Water-Supply and Irrigation Paper No. 136

Series { B, Descriptive Geology, 67
K, Pumping Waters, 10
O, Underground Waters, 37 }

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

UNDERGROUND WATERS

OF

SALT RIVER VALLEY, ARIZONA

BY

WILLIS THOMAS LEE

WASHINGTON

GOVERNMENT PRINTING OFFICE

1905

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., June 1, 1904.

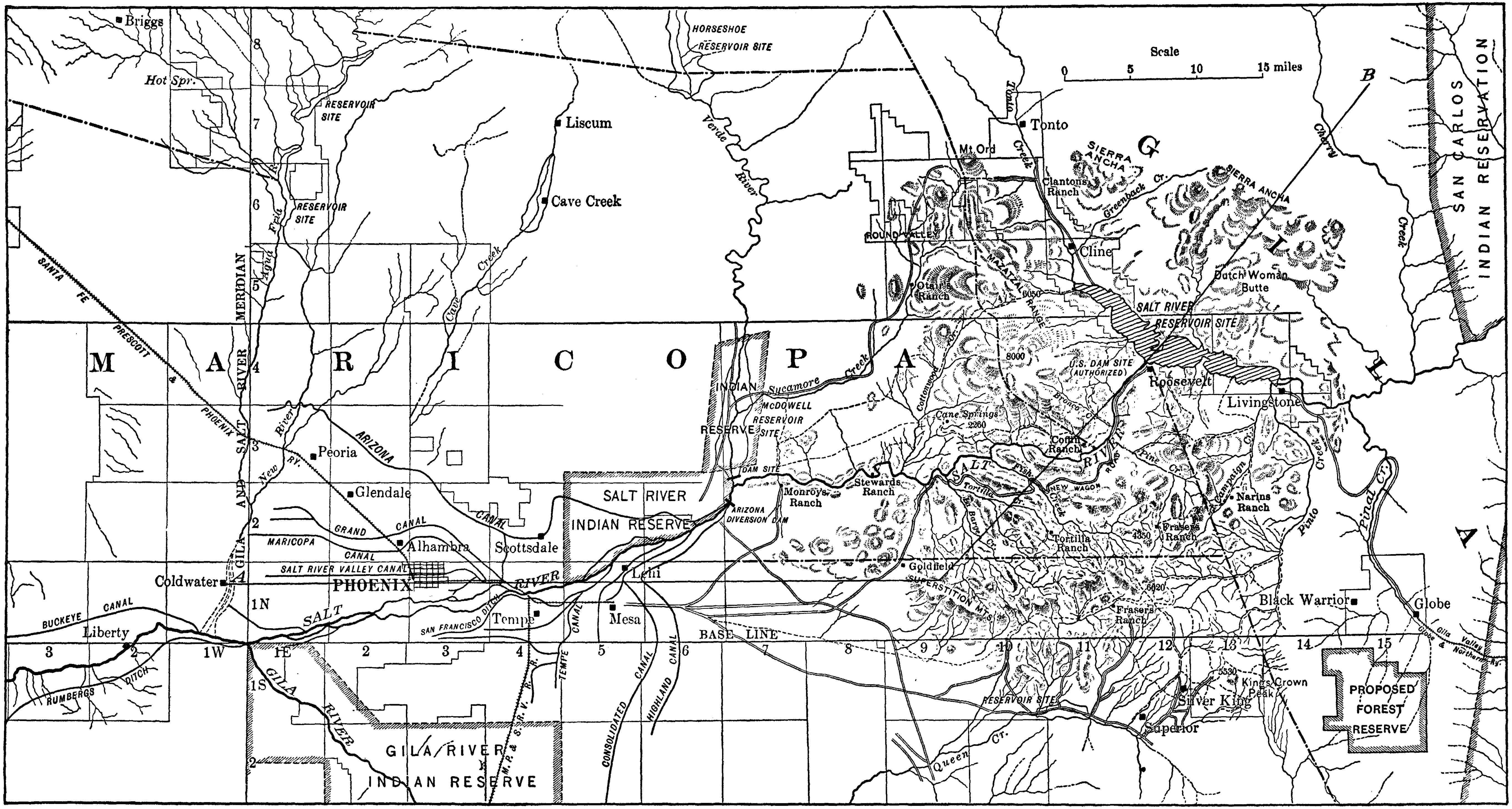
SIR: I forward herewith a report on the underground waters of Salt River Valley, Arizona, by Willis T. Lee, and recommend that it be published as a water-supply and irrigation paper.

Mr. Lee, under the direction of Mr. N. H. Darton, geologist in charge of the western section of hydrology, has made a detailed investigation of the underground waters and geology of Salt River Valley, in the Phoenix region and eastward, and I believe the results will be of value and interest to a large number of persons. The region is one in which the problem of water supply is of great importance, for its prosperity is entirely dependent upon the utilization of the surface and underground waters.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

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



MAP OF CENTRAL ARIZONA, SHOWING AREA DESCRIBED.

UNDERGROUND WATERS OF SALT RIVER VALLEY, ARIZONA.

By Willis T. Lee.

INTRODUCTION.

PURPOSE OF THE INVESTIGATION.

The purpose of this paper is to bring together the facts, so far as known, regarding the underground waters of Salt River Valley, with a view to ascertaining their available quantity, the areas where they occur sufficiently near the surface for economic pumping, and their adaptability for irrigation.

The area of special investigation lies within a line drawn from the junction of Verde and Salt rivers westward a few miles beyond the Agua Fria and southward to Gila River; thence along the northern border of the Pima Indian Reservation to the Superstition Mountains north of Florence, and along the foot of these mountains to the mouth of Verde River—an area, irrespective of the mountains, of about 1,000 square miles. A number of side trips were made beyond this area into the neighboring mountainous districts, but the principal part of the work was done in the lowlands included within the above boundaries. This area is conveniently divided into two districts by a line of buttes that extends across the valley in the vicinity of Tempe, connecting the Phoenix Mountains with the Salt River Mountains. The physical conditions existent east of this line of buttes differ notably from those to the west of it. The division of the valley into two districts is therefore to more purpose than mere convenience of description. The first district, which extends from the mouth of the Verde to Tempe, is known as the Mesa region, and the second, which extends from Tempe to the Agua Fria, is known as the Phoenix region. (See Pl. I.)

CHAPTER I.

WELL RECORDS.

THE MESA REGION.

MURPHY-McQUEEN WELLS (SEC. 34, T. 1 N., R. 5 E.).

The series of deep wells first completed and used for irrigation in Salt River Valley is that on the Murphy-McQueen ranch, near the town of Mesa. This series of wells has been described by W. H. Code in two publications,[a] and his descriptions are here transcribed. In the first he writes:

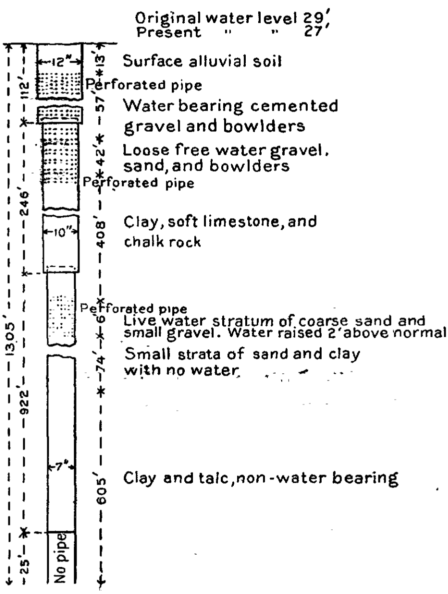


FIG. 1.—Bored well of S. J. Murphy, on Murphy-McQueen ranch, Mesa.

> The Murphy well (fig. 1) was started as a 12-inch double-steel-cased one, but on account of the great difficulties encountered in the way of bowlders and cement strata, together with a peculiar formation of clay known as the swelling variety, it has been necessary to reduce the size of the well three times in the depth of 1,305 feet, ending with a casing 7 inches in diameter.

In the later and more complete report Mr. Code writes as follows:

> Four 12-inch bored wells were sunk on a line, with 12½-feet centers. The first one was put down 1,305 feet in the hope that an artesian flow might be obtained. As the drill was still in a nonwater-bearing stratum of clay and talc when this depth was reached it was decided, after having penetrated this stratum 605 feet, to abandon the search for artesian flow and depend upon pumps for raising the water. The remaining three wells, therefore, were drilled to a depth of approximately 212 feet, the formations intercepted being as follows:

[a] Code, W. H., Report of irrigation investigations for 1900, No. 2: U. S. Dept. Agric., Bull. 104, 1901, p. 93; Report of irrigation investigations for 1901, No. 1: U. S. Dept. Agric., Bull. 119, 1902, pp. 65–68.

MURPHY-McQUEEN PUMPING PLANT.

Record of wells bored on Murphy-McQueen ranch.

	Feet.
Surface alluvial soil	13
Cemented gravel and bowlders	157
Loose free water gravel, sand, and bowlders	42
Total	212

Below this depth lay another stratum of clay, soft limestone, and chalk rock, 408 feet in thickness.

The pipes were all perforated thoroughly, and a central shaft was sunk to a depth of about 23 feet, which was very close to the normal water level, and from the bottom of this shaft tunnels were run in either direction in order that small sections of the steel well casings might be removed at this level and the wells all connected to one horizontal suction pipe. The four wells were connected by means of a longitudinal suction pipe, from which were suspended the vertical suction pipes leading down in each well to a depth of 25 feet or more below normal water level. The longitudinal pipe was attached to a 12-inch horizontal centrifugal pump having a capacity of 4,000 gallons per minute and located at the bottom of the shaft. The pump was driven by a steam plant, which, in brief, consisted of the following: One boiler, 5 by 16 feet, estimated capacity 80 horsepower; 1 automatic 12 by 16 inch engine, running condensing; 1 brick cement-lined condensing pit, 10 by 22 feet and with a depth of 5 feet, containing 40 2-inch pipes 20 feet in length.

The steam is condensed in the pipes by the water discharged from the centrifugal pump, which passes through the pit previous to its discharge into the irrigating ditches leading to the alfalfa fields. The machinery is all inclosed by a neat brick house, and the entire plant has a substantial appearance. [Pl. II.]

The writer was employed to superintend a test run of the plant after its completion, and through the courtesy of the owners is privileged to embody the following data from the report made to them.

The test run of the plant was begun at 7 a. m., July 4, 1901, and was completed at 7 p. m., July 11, 1901. The intention was to operate continuously for six days, but, owing to a twelve hours' enforced stop for repairs to the engine on July 8, the time was extended to six and one-half days. The average height to which the water was raised during the test was about 44 feet, the discharge pipe being several feet above the ground level. The machinery was run to its maximum economical capacity, and the results obtained were as follows:

Data obtained by test run of pump on Murphy-McQueen ranch.

Number of hours consumed in test	156
Number of hours consumed in stoppages (breaks, oilings, etc.)	26.4
Total number of hours operated	129.6
Average number of inches pumped (Arizona measure)	270
Average number of inches pumped (California measure)	338
Total number of acre-feet pumped	72.4
Total cords of fuel used	34.75

Daily expense of twenty-four hours' run, aside from fuel:	
Two engineers, at $2.25 per diem	$4.50
Two firemen, at $1.50 per diem	3.00
Oil and waste	.75
Estimated cost of repairs and maintenance	1.00
Total	9.25

Total expense of operation during test:	
6½ days, at $9.25 per diem	$60.12
34¾ cords of wood, at $3 per cord	104.25
Total	164.37
Cost per acre-foot of water pumped:	
Total cost of pumping	$164.37
Acre-feet of water pumped	72.40
Cost per acre-foot	$2.27
Expense for each hour actually running:	
Total expense	$164.37
Number of hours actually run	129.60
Cost per hour	$1.26
Lift, in feet	44
Average cost per foot of raising an acre-foot of water	$0.05+

The normal level of water previous to the test was 22½ feet below the average surface of the ground. The water level in each of the wells at the end of the test is shown in fig. 2. The sketch shows that the water in the deep well was not drawn

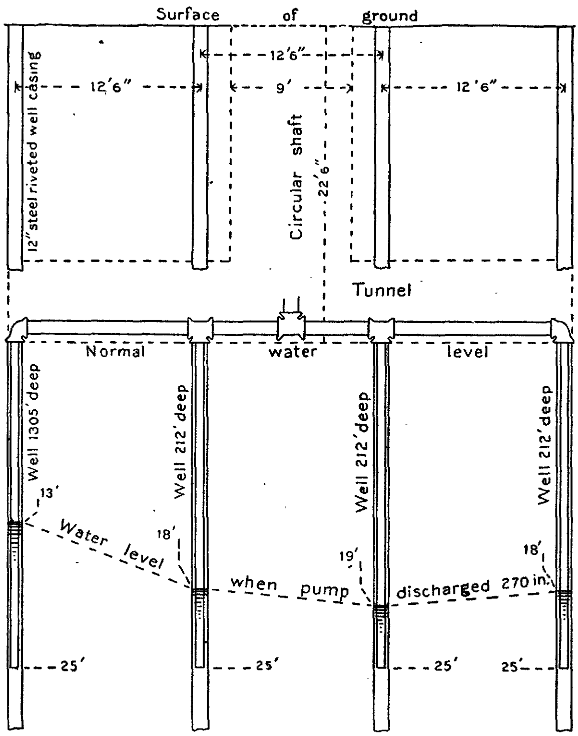


FIG. 2.—Diagram showing water level, after pumping, in wells at Murphy-McQueen plant, near Mesa.

down to within 5 feet or more of the level in the other three wells, which seemed to indicate that the well driller was right when he affirmed that it would furnish the greatest supply of water. He based his opinion upon the fact that at a depth of 620 feet, after having penetrated an impervious stratum of clay 408 feet in thickness, a 6-foot gravel stratum was encountered which caused the water level in the pipes to rise 2 feet above the normal level.[a]

Two samples of pumped water were sent to Prof. R. H. Forbes, of the University of Arizona, at Tucson, to be analyzed for the purpose of ascertaining its value for irrigation purposes. The first was obtained shortly after the pump was started, and the second near the end of the test run; and it will be noted that the analysis of the latter showed considerable decrease of salts, which would warrant the assumption that continued pumping would effect further improvement. In the opinion of Professor Forbes it would not be wise to depend on well water alone for irrigation purposes, but where it can be used in connection with large quantities of silty river water the danger of depositing an excess of salts on the lands is minimized. The following table gives the results of the analyses made by Professor Forbes:

Analyses of water from Murphy-McQueen wells.

[Laboratory No. 2615, May 17, 1901.]

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	133.20
Chlorine as NaCl (common salt)	82.00
Hardness as $CaSO_4$ (sulphate of lime)	11.15
Nitrogen as nitrates	.426
Nitrogen as nitrites	.0067
Qualitative:	
Sulphates	Very strong.
Magnesia	Very strong.
Lime	Very strong.
Bicarbonates	Pronounced.
Silt	Small amount.

[Laboratory No. 2670, June 27, 1901.]

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	123.20
Chlorine as NaCl (common salt)	74.60
Hardness as $CaSO_4$ (sulphate of lime)	9.79
Nitrogen as nitrates	.263
Nitrogen as nitrites	Trace.
Qualitative:	
Sulphates	Very strong.
Magnesia	Very strong.
Lime	Very strong.
Bicarbonates	Pronounced.
Silt	Slight traces.

Since the first Murphy-McQueen well is the deepest in the valley and penetrates formations that no other well penetrates, it may be in place here to anticipate certain conditions which will be described later and to comment on questions which are of vital importance to those who intend to establish pumping plants in other parts of the valley. First, the principal water-bearing formation is comparatively near the surface, but after penetrating a thickness of 408 feet of impervious material another water-bearing stratum is encountered. This stratum,

[a] The writer measured the depth to water in these wells on January 19, 1904, and found the distance to be 34 feet. In the four years, therefore, since Code's measurements were made the water table at this point has lowered 11.5 feet.

although only 6 feet thick, is not local in occurrence, as is shown by the quantity of water it supplies. As already stated, the water from this stratum rose 2 feet higher than that from the horizon above. The log of the well is given below:

Log of bored well of S. J. Murphy, on Murphy-McQueen ranch, Mesa, Ariz.

