best it is wholly inadequate for the needs of the Indians.

PUMPING PLANTS.

The second method of obtaining water from the underflow is by pumping. Unfortunately, the pumping plant which is being established at Sacaton is not complete at this writing and the quantity of water obtainable from the wells is unknown. There are good indications, however, that the quantity of water obtainable at Sacaton and elsewhere in the Gila Valley is as great as that obtained at the pumping plants in the Salt River Valley. Judging from the amount of water discharged by pumps now in operation, and also considering the lift in each case, the five wells at Sacaton should furnish 5,000 gallons per minute continuously. If such a plant be operated without stoppages it will furnish 6,435 acre-feet of water per year. Ten plants of this capacity would furnish 64,350 acre-feet, or, in other words, would supply the required 40,000 acre-feet per year, with an allowance of 36 per cent of the time for stoppages, repairs, etc.

The length of the Gila River within the limits of the reservation is about 60 miles. It is probable that many more than the proposed ten pumping plants could be operated within this distance without seriously affecting each other. The pumping tests on the Chandler wells, in Salt River Valley, indicate that wells may be operated within a few yards of each other and the output of the one not seriously affect that of the other. It is probable, therefore, that water could be drawn from the underflow of the Gila Valley, not only to supply the needs of the Indians, but to materially extend the cultivated area without exhausting the available supply. Throughout the length of the reservation the water level is practically the level of the river bed. Pumping plants could be established on grounds high enough to be out of danger from floods and to place the pumped waters upon the desired lands and still have a lift well within practicable limits.

The lack of data, owing to the uncompleted condition of the pumping plant at Sacaton, renders the above estimate of doubtful value. The success of similar pumping plants in Salt River Valley, however, has placed this method of profitably securing water for irrigation beyond serious question. Even should the Sacaton plant prove a failure it would not argue that pumping could not be profitably carried on in the Gila Valley, for there are instances in Salt River Valley where wells have proved unproductive, although within a short distance of the best producers of the valley.

Great variation of structure is to be expected in the valley fill. It is impossible to foresee in more than a general way what conditions are to be met with in sinking wells. The external conditions of the Gila and the Salt River valleys are practically the same, and in general the same internal structure of the valley fill is to be expected. The greater number of wells in Salt River Valley make a study of internal conditions to some extent possible. The figures which follow are diagrammatic illustrations of conditions known to exist in Salt River Valley. In fig. 9 *A* and *B* represent two wells, in which the water stands 20 feet below the surface in each well. If it be assumed that the material through which they pass is all water-bearing gravel, it is plain that a lowering of 30 feet, for example, will yield water represented by one-third of the space *a f h b*, the shaded portion of No. 1. If it be assumed that *a c g* is impervious clay and *a f c* is water-bearing, a lowering of 30 feet in either well would yield water represented by one-third of the space *a f h i*, the shaded portion of No. 2. If it be assumed that *a c g* is gravel and the rest clay, a lowering of 30 feet in well *A* will yield water represented by one-third of space *a i b*, the shaded portion of No. 3, and well *B* will yield nothing. If it be assumed that *d f e* is gravel and the remainder clay, well *A* will have no water and well *B* will yield water represented by one-third of the space *k f h j*. If it be assumed that *a d e c* is gravel and the remainder clay, well *B* will yield no water and well *A* only so much as is represented by one-third of the space *a k j i*, the shaded portion of No. 5. If it be assumed that *a d e c* is clay and the remainder gravel, well *A* will yield water represented by one-third of space *a i b*, while well *B* will yield water represented by the space *k f h j*, the shaded portion of No. 6, and the waters may differ in quality as well as amount.

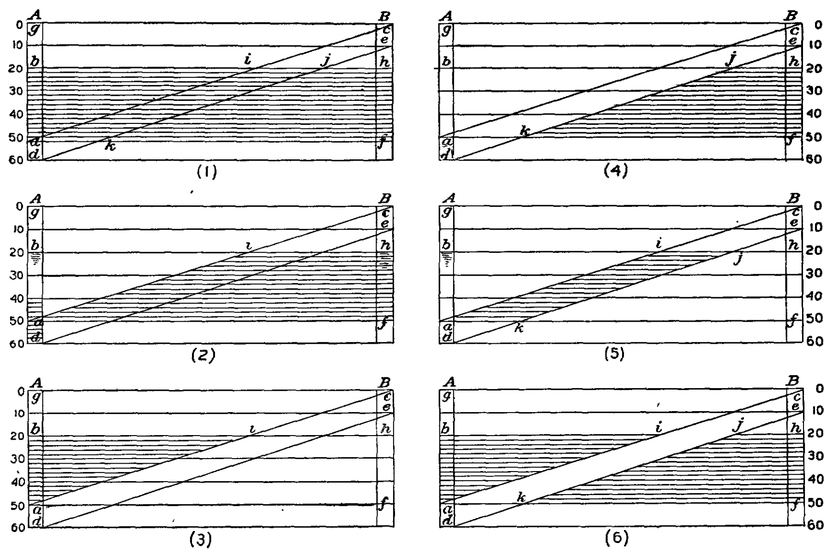

FIG. 9.—Illustrations of conditions influencing the available quantity of underground water.