	Feet.
Surface soil	13
Cemented gravel and bowlders, water bearing	159
Loose gravel, sand, and bowlders, water bearing	42
Clay, "soft limestone, and chalk rock"	408
Gravel and coarse sand, water bearing	6
Alternating layers of sand and clay	72
Clay and "talc"	605
Total	1,305

Only one other well in the Mesa region has penetrated to the depth of the lower flow. One of the first series of wells on the Chandler ranch is 705 feet deep, but did not encounter this sand. This, however, does not necessarily indicate that the lower stratum may not be

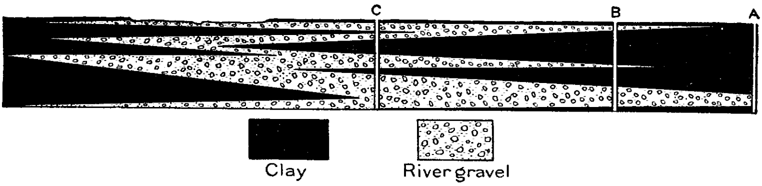


FIG. 3.—Ideal cross section in Salt River Valley, illustrating migrations of river as valley floor was built up.

found in other parts of the valley. Variation and abrupt change in the character of the valley fill, both vertically and horizontally, render it as probable that this stratum increases in thickness and perhaps passes into bowlder beds riverward as that it thins and disappears. Since the river is the main source of the valley fill, and since it is the only source of the extensive bowlder beds in the center of the valley, we naturally expect more or less coarse material from bottom to top of the valley fill. As the river swung back and forth across the valley in the process of depositing the valley fill, we should expect to find the greatest amount of coarse material in the center of the valley, although occasional layers should be found near the outer edges where the river left it during an excursion to the side. However, as explained in another place, the hill wash is always working downward to meet the river wash. The natural result is that at any given horizon bowlders should be found where the river flowed at the time the horizon was the land surface. Back from the river the material should be finer, perhaps sand, and still farther back it should run into clay, silt, cement, or wash, as the case may be.

This change in deposits is illustrated in fig. 3, in which A represents a well some distance from the center of the valley, and B another, more nearly medial. In A bowlders and water are encountered only at a considerable depth (the case with one of the Chandler wells), while at B they are found near the top and again midway. If the well does not go through the second clay we have the case of the Murphy-McQueen well. In this case the same horizon in A yields no water—as was just cited in the 705-foot Chandler well. Wells put down in the center of the valley would probably encounter a greater aggregate thickness of water-bearing gravel, while a well at the extreme left would be entirely outside of the water-bearing sands and gravels and yet be in purely fluviatile material.

An attempt was made to take the temperature of the 1,305-foot well. At a depth of 349 feet the thermometer lodged apparently in sand. The temperature at this depth was found to be 78.1° F. At a depth of 150 feet the temperature is 77.6° F., an increase downward of only 0.5° for 199 feet.

CONSOLIDATED CANAL COMPANY'S WELLS.

The Consolidated Canal Company owns a large central power plant situated at the edge of the mesa north of the town of Mesa. The plant is so constructed that water power may be used when water can be secured in sufficient quantities. Water for the Tempe canal is taken from the river at the upper end of the valley and conducted through the consolidated canal to the surface of the mesa, where it descends through the power plant to the lower level of the Tempe canal. During times of low water the power is created by steam, using crude oil as fuel. According to P. E. Fuller, the engineer in charge, the plant is supplied with two 250-horsepower water-tube boilers, one 400-horsepower compound condensing engine, one 300-kilowatt electric generator, and a complete fuel-oil system, together with necessary auxiliary equipment. The plant supplies electric power to the towns of Mesa and Tempe, but is principally used in pumping water for irrigation. The electric power is transmitted to the pump stations at 11,000 volts, where it is transformed to 220 volts for the 50-horsepower motors. Power is supplied at present to four pumping plants, each yielding about 200 inches of water continuously. The power plant is designed for a maximum of six pumping plants, yielding a total of 1,200 inches of water. About 3,300 acres of land are now supplied with water from the four pumps and this acreage is being rapidly increased. Each pumping plant cost $8,000 complete, while the central power plant cost $50,000.

Mr. Fuller has conducted certain experiments on the cost of pumping water, some of which are quoted in detail later. His general conclusion is as follows:

The water is lifted a total distance of 50 feet and the water-horsepower is 28.33. The actual power consumed at the motor in pumping this water is 42.88, representing a combined efficiency of 66.06 per cent. A number of losses occur from the engine shaft to the motor, and it therefore requires 57.17 horsepower at the engine shaft to pump 200 inches of water, and, as this represents 28.33 water-horsepower, there is a total efficiency for the plant of 49.55 per cent.

Oil costs $1.65 a barrel of 42 gallons. The fuel item I found to be 1 cent per horsepower per hour at the engine shaft, or 57.17 cents per hour for 200 inches of water, or 0.285 cents per inch per hour. Inasmuch as the lifts in the various plants here discussed are different, I have resolved into cost per inch, per foot, and per hour. The above plant costs on this basis 0.0057 of a cent per inch per foot lift per hour.

PLANT NO. 1.

The first pumping plant was established about 6 miles south of Mesa (sec. 22, T. 1 S., R. 5 E.). There are three double-steel-cased 12-inch drilled wells 15 feet apart. They are 705 feet, 236 feet, and 146 feet deep, respectively. At a depth of 80 feet a gravel and bowlder bed 156 feet thick was encountered. The water from this bed is admitted through perforations in the casing and rises to within 36 feet of the surface. Below the bowlder bed occurs a clay containing small bands of sand and gravel and continuing downward at least to a depth of 705 feet, the depth of the well. Following is a log of the well:

Log of the Consolidated Canal Company's well at plant No. 1.

	Feet.
Soil and clay	42
Sand	3
Clay and cement	35
Gravel and bowlders, water bearing	156

Over the central well a shaft 9 feet in diameter is sunk to a depth of 31 feet. From the bottom of this tunnels are run laterally to communicate with the wells on either side. A horizontal suction pipe, from which a vertical suction pipe extends into each well, as described for the Murphy-McQueen plant, connects the wells. An 8-inch horizontal centrifugal pump is placed at the bottom of the shaft in order to be within suction distance of the water, and an electric motor is attached by direct connection. The water is thus drawn from the wells by suction and forced to the surface above through a large delivery pipe. (See Pl. III.)

Several instructive pumping tests were made at this plant in the spring of 1902 for the purpose of ascertaining the capacity of the wells both individually and collectively and the effect upon the general water level.

Pumping tests of the Consolidated Canal Company's plant No. 1.

[March 10, 1902.]

Original depths of wells:	Ft.	in.
North well	705	0
Central well	146	0
South well	236	0

PUMPING WATER BY ELECTRICITY AT CONSOLIDATED CANAL COMPANY'S PLANT NO. 1.

Depth of water below the surface previous to starting the pump:

	Ft.	in.
North well	34	8½
Central well	34	8
South well	34	11

Test No. 1.—Central well alone (others being shut off): After two hours' steady pumping the water stood (below surface):

	Ft.	in.
North well	36	7½
Central well	55	4
South well	36	3

Quantity pumped: 50 inches (563 gallons per minute).[a]

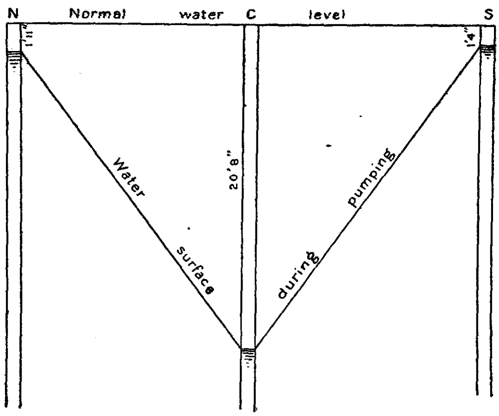


FIG. 4.—Depression of water table during test No. 1.

Test No. 2.—North well (others being shut off): After seven hours' steady pumping the water stood (below surface):

	Ft.	in.
North well	46	6.
Central well	38	0
South well	36	8

Quantity pumped: 83 inches (934 gallons per minute).

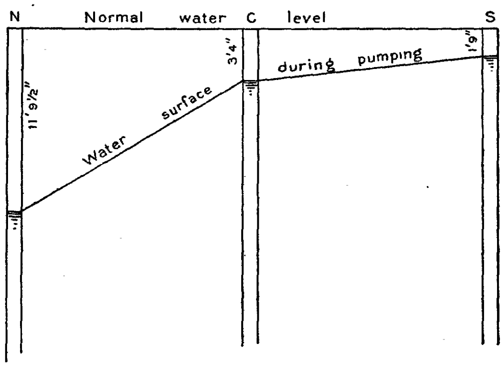


FIG. 5.—Depression of water table during test No. 2.

[a] Measurements of water in this paper are given in "Arizona inches." The measurements are reduced to absolute quantities by reckoning 40 inches as equivalent to the discharge of 1 cubic foot of water per second.

Test No. 3.—South well alone (others being shut off): After two hours' steady pumping the water stood (below surface):

	Ft.	in.
North well	36	5
Central well	36	5
South well	48	5

Quantity pumped: 75 inches (844 gallons per minute).

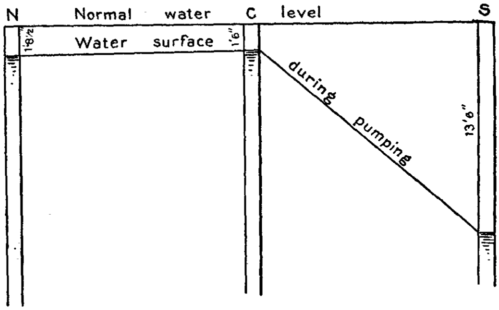


FIG. 6.—Depression of water table during test No. 3.

Test No. 4.—North and south wells coupled (central well shut off): After pumping one hour the water stood (below surface):

	Ft.	in.
North well	42	7
Central well	38	9
South well	43	7

Quantity pumped, 128 inches (1,440 gallons per minute).

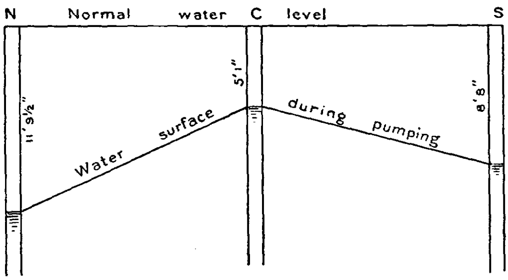


FIG. 7.—Depression of water table during test No. 4.

Test No. 5.—All wells combined: After pumping several hours the water stood (below surface):

	Ft.	in.
North well	41	4
Central well	41	2
South well	40	8

Quantity pumped, 128 inches (1,440 gallons per minute).

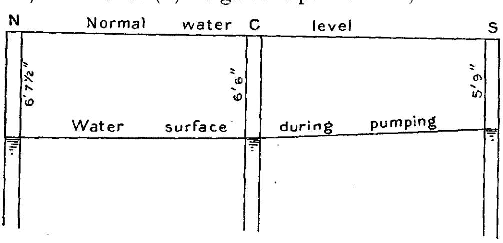


FIG. 8.—Depression of water table during test No. 5.

Analyses of water from wells at Consolidated Canal Company's plant No. 1.[a]

	1. Analysis of water taken from 705-foot well before any extensive pumping had been done.	2. Analysis of water taken from 236-foot well soon after establishment of plant but after thorough pumping.	3. Analysis of water from wells at plant No. 1 after the pump had been in occasional operation for about fifteen months.	4. Analysis of water from wells at Consolidated Canal Co.'s plant No. 1 after long-continued pumping.
Quantitative (parts in 100,000):				
Total soluble solids at 110° C	299.60	163.80	127.40	179.00
Chlorine in terms of NaCl (common salt)	154.80	104.40	75.60	116.80
Hardness in terms of $CaSO_4$ (sulphate of lime)	20.90	44.50	23.10	53.30
Alkalinity in terms of Na_2CO_3 (black alkali)	.00	.00	.00	.00
Nitrogen in the form of nitrates	.29	.12	.07	Trace.
Nitrogen in the form of nitrites	.0105	Very faint.	Trace.	.00
Qualitative:				
Sulphates	Very strong.	Very strong.	Strong.	Very strong.
Magnesia	Strong.	Very strong.	Distinct.	Strong.
Lime	Strong.	Very strong.	Pronounced.	Strong.
Bicarbonates	Strong.	Strong.	Strong.	Slight.

[a] These analyses, as well as the greater number of those to follow, were made by Prof. R. H. Forbes and W. W. Skinner, at the Government experimental laboratory at Tucson, Ariz.

The sample of water represented by analysis No. 2 was taken after the well had been thoroughly cleared by pumping. It may therefore be taken as representative of the true quality of the water pumped at the time the sample was taken. Samples from the other two wells were taken at the same time. That from the 705-foot well yielded 157.40 parts of total soluble solids in 100,000 parts of water, and that from the 146-foot well showed 172.20 parts in 100,000. The analysis of the water from the 236-foot well given above may be taken, therefore, as an average representative of the three wells.

An inspection of these figures brings clearly to mind the fact that the water in a well not in active operation is not a fair representative of the general supply, there being in this case at least a difference of 135.8 parts of soluble salts in 100,000 parts of water. There are many instances in the valley where water for analysis has been taken under similar circumstances and are therefore of questionable value. The inspection also reveals a difference in the proportion of the various salts, which may be due to one or more of several causes, such as the commingling of the waters of different composition, the contact of these waters with new formations, chemical reactions within the steel casing, exposure to the atmosphere, or the relief of pressure. The last two would apply especially to alterations in the bicarbonates, which are abundant in these waters. The relief of pressure and the exposure to the atmosphere would have a tendency to allow the escape of the carbon dioxide necessary to keep the normal carbonates in solution and thus allow the bicarbonates to change to their insoluble form and be deposited. There should therefore be a smaller showing of lime in standing water than in that drawn from the deeper unexposed sources. In the above samples the proportion is 20.90 to 44.50, the samples being taken from the same well before and after thorough clearing of the well by pumping.

The lime is stated in terms of calcium sulphate. This does not mean that the lime is of necessity combined as a sulphate. Much of the lime reckoned as calcium sulphate probably occurs as calcium bicarbonate. The loss of carbon dioxide (CO_2) from this compound, which occurs when the pressure is relieved, as in the case of transferring the water from the well to the surface, changes it to the comparatively insoluble calcium carbonate ($CaCO_3$), which is deposited as a solid. This phenomenon of deposition of lime when water stands exposed is well illustrated in the annoying deposition of lime in kettles and drinking cups in which water containing carbonates is used.

The third analysis indicates a marked decrease in the amount of soluble salts. There is a popular belief throughout the valley that wells improve by use. In many cases where the judgment is based upon taste it is probable that the quality of the water has changed less than the taste of the persons using it. In the case of the Chandler wells, however, the analyses seemed to indicate that there might be an actual and notable improvement in the water as the wells are used. On the other hand, a change in the opposite direction is indicated by the analyses of the Phoenix city supply, which are given in the description of the Phoenix wells. The improvement of the water by the continued use of the wells is so desirable that too much importance is likely to be attached to any indication of such improvement. This is well illustrated in analysis No. 4, above. After the sample for No. 3 was taken the well was in continuous operation for about nine months, when the sample was taken for analysis No. 4. If continuous pumping will improve the quality of the water the last analysis should show improvement. On the contrary, it indicates a notable increase in the salt contents.

An attempt was made January 19, 1904, to take the temperature of the 705-foot well. It was found, however, that the well had filled with sand to the 375-foot level. The temperature at this depth is 84.6° F., while the temperature at the depth of 150 feet was found to be 81.1° F., making an increase in temperature downward of 1° F. for 64.3 feet.

PLANT NO. 2.

A second pumping plant, similar in construction to No. 1, has been established 1,000 feet east of the former. Two 15-inch double-steel-cased wells have been put down to a depth of a little over 246 feet, and a central shaft 31 feet deep, with a tunnel connecting it with the wells on either side, has been constructed, containing a 10-inch centrifugal pump and electric motor, as described for the first plant.

This plant was completed in June, 1903, and a careful pumping test was made, the results of which are kindly furnished by Dr. A. J. Chandler for this report. The tests were conducted under the direction of Mr. P. E. Fuller.

Log of well at Consolidated Canal Company's plant No. 2.

	Feet.
Soil, clay, and cement	22
Cement	14
Sand, water bearing	10
Cement	6
White clay	30
Sand, gravel, and bowlders	164
Yellow clay	(?)

Pumping test of wells at Consolidated Canal Company's plant No. 2.

[Data furnished by Dr. A. J. Chandler.]

AVERAGE OF READINGS OF BYRON JACKSON 10-INCH HORIZONTAL CENTRIFUGAL PUMP.

[Readings for 30 minutes averaged.]

Speed, r. p. m	852
Vacuum, in feet	15.30
Pressure, in pounds	13.75
Head, in feet, between gages	3.66
Head, in feet, due to vacuum	15.30
Head, in feet, due to pressure	31.68
Total head, in feet	50.65
Depth of water in 36-inch weir	7.75
Miner's inches flowing	197.5
Net water horsepower	28.33

Miner's inch taken at 1½ cubic feet per minute.

AVERAGE OF READINGS OF WESTINGHOUSE TYPE "O" TWO-PHASE MOTORS.

Speed of motor, r. p. m	852
Total amperes in both phases	188
Difference of potential	205
Apparent energy, kilowatts	38.54
Watt meter speed	40
True energy, in kilowatts	32.80
Power factor	83.03
Actual horsepower consumed	42.88
Combined efficiency	66.06
Efficiency for motor	82.50
Efficiency for pump	80

Efficiencies for units are correct. Others based upon pump guaranty.

From the figures thus obtained the cost of raising water is computed:

Computation of cost for pumping plant No. 2 of the Consolidated Canal Company.

Cost of wells and machinery	$8,000.00
Interest on investment at 7 per cent per annum for 2.44 hours	$0.16
Depreciation at 10 per cent per annum for 2.44 hours	$0.23
Time in hours to pump 1 acre-foot of water	2.44

80.03 kilowatts, at 3 cents	$2.40
Oil and incidentals (estimated)	$0.05
Total cost per acre-foot	$2.84
Lift, in feet	50.64
Average cost per foot in lifting 1 acre-foot of water	$0.056

In computing the cost, the cost of the power used could not be ascertained owing to the lack of definite experiments in the development of that power. This item is therefore reckoned at the rate at which it would be furnished by the Electric Light and Fuel Company of Phoenix.

PLANT NO. 3 (SEC. 34, T. 1 S., R. 5 E.).

A third pumping station has been established about 2 miles south of the first. Two double-steel-cased 15-inch wells have been drilled 262 feet deep, and provided with a 10-inch centrifugal pump and an electric motor, as in the wells previously described. The water-bearing gravels lie 42 feet deeper here than in the first set of wells, and the gravel beds are correspondingly thinner. But the water rises to practically the same elevation as in the other wells, 37 feet below the ground surface. Following is a log of the well:

Log of well at Consolidated Canal Company's plant No. 3.

	Feet.
Surface soil	4
Sand	3
Hardpan	5
Sand	4
Clay	8
Sand	12
Clay	8
Cement	6
Sand, water bearing	10
Clay	20
Cement	4
White clay	16
Yellow clay	10
Green clay	12
Gravel and bowlders, water bearing	136
Clay and sand	4

The plant was put in operation in June, 1903, and a pumping test made under the direction of Mr. Fuller.

Pumping test of wells at Consolidated Canal Company's plant No. 3.

[Data furnished by Dr. A. J. Chandler.]

AVERAGE OF READINGS OF BYRON JACKSON 10-INCH HORIZONTAL CENTRIFUGAL PUMP.

[Readings for 30 minutes averaged.]

Speed, r. p. m.	860
Vacuum, in feet	14.30
Pressure, in pounds	12.50

Head, in feet, between gages	3.85
Head, in feet, due to vacuum	14.34
Head, in feet, due to pressure	29.37
Total head, in feet	47.56
Depth in water in 36-inch weir	7.87
Miner's inches flowing	202
Net water horsepower	27.22

Miner's inch taken at 1½ cubic feet per minute.

AVERAGE OF READINGS OF WESTINGHOUSE TYPE "O" TWO-PHASE MOTORS.

Speed of motor, r. p. m	860
Total amperes in both phases	186
Difference of potential	205
Apparent energy, kilowatts	38.13
Watt meter speed	40
True energy, in kilowatts	32
Power factor	83.09
Actual horsepower consumed	42.88
Combined efficiency	63.48
Efficiency for motor	80.80
Efficiency for pump	78.50

Efficiencies for units are correct. Others are based upon pump guaranty.

From the figures obtained in this test the computation of cost is as follows:

Computation of cost of well No. 3 of the Consolidated Canal Company.

Cost of wells and machinery	$8,000.00
Interest on investment at 7 per cent per annum for 2.4 hours	$0.15
Depreciation at 10 per cent per annum for 2.4 hours	$0.19
Time in hours to pump 1 acre-foot	2.4
Kilowatts used to pump 1 acre-foot	76.8
76.8 kilowatts, at 3 cents	$2.30
Oil and incidentals (estimated)	$0.05
Total cost per acre-foot	$2.69
Lift, in feet	47.56
Average cost per foot in lifting 1 acre-foot of water	$0.054

Analyses of water from wells at Consolidated Canal Company's plant No. 3.

	Sample taken before any pumping had been done.	Sample taken after thorough pumping.	Sample taken after the pump had been in continuous operation for about eight months.
Quantitative (parts in 100,000):			
Total solids soluble at 110° C	162.40	84.80	82.60
Chlorine in terms of NaCl (common salt)	80.40	44.60	41.20
Hardness in terms of $CaSO_4$ (sulphate of lime)	52.20	18.50	1.10
Alkalinity in terms of Na_2CO_3 (black alkali)	.00	.00	.00
Nitrogen in the form of nitrates	.274	.266	.10
Nitrogen in the form of nitrites	.0061	Trace.	.0
Qualitative:			
Sulphates	Very strong.	Strong.	Strong.
Magnesia	Strong.	Distinct.	Distinct.
Lime	Very strong.	Strong.	Distinct.
Bicarbonates	Strong.	Very strong.	Strong.

PLANT NO. 4 (SEC. 34, T. 1 S., R. 5 E.).

A fourth pumping station has been established about a quarter of a mile east of No. 3. There are two double-steel-cased wells about 200 feet deep, equipped with electric motor and pump as described for the other plants belonging to this company. The plant was put in operation about January 1, 1904. No pumping tests have yet been made, but the plant yields apparently the same volume of water as the wells just described.

Analysis of water from wells at Consolidated Canal Company's plant No. 4.

[Sample taken January 28, 1904.]

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	69.00
Chlorine in terms of NaCl (common salt)	40.00
Hardness in terms of $CaSO_4$ (sulphate of lime)	14.70
Alkalinity in terms of Na_2CO_3 (black alkali)	.00
Nitrogen in the form of nitrates	.20
Qualitative:	
Sulphates	Strong.
Magnesia	Distinct.
Lime	Distinct.
Bicarbonates	Strong.

PLANT NO. 5 (SEC. 15, T. 2 S., R. 5 E.).

A fifth pumping plant was started about 11 miles south of Mesa, where a 15-inch double-steel-cased well was sunk 365 feet. The conditions encountered were unfavorable for a satisfactory pumping plant, and no more wells were put down. At a depth of 58 feet a 4-foot water-bearing sand stratum was encountered from which the water rose 7 feet—that is, to within 51 feet of the surface. No more water was found until the bowlders were encountered at a depth of 365 feet. Water from the bowlder bed rose to the same level as that from the stratum above—that is, to within 51 feet of the surface. No test of the quantity available has been made.

Log of well at Consolidated Canal Company's plant No. 5.

	Feet.
Soil	7
Gravel	5
Yellow clay	12
Sand and gravel	12
White clay	22
Sand, water bearing	6
Packed gravel	22
Cemented sand	24
Clay	8
Cemented sand	6
Clay	4
Gravel	6
Clay	74
Sand	2
Clay	20
Sand	2
Yellow clay	78
Red clay	23
Soft white clay	34
Bowlders	(?)

The material passed through in this well is in marked contrast with that of the neighboring wells. The upper 136 feet has much coarse material, but contains little water. There is thus far little difference in material from the upper 126 feet of the wells at No. 3, about 3 miles to the north. In the wells at No. 3 water-bearing bowlders occur from the 126-foot level down to 262 feet, where clay is encountered. In the wells at No. 5 clay begins at the 134-foot level and extends downward to a depth of 365 feet, where the bowlders are encountered. Here, then, is a case where a bowlder bed 136 feet thick either pinches out entirely, giving place to clay within a distance of about 3 miles, or inclines downward 239 feet in this distance.

PLANT NO. 6.

About 1 mile east of pumping plant No. 1 a dug well 58 feet deep contains water in sufficient quantity to warrant the establishment of a pumping plant. It is said that in digging this well a hard layer of cement was encountered at a depth of a little less than 58 feet. When this was broken through the water at once rose 16 feet in the open well—that is, to within 42 feet of the surface. This well is in slightly higher ground, but the water level is practically the same as that in the wells 1 mile to the west, at pumping plant No. 1. The water beneath the cement layer is probably the same as that encountered in the wells of plant No. 1 at a depth of 36 and 42 feet, respectively, and in the wells 2 miles to the south at 50 feet deep. In the deep wells this water-bearing sand was found to be from 3 to 10 feet thick, and to contain a large amount of water.

The analysis indicates that this water is completely separated from the water in the bowlder bed beneath. Two characteristics are worthy of special notice—the absence of sulphate of lime and the presence of a large amount of black alkali. In these respects the water is in marked contrast with that found only 36 feet below, which has much sulphate of lime and no black alkali.

Analysis of water from well at Consolidated Canal Company's plant No. 6.

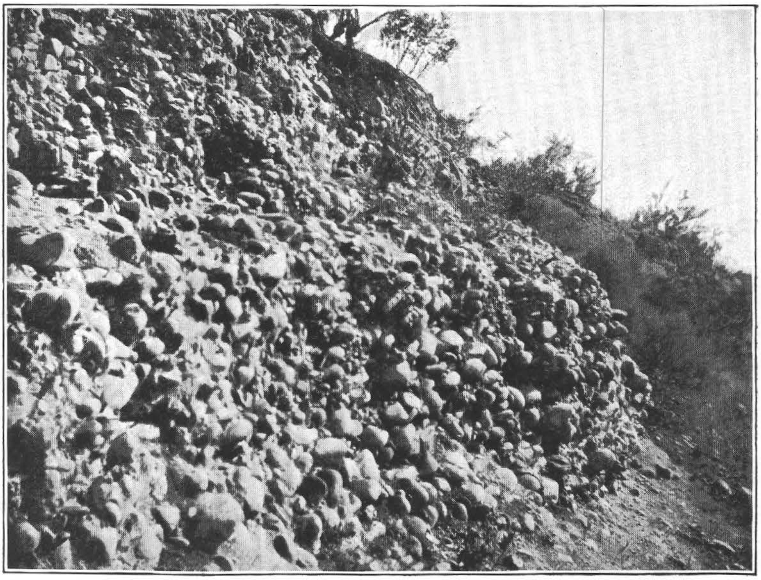
Quantitative (parts in 100,000):	
Total solids soluble at 110° C	103.20
Chlorine in terms of NaCl (common salt)	48.80
Hardness in terms of $CaSO_4$ (sulphate of lime)	.00
Alkalinity in terms of Na_2CO_3 (black alkali)	7.63
Nitrogen in the form of nitrates	.21
Nitrogen in the form of nitrites	.0094
Qualitative:	
Sulphates	Strong.
Magnesia	Distinct.
Lime	Distinct.
Carbonates	Slight.

PLANT NO. 7.

A well has been drilled at the power house of the Consolidated Canal Company, 2 miles northwest of Mesa, for the purpose of obtaining water for use at the engine house. It is a 15-inch double-steel-cased well, and is 68 feet deep. The upper 14 feet is an admixture of sand, silt, and bowlders of the recent river deposit. Below this a cemented bowlder bed occurs and continues unchanged to the bottom of the well. The bowlder bed is probably the same as that represented in the edge of the mesa at that point. The well is but a few feet from the bluff represented in Pl. IV, *A*.

Log of well at Consolidated Canal Company's plant No. 7.

	Feet.
Sand, silt, and gravel	14
Cemented bowlders	54



A. EDGE OF THE MESA NEAR CONSOLIDATED CANAL COMPANY'S POWER PLANT.

B. A. J HANSEN'S PUMPING PLANT.

Discharging 518 inches of water.

SEEPAGE WELL.

A seepage well was constructed near the power house of the Consolidated Canal Company, under the direction of W. H. Code, who has described it in the report previously referred to.[a] The plant is not now in operation. Mr. Code's description and figure are here transcribed because of their bearing upon the quantity of water obtainable from surface gravels near the river.

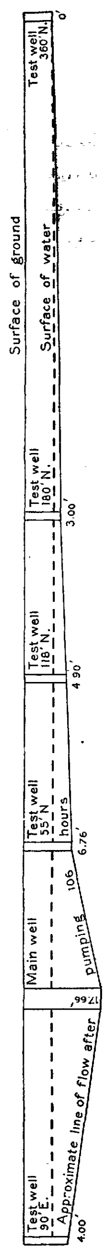


FIG. 9.—Water levels before and after pumping from seepage well of Consolidated Canal Company.

The writer has had some experience in the sinking of open wells in Salt River Valley, which may be of value to some horticulturists or farmers who contemplate a similar work. To a man who has not had actual experience with the bowlder and quicksand strata encountered in digging wells in this vicinity, the mere excavation of an open well may seem ordinarily easy.

The Consolidated Canal Company decided to investigate the underground water supply in the vicinity of their water-power plant near Mesa, Ariz. Since it was to be simply an experimental well, it was thought best to construct it in the least expensive manner possible. With this end in view a contract was given to some miners to sink a well as deep as we should desire, at a stipulated price per linear foot in depth, we to keep the water out of their way and also to furnish the lumber for cribbing the well. The miners proceeded in the manner common in the sinking and timbering of mining shafts, and we kept the water out of their way as per contract. The natural elevation of the ground water was 7 feet below the surface level at the point selected, and for this distance the excavation was in earth. From this depth on the formation was alternate layers of quicksand and bowlders. The well was 8 by 16 feet, inside measurement, and by dint of perseverance in the face of many obstacles, we sunk it to a depth of 23 feet below the normal level of the water. It is needless to enter into detail concerning the trouble and expense connected with sinking this kind of a well through the material above mentioned to a depth sufficient to give a maximum flow of 4 cubic feet per second (160 miner's inches). We were taught by this experience how not to sink open wells, for although this one is still in fair condition after a service of several years, we know it is not a permanent structure.

After the well was sunk as deep as we deemed practicable, the writer made some observations as to the effect of the steady pumping of 3.75 cubic feet per second (150 miner's inches) on the water levels of adjacent wells. Pits were sunk at varying distances from the large central well, and careful levels were taken of the surface of the water in each well previous to the test run, the elevations being found practically the same. The pump was started in the central well and discharged a constant stream of 3.75 cubic feet per second for one hundred and four hours, near the end of which time levels were again taken of the water in the various sumps. The sketch herewith submitted shows the result of the experiment (fig. 9). It will be seen that the water in the large well pumped from was lowered to a depth of 17.68 feet below normal level. No. 1, distant 55 feet, to a depth of 6.76 feet below normal level; No. 2, distant 90 feet, to a depth of 5.94 feet below normal level; No. 3, distant 118 feet, to a depth of 4.90 feet below normal level; No. 4,

[a] Code, W. H., Report of irrigation investigation for 1900, No. 2: U. S. Dept. Agric., Bull. 104, 1901, pp. 94–96, fig. 14.

distant 180 feet, to a depth of 3.50 feet below normal level; and No. 5, distant 360 feet, to a depth of 1 foot below normal level.

It will be noted that the sump at a distance of 360 feet from the main well was lowered a depth of about 1 foot and that the steepest cone of depression was that between the main well and the test hole No. 1.

OLSEN WELLS (SEC. 18, T. 1 S., R. 5 E.).

Mr. E. Olsen's pumping plant is situated about 6 miles southwest of Mesa. There are five 12-inch double-steel-cased drilled wells, 212 feet deep, placed 30 feet apart. A central shaft sunk to water level communicates with the wells as in the pumping plants previously described. A 12-inch horizontal centrifugal pump is placed near the bottom of the shaft and operated by steam power from above. When run at ordinary speed the pump is said to discharge 375 inches of water (4,219 gallons) per minute. The wells yield this amount readily, the action of the pump lowering the water only 8 feet below the normal level.