With regard to the foregoing illustrations it should be remembered: First, that a given set of conditions in one locality will not necessarily be repeated in another, although the two localities may be close together. Second, that favorable conditions at one place are not to be interpreted too freely, and, vice versa, that unfavorable conditions at one place are not proof that like conditions will obtain elsewhere.

In the illustrations the various beds are assumed to be wholly impervious or wholly unconsolidated, allowing a free passage of water. As I have already stated, they really vary in porosity from impervious clay to the most open gravels and bowlders, and any particular bed may vary in a short distance from a clay to a mass of bowlders.

Applying the principles more specifically, it may be stated that in Salt River Valley wells which are practically worthless have been sunk within short distances of wells which are very productive. In certain cases the material penetrated was found to be of too close a texture to allow the water to pass readily through it. Such wells failed not from any lack of water, but because the water could not enter them fast enough to yield the large amount required for irrigation. This retardation of flow may be due to various causes, prominent among which are—first, silt deposited with the gravels; second, beds of clay which the well happens to penetrate; and, third, a cementing of the gravels by a deposit of caliche, which renders them more or less impervious. The occurrence of cement or caliche in the valley fill is very common.

The wells at Sacaton are the first to be put down in the Gila Valley. The indications thus far are favorable and it is expected that they will prove successful, but their success can not, however, be assured until a trial has been made. In the light of facts already known, however, even a failure of these wells should not be interpreted as a demonstration that pumping is impracticable in the Gila Valley.

It may furthermore be stated that Sacaton is not situated in the most promising locality for obtaining water by pumping. In the western third of the reservation the underflow from the Santa Cruz and a part at least of the underflow from Salt River joins that of the Gila, resulting, as previously described, in the return to the surface of a large volume of water. It is obviously in this part of the reservation that the most promising conditions are to be expected. Pumping plants can probably be operated with profit throughout the length of the reservation, but indications point to the probability that those situated in the western third would prove more profitable than plants at other localities, for the following reasons:

(1) The water lies near the surface over a large area, assuring a low lift.

(2) The large volume of return water gives assurance of a large quantity available for pumping.

(3) The freedom of movement of the underground waters, evidenced by the quantity of return waters and the occurrence of large springs, etc., indicate that a small number of wells would yield a given amount here while a much greater number would be required in a region where the movement of the water through the sands and gravel is more retarded. In certain places in Salt River Valley single wells are yielding 175 inches of water, while in other places there are wells yielding less than 50 inches. Pumping plants established in a region where there is a free movement of the underground waters require fewer wells for the required amount, and the initial cost of installation is correspondingly less.

(4) The greater the freedom of movement of the water through the gravels the less will be the local depression of the water level by the pumping and the less the total lift, with a corresponding decrease in running expense.

(5) The more segregated the land irrigated the more economically can the water be used.

For the above reasons the most promising place for the establishment of pumping plants is in the western third of the reservation.

COST OF PUMPING.

There is little doubt that sufficient water is present in the Gila underflow near the surface to more than supply the needs of the Indians. There is little doubt, furthermore, that the methods now being employed at Sacaton and at several points in Salt River Valley are adequate to secure this water in satisfactory quantities. It remains to inquire at what cost the water can be placed at the disposition of the water users. As no estimate has been made of the cost of operating pumping plants in the Gila Valley, the cost of those in Salt River Valley may be taken as a criterion.

Mr. Code[a] shows that water is raised 44 feet at the Murphy-McQueen ranch, near Mesa, Ariz., at a cost of $2.27 per acre-foot, using steam power, with wood for fuel. The Consolidated Canal Company, of Mesa, raises water 47 and 50 feet at a cost of approximately $2.50 per acre-foot. The power used is electricity, and is rated at its retail value in Phoenix. Computations of cost for other pumping plants in Salt River Valley give costs per acre-foot varying from $2 to $4. The horsepower of the Murphy-McQueen engine is estimated at 80. The cost per hour in operating the plant is $1.26. At this rate the cost per horsepower per year is $137.97. It has been estimated that electric power can be produced at a cost of $50 or less per horsepower per year. Other things equal, this rate of expense would reduce the cost of raising water at the Murphy-McQueen plant to about 82 cents per acre-foot. Data obtained from other pumping plants of Salt River Valley indicate that if the cost of power does not exceed $50 per horsepower per year water can be pumped from the underflow at a cost of about 75 cents to $1 per acre-foot, according to the amount of lift, kind of pump used, etc.