Log of E. Olsen's well.

	Feet.
Sandy soil with bands of cement	46
Clay	2
Coarse gravel and bowlders, water bearing	82
Sand	4
Clay	12
Coarse gravel	14
Sand	10
Sand and gravel	6
Clay	24
Sand	12

The principal water-bearing stratum was encountered at a depth of 48 feet and is 82 feet thick. The water from this stratum rises to a level 19 feet below the surface of the ground. This level, however, varies somewhat at different times. On February 1, 1903, measurements were made to determine the amount of the lowering of the water level caused by the pump. On April 14, 1903, measurements were again made under the same conditions, the quantity of water discharged by the pump being the same in each case, 4,219 gallons per minute. The water level at the time of the first measurement was 2 feet lower than at the time of the second measurement. The normal water level, indicated by the elevation of the water when the pumps were not running, had also risen about 2 feet during this time. This variation of water level seems to be due to an annual change, although observations have not extended over a sufficient length of time for determination.

The analysis of water from Mr. Olsen's wells indicates a large content of salts. The sodium carbonate or black alkali, which is most harmful, is, however, absent. The sulphate of lime is harmless, and the common salt, although very abundant, could be washed out of the soil with comparative ease should it accumulate in too large quantities. The nitrates, so valuable in irrigation, are abundant. It is possible, as many believe, that the continued use of so saline an irrigation water for a series of years will prove harmful to the land, unless precautions are taken to prevent the accumulation of salts in harmful quantities. The quantity and kind of salt which may be present in irrigation waters depend so largely upon the physical and chemical composition of the land irrigated and upon the manipulation of that land that prediction is useless without a more extended knowledge of facts.

Analysis of water from E. Olsen's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C.	381.00
Chlorine in terms of NaCl (common salt)	235.20
Hardness in terms of $CaSO_4$ (sulphate of lime)	59.84
Alkalinity in terms of Na_2CO_3 (black alkali)	.0
Nitrogen in the form of nitrates	2.00
Nitrogen in the form of nitrites	Faint.
Qualitative:	
Sulphates	Very strong.
Magnesia	Strong.
Lime	Very strong.
Bicarbonates	Very strong.

HANSEN WELLS (SEC. 35, T. 1 S., R. 4 E.).

Mr. A. J. 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 as explained for the Murphy-McQueen plant, and the wells are connected by a horizontal suction pipe. The pump is operated at the surface by steam power, connected by belt to the pump.

No satisfactory tests have been made on the capacity of the plant. The best measurements obtainable indicate a yield of about 518 inches (see Pl. IV, *B*), or something over 5,000 gallons of water per minute. Mr. Hansen is preparing to irrigate, in this way, his entire tract of something over 1,100 acres. At the present writing about 500 acres are supplied with pumped water.

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 lower 18 feet, while in the well 90 feet distant it lowers 5 feet. The effect on the intervening wells was not determined.

In drilling the wells very little surface water was encountered, but at a depth of 76 feet water-bearing gravels and bowlders were encountered, from which the water rose 53 feet—that is, to 17 feet below the surface of the ground.

Log of A. J. Hansen's wells.

	Feet.
Soil, sand, and cement	72
Hard cement	4
Coarse sand, gravel, and bowlders, water bearing	124

In the course of the drilling two circumstances were noted indicating the looseness of the water-bearing gravels. In drilling the last well it was noted that the water in the first one, 90 feet distant, 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 slightly, maintaining a churning motion in unison with the drill. The second circumstance was noted in connection with sinking the casing. The casing is usually forced downward under heavy pressure by means of hydraulic jacks into the hole made by the sand pump. 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.

Three analyses have been made of water from these wells, the first taken January 2, 1903, and the second March 2, 1903, before any extensive pumping had been done. A third analysis was made May 14, 1904, after the pump had been in constant operation for about five months.

Analyses of water from A. J. Hansen's wells.

	No. 1.	No. 2.	No. 3.
Quantitative (parts in 100,000):			
Total solids soluble at 110° C	509.0	446.8	442.0
Chlorine in terms of NaCl (common salt)	355.0	307.0	311.0
Hardness in terms of $CaSO_4$ (sulphate of lime)	60.9	135.4	151.2
Alkalinity in terms of Na_2CO_3 (black alkali)	.0	.0	.0
Nitrogen in the form of nitrates	....	Faint.	Trace.
Nitrogen in the form of nitrites	....	Faint.	.01
Qualitative:			
Sulphates	Very strong.	Very strong.	Very strong.
Magnesia	Very strong.	Very strong.	Strong.
Lime	Very strong.	Very strong.	Very strong.

TEMPE CANAL COMPANY'S WELLS (SEC. 19, T. 1 N., R. 4 E.).

The Tempe Canal Company has undertaken the construction of a large pumping plant, designed to augment the water supply of the Tempe canal. A battery of ten 15-inch wells is planned. Two of these are completed at the present writing. The wells are 50 feet apart, and will be operated from a central station. It is expected that the ten will yield 1,000 inches of water. It is the purpose of the company to increase the output to 3,000 inches, if water is found in sufficient quantity to warrant such expansion.

The pumps will be so placed as to discharge the water into the Tempe canal, thus mixing the pumped water with the river water and distributing it uniformly.

The material encountered in these wells differs notably from that in neighboring wells in the absence of the great number of bowlders. The material is described as sand and gravel rather than as gravel and bowlders, as in other wells, and the lower 33 feet is clay.

Log of Tempe Canal Company's wells.

	Feet.
Soil	10
Sand and gravel	157
Clay	33

VALLEY SEEDLESS GRAPE COMPANY'S WELLS (SEC. 4, T. 1 S., R. 4 E.).

The company's vineyard is situated about 4 miles south of Tempe. There are two 12-inch drilled wells, one at the southern end of the vineyard, 348 feet deep, and one at the northern end, 250 feet deep. In the 250-foot well water-bearing gravels were encountered at a depth of about 190 feet. The water from the gravel bed rose to a level 18 feet below the surface of the ground. The 348-foot well is on higher land and the water level is 30 feet below the surface. No careful driller's record was kept, but the foreman in charge reported that the material passed through was a mixture of sand, clay, and cement to a depth of about 120 feet. At this depth sands and gravels begin and alternate with granitic wash to a depth of about 300 feet. No water worthy of mention was found until a bed of gravel 9 feet thick was encountered at a depth of about 275 feet. Below the 300-foot level the material is granitic wash down to 340 feet, where hard red granite was found. The well penetrates the granite 8 feet.

The 250-foot well is not in use at the present time. The 348-foot well is operated to irrigate the vineyard by a centrifugal pump placed in a shaft sunk to near water level and operated by a 12-horsepower gasoline engine. The water is pumped into a small cement reservoir from which it is distributed for irrigation.

Repeated efforts were made to secure measurements in a test run of this plant for the purpose of computing the cost of water thus obtained. In the meantime Prof. S. M. Woodward, of the Arizona Experiment Station, working independently to the same end, obtained measurements which he has kindly allowed me to use. The test run consumed 1.5 hours, the quantity of water pumped during that time being measured in the cement reservoir and the rate per second computed. The water in the well was lowered 11.5 feet when the pump started and remained constant during the run. The water was lifted 5.5 feet above the level of the ground, making a total lift of 47 feet. The plant is still in an experimental stage and certain easily remedied faults in construction will reduce the cost given below. Owing also to these imperfections, the liability to error in measurements is needlessly great. Those taken by Professor Woodward are probably as accurate as can be obtained at the present time. The original cost of the plant could not be obtained and attendance is not included in the following computations:

Cost of pumping water at the Valley Seedless Grape Company's vineyard.

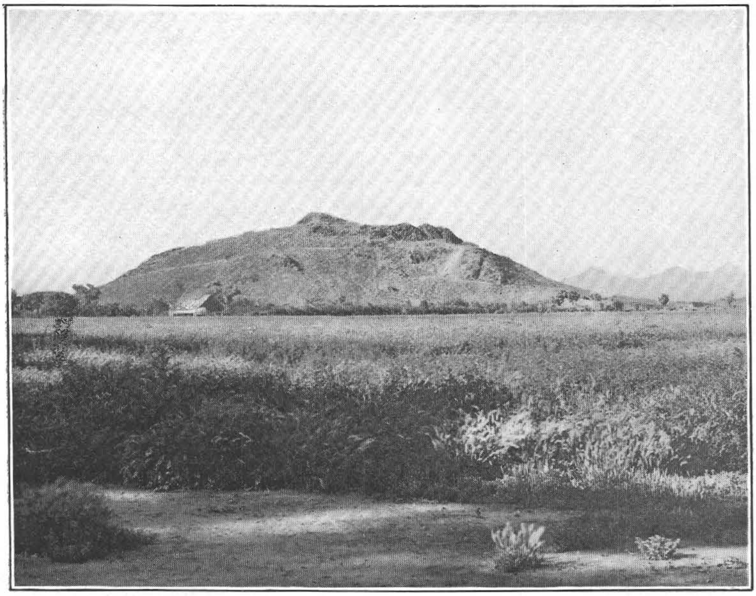
Rate of discharge in cubic feet per seconds	1.15
Distillate consumed per hour, in gallons	1.6
Time to pump 1 acre-foot, in hours	10.52
Distillate consumed per acre-foot of water pumped, in gallons	16.83
16.83 gallons of distillate, at 22 cents	$3.70
Oil and incidentals	$0.05
Total cost per acre-foot	$3.75
Lift in feet	47
Average cost per foot in raising an acre-foot	$0.08

Analyses of water from the Valley Seedless Grape Company's wells.

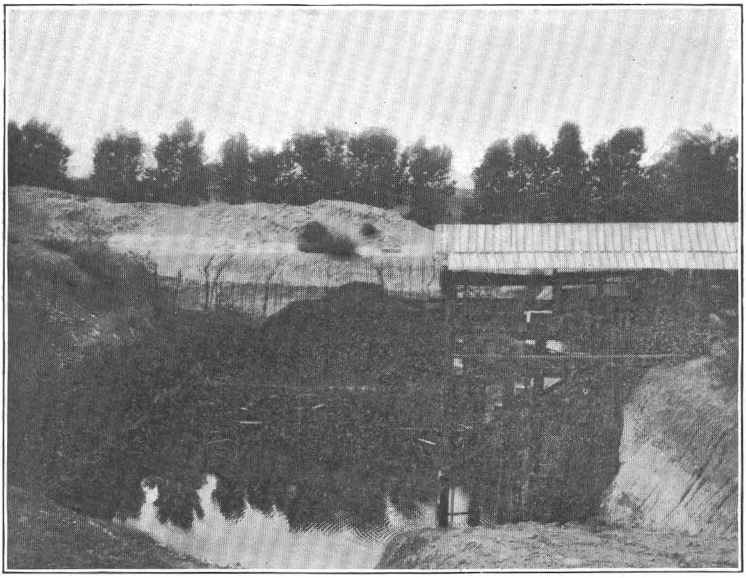
	348-foot well.	250-foot well.
Quantitative (parts in 100,000):		
Total solids soluble at 110° C	155.8	115.2
Chlorine in terms of NaCl (common salt)	105.4	78.6
Hardness in terms of $CaSO_4$ (sulphate of lime)	21.8	11.4
Alkalinity in terms of Na_2CO_3 (black alkali)	.0	.0
Qualitative:		
Sulphates	Strong.	Strong.
Magnesia	Pronounced.	Pronounced.
Lime	Strong.	Strong.

TEMPE WATERWORKS WELLS.

The town of Tempe is supplied with water from three 12-inch double-steel-cased wells, 152 feet, 147 feet, and 145 feet deep, respectively. The water-bearing gravels were entered at a depth of 12 feet



A. TEMPE BUTTE, SHOWING RESERVOIR NEAR THE TOP.



B. COLLINS WELL, NEAR PHOENIX.

and the surface of the water at 23 feet. The water is under no pressure and is not capped by an impervious clay, as it is in most places throughout the valley.

The plant is a well-equipped one, with a shaft 20 by 20 feet, sunk 15 feet, and containing a Goulds triplex single-acting pump and 30-horsepower electric motor. The three wells are connected by a horizontal suction pipe, from which a vertical suction pipe extends into each well, inside the casing. The water is forced to a reservoir near the top of Tempe Butte, making a total lift of 249 feet. (Pl. V, *A*.)

It is especially worthy of note that at Tempe the water-bearing gravels extend practically to the surface, the shallow wells reaching the same water body from which the deep wells draw. This is not the case 1 mile south of Tempe at H. L. Chandler's well, where the surface waters are separated from the waters of the great bowlder bed by impervious clay. Analyses of water from the deep wells and from shallow wells near by indicate the same kinds of salts in both the shallow and deep wells, but show varying amounts. The following analyses are from wells only a few blocks apart. The town well is perforated only below 90 feet, and the water analyzed from this well is presumably from that depth. The others are from wells about 30 feet deep.

Log of Tempe waterworks well.

	Feet.
Surface soil	4
Clay and bowlders	6
Clay, sand, and bowlders, cemented	2
Loose sand, gravel, and bowlders, water bearing	117
Igneous rock	23

Analyses of water from wells at Tempe, Ariz.

	City waterworks; 152 feet.	Casa Loma Hotel.	Normal School; 30 feet.
Quantitative (parts in 100,000):			
Total solids soluble at 110° C	103.0	169.8	219.2
Chlorine in terms of NaCl (common salt)	58.8	105.8	133.6
Hardness in terms of $CaSO_4$ (sulphate of lime)	9.52	12.9	15.78
Alkalinity in terms of Na_2CO_3 (black alkali)	.0	.0	.0
Nitrogen in the form of nitrates	.17	.18	.51
Nitrogen in the form of nitrites	.0	.0027	.0
Qualitative:			
Sulphates	Strong.	Very strong.	Very strong.
Magnesia	Strong.	Pronounced.	Very strong.
Lime	Strong.	Very strong.	Very strong.

At the request of the writer, Mr. P. E. Fuller, the engineer under whose direction the pumping plant was constructed, made a careful test of the quantity of water pumped, power consumed, etc. Mr. Fuller has been kind enough to put the observations in the tabular form given below:

Test of pumping plant of Tempe city waterworks, August 2, 1903.

READINGS.

Time.	Voltage between phases.	Total amperes.	Pressure gage.	Vacuum.	Watt meter, one phase.	Revolutions of pump; 6⅓ gallons per revolution.	Velocity watt meters per minute.	Difference between gages.
			Pounds.	*Inches.*				
4.20[a] ..	175.0	170	99	15.25	1,747,200	810.310	37.00	3.33
4.40....	177.5	170	99	15.25	1,747,700	811.221	....	3.33
4.50....	182.5	170	99	15.25	1,748,050	811.623	34.50	3.33
5.......	172.5	170	99	14.75	1,748,320	812.056	34.50	3.33
5.10....	165.0	170	99	14.75	1,748,580	812.487	35.50	3.33
5.20[b] ..	152.5	172	99	14.50	1,748,830	812.848	33.50	3.33
Total.	170.83	170.33	99	14.96	1,630 kw.	2,538 rev.	35.00	3.33

[a] Running start was made; watt meter was 37.3 per cent fast, volt meter was 1 per cent low—for all readings of watts and voltage.
[b] Low readings due to low voltage at power house.

DEDUCTIONS.

Average voltage corrected for error	172.55
Average amperes in both phases	170.33
Apparent energy consumed by motor ....kilowatts..	29.39
Actual energy consumed ....do...	23.51
Power factor ....per cent..	80.00
Horsepower actually consumed by motor	31.51
Average gallons of water pumped per minute	274.95
Total head, in feet, pumped against	248.87
Net water horsepower	18.49
Combined efficiency of motor, pump, suction piping, and ¾-mile 8-inch main ....per cent..	58.68
Power rate paid per thousand gallons pumped ....cents..	4
Equivalent cost per horsepower per hour and per kilowatt per hour ...do...	2.13 2.85

Reducing the figures to the basis of cost per acre-foot of water lifted, we have the following:

Cost of pumping water at the Tempe, Ariz., waterworks.

Cost of plant (not including the reservoir and distributing system)	$3,700.00
Interest on investment at 7 per cent per annum for 19.8 hours	$0.59
Depreciation at 10 per cent per annum for 19.8 hours	$0.84
Hours to pump 1 acre-foot	19.8
Cost of power to raise 1 acre-foot (power furnished at 4 cents per 1,000 gallons of water pumped)	$13.07
Oil and incidentals (estimated)	$0.05

Total cost per acre-foot	$14.55
Total lift in feet	249
Average cost per foot in lifting 1 acre-foot of water	$0.058

CHANDLER WELL (SEC. 21, T. 1 N., R. 4 E.).

Mr. H. L. Chandler proposes to establish a pumping plant for irrigation about 1 mile south of Tempe. Two 12-inch double-steel-cased wells were started, but accidents have caused a discontinuance of the work. One well, however, reached a depth of 186 feet, and the record, furnished by the driller, is given herewith. The well is in water-bearing gravels and bowlders throughout nearly the entire depth. There seem, however, to be two distinct bodies of bowlders separated by 8 feet of clay. The upper or surface water is alkaline, from which the lower water is probably free, as is the case in other wells of the region. The lower water was struck at a depth of 41 feet below the surface. An unusually large number of heavy bowlders were encountered in these wells, making the drilling a matter of some difficulty, but at the same time indicating a comparatively free passage for the underflow. It is in the beds of coarse gravels and bowlders that the greatest available quantity of water is to be expected.

Log of H. L. Chandler's well.

	Feet.
Soil and cement	11
Gravel and bowlders, water bearing	22
Clay	8
Gravel and bowlders, water bearing	145

A sample of the water was taken for analysis from near the bottom of the well, the water being obtained from the sand pump as the bucket was hoisted. The sample is not therefore representative of the water at this locality. The alkali is probably from water of the upper stratum. Samples of water taken in this way from other wells which were afterwards cleared by pumping show a greater proportion of salts than samples taken after pumping. The analysis, however, is here given for the sake of completeness and for the purpose of indicating something of the quantity of salts contained in the waters of this locality.

Analysis of water from H. L. Chandler's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	224.00
Chlorine in terms of NaCl (common salt)	146.00
Hardness in terms of $CaSO_4$ (sulphate of lime)	.00
Alkalinity in terms of Na_2CO_3 (black alkali)	2.12
Qualitative:	
Sulphates	Very strong.
Magnesia	Very strong.
Lime	Strong.

This well was utilized to some extent during the summer of 1904. A solar motor, established temporarily, for the past four months has pumped 350 to 380 gallons of water per minute during the hours of sunshine.

FLUMMERFELT WELL (SEC. 11, T. 1 S., R. 4 E.)

Mr. Bristol Flummerfelt has a 6-inch drilled well 61 feet deep. The surface water at his place proved unsatisfactory both in quantity and quality, and his object in drilling was to obtain a supply for domestic use. A solid casing was used to shut off the surface water and the well was put down only 6 feet into the gravels, since all the water needed was obtained at that depth. The quantity and quality of the water from the 55-foot level indicate that it comes from the body encountered as the second horizon in the deeper wells of the same region.

Log of Bristol Flummerfelt's well.

	Feet.
Soil	10
Cement, with sand and gravel	30
Clay	15
Gravel and bowlders, water bearing	6+

Analysis of water from Bristol Flummerfelt's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	186.00
Chlorine in terms of NaCl (common salt)	122.00
Hardness in terms of $CaSO_4$ (sulphate of lime)	13.60
Alkalinity in terms of Na_2CO_3 (black alkali)	0.00
Qualitative:	
Sulphates	Strong.
Magnesia	Strong.
Lime	Very strong.
Bicarbonates	Very strong.

BARTLETT-HEARD LAND AND CATTLE COMPANY'S WELLS.

D. B. Heard has sunk two wells south of Tempe. The first is 1,000 feet west of the railroad and the second about 2,000 feet east of the railroad. Both are 15-inch double-steel-cased wells, the first 259 feet deep and the second 217 feet. Water was not obtained in satisfactory quantities in either well; the first yielding practically none and the second too little to warrant the establishment of an extensive pumping plant such as was planned. These wells were therefore practically abandoned, and the plant is to be established farther to the west as described elsewhere.

In well No. 1, sunk 1,000 feet west of the railroad (sec. 4, T. 1 S., R. 4 E.), gravels and bowlders were encountered similar to those in other wells of the vicinity, except that they were cemented together with caliche allowing little water to pass among them. The well is 1,000 feet west of one of the wells at the Valley Seedless Grape Company's vineyard which yields a good supply of water. At this point therefore the line marking the zone of abundant underground water is to be drawn between these wells.

Log of Bartlett-Heard well No. 1.

	Feet.
Soil and cement	34
Gravel	6
Cemented wash	83
Cemented bowlders	136

Well No. 2, sunk 2,000 feet east of the railroad (sec. 3, T. 1 S., R. 4 E.), was found somewhat more promising than the first but the available quantity of water was limited. The material passed through was almost entirely fine wash cemented by caliche; bed rock was struck at a depth of 217 feet. Well No. 2 is farther from the Salt River Mountains by 3,000 feet than well No. 1. It is furthermore in the direction in which, judging from records of other wells, favorable conditions for a satisfactory water supply are naturally expected; yet the well penetrates very little water-bearing material and reaches granite at the bottom.

Log of Bartlett-Heard well No. 2.

	Feet.
Soil and cement	22
Cement, water in pores	14
Cement	30
Bowlders and clay	6
Clay and cement	38
Gravel, water bearing	6
Clay and cement	36
Cement	4
Clay	8
Cement	6
Clay	16
Cement	4
Clay	10
Granitic wash	17
Bed rock	?

JOHNSON WELL (SEC. 30, T. 1 N., R. 5 E.).

Mr. B. F. Johnson has a shallow well 10 by 6 feet and 33 feet deep with 10 feet of water, from which he is pumping about 150 inches of water, using an 8-inch centrifugal pump and a 30-horsepower gasoline engine. The well yields this amount of water readily, the water being lowered by the pump only 3.5 feet.

The available quantity of water seems to warrant more extensive development. Two 12-inch double-steel-cased wells have been drilled and the installation of the pumping plant is in progress. The wells are 180 feet deep, and penetrate the gravel and bowlders common in that region. It is worthy of note that clay and granitic wash were found beneath the bowlders.

Log of well of B. F. Johnson, near Mesa, Ariz.

	Feet.
Soil	10
Sand, gravel, and bowlders	125
Clay	37
Granitic wash	8

TEMPE-MESA PRODUCE COMPANY'S WELL (SEC. 23, T. 1 N., R. 4 E.).

The company has recently established a pumping plant at its creamery near Tempe. There is one 12-inch double-steel-cased well 100 feet deep. As indicated in the log it is in loose gravel and bowlders through practically the whole depth.

Log of Tempe-Mesa Produce Company's well.

	Feet.
Soil	10
Gravel and bowlders	90

DESERT WELL (SEC. 11, T. 1 S., R. 7 E.).

This well is located about 15 miles southeast of Mesa, on the road leading from Mesa to Florence, and is owned at the present time by Thomas Buchanan. The well, which was dug in 1885, is 212 feet deep and contains 24 feet of water. On a platform near the surface of the water is a pump and small steam engine, supplied by steam generated above ground, which lifts water at the rate of 25 gallons per minute. The surface of the water is lowered 10 feet by the pump, at which stage the inflow equals the demand of the pump.

Log of Desert well.

	Feet.
"Wash" (sand, pebbles, clay, and cement)	150
Sand	2
Cement	20
Sand and gravel	5
Cement	?
Water-bearing gravel	?

The material penetrated in digging the well varies little in the 188 feet exposed above the water. The sides are not cased, except in three places where loose sand was encountered. The material is "wash" from the hills. It is an intimate admixture of clay, sand, and pebbles more or less cemented in places by caliche. The pebbles are angular and give slight indication of the action of water. Although the sides of the well are not protected in any way, they have stood for eighteen years without material change. Little moisture reaches them from the surface, and no water-bearing seams were encountered until near the bottom. At a depth of 212 feet a cement layer was penetrated and water encountered under sufficient pressure to raise it 24 feet.

Mr. Buchanan reports that the water has been steadily rising in the well for eight years—ever since he has owned the well. Even during the exceptionally dry years of 1901 and 1902, when many of the shallower wells of the valley entirely failed, the water in Desert well steadily increased in volume. This increase is somewhat vividly indicated by the present position of the engine and pump in the well. When placed there the platform upon which they rest was built at a convenient distance above the surface of the water. At the time of my visit the water was 3 feet deep over the platform and the engine and pump were submerged.

The quantity of water does not appear to be such as to warrant the supposition that this well draws from the great gravel beds furnishing the principal flow in the wells farther west. Twenty-five gallons per minute is a small volume compared with that yielded by some of the wells, and yet this yield lowers the water in Desert well about 10 feet. The quality of the water as shown by the following analysis and the elevation of the water 1,260 feet as against 1,134 in the Murphy-McQueen well renders it probable that the stratum from which the desert well draws its supply is connected with what is known as the surface flow of the valley rather than with the deeper and larger flow. In order to strike the level of the water-bearing gravels which supply the water for the large pumping plants of the valley Desert well would have to be lowered about 100 feet.

Analysis of water from Desert well.

Quantitative (parts in 100,000):	
Total-solids soluble at 110° C	32.00
Chlorine in terms of NaCl (common salt)	5.20
Hardness in terms of $CaSO_4$ (sulphate of lime)	.00
Alkalinity in terms of Na_2CO_3 (black alkali)	4.66
Nitrogen in terms of nitrates	.494
Nitrogen in terms of nitrites	Very faint.
Qualitative:	
Sulphates	Faint.
Magnesia	Very faint.
Lime	Faint.
Bicarbonates	None.

KLEINMAN WELL (T. 2 S., R. 9 E.).

Mr. Daniel Kleinman's well is about 10 miles southeast of Desert well and 25 miles southeast of Mesa, on the Mesa-Florence road. It was dug to a depth of 272 feet, and from the bottom a 14-inch pipe was driven 12 feet, making the total depth 284 feet. The log of the well could not be obtained. The quantity of bowlders taken from the well, however, indicates that bowlder and gravel beds make up a large part of the material passed through. These bowlders have a maximum diameter of something over 1 foot and are thoroughly water worn. They are composed of quartzite and several varieties of granitic rock, together with gneisses and schists, in about the same proportion as they are found in the river bed at the present time.

The water flows from the top of the pipe into the open well, where it stands 2.5 feet deep. It is pumped by horsepower. A team of horses working continuously raises on an average 12.5 gallons per minute.

BOWEN WELL (T. 2 S., R. 9 E.).

Mr. Robert Bowen's well is situated near the south bank of Queen Creek, about 1 mile west of the point where the Florence-Mesa road crosses Queen Creek. The well is dug 212 feet deep and contains 2.5 feet of water. Although the water is so shallow there seems to be no possibility of exhausting it by the means at hand. The well is supplied with both windmill and horsepower for pumping and about 9 gallons per minute may be raised, a yield which does not lower the water level in the well to any appreciable extent. The water is said to show a distinct current flowing toward the west. Floating material gathers at the west side of the well. A float placed at the east side is said to traverse the diameter of the well 4 feet in about three minutes.

The material passed through is nearly all loose gravel and bowlders. The water is not confined by a clay or cement layer, but seems to mark the free surface of the underflow of Queen Creek.

Log of Robert Bowen's well.

	Feet.
Soil	8
Sand, gravel, and bowlders	25
Soft clay	6
Sand, gravel, and bowlders	50
Soft clay	2
Sand, gravel, and bowlders	24
Soft clay	26
Sand, gravel, and bowlders with streaks and bands of clay from a few inches to 2 feet thick	70

Analysis of water from Robert Bowen's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	54.00
Chlorine in terms of NaCl (common salt)	24.00
Hardness in terms of $CaSO_4$ (sulphate of lime)	16.30
Alkalinity in terms of Na_2CO_3 (black alkali)	.00
Qualitative:	
Sulphates	Distinct.
Magnesia	Distinct.
Lime	Strong.
Bicarbonates	Strong.

HARRINGTON WELL (SEC. 2, T. 2 S., R. 8 E.).

This well, which is owned at the present time by José Granillo, is dug 135 feet deep, and contains about 4 feet of water. No log could be obtained. The well was dug in 1892. The water is raised by horse-power with barrel and rope, and is used for stock and for the traveling public.

ANDRADA WELL (T. 2 S., R. 7 E.).

Sylvester Andrada's well is dug 114 feet deep, and had 14 feet of water when measured. The well, which is used somewhat extensively for watering stock, is provided with a small traction engine and pump. A large cement and cobblestone tank, about 20 feet square and 6 feet deep, serves as a reservoir. The capacity of the pump could not be ascertained, but is not great. When the pump is in operation the water is said to lower about 7 feet, and remains at that level until the pump stops, when the water soon regains its former level. The water is soft, and, judging from taste, contains little salt of any kind.

PRICE WELL (SEC. 11, T. 1 N., R. 4 E.).

Col. J. A. Price has a well 15 feet deep, in which the water was found in the loose gravel and bowlders of the recent river accumulations. Until the plant was burned a few years ago, he pumped it for irrigation continuously at the rate of about 600 gallons per minute, obtaining water at this rate during the dryest times; ordinarily it might have yielded a greater amount.

PARRY WELL (SEC. 14, T. 1 N., R. 4 E.).

Mr. T. J. Parry's well is dug about one-fourth mile south of the river and 1 mile east of Tempe. It is about 40 by 60 feet and 21 feet deep, the water standing 17 feet below the surface of the ground. The level, however, varies with the water in the river; when there are floods in the river the water in the well rises, water marks on the sides of the well indicating that variations of at least 4 feet occur. It is said that the water in the well begins to rise about two days after the crest of the flood has passed.

Water is lifted by means of a 6-horsepower gasoline engine and bucket pump. When run at ordinary speed, the pump discharges 673 gallons per minute. It is operated about six hours a day; a run of four hours in the morning drains the well, but toward evening enough water has accumulated for a two-hour run. The well penetrates only a few feet beneath the water-bearing sands and gravels and is not cribbed or otherwise protected. If sunk a few feet deeper it would undoubtedly yield a much larger and more constant supply.

This plant offered a good opportunity of testing the cost of raising water by means of a bucket pump and gasoline engine. The amount of gasoline was accurately measured and the quantity of water computed from the average number of buckets lifted. (It was found later that owing to a defective valve more gasoline may have been used than was necessary.)

Cost of pumping water at T. J. Parry's pumping plant.

Cost of well (estimated)	$400.00
Cost of engine and pump	$500.00
Interest on investment, at 7 per cent per annum for 8.1 hours	$0.06
Depreciation, at 10 per cent per annum for 8.1 hours	$0.08
Amount of water lifted in 1 hour, in gallons	40,320
Hours required to lift 1 acre-foot	8.1
Gallons of gasoline used in 1 hour	1.2
Gallons of gasoline used in 8.1 hours	9.72
9.72 gallons, at 28 cents	$2.72
Oil, etc. (estimated)	$0.05
Total cost per acre-foot	$2.91
Total lift, in feet	18
Average cost per foot in lifting 1 acre-foot of water	$0.161

JENKINS SEEPAGE DITCH (SEC. 20, T. 1 N., R. 4 E.).

Mr. A. R. Jenkins has a seepage ditch southwest of Tempe. The ditch heads into the area east of Bell Butte, where the underground water surface is at a depth of about 8 feet. It has a maximum depth of 10 feet, thus penetrating the water-charged gravels about 2 feet at the deepest point. Water seeps into the ditch for about one-fourth of a mile, and yields at present about 30 inches. When the ditch was first constructed the underground water stood within 2 feet of the surface, but during the last few years the surface of the underground water throughout this region has been lowering.

The ditch was constructed in 1895 and the land irrigated from it has had little other water since that time. The water is derived from the surface flow south of Tempe and contains the black alkali which is so much feared by the farmers of that region. Mr. Jenkins reports no ill effects to the land from the use of this water, although it has been used almost exclusively for eight years.

Two analyses of water from this ditch show salts as follows:

Analyses of water from A. R. Jenkins's seepage ditch.