Professor McClatchie, of the Arizona Agriculture Experiment Station, has determined the value of an acre-foot of water in this region to vary from $3.65 in the case of wheat sown under unfavorable conditions to $56.45 when strawberries are raised. Wheat may be taken as the staple crop of the Indians. Professor McClatchie's figure for the value of an acre-foot of water applied to wheat is $3.65 to $5.60.[b] It is therefore evident that water can be furnished to the Indians by means of pumps at a cost sufficiently below the commercial value of the water thus obtained to make money spent in the establishment

[a] Code, W. H., Irrigation investigation in Salt River Valley: United States Department of Agriculture; report of irrigation investigation for 1901, No. 1, p. 66.

[b] McClatchie, Alfred J., Irrigation at the station farm, 1898-1901: Univ. Ariz. Agric. Exp. Station Bull. No. 41, 1902.

of properly constructed pumping plants a safe and profitable investment. It should be stated, however, that the Indians can scarcely be expected to make as good use of water as Professor McClatchie makes, even under the most adverse conditions, on his experimental farm. The profit in the case of the Indians would be notably less than the figures indicate, owing to antiquated methods and lack of enterprise so common among them.

CHEMICAL CHARACTER OF THE UNDERFLOW.

Since the underground water of Gila Valley is found to be available for irrigation, it remains to inquire into the character of this water and its adaptability to irrigation.

Since the beginning of investigations and experiments looking to the establishment of pumping plants in Gila Valley, strong opposition to the use of pumped water has arisen from various sources, largely, it would seem, because of the assumption that the establishment of pumping plants would delay certain storage projects on Gila River. The obvious need of the Indians has been used as the strongest argument for pushing the storage projects, and many statements which are not substantiated by facts have been made regarding the use of pumped water and its effects on soil and vegetation. It has been stated that underground water contains salts detrimental to plant life; that orchard trees have been killed by the use of pumped water; that fields of grain and alfalfa have been destroyed by it; and that land once productive has been rendered useless by accumulations of alkali due to its use.

In regard to the saline character of the Gila underflow the chemical studies of Profs. R. H. Forbes and W. W. Skinner, of the Arizona experimental station, have supplied definite information.

SALT CONTENT OF THE SURFACE FLOW.

Those who oppose the use of underground water for irrigation assert that the surface water of the river is beneficial to the land while the underflow water is detrimental. Concerning the surface flow Professor Forbes writes:[a]

> The Gila River, under the direction of the late Judge W. H. Benson, was sampled daily near the head of the Florence canal. Sampling began November 28, 1899, and continued nearly all the time that water flowed until November 5, 1900, the daily samples being taken in the usual manner and combined in sets of 7, in demijohns. No record of the flow of the Gila for this period is available, but the volume of water during this time ranged from practically nothing, from March 7 to about July 20, 1900, to considerable floods in August and September, 1900. A maximum range in the character of the water was therefore observed, although as a whole the year was dry and the river low. * * *

[a] Forbes, R. H., The river irrigating waters of Arizona: Univ. of Ariz. Agr. Exp. Station. Bull. No. 44, 1902, pp. 182, 185, 191-192.

TABLE V.—*Silt and salts in Gila River waters November 28, 1899, to November 5, 1900.*

[Parts in 100,000.]

Period.	Silt.	Salts.	Period.	Silt.	Salts.
Nov. 28–Dec. 4, 1899	73	120.0	Aug. 8–14, 1900	4,380	39.4
Dec. 5–11, 1899	56	119.6	Aug. 15–21, 1900	159	88.8
Dec. 12–18, 1899	36	120.2	Aug. 22–28, 1900	75	96.2
Dec. 19–25, 1899	58	116.6	Sept. 1–7, 1900	2,959	39.4
Dec. 26–Jan. 1, 1900	78	110.4	Sept. 8–14, 1900	9,406	54.4
Jan. 2–8, 1900	55	112.6	Sept. 15–21, 1900	7,620	48.4
Jan. 11–18, 1900	36	118.0	Sept. 22–28, 1900	1,937	46.0
Feb. 1–7, 1900	16	115.8	Sept. 29–Oct. 7, 1900	29	110.2
Feb. 8–14, 1900	9	113.0	Oct. 8–14, 1900	28	110.6
Feb. 15–21, 1900	15	112.8	Oct. 15–21, 1900	52	104.0
Feb. 22–28, 1900	8	112.4	Oct. 22–28, 1900	406	104.6
Mar. 1–7, 1900	12	112.4	Oct. 29–Nov. 5, 1900	293	113.2
Aug. 1–7, 1900	7,534	69.0			

* * * The dissolved solids in the Gila vary from a small amount (39.4 parts in 100,000) in time of flood to marked salinity (120 parts) in time of low water. For fifty-nine days of the partial year under observation the total solubles were less than 100 parts in 100,000, and more [than that amount] for one hundred and thirty-eight days.