	No. 1.	No. 2.
Quantitative (parts in 100,000):		
Total solids soluble at 110° C	189.4	216.4
Chlorine in terms of NaCl (common salt)	136.0	142.9
Hardness in terms of $CaSO_4$ (sulphate of lime)	.0	.0
Alkalinity in terms of Na_2CO_3 (black alkali)	8.4	7.7
Qualitative:		
Sulphate	Very strong.	Strong.
Magnesia	Strong.	Faint.
Lime	Strong.	Strong.

SHALLOW WELLS.

PHIL METS AND ALHAMBRA HOTEL WELLS.

The well at Mets's livery stable may be taken as a fair representative of the shallow wells at Mesa. A careful record of material passed through is given below. It consists of river drift, composed of sand, pebbles, and bowlders, with a subordinate amount of clay and cement. The bowlders are principally composed of quartz, quartzite, and some of the more resistant granitic rocks and have a maximum diameter of 1 foot or more. They are thoroughly waterworn and differ in no essential respect from the materials found at the present time in the bed of the river. The bands of clay and cement contain sand and pebbles in varying proportions.

Log of P. Mets's well, Mesa.

	Feet.
Sandy soil	13
Gravel and bowlders	7
Cement	1
Coarse sand	9
Hard, sandy cement	3
Sand and gravel	19
Hard cement containing sand and small pebbles	4
Gravel, water bearing	2

Water was first struck in the gravels at a depth of 39 feet. This failed in dry times and the well was lowered, obtaining a better supply a little deeper. This supply diminished in time and the well was again lowered. The process of lowering the well continued until at a depth of 52 feet a hard, impervious cement layer 4 feet thick was encountered. The bar with which this was being dug struck through into a bed of loose gravel containing water under slight pressure. The water quickly rose 6 feet. Since that time there has been no shortage, the water standing steadily 6 feet deep. A yield of 700 gallons per hour, even in the driest times, has little effect on the amount of water in the well.

The water from the 56-foot level is of somewhat different quality from that of higher levels. The water from the Mets well tastes salty, but is otherwise a more palatable drinking water than that of many of the shallower wells of the vicinity.

An analysis of this water is given below, and also one of water from the well at the Alhambra Hotel, in the adjoining block. The Alhambra supply comes from a horizon a few feet above that of the Mets well, probably above the cement stratum at the bottom of the Mets well. Judged by the taste alone the two waters are very different, but the analyses show them very much alike.

Analysis of water from P. Mets's well and the Alhambra Hotel well, at Mesa.

	Mets.	Alhambra.
Quantitative (parts in 100,000):		
Total solids soluble at 110° C	167.80	152.00
Chlorine in terms of NaCl (common salt)	108.00	89.60
Hardness in terms of $CaSO_4$ (sulphate of lime)	.00	.00
Alkalinity in terms of Na_2CO_3 (black alkali)	9.33	5.51
Nitrogen in the form of nitrates	.385	.33
Nitrogen in the form of nitrites	Very faint.	Very faint.
Qualitative:		
Sulphate	Strong.	Strong.
Magnesia	Faint.	Faint.
Lime	Strong.	Strong.
Bicarbonates	Very strong.	Very strong.

VARIATION IN QUALITY.

The water of the various shallow wells in and about Mesa varies in quality to a marked extent. They are all strongly charged with various soluble salts. A study of the analyses shows that common salt, the carbonates, and the sulphates are the most common and are present in large amount in nearly all the waters, but the variation in the proportions of these salts causes the many varieties of water which arouse so much wonder and speculation in the minds of the owners of the wells. In most of the well waters common salt predominates. Nearly all the well water is said to be hard, and lye is very generally used to "break" it; only a few wells contain water which is said to be soft, though the analyses just given show an absence of any permanent hardness. It is possible that the abundance of other salts in the water renders difficult the detection of hardness by the taste.

Many of the wells are so strong in alkali and the bitter salts that they have been abandoned. In other cases the owners have accustomed themselves to the use of water which a stranger could not safely use. In still other cases the water seems to have gradually improved as the well was used. The published analyses do not indicate the range of variation in chemical character, for the reason that only wells yielding waters sufficiently good to be used are preserved. Many wells have been destroyed which yielded water too alkaline or too bitter for use. In other cases wells yielding bitter or intensely alkaline waters are said to have been greatly improved by pumping. In some cases this reported improvement is no doubt due to the education of the taste rather than to the change in character of the water, but in other cases there seem to be good reasons for believing that wells have entered small pockets containing saline solutions and more or less separated from the main body of underground waters. An exhaustion of the limited supply of such saline solutions would allow the entrance of water from the main water body and would effect a corresponding change in character.

TABULATION OF WELLS.

It seemed advisable in the study of the underground waters of the valley to test the existence of a definite regular water table and to determine the relations of such water table to the land surface and to the river, the principal source of the underground supply. Mesa Township (see Pl. XVIII) was selected for this test on account of favorable location and the existence there of a large number of wells. In the townships bordering Mesa the wells are fewer in number, but with the definite information obtainable from the great number of wells in Mesa Township the water table of the Mesa district is satisfactorily determined and is described in Chapter III.

Tabulation of shallow wells.

MESA TOWNSHIP (T. 1 N., R. 5 E.).

[Records obtained by Robert Muldrow.]

Number.	Owner.	Post-office.	Location. Township.	Range.	Section.	Completed.	How put down.	Depth of well.	Depth to water.	Does water vary at different times of year?	Is water easily lowered?	Did water rise when struck?	Has the volume of water increased or diminished?	Elevation of surface.	Elevation of water.	Remarks.
								Feet.	*Feet.*					*Feet.*	*Feet.*	
347	E. E. Jones	Lehi	1 N.	5 E.	1	1887	Dug	41	40	Yes	Yes	No	Diminished	1,241	1,201	Constantly lowered.
346	Ed. Prothero	do	1 N.	5 E.	1	1890	do	43	42	Yes	Yes	No	do	1,242	1,200	Do.
344		do	1 N.	5 E.	1		do	50	49	Yes		No	do	1,250	1,201	Do.
237	George Rogers	do	1 N.	5 E.	2	1889	do	27	26	Yes	Yes	No	do	1,232	1,206	Do.
238	Charles Davis	do	1 N.	5 E.	2	1884	do	33	30	Yes	No	No	do	1,230	1,200	
239	S. B. Steele	do	1 N.	5 E.	2	1890	do	35	32	Yes	No	No	do	1,230	1,200	
240	J. W. Clark	do	1 N.	5 E.	2	1892	do	35	34	Yes	Yes	No	do	1,233	1,199	Do.
241	C. H. Rollins	do	1 N.	5 E.	2	1902	do	35	34		No	No	Neither	1,234	1,200	
342	Joseph Hawkins	do	1 N.	5 E.	2	1901	do	38	37		No	No	Diminished	1,235	1,198	
343					2		do	33						1,236		Dry.
345	B. Noble	Lehi	1 N.	5 E.	2	1887	do	38	37	Yes	No	No	Diminished	1,234	1,193	Constantly lowered.
348	George Tiffany	do	1 N.	5 E.	2	1900	do	40		Yes	Yes	No	do	1,238		Dry.
349	S. C. Sorenson	do	1 N.	5 E.	2		do	40	39	Yes	Yes	No	do	1,237	1,198	Constantly lowered.
353	Wm. Nelson	do	1 N.	5 E.	2	1898	do	32	31	Yes	No	No	do	1,228	1,197	Do.
354	Ruth Gibson	do	1 N.	5 E.	2		do	31		Yes	No	No	do	1,228		Dry.
356	E. D. Biggs	do	1 N.	5 E.	2	1894	do	33	32	Yes	No	No	do	1,228	1,196	Constantly lowered.
357	Leuella Davis	do	1 N.	5 E.	2	1901	do	30		Yes	No	No	do	1,232		Dry.
361	Thomas E. Jones	do	1 N.	5 E.	2	1902	do	39	37	No	No	No	Neither	1,226	1,199	
363	L. F. Kiggins	Mesa	1 N.	5 E.	3		do	28		Yes	No	No	Diminished	1,221		Do.
362	Harvey Harper	Lehi	1 N.	5 E.	3	1895	do	28	27	Yes	Yes	Yes	do	1,225	1,198	Constantly lowered.
360	D. R. Jones	do	1 N.	5 E.	3	1892	do	30	29	Yes	No	No	do	1,222	1,193	Do.
358	C. G. Shill	do	1 N.	5 E.	3	1902	do	30	29	Yes	Yes	No	do	1,229	1,200	Do.

355	F. J. Davis	do	1 N.	5 E.	3	1898	do	31	30	Yes	No	No	do	1,228	1,198	Do.
352	O. A. Wing	do	1 N.	5 E.	3	1897	do	33	31	No	Yes	Yes	do	1,227	1,195	Do.
302		Mesa	1 N.	5 E.	4		do	8		Yes			do	1,211		Dry.
299	Wm. Schwartz	Lehi	1 N.	5 E.	4	1900	do	27	26	Yes	Yes	No	do	1,220	1,193	
123	Charles Bowers	Mesa	1 N.	5 E.	4		do	26						1,206		Do.
301	E. E. Weller	do	1 N.	5 E.	4	1901	do	20		Yes	Yes	No	Diminished	1,213		Do.
364	Indian	do	1 N.	5 E.	5		do	27	25	Yes		No	do	1,212	1,187	
365	do		1 N.	5 E.	5		do	21	18					1,210	1,182	
382	do		1 N.	5 E.	5		do	27	26					1,215	1,189	
385	do		1 N.	5 E.	5		do	26	25					1,216	1,191	
379	do		1 N.	5 E.	6		do	25	24	Yes	No		Diminished	1,208	1,184	
376	do		1 N.	5 E.	6		do	25	24	Yes	No	No	do	1,210	1,186	
377	do		1 N.	5 E.	6		do	21	20	Yes			do	1,206	1,186	
378	do		1 N.	5 E.	6		do	22	21	Yes	No	No	do	1,210	1,189	
369	do		1 N.	5 E.	6		do	21						1,207		Dry.
380	do		1 N.	5 E.	7		do	18	16				Diminished	1,192	1,176	
387	J. B. Wallace	Tempe	1 N.	5 E.	8	1886	Driven	15	9	Yes	Yes	No	do	1,201	1,192	
388	Wm. Wallace	do	1 N.	5 E.	8	1892	do	15	9	Yes	Yes	No	do	1,202	1,193	
303	E. B. Kearley	Mesa	1 N.	5 E.	8	1895	Dug	22	18	Yes	No		do	1,203	1,185	
300	Frank Sanders	Lehi	1 N.	5 E.	9	1898	do	30	24	Yes	Yes	Yes	do	1,215	1,191	Constantly lowered.
304	J. A. Williams	Mesa	1 N.	5 E.	9	1898	do	23	20	Yes	No	No	do	1,210	1,190	Do.
305	David Wallace	do	1 N.	5 E.	9		Driven									
351	H. Simpkins	Lehi	1 N.	5 E.	11	1902	Dug	36	35	Yes	No	No	Diminished	1,232	1,197	
350	Hannah Williams	do	1 N.	5 E.	11	1902	do	40	39	No	No	No	Neither	1,235	1,196	
333	P. W. Byers	do	1 N.	5 E.	11	1895	do	23		Yes	Yes		Diminished	1,230		Dry.
334			1 N.	5 E.	11		do	25					do	1,226		Do.
335			1 N.	5 E.	11		do	25	24	Yes	Yes		do	1,230	1,206	Constantly lowered.
336	C. W. Simpkins	Lehi	1 N.	5 E.	11	1901	do	20		Yes	No	No	do	1,230		Dry.
372			1 N.	5 E.	12		do	32					do	1,244		Do.
373			1 N.	5 E.	12		do	67	66	Yes	No	No	do	1,263	1,197	
374			1 N.	5 E.	12		do	64					do	1,263		Do.
375			1 N.	5 E.	12		do	64					do	1,282		Do.
122	O. C. Bullock	Mesa	1 N.	5 E.	13	1900	do	51		Yes	Yes	Yes	do	1,244		Do.
314	David Wallace	do	1 N.	5 E.	14	1892	do	54	53	Yes	No	No	do	1,244	1,181	Constantly lowered.
315	Thos. Jensen	do	1 N.	5 E.	14		do	57	55	Yes	No	No	do	1,249	1,184	Do.

Tabulation of shallow wells—Continued.

MESA TOWNSHIP (T. 1 N., R. 5 E.)—Continued.

Number.	Owner.	Post-office.	Location. Township.	Range.	Section.	Completed.	How put down.	Depth of well.	Depth to water.	Does water vary at different times of year?	Is water easily lowered?	Did water rise when struck?	Has the volume of water increased or diminished?	Elevation of surface.	Elevation of water.	Remarks.
								Feet.	Feet.					Feet.	Feet.	
371	A. J. Chandler	Mesa	1 N.	5 E.	14		Dug	26						1,249		Dry.
117	M. A. Crouse	do	1 N.	5 E.	14		do	55	54	No	No	No	Diminished	1,242	1,187	Constantly lowered.
120	D. Drorbaugh	do	1 N.	5 E.	14		do	50	48	Yes	Yes		do	1,243	1,195	Do.
332	J. M. Schule	do	1 N.	5 E.	15	1887	do	57	56	Yes	No	No	do	1,245	1,189	Do.
110	F. P. Drew	do	1 N.	5 E.	15		do	55	52				do	1,242	1,190	
311	Ed Lewis	do	1 N.	5 E.	16		do	61	60	Yes	Yes	No	do	1,246	1,186	Do.
312	M. F. Davis	do	1 N.	5 E.	16	1900	do	62	60	Yes	No	No	do	1,242		Dry.
313			1 N.	5 E.	16	1897	do	52						1,242		Do.
279	O. S. Stapley	Mesa	1 N.	5 E.	16	1900	do	55	54	Yes	Yes	No	Diminished	1,242	1,188	Constantly lowered.
281			1 N.	5 E.	16		do	52						1,240		Dry.
282	L. D. Crook	Tempe	1 N.	5 E.	16	1900	do	57	55	Yes	No	No	Diminished	1,235	1,180	Constantly lowered.
297	J. P. Leebrick	Mesa	1 N.	5 E.	16	1900	do	61	60	Yes	No	Yes	do	1,246	1,186	Do.
298	I. D. Shumway	do	1 N.	5 E.	16	1897	do	56		Yes	No		do	1,248		Dry.
306	Henry Baker	do	1 N.	5 E.	16		do	56	55	Yes	No	No	do	1,238	1,183	Constantly lowered, very salty.
307	J. T. Lisonbee	do	1 N.	5 E.	16		do	54		Yes	Yes	No	do	1,240		Dry.
308			1 N.	5 E.	16	1897	do	58	56	Yes	No	Yes	do	1,240	1,184	Constantly lowered.
309			1 N.	5 E.	16		do	58	57	Yes	No	No	do	1,243	1,186	Constantly lowered; very salty.
310	J. C. Kimsey	Mesa	1 N.	5 E.	16	1900	do	60	58	Yes	Yes	No	do	1,244	1,186	Constantly lowered; salty.
287	James Nelson	Tempe	1 N.	5 E.	17	1894	do	50	48	Yes	Yes		do	1,230	1,182	Constantly lowered.
386	Wolf Sachs	do	1 N.	5 E.	17	1898	do	19					do	1,195		Dry.
389	J. D. Spooner	do	1 N.	5 E.	18	1898	Driven	18	10	No	Yes	No	Neither	1,188	1,178	
293	E. C. Woodmansee	do	1 N.	5 E.	18	1900	Dug	18	12			Yes	Diminished	1,188	1,176	

294	School	....do...	1 N.	5 E.	18	1901	....do...	19	17	Yes...	No....	No....	.....do........	1,188	1,171	
295	Wm. Rohrig	....do...	1 N.	5 E.	18	1893	....do...	17	16	Yes...	No....	No....	Neither........	1,188	1,172	
296	.....do	....do...	1 N.	5 E.	18	1901	....do...	19	13	....	No....	No....	.....do........	1,188	1,175	
118	J. M. Boundtree	Mesa ...	1 N.	5 E.	18	1902	....do...	54	53	Yes...	Yes...	Yes...	Diminished...	1,242	1,189	
82	W. A. Trent	....do...	1 N.	5 E.	19	....	....do...	50	49	Yes...	Yes...	....	.....do........	1,284	1,235	
268	Z. Martin	....do...	1 N.	5 E.	19	1888	....do...	39	37	....	Yes...	Yes...	.....do........	1,215	1,178	Constantly lowered.
269	.....do	....do...	1 N.	5 E.	19	1899	....do...	31	....	Yes...	Yes...	Yes...	.....do........	1,215	1,184	
270	....	....	1 N.	5 E.	19	....	....do...	....	....	....	....	....	....	1,213	....	
271	—— Gibson	Phoenix	1 N.	5 E.	19	1886	....do...	37	35	Yes...	....	....	Diminished...	1,211	1,176	Do.
272	J. Johnson	Mesa ...	1 N.	5 E.	19	1900	....do...	34	33	Yes...	....	....	.....do........	1,207	1,174	Do.
273	R. N. Westover	....do...	1 N.	5 E.	19	1887	....do...	27	26	Yes...	....	....	.....do........	1,207	1,181	
275	G. N. Finch	Tempe..	1 N.	5 E.	19	1894	....do...	28	26	Yes...	Yes...	No....	.....do........	1,193	1,167	Do.
288	Fanny Dobbie	Mesa ...	1 N.	5 E.	19	....	....do...	39	37	Yes...	Yes...	....	.....do........	1,215	1,178	
289	.....do	....do...	1 N.	5 E.	19	1901	....do...	37	....	Yes...	Yes...	No....	.....do........	1,215	....	Dry.
290	L. A. Tewksbury	Tempe..	1 N.	5 E.	19	1901	....do...	38	37	Yes...	Yes...	Yes...	.....do........	1,215	1,178	Constantly lowered.
292	J. W. Stewart	....do...	1 N.	5 E.	19	1887	....do...	38	37	Yes...	Yes...	....	.....do........	1,211	1,174	Do.
235	Loy Schank	....do...	1 N.	5 E.	19	1901	....do...	25	24	Yes...	No....	No....	.....do........	1,196	1,172	
236	.....do	....do...	1 N.	5 E.	19	1901	....do...	26	25	Yes...	No....	No....	.....do........	1,198	1,173	
237	N. W. Brimhall	....do...	1 N.	5 E.	19	....	....do...	27	26	Yes...	Yes...	Yes...	.....do........	1,200	1,174	
238	Nora Brimhall	....do...	1 N.	5 E.	19	1899	....do...	30	28	Yes...	Yes...	Yes...	.....do........	1,202	1,174	
213	S. A. Stewart	....do...	1 N.	5 E.	20	1894	....do...	44	43	Yes...	No....	No....	.....do........	1,224	1,181	
214	J. S. Toney	Phoenix	1 N.	5 E.	20	1892	....do...	43	42	Yes...	....	Yes...	.....do........	1,222	1,180	
215	....	....	1 N.	5 E.	20	1887	....do...	37	....	Yes...	Yes...	Yes...	.....do........	1,220	....	Dry.
217	J. V. Spainhower	Mesa ...	1 N.	5 E.	20	1896	....do...	40	38	Yes...	Yes...	....	.....do........	1,216	1,178	
259	....	....	1 N.	5 E.	20	....	....do...	50	48	Yes...	No....	....	.....do........	1,228	1,180	Constantly lowered.
261	W. H. Pew	Mesa ...	1 N.	5 E.	20	1892	....do...	43	....	Yes...	No....	Yes...	.....do........	1,226	....	Dry.
262	D. P. Pew	....do...	1 N.	5 E.	20	1897	....do...	46	45	Yes...	No....	Yes...	.....do........	1,225	1,180	
263	M. S. Longmore	....do...	1 N.	5 E.	20	1902	....do...	46	45	Yes...	No....	Yes...	Neither........	1,224	1,179	Constantly lowered.
264	....	....	1 N.	5 E.	20	....	....do...	43	41	Yes...	....	Yes...	Diminished..	1,219	1,178	Do.
265	A. W. Crismon	Mesa ...	1 N.	5 E.	20	1897	....do...	41	40	Yes...	No....	Yes...	.....do........	1,218	1,178	Do.
266	Ellen Crismon	....do...	1 N.	5 E.	20	1899	....do...	39	....	....	....	....	.....do........	1,218	....	Dry.
267	C. T. Wise	....do...	1 N.	5 E.	20	1892	....do...	42	40	Yes...	No....	Yes...	.....do........	1,216	1,176	Constantly lowered.
283	Loretti E. Everton	....do...	1 N.	5 E.	20	1891	....do...	50	....	Yes...	No....	Yes...	.....do........	1,233	....	Dry.
285	Otis Rogers	....	1 N.	5 E.	20	....	....do...	52	50	Yes...	....	....	.....do........	1,233	1,183	Constantly lowered.

Tabulation of shallow wells—Continued.

MESA TOWNSHIP (T. 1 N., R. 5 E.)—Continued.

Number.	Owner.	Post-office.	Location. Township.	Location. Range.	Location. Section.	Completed.	How put down.	Depth of well.	Depth to water.	Does water vary at different times of year?	Is water easily lowered?	Did water rise when struck?	Has the volume of water increased or diminished?	Elevation of surface.	Elevation of water.	Remarks.
								Feet.	*Feet.*					*Feet.*	*Feet.*	
286	H. N. Pew	Mesa	1 N.	5 E.	20	1896	Dug	41		Yes	No	Yes	Diminished	1,231		Dry.
291	M. L. Gray	Tempe	1 N.	5 E.	20	1890	do	39	37	Yes	No	No	do	1,215	1,178	Constantly lowered.
250	Mrs. Lofgreen	Mesa	1 N.	5 E.	21	1902	do	52	50	Yes	Yes		do	1,239	1,189	Do.
251	J. Pierce	do	1 N.	5 E.	21		do	55	54	Yes	Yes		do	1,237	1,186	Do.
252	Julia Dykes	do	1 N.	5 E.	21	1896	do	52	51	Yes	No		do	1,237	1,186	Do.
253	A. Hunsacker	do	1 N.	5 E.	21	1897	do	54	53	Yes	Yes		do	1,235	1,182	Do.
254	do	do	1 N.	5 E.	21	1897	do	55	54	Yes	Yes		do	1,234	1,180	Do.
255	do	do	1 N.	5 E.	21	1899	do	54	53	Yes	Yes	Yes	do	1,233	1,180	Do.
256	W. N. Standage	do	1 N.	5 E.	21		do	58	56	Yes			do	1,234	1,178	Do.
257	Charles Pew	do	1 N.	5 E.	21	1898	do	50	48	Yes	Yes	Yes	do	1,230	1,182	Do.
258	J. A. Stewart	do	1 N.	5 E.	21	1890	do	52		Yes	Yes	Yes	do	1,230	1,178	
260	Alma School	do	1 N.	5 E.	21	1898	do	47	46	Yes		Yes	do	1,227	1,181	Do.
276	H. Stewart	do	1 N.	5 E.	21	1901	do	55	52		No	Yes	do	1,239	1,187	
277	Jessie Pierce	do	1 N.	5 E.	21	1892	do	53	52	Yes			do	1,240	1,188	Do.
278	J. W. Bond	do	1 N.	5 E.	21	1901	do	56		Yes	Yes	No	do	1,244		Dry.
280	M. F. Davis	do	1 N.	5 E.	21	1895	do	55	53	Yes	No	Yes	do	1,240	1,187	Constantly lowered; salty.
284	J. E. Johnson	do	1 N.	5 E.	21	1894	do	56	55	Yes		Yes	do	1,234	1,179	
186	D. A. Johnson	do	1 N.	5 E.	21	1901	do	55	54	Yes	Yes	Yes	do	1,231	1,177	
187	M. A. Crouse	do	1 N.	5 E.	21		do	53			Yes	Yes	do	1,231		Dry.
188	J. S. Coffin	do	1 N.	5 E.	21	1898	do	54	52	Yes	No	Yes	do	1,230	1,178	
205	M. L. Horrell	do	1 N.	5 E.	21	1899	do	44	43	Yes	No	Yes	do	1,225	1,182	
207	J. R. Standage	do	1 N.	5 E.	21	1897	do	47	46	Yes	Yes		do	1,222	1,181	
246	Wm. Crismon	do	1 N.	5 E.	21		do	50	49	Yes	Yes	Yes	do	1,235	1,186	Constantly lowered

248	A. L. Cuber	do	1 N.	5 E.	21	1882	do	53		Yes	Yes	No	do	1,237		Dry.
249	do	do	1 N.	5 E.	21	1889	do	53	51	Yes	Yes	No	do	1,237	1,186	Constantly lowered.
66	E. N. Grard	do	1 N.	5 E.	22	1897	do	40	39				do	1,233	1,194	
65	H. Dana	do	1 N.	5 E.	22	1901	do	49	47				do	1,233	1,186	
181	P. M. Coleman	do	1 N.	5 E.	22	1892	do	45	43	Yes	No	Yes	do	1,232	1,189	
184	George Woy	do	1 N.	5 E.	22		do	37		Yes	Yes		do	1,232		Dry.
244	D. Le Baron	do	1 N.	5 E.	22	1901	do	49	48	Yes	Yes	Yes	do	1,234	1,186	Constantly lowered.
245	M. Forrester	do	1 N.	5 E.	22	1901	do	50	49	Yes	Yes	Yes	do	1,235	1,186	Do.
247	H. B. Morris	do	1 N.	5 E.	22	1884	do	55	54	Yes	Yes	No	do	1,236	1,182	Do.
104	O. S. Stapley	do	1 N.	5 E.	22	1902	do	50	47	Yes	Yes		do	1,238	1,191	
105	Chas. Sellers	do	1 N.	5 E.	22	1902	do	52	50	Yes	No	Yes	do	1,234	1,184	
107	Mesa Milling Co	do	1 N.	5 E.	22	1899	do	52	48		Yes	Yes	do	1,238	1,190	
108			1 N.	5 E.	22		do	42						1,239		
396	Geo. M. Fryer	Mesa	1 N.	5 E.	22	1898	do	50	46	Yes	No	No	Neither	1,237	1,191	
397	H. H. Gillispie	do	1 N.	5 E.	22	1897	do	52	45	Yes	No	No	do	1,237	1,192	
399	L. V. Guthrie	do	1 N.	5 E.	22	1898	do	44	38	Yes	Yes	No	Diminished	1,233	1,195	
400	P. A. Williams	do	1 N.	5 E.	22	1898	do	47	43	Yes	Yes		do	1,233	1,190	
401	Phillip Coleman	do	1 N.	5 E.	22	1902	do	46	40	Yes	No	No	do	1,233	1,193	
403	Phil Mets	do	1 N.	5 E.	22	1901	do	56	48		No	Yes	do	1,239	1,191	
404	John Nelson	do	1 N.	5 E.	22	1902	do	55	49		Yes	Yes		1,243	1,194	
316	Joe Meyers	do	1 N.	5 E.	22	1893	do	49	48	Yes	Yes	No	Diminished	1,235	1,187	Do.
317	S. L. Elder	do	1 N.	5 E.	22		do	49	48	Yes	Yes	No	do	1,236	1,188	Do.
318	School	do	1 N.	5 E.	22		do	50	49	Yes	Yes	No	do	1,236	1,187	Do.
319	M. B. Ullman		1 N.	5 E.	22		do	50	49	Yes	Yes	No	do	1,237	1,188	Constantly lowered; salty.
230	E. W. Jones	Mesa	1 N.	5 E.	22	1896	do	52	51	Yes	No	No	do	1,237	1,186	Constantly lowered.
321	Kimball Pomeroy	do	1 N.	5 E.	22	1894	do	52	51	Yes	Yes	No	do	1,237	1,186	Do.
322	J. H. Pomeroy	do	1 N.	5 E.	22	1882	do	52	51	Yes	Yes	No	do	1,238	1,186	Do.
323	Jack Frazier	do	1 N.	5 E.	22	1890	do	52	51	Yes	Yes	No	do	1,239	1,188	Do.
324	H. L. Chandler	do	1 N.	5 E.	22	1882	do	52	49	Yes		No	do	1,240	1,191	Do.
325	J. Sirrine	do	1 N.	5 E.	22		do	52	51	Yes	No	No	do	1,240	1,189	Do.
326	Chas. Starr	do	1 N.	5 E.	22	1890	do	53	52	Yes	No	No	do	1,240	1,182	Do.
327	School	do	1 N.	5 E.	22	1890	do	54	52	Yes	No	No	do	1,241	1,189	Do.
328	J. Sirrine	do	1 N.	5 E.	22		do	49	48	Yes	No	No	do	1,241	1,193	Do.
329	G. W. Woy	do	1 N.	5 E.	22		do	56	54	Yes	Yes	No	do	1,242	1,188	Do.

Tabulation of shallow wells—Continued.

MESA TOWNSHIP (T. 1 N., R. 5 E.)—Continued.

Number.	Owner.	Post-office.	Location.			Completed.	How put down.	Depth of well.	Depth to water.	Does water vary at different times of year?	Is water easily lowered?	Did water rise when struck?	Has the volume of water increased or diminished?	Elevation of surface.	Elevation of water.	Remarks.
			Township.	Range.	Section.											
								Feet.	*Feet.*					*Feet.*	*Feet.*	
330	City	Mesa	1 N.	5 E.	22	1901	Dug	59	53		No	No	Diminished	1,240	1,187	
331	Geo. Schornick	do	1 N.	5 E.	22	1901	do	56	53	Yes	No		do	1,239	1,186	
176	P. B. Hughes	do	1 N.	5 E.	22		do	47	46	Yes	No		do	1,233	1,187	
177	L. V. Guthrie	do	1 N.	5 E.	22	1896	do	48	46	No	Yes		do	1,233	1,187	
53	N. Fuller	do	1 N.	5 E.	23	1895	do	43					do	1,233		
50	L. Allen	do	1 N.	5 E.	23		do	42	41				do	1,232	1,190	
89	C. W. Fellows	do	1 N.	5 E.	23	1887	do	45		Yes	Yes		do	1,238		Dry.
90	M. K. McArthur	do	1 N.	5 E.	23		do	40	38	Yes	Yes	No	do	1,236	1,195	
91	W. B. Telford	do	1 N.	5 E.	23		do	50					do	1,235		Dry, salty.
92	do	do	1 N.	5 E.	23		do	31			Yes		do	1,235		Dry, soft.
93	Sarah Whitehead	do	1 N.	5 E.	23	1892	do	50	47	Yes	Yes	Yes	do	1,237	1,190	
94	Hiram Phelps	do	1 N.	5 E.	23	1897	do	46		Yes	Yes	Yes	do	1,237		Dry.
95	H. J. Horne	do	1 N.	5 E.	23	1892	do	45	44	Yes	Yes	Yes	do	1,236	1,192	
96	Hiram Phelps	do	1 N.	5 E.	23	1896	do	50	48	Yes	Yes	Yes	do	1,236	1,188	
97	do	do	1 N.	5 E.	23	1888	do	48		Yes	No	No	do	1,236		Do.
98	M. C. Phelps	do	1 N.	5 E.	23	1892	do	49	47	Yes	No	No	do	1,236	1,189	
99	J. M. Horne	do	1 N.	5 E.	23	1892	do	43	40	Yes	Yes	No	do	1,233	1,193	
100	do	do	1 N.	5 E.	23	1901	do	45	44	Yes	Yes	No	do	1,233	1,189	
101	J. R. Morse	do	1 N.	5 E.	23	1887	do	48	47	Yes	No	No	do	1,238	1,192	
102	J. E. Sirrine	do	1 N.	5 E.	23	1892	do	48	47	Yes	Yes	Yes	do	1,238	1,191	
103	Hannah Johnson	do	1 N.	5 E.	23	1898	do	50	48	Yes	Yes	Yes	do	1,238	1,190	
106	Tempe-Mesa Produce Co.	Tempe	1 N.	5 E.	23	1902	do	49	48			Yes	do	1,238	1,190	
109			1 N.	5 E.	23		do	47						1,239		