The character of these salts varies markedly with the stage of flow. Low waters are hard in character, containing chiefly common salt, calcium sulphate or gypsum, and calcium and magnesium carbonates, but no excess of sodium carbonate or black alkali. Flood waters, on the other hand, are distinctly black alkaline, being of this character for six weeks of the highest water during August and September, 1900. The weather maps show that the Gila floods of August and September, 1900, both originated in the largely granitic watershed of the San Pedro and in the less-known country of the far upper Gila, granitic rocks being a leading source of sodium carbonate. * * *

TABLE VIII.—*Composition of waters of the Gila River.*

Samples taken at the head of the Florence canal, below The Buttes, Ariz.	Low winter water: Average of 7 weekly composites of daily samples, Nov. 28, 1899–Jan. 18, 1900.	Low winter water: Average of 5 weekly composites of daily samples, Feb. 1, 1900–Mar. 7, 1900.	Summer flood water: Average of 2 weekly composites of daily samples, Aug. 1–14, 1900.	Summer low water: Average of 2 weekly composites of daily samples, Aug. 15–28, 1900.	Summer flood water: Average of 4 weekly composites of daily samples, Sept. 1–28, 1900.	Summer low water: Average of 5 weekly composites of daily samples, Sept. 29–Nov. 5, 1900.
1.—*Partial analysis.*						
Silt, per cent by weight	0.056	0.012	5.957	0.117	5.481	0.162
Soluble solids, parts in 100,000	116.8	113.6	54.2	92.5	47.1	108.5
Containing:						
Chlorine, stated as common salt, $NaCl$	66.2	63.3	15.9	39.5	9.4	59.7
Alkalinity, stated as sodium carbonate, Na_2CO_3	--------	--------	3.66	--------	6.65	--------
Hardness, stated as calcium sulphate, $CaSO_4$	7.4	10.04	--------	9.11	--------	10.01
Nitrogen, parts in 1,000,000:						
Total nitrogen in silt and water	2.37	1.54	63	1.97	40.60	1.37
Nitrogen in nitrates	.45	.56	.88	.79	.61	.51
Nitrogen in nitrites	Traces.	Traces.	None.	None.	None.	None.
2.—*Complete analysis of soluble solids, stated by ions: Parts in 100,000 of water.*						
Solium, Na	31.21	28.07	--------	--------	8.23	27.18
Potassium, K	1.78	1.38	--------	--------	2.26	1.51
Calcium, Ca	5.24	6.63	6.86	8.36	5.71	9.37
Magnesium, Mg	2.64	2.89	1.75	1.57	1.21	2.48
Chlorine, Cl	40.11	38.34	9.65	--------	5.74	36.48
Sulphuric, SO_4	15.59	16.50	9.47	13.07	9.64	14.56
Carbonic, CO_3	6.53	6.93	--------	--------	11.08	12.78
Silicic, SiO_3	7.52	6.52	--------	--------	2.66	5.11
3.—*Complete analysis of soluble solids, calculated to compounds: Parts in 100,000 of water.*						
Sodium carbonate, Na_2CO_3	--------	--------	3.66	--------	6.65	--------
Sodium silicate, Na_2SiO_3	12.08	10.47	--------	--------	4.27	8.20
Sodium chloride, $NaCl$	66.19	61.31	--------	--------	9.48	60.20
Sodium sulphate, Na_2SO_4	1.76	--------	--------	--------	--------	1.14
Potassium chloride, KCl	--------	2.43	--------	--------	--------	--------
Potassium sulphate, K_2SO_4	3.97	.24	--------	--------	5.04	3.37
Magnesium sulphate, $MgSO_4$	.19	.58	--------	--------	--------	--------
Magnesium carbonate, $MgCO_3$	9.14	9.70	--------	--------	4.24	8.68
Calcium sulphate, $CaSO_4$	17.30	22.54	--------	--------	9.71	16.92
Calcium carbonate, $CaCO_3$	--------	--------	--------	--------	7.15	10.97

SALT CONTENT OF THE UNDERFLOW.

Analyses of underground waters have been made in and near Gila Valley as indicated in the following table:

Analyses of underground waters of Gila Valley, Arizona.

Location.	Quantitative: Parts in 100,000.						Qualitative.[a]			
	Total soluble solids at 100° C.	Chlorine, NaCl (common salt).	Hardness, $CaSO_4$ (calcium sulphate).	Alkalinity, Na_2CO_3 (black alkali).	Nitrogen, $NaNO_3$	Nitrogen, $NaNO_2$	Sulphates.	Magnesia.	Lime.	Bicarbonates.
T. C. Sharp, Sacaton (shallow well)	132.6	66.8	29.4	0.00	0.083	0.031	v. s.	s.	v. s.	
Agency, Sacaton (deep well)	68.0	28.8	0.0	2.97	.08		d.	s.	s.	s.
Mission well, Gila Crossing	160.0	110.8	28.4	.0			v. s.	s.	s.	s.
Gila River, Gila Crossing	127.0	76.4	12.5	.0			v. s.	s.	s.	p.
Cooperative Company's ditch, Gila Crossing	106.0	62.8	13.1	.0			s.	s.	s.	s.
Lake at head of Hoover's ditch	107.0	61.2	2.72	.0			v. s.	s.	s.	s.
Consolidated Canal Co.'s well	84.0	44.60	18.50	.0	.266	t.	s.	d.	s.	v. s.
Hansen's well	446.8	307.0	135.4	.0	f.	f.	s.	s.	v. s.	
Maricopa	39.8	6.4	5.41	.0	.104	v. f.	s.	s.	f.	

[a] f., faint; v. f., very faint; s., strong; v. s., very strong; p., pronounced; d., distinct; t., trace.

The analysis of water from Maricopa indicates the character of the water joining the Gila underflow from the Santa Cruz; that from the Consolidated Canal Company's well and Hansen's well the character of that entering from Salt River, while those from Gila crossing, since they are return waters from the underflow, represent the combined waters of the Gila, Salt River, and Santa Cruz. The high salt content in the Hansen well is an exception to the general rule. The water of this well contains the greatest amount of saline matter of any irrigation well in Salt River Valley.

In answer to certain objections raised by Dr. Charles H. Cook, of Sacaton, Mr. T. H. Means, of the United States Department of Agriculture, in a letter to the chief engineer of the reclamation service, writes:

Your letter of March 31, inclosing copy of letter from Mr. Charles H. Cook, has been received.

I am much interested in the comments Mr. Cook makes regarding the use of the Sacaton pumped water. I have just received from Professor Forbes, of Tucson, a copy of an analysis of the water from the Sacaton wells. This analysis is as follows:

Analysis of water from Sacaton wells, Arizona.

	Parts per 100,000.
Total solids	68.00
Sodium chloride	28.80
Sodium carbonate	2.97
Nitrates	.08

If I were called upon to pass judgment upon the value of such a water for irrigation purposes I would say unqualifiedly that the water does not contain soluble salts in harmful quantity, and that irrigation with it, where anything like reasonable care is exercised in its use, should not injure the land.

I am not acquainted with the soil conditions at Sacaton, but do not see any condition in a good soil which would modify the above statement. Mr. Cook's comparison of conditions at Hansen's place and those at Sacaton is scarcely fair in view of the fact that the water from Hansen's well carries from 446 to 509 parts of soluble matter per 100,000, or about 7 times as much as does the Sacaton water; and from parties around Tempe I understood that the irrigation on Mr. Hansen's place was a perfect success. The normal water supply in the Buckeye canal carries about 180 parts per 100,000, or nearly three times as much as the Sacaton water. Irrigation at Buckeye has been carried on for fifteen years with no detriment to well-drained soils. The normal low-water flow of Salt River at the Arizona dam carries 100 parts salt or more, or 1⅝ times as much as the water from Sacaton wells.

The only element in the Sacaton water which does not occur in the sources cited above is sodium carbonate to the extent of 2.97 parts. This amount of black alkali should not interfere with cultivation. A small application of gypsum to the soil would overcome any alkaline tendency, but I do not think that even that would ever be necessary. All of the sources of irrigation water in the Salt River Valley occasionally carry small amounts of black alkali, but no harm has ever come of their use, so far as I know.

So it would seem to me that at Sacaton there is developed a source of water better than the average water from Salt or Gila rivers. I have eleven analyses from artesian wells at Safford and neighborhood, and in every analysis but two the black alkali exceeds that in the Sacaton water. I am told that irrigation with the artesian water at Safford is a success.

UNDERFLOW AND SURFACE FLOW COMPARED.

A comparison of the total salt content of the surface flow with that of the underflow indicates that the surface waters contain salts varying from 39.4 to 120.2 parts in 100,000 parts of water. The twenty-five analyses given indicate an average of 96.3 parts. The salt content of the underflow varies from 68 to 160 parts in 100,000 parts of water. The average of the six analyses from the Gila Valley is 126.6. The underground water at Sacaton is better for irrigation, so far as the salt content is concerned, than the average surface water of the river.

Sodium carbonate, or black alkali, is the salt most feared by water users in this region. Confusion in the use of the term "alkali" leads to misunderstanding. Alkali, as used by some, means all salts in solution, while as used by others alkali means only the harmful black alkali (Na_2CO_3). Thus the whole salt content is frequently understood to be black alkali.

In Gila Valley there are large areas of land covered with white incrustations of salt, deposited by the evaporation of water reaching the surface from beneath. These deposits of "alkali" are believed by residents of the region to be composed largely of "black alkali," or sodium carbonate, and they reason that land thus affected is past redemption. In every case tested these incrustations were found to be composed so largely of common salt that no other salt could be detected by testing. The analyses of the Gila waters indicate that black alkali is only occasionally found in the waters, and that the great bulk of the soluble material is composed of common salt and the comparatively harmless salts of lime.

Examples of the successful use of waters more saline than those of the Gila underflow are numerous:

The Collins well, near Phoenix, has for several years supplied land with irrigating water containing 150 parts of soluble salts in 100,000 parts of water; no detrimental effect has been detected.

Mr. Kunz, near Phoenix, has watered a botanical garden for five years with water containing 223 parts of salt.

The court-house yard at Phoenix, in which trees, shrubs, and flowers grow luxuriantly, has been watered for about twenty years with well water containing 136 parts of salt.

The Indians at the western end of the Pima Reservation use seepage water from Salt River containing about 200 parts of salt. Land upon which this water has been used continuously for at least thirty years is at the present time the most productive land on the reservation.

Similar examples from other regions might be given. Perhaps one which is certainly an extreme case may be sufficient. Mr. Thomas H. Means, of the United States Department of Agriculture, has published a pamphlet entitled "The Use of Alkaline and Saline Waters for Irrigation,"[a] in which he states that in the Sahara deciduous fruits, garden vegetables, and alfalfa, as well as the more hardy forms of vegetation, are successfully raised by the use of water containing in certain cases more than 800 parts of soluble salts in 100,000 parts of water.

There is no doubt that in certain instances salts have accumulated in the soil to such an extent that vegetation has been destroyed, but such accumulations are usually due to improper drainage. There are scores of instances in Salt River Valley where water more saline than that of the Gila underflow is being successfully used in raising fruits, garden vegetables, and farm produce of every kind. Mr. Hansen is, at present writing, watering a large tract of cantaloupes with the most saline water in the valley—6.5 times more saline than the water at Sacaton.

The alleged destruction of fruit trees is doubtful. In spite of the frequent statements made in this region I have yet to find an authentic case of a tree dying as a direct result of the application of pumped water, although there are scores of orchards in this region in which trees have died for lack of water. There may be instances of orchards destroyed because of improper drainage, but this is as likely to occur with river as with pumped water. There are many instances, on the

[a] Means, Thomas H., U. S. Dept. of Agr., Bureau of Soils, Circular No. 10.

other hand, where orchards are thriving on pumped water when enough is supplied. For instance: At a certain place in Salt River Valley a few years ago some trees were planted and watered with pumped water. The facilities for supplying water were meager. The trees lived for some time, but did not thrive, and finally died. It was stated at the time, and the statement has been frequently repeated, that the well water killed them. Later the Consolidated Canal Company established one of its pumping plants at this point. The same kind of trees were again set out in place of those that had died; they were watered with an abundance of well water, and are now in a thriving condition.

The reclamation of land affected by accumulations of alkali may be troublesome, but it is not impossible. Much of the land along Gila River is affected with accumulations of salt. This land could be reclaimed if such reclamation were found preferable to the utilization of land comparatively free from such accumulations. There is probably enough of the latter on the reservation to meet all requirements for years to come. As applied, however, to the objection of the use of pumped water, the danger from alkali accumulations fails, since the surface waters are as likely to cause such accumulations as the underground waters.

ECONOMIC CONDITION OF THE INDIANS.

Since there is little doubt that large quantities of water are available in the underflow of Gila Valley, and since there is good reason for believing that it can be secured by pumping at a cost sufficiently low to render this method of securing it practicable, it remains to inquire whether the Indians would make proper use of this water if it were placed at their disposal. The facts, opinions, and estimates given below have been gleaned from men who have lived among the Indians for a longer or shorter time and from my own observations. Very little of a definite nature can be given owing to the lack of records.

MARICOPAS.

At my request, Mr. M. M. Murphy, superintendent of irrigation for the Maricopa Indians, gave me the following statements regarding the Maricopas and those Pimas at the western end of the reservation, with whom he is well acquainted:

Maricopa Indians on the west end of the Pima Reservation number about 275. There are 67 families; they own 1,069 acres of cultivated land, divided into 133 tracts or farms, many Indians owning as many as five farms in different parts of the village. The Maricopas have 74 children in school—40 in the Maricopa day school and 34 in the Phoenix Indian school.

In 1901 the Maricopas cultivated about 800 acres of wheat and 15 or 20 acres of corn, etc. In 1902 they cultivated about 800 acres of wheat and about 150 acres in corn, etc. In 1903 they cultivated about 1,000 acres of wheat and about 450 acres of corn, etc. The corn and other summer crops are planted after wheat is harvested.

In addition Mr. Murphy informs me that the Maricopas raised 5,600 bushels of wheat in 1902, and 16,000 bushels in 1903. Many of them have money laid away, amounting sometimes to $3,000 or more. In general, in his opinion, their money is not spent foolishly, and there is a marked tendency toward prosperity. They know little of banking. Their money is laid away for the most part in gold or silver coin, and it is naturally difficult to learn the amount. A number of the more intelligent Indians have recently asked Mr. Murphy to place their savings for them. Gambling was formerly prevalent among them, but has now been largely rooted out.

My own observations while among the Maricopas bear out the general conclusions given by Mr. Murphy. The cultivated lands are well tended. The fields are inclosed by wire fences, and the irrigation ditches clean. The school children appeared comfortably dressed and well cared for. On the whole, the Maricopa Indians are industrious and moderately prosperous. It should be stated, however, that this is largely due to the efficient supervision of Mr. Murphy. While there are a few who would prosper unaided, the Indians as a people need direction. Mr. Murphy has found it necessary to be dictatorial with them, telling them what to do and when to do it. They are willing to work, and usually willing to be directed. The result of this supervision is seen in the increased wheat crop. The amount of water was the same in both years, but under his supervision the wheat crop was increased from 5,600 bushels in 1902 to 16,000 bushels in 1903.

PIMAS OF GILA CROSSING.

Concerning the Pimas of the western end of the reservation, Mr. Murphy says:

> The other Indians living west of Maricopa and Phoenix and Salt River Valley Railroad are Pimas. They reside at a point on Gila River known as Gila Crossing; they occupy six villages; each village maintains a dam and ditch for securing the seepage water available at that point. The aggregate population is about 1,200, and they have about 1,500 acres in cultivation. These Indians have never been disturbed by whites in anyway. They have always had an ample water supply for from 4,000 acres to 6.000 acres. They are very poor and there is considerable suffering among them every year from cold and hunger, but their poverty and distress are due to their own ignorance and idleness.
>
> Indians are deficient in judgment and in executive ability, hence it is necessary to place them under proper supervision until desired reforms become fixed habits.

These Indians own their irrigation ditches and maintain them by cooperative work. The want of law and system leads to trouble, injustice, and waste of water. The man who owns 1 acre must work as much in maintaining the ditch as the man who owns 10 acres. The distribution of water is equally unjust. Each man takes what he can get whenever he wants it. The result is that certain farms fail entirely for want of water even when there is water enough for all. On the other hand, a large proportion of the water runs to waste owing to want of repairs in ditches and dams.

During the present year the diversion dams have been carried away five times. The result is not only that no flood water is secured, but that a large part of the ordinary current due to seepage or return of the underflow is wasted before the dams are repaired. The Indians seem to be incapable of building or maintaining such constructions as will conserve their available water supply. They have shown themselves incapable of equitably distributing such water as they secure. The available water at Gila Crossing, if used to the best advantage, is probably sufficient to maintain in some degree of comfort those Indians now living in that locality. A large part of the water, however, is allowed to run to waste. The greatest need of the Indians at Gila Crossing is a man of experience and infinite patience, who will, like a schoolmaster, assign daily tasks and enforce obedience.

Dr. C. H. Ellis, who resides at Gila Crossing, states that the Pimas of that locality are poor and shiftless, not so much because of a lack of water as because of a lack of executive ability. They will work if they are compelled to work, and it is not difficult to compel them. A simple command is usually sufficient, but the command must be repeated day by day. They are not more shiftless by nature than the Maricopas. They need above all else a practical man to direct them. They must be compelled to have their land ready at a certain time for the use of water. Each Indian must be informed individually what he must do and when he must do it. The commands of a properly appointed overseer are usually recognized, though occasionally force is necessary.

In talking with various men acquainted with the situation at Gila Crossing there was general agreement regarding the trouble and its causes. The old customs, usages, and practices remain, the Indians seeming unable to adjust themselves, unaided, to new conditions. Their laws and customs, especially with respect to the ownership of land and the maintenance of irrigation ditches and the use of water, are sadly in need of revision. Mr. Murphy's conclusion that "it is necessary to place them under proper supervision until desired reforms become fixed habits," seems to be the only rational way of dealing with the situation.

On the other hand, there are at Gila Crossing a number of Indians who are moderately prosperous. One is reported as having several thousand dollars laid away, and owns several hundred cattle and horses. Several small bunches of cattle belonging to Indians were seen.

PIMAS OF SACATON.

The Indians living east of the Maricopa, Phoenix and Salt River Railroad have much worse conditions to contend against than those at the western end of the reservation. Doctor Cook, who has lived among the Pimas for thirty-two years and probably knows them better than any other man, states that there are about 2,800 Pimas living east of the railroad. These Indians have had little water since 1890. Many farms which were productive before that time have lain idle for the past thirteen years. Occasionally enough water is obtained from a flood or from a shower to raise a scanty crop if the land happens to be ready at the right time. This, however, is so uncertain that most of the Indians have long since ceased to prepare their fields for the possibility.

A small amount of seepage water is obtained near Sacaton, and with this a few Indians raise wheat and corn.

Mr. Bell, who has kept a store at Sacaton for twenty years, speaks highly of the Indian character. He trusts them fully for goods, and finds that they pay their debts faithfully when they have anything to pay with. Mr. Bell was kind enough to show me his account books, and stated that his loss through bad debts was no greater than when dealing with whites. This year (1903) he bought from the Indians about 400,000 pounds of wheat, and estimates that at least four times as much has been bought by other traders; 325,000 pounds have been bought at the agency. The largest individual sales of wheat which came to my notice are 21,000 pounds by an Indian from Blackwater village and 3,000 pounds by another from the same place. These, however, are exceptional cases. The great majority of the Indians do not have water enough to raise grain sufficient for their own needs.

It is difficult to secure any adequate conception of what the Indians would do if supplied with water. It seems, however, safe to state that much land now idle would be made productive, and something like the former prosperity restored. Doctor Cook states that in 1879, before the water was taken from the Indians, he bought from them in one summer 750,000 pounds of wheat. There were at that time five other traders, who did about the same amount of business, making the aggregate amount of wheat sold at that time about 4,500,000 pounds.

Here, as at the western end of the reservation, the Indians are described as willing to work, but unable to wisely direct their own movements. With proper supervision and proper opportunities—the two must go together—the Indians would not only be self-supporting, but would raise much produce for market. The men who know the Indians best almost unanimously agree that next after an adequate water supply their most urgent need is adequate supervision. They have willing hands, but the head must be supplied to make them prosper.

The Indians are slow to adopt modern improvements. They can not adapt themselves readily to new conditions. They still reap their wheat with the sickle and thrash it on the ground by driving horses over it. It is winnowed by throwing it into the air, and it is washed and picked over by hand before it is marketed. Modern implements of agriculture are useless, the Indians not knowing how to use them and seldom caring to learn. It will take years of patient supervision to supplant the antiquated methods, but the case is not hopeless.

During my last visit to Sacaton I was fortunate enough to meet the chief men of the tribe, who had gathered in council at the call of their chief. Antonio Azul, a well-preserved old man of 90 years, has been chief of the Pimas for forty-three years. He has been probably the most prosperous man of his tribe, and formerly had large cultivated fields and large herds of cattle.

At the council of the chief men I took occasion to explain to them something of the cost incurred in developing water, and inquired if they were willing to pay the cost of water which might be supplied. This had been previously explained to them individually, so that they understood thoroughly, and all signified their willingness to pay for the benefits received. I next inquired of men who know the Indians best whether they would be able to meet such obligations. The opinion expressed by some was that payment would be prompt; by others, that the cost, estimated at $1 to $1.50 per acre-year, is greater than the Indians could possibly pay; by others, that some could pay and many could not; and by still others, that the question of remuneration was purely a question of the quantity and quality of supervision afforded them by overseers. If left to their own devices, few would do more than support themselves. If compelled to work by modern methods, many, if not all, would be able to pay the cost of water supplied to them.

The question of the development of underground water by the Indians themselves, either individually or collectively, is easily answered. They are not progressive enough, nor have they executive ability enough to put a pumping plant into operation, and it is very doubtful whether they could be trusted to keep one of even the most simple construction in operation if it were installed for them. If water is supplied to the Indians by pumping, the pumping plants must be installed and operated by white men.

The question of whether the Indians would properly use water which may be developed for them can be answered only by actual trial. It is my judgment, based on what I have seen and heard during the past six months, that they can be instructed to use it properly and profitably. The more important facts which lead to this conclusion may be stated as follows:

1. The Indians of Gila Valley have long been an agricultural people. They irrigated their land from the Gila River long before white men came to interfere with their rights.

2. They are peaceful, never having been at war with the whites.

3. They are industrious, though their industry needs direction and supervision.

4. They are honest; they are not given to thieving; they pay their debts.

5. They have generous natures; giving freely toward the support of those who are in need is common among them.

RÉSUMÉ.

Since the purpose of this investigation is to determine the possibility of developing the waters of the underflow of the Gila Valley for the benefit of the Indians, the following facts and considerations are deemed worthy of special attention:

1. The Indians have a right by the law of priority to the use of the water of the Gila River.
2. This water has been taken from them, the surface waters of the Gila no longer reaching the reservation, with the result that the land cultivated by them has been reduced from 14,000 to about 7,000 acres, and even this reduced area is imperfectly supplied.
3. The valley fill is saturated with the water of the Gila underflow.
4. Near Sacaton and at Gila Crossing the underground waters return to the surface, to some extent forming a surface flow.
5. Both experiment and computation based on conservative assumptions indicate that the volume of water in the Gila underflow is probably greater than the estimated needs of the Indians.
6. A comparatively small amount of the underflow returns to the surface as seepage water and is used for irrigation.
7. An amount of underflow sufficient for the needs of the Indians is near enough the surface to be within easy pumping distance.
8. The chemical character of the waters of the underflow is favorable to their use in irrigation.
9. Pumping plants used in irrigation near Gila Valley prove that water can be pumped rapidly enough and at a cost low enough to make pumping a practicable method of securing water for irrigation for the Indians, provided its use is properly directed.
10. The Pima and Maricopa Indians are peaceful, honest, industrious, but are lacking in executive ability.
11. They are easily managed and are prosperous when wisely directed.
12. When left to their own devices they do not properly appreciate or utilize their advantages.
13. At Gila Crossing their most imperative need is adequate supervision. Their need elsewhere is, first, a water supply; second, supervision.
14. A water supply without supervision would be unwise.
15. As a general conclusion, it is the writer's judgment that water can be supplied for the Indians of the Gila Valley by pumping and that by proper supervision they can with comparative ease be made moderately prosperous.

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