111	George Woy	Mesa	1 N.	5 E.	23			45						1,242		
112			1 N.	5 E.	23		Dug	38						1,241		Do.
113			1 N.	5 E.	23		do	55	53	Yes	Yes		Diminished	1,241	1,188	
114			1 N.	5 E.	23		do	60						1,241		
115	Oscar Whitlow	Mesa	1 N.	5 E.	23		do	50	47	Yes	No		Diminished	1,240	1,193	
116	Anna Hall	do	1 N.	5 E.	23		do	60	58	Yes	Yes		do	1,239	1,181	
119	Oscar Whitlow	do	1 N.	5 E.	23		do	31				Yes	do	1,240		Do.
121	O. Daley	do	1 N.	5 E.	23	1900	do	51	50	Yes	Yes	Yes	do	1,244	1,194	Constantly lowered.
83	C. R. Hakes	do	1 N.	5 E.	24	1902	do	52	51	Yes	Yes	No	do	1,246	1,195	
84	W. B. Telford	do	1 N.	5 E.	24	1899	do	55	54	Yes	Yes	Yes	do	1,244	1,190	Water has lowered 34 feet since 1899.
85	L. E. Lamb	do	1 N.	5 E.	24	1900	do	50	49	Yes	Yes	No	do	1,243	1,194	
86	W. B. Telford	do	1 N.	5 E.	24	1895	do	50	49	Yes	Yes	Yes	do	1,242	1,193	
87	W. L. Sirrine	do	1 N.	5 E.	24	1896	do	48						1,242		Dry.
88	E. W. Wilbur	do	1 N.	5 E.	24	1896	do	50	48	No	Yes	Yes	Diminished	1,238	1,190	Constantly lowered.
35	Mary Peterson	do	1 N.	5 E.	24	1893	do	60	58	No	Yes		do	1,238	1,180	
39	H. L. Peterson	do	1 N.	5 E.	24	1898	do	50	47	Yes			do	1,236	1,189	
41	C. Peterson	do	1 N.	5 E.	24	1884	do	52	49	Yes				1,235	1,186	
30	J. A. Allison	do	1 N.	5 E.	25	1896	do	45	44	Yes	No		Diminished	1,235	1,195	
31	do	do	1 N.	5 E.	25	1899	do	52	50	Yes	No		do	1,247	1,195	
32	H. H. Taylor	do	1 N.	5 E.	25	1900	do	50						1,241		
34	P. Weisner	do	1 N.	5 E.	25	1897	do	52	50	Yes			Diminished	1,239	1,189	
37	D. S. Lewis	do	1 N.	5 E.	25	1895	do	52	49	Yes	Yes		do	1,236	1,187	
38	do	do	1 N.	5 E.	25	1890	do	52					do	1,233		
40	H. M. Lewis	do	1 N.	5 E.	25	1897	do	52	50	Yes			do	1,235	1,185	
42	G. W. Lewis	do	1 N.	5 E.	25	1897	do	52	50	Yes			do	1,234	1,184	
46	L. Lewis	do	1 N.	5 E.	25	1897	do	38	37				do	1,226	1,189	
10	N. H. Price	do	1 N.	5 E.	26	1887	do	44	43	Yes	Yes			1,233	1,189	
44	C. H. Allen	do	1 N.	5 E.	26	1892	do	39	37	Yes			Diminished	1,228	1,189	
45	W. J. Clark	do	1 N.	5 E.	26		do	39	38	Yes			do	1,228	1,190	
48	J. L. Coleman	do	1 N.	5 E.	26	1900	do	37	36				do	1,225	1,189	
49	J. S. Allen	do	1 N.	5 E.	26	1896	do	42						1,232		
51	W. Allen	do	1 N.	5 E.	26	1898	do	50						1,231		
52	J. Allen	do	1 N.	5 E.	26	1898	do	50						1,231		
54	W. Brundage	do	1 N.	5 E.	26	1898	do	43	41	Yes			Diminished	1,233	1,192	

Tabulation of shallow wells—Continued.

MESA TOWNSHIP (T. 1 N., R. 5 E.)—Continued.

Number.	Owner.	Post-office.	Location.			Completed.	How put down.	Depth of well.	Depth to water.	Does water vary at different times of year?	Is water easily lowered?	Did water rise when struck?	Has the volume of water increased or diminished?	Elevation of surface.	Elevation of water.	Remarks.
			Township.	Range.	Section.											
								Feet.	Feet.					Feet.	Feet.	
55	N. A. Brundage	Mesa	1 N.	5 E.	26	1898	Dug	42	39				Diminished			
68	S. T. Barnett	do	1 N.	5 E.	26	1896	do	40						1,228		
69	E. Ellsworth	do	1 N.	5 E.	26		do	39	38					1,225	1,187	
72	C. Fuller	do	1 N.	5 E.	26	1900	do	37	35				Diminished	1,220	1,185	
179	M. B. Ullman	do	1 N.	5 E.	27		do	44		Yes	Yes		do	1,232		Dry.
180	Frank Dana	do	1 N.	5 E.	27	1898	do	47	45	Yes	Yes		do	1,232	1,187	Do.
182	Frank Dana	do	1 N.	5 E.	27		do	43		Yes	Yes		do	1,232		
183	A. W. Babbitt	do	1 N.	5 E.	27		do	47	46	Yes	Yes		do	1,232	1,186	
209	H. M. Cooper	do	1 N.	5 E.	27		do	37		Yes	Yes	Yes	do	1,222		Do.
211	do	do	1 N.	5 E.	27		do	41	40				do	1,225	1,185	
212	Joseph D. Crose	do	1 N.	5 E.	27	1899	do	44	42	Yes	Yes	Yes	do	1,228	1,187	
11	H. F. Simmons	do	1 N.	5 E.	27	1900	do	47	44	No	No	Yes	Neither	1,233	1,186	
12	Diffenderfert Ruse	do	1 N.	5 E.	27	1902	do	35	33	Yes	Yes	No	Diminished	1,220	1,187	
13	T. G. Marksbury	do	1 N.	5 E.	27	1886	do	40	38	Yes	Yes	No	do	1,215	1,175	
14	Francisco Arrows	do	1 N.	5 E.	27		do	35						1,219		
15	F. J. Kelley	do	1 N.	5 E.	27	1894	do	34	32	Yes	Yes	No	Diminished	1,217	1,183	
62	F. Marksbury	do	1 N.	5 E.	27	1886	do	41	39				do	1,224	1,185	
63	H. Coleman	do	1 N.	5 E.	27	1893	do	40	39				do	1,224	1,185	
64	J. Drane	do	1 N.	5 E.	27	1893	do	50	48				do	1,233	1,185	
67	A. Millet	do	1 N.	5 E.	27	1891	do	38	37				do	1,228	1,191	
70	R. Longmoor	do	1 N.	5 E.	27		do	40	39				do	1,225	1,186	
75	H. V. Parker	do	1 N	5 E.	27	1900	do	50	49				do	1,220	1,177	
73	L. M. Vance	do	1 N.	5 E.	28	1899	do	33						1,217		
74	J. T. Vance	do	1 N.	5 E.	28	1882	do	36	35				Diminished	1,219	1,184	

140	D. W. Grivel	do	1 N.	5 E.	28	1890	do	32	31	Yes	Yes	Yes	do	1,211	1,180	
189	D. D. Smith	do	1 N.	5 E.	28	1901	do	31					do	1,230		Do.
190	B. L. Bradford		1 N.	5 E.	28		do	42	41	Yes	Yes	Yes	do	1,223	1,182	
191	P. D. Smith	Mesa	1 N.	5 E.	28	1900	do	37		Yes	Yes	Yes	do	1,223		Do.
192	Henry Baker	do	1 N.	5 E.	28	1891	do	39	38	Yes	Yes	Yes	do	1,222	1,182	
193	J. T. Vance	do	1 N.	5 E.	28	1892	do	32		Yes	Yes	Yes	do	1,215		Do.
195	Merritt Clark	do	1 N.	5 E.	28	1890	do	35	34	Yes	Yes		do	1,215	1,181	
199	J. F. Bradberry	do	1 N.	5 E.	28		do	37	36	Yes	Yes		do	1,217	1,181	
203	George Patterson	do	1 N.	5 E.	28	1898	do	41	40	Yes	Yes	Yes	do	1,221	1,181	
206	Church	do	1 N.	5 E.	28	1899	do	45	44	Yes	Yes		do	1,226	1,182	
208	James H. Brooks	do	1 N.	5 E.	28	1896	do	39	38	Yes	Yes		do	1,220	1,182	
185	I. L. Spain	do	1 N.	5 E.	28		do	46	45	Yes	No		do	1,230	1,185	
194	E. Cartwright		1 N.	5 E.	29		do	35	33	Yes	Yes		do	1,214	1,181	
196	C. M. Huffman	Mesa	1 N.	5 E.	29		do	31		Yes	Yes		do	1,215		Do.
197	do	do	1 N.	5 E.	29		do	34	33	Yes	Yes		do	1,216	1,183	
198	J. W. Baldwin	do	1 N.	5 E.	29	1901	do	34			Yes	Yes	do	1,216		Do.
200	G. Kleinman	do	1 N.	5 E.	29		do	28		Yes	Yes		do	1,217		Do.
201	J. P. Huber	do	1 N.	5 E.	29	1893	do	34	33	Yes	No	Yes	do	1,216	1,183	
202	A. P. Kleinman	do	1 N.	5 E.	29	1885	do	38		Yes	No		do	1,220		Do.
204	Geo. Patterson		1 N.	5 E.	29	1901	do	42	41		Yes	Yes	do	1,222	1,181	
216			1 N.	5 E.	29		do	36		Yes	Yes		do	1,220		Do.
218	James Biddlecome	Tempe	1 N.	5 E.	29	1901	do	34	33	Yes	No	Yes	do	1,210	1,177	Decreasing.
222	Arthur Openshaw	do	1 N.	5 E.	29	1898	do	30	29	Yes			do	1,207	1,178	
226	George Way		1 N.	5 E.	29		do	21					do	1,205		Dry.
242	R. D. Rosenberger	Mesa	1 N.	5 E.	29		do	31	30	Yes	No	No	do	1,208	1,178	
243	Thos. Stapley	do	1 N.	5 E.	29	1886	do	33	31	Yes		Yes	do	1,210	1,179	
133	J. M. Roundtree	do	1 N.	5 E.	29		do	29	28		Yes		do	1,205	1,177	
171	Frank Johnson	Tempe	1 N.	5 E.	30	1896	do	22	20	Yes	No	Yes	do	1,203	1,181	
172	do	do	1 N.	5 E.	30	1895	do	25		Yes	No	Yes	do	1,202		
174	B. F. Johnson	do	1 N.	5 E.	30	1897	do	33	22	Yes	Yes	Yes	do	1,200	1,178	
175	do	do	1 N.	5 E.	30	1885	do	24	23	Yes	Yes	Yes	do	1,200	1,177	
219	E. C. Openshaw	do	1 N.	5 E.	30	1895	do	32	31	Yes	No	No	do	1,207	1,176	
220	School No. 29	do	1 N.	5 E.	30		do	20					do	1,207		Do.
221	D. C. Brimhall	Mesa	1 N.	5 E.	30	1892	do	30	29	Yes	No	Yes	do	1,207	1,178	
223	S. Openshaw	Tempe	1 N.	5 E.	30	1892	do	30	28	Yes	Yes	Yes	do	1,206	1,178	

Tabulation of shallow wells—Continued.

MESA TOWNSHIP (T. 1 N., R. 5 E.)—Continued.

Number.	Owner.	Post-office.	Location.			Completed.	How put down.	Depth of well.	Depth to water.	Does water vary at different times of year?	Is water easily lowered?	Did water rise when struck?	Has the volume of water increased or diminished?	Elevation of surface.	Elevation of water.	Remarks.
			Township.	Range.	Section.											
								Feet.	*Feet.*					*Feet.*	*Feet.*	
224	R. Holliday	Mesa	1 N.	5 E.	30		Dug	29	28	Yes	Yes	Yes	Diminished	1,206	1,178	Dry.
225	Wm. C. Parks	do	1 N.	5 E.	30	1882	do	28	27	Yes	Yes	No	do	1,205	1,180	
227	Don Le Baron		1 N.	5 E.	30	1894	do	29	27	Yes	Yes	Yes	do	1,204	1,177	
228	Peter Lawson	Tempe	1 N.	5 E.	30	1886	do	28	27	Yes	No		do	1,203	1,176	
229	J. E. Johnson		1 N.	5 E.	30	1890	do	22	20	Yes			do	1,201	1,181	
230	Frankenburg Bros	Tempe	1 N.	5 E.	30	1902	do	25	21	Yes	No		do	1,195	1,174	
233	do	do	1 N.	5 E.	30	1890	do	27	24	Yes	No	Yes	do	1,198	1,174	
334	do	do	1 N.	5 E.	30	1902	do	24	21	Yes	No	Yes	do	1,193	1,172	
239	R. W. Westover	do	1 N.	5 E.	30	1887	do	31	30	Yes	Yes	No	do	1,205	1,175	
240	Luther Spainhower		1 N.	5 E.	30		do	33	31	Yes	Yes	Yes	do	1,207	1,176	
241	J. H. Spainhower	Tempe	1 N.	5 E.	30	1895	do	33	32	Yes	No	No	do	1,209	1,177	
2	Allison Bros	Mesa	1 N.	5 E.	30	1892	do	55	53	Yes	No	No	do	1,244	1,191	
129	F. T. Powers	do	1 N.	5 E.	31	1896	do	26	23	Yes			do	1,199	1,176	
130	do	do	1 N.	5 E.	31	1894	do	23	22	Yes	Yes	Yes	do	1,199	1,177	
131	Forley Johnson	do	1 N.	5 E.	31		do	22	21		Yes	Yes	do	1,198	1,177	
132	do	do	1 N.	5 E.	31		do	21	20	Yes	Yes		do	1,198	1,178	
161	Ed. Weston	Tempe	1 N.	5 E.	31		do	18						1,197		Do.
168	G. S. Johnson	do	1 N.	5 E.	31		do	21	19	Yes	Yes		Diminished	1,192	1,173	
169	do	do	1 N.	5 E.	31		do	21	19	Yes	Yes		do	1,192	1,173	
173	B. F. Johnson	do	1 N.	5 E.	31	1885	do	24	22	Yes	Yes	Yes	do	1,202	1,180	
134	J. R. Blakely	Mesa	1 N.	5 E.	32		do	29	27		Yes	Yes	do	1,205	1,178	
135	J. S. Standage	Tempe	1 N.	5 E.	32	1899	do	26	25	Yes	Yes	Yes	do	1,204	1,179	
136	A. L. Porter	do	1 N.	5 E.	32	1898	do	26	25	Yes	Yes	No	do	1,203	1,178	
137	Arthur Porter	Mesa	1 N.	5 E.	32		do	26			Yes	No	do	1,210		Do.

138	Arthur Millet	do	1 N.	5 E.	32	1888	do	31	30	Yes	Yes	Yes	do	1,210	1,180	
139	Alma Millet	Tempe	1 N.	5 E.	32	1899	do	31	30	Yes	Yes	Yes	do	1,210	1,180	
144	Wm. Dorman	Mesa	1 N.	5 E.	32		do	30	28	Yes	Yes		do	1,209	1,181	
178	P. A. Williams	do	1 N.	5 E.	32	1897	do	51	50	Yes	No	No	do	1,232	1,182	
127	E. W. Wilbur	do	1 N.	5 E.	32	1897	do	28	23	Yes	Yes	Yes	do	1,201	1,176	
141	S. W. J. Bowen	do	1 N.	5 E.	33	1899	do	32	31	Yes	Yes		do	1,211	1,181	
142	Mrs. Ingrams	do	1 N.	5 E.	33		do	30	29	Yes	Yes	Yes	do	1,209	1,180	
143	Herman Priestly	Tempe	1 N.	5 E.	33		do	27						1,209		Do.
145	do	do	1 N.	5 E.	33		do	28	27	No	Yes		Diminished	1,209	1,182	
146	do	do	1 N.	5 E.	33		do	25						1,209		Do.
147	John Hibbert	Mesa	1 N.	5 E.	33	1900	do	29	28	Yes			Diminished	1,208	1,180	
148	D. T. Hibbert	do	1 N.	5 E.	33	1890	do	28	26	No	Yes	No	do	1,208	1,182	
149			1 N.	5 E.	33		do	28	27				do	1,209	1,182	
150	Robert Hornbeck	Mesa	1 N.	5 E.	33	1893	do	30	28	Yes	No	Yes	do	1,211	1,183	
151	Leonard Metz	Tempe	1 N.	5 E.	33		do	33	32	Yes	Yes		do	1,213	1,181	
152	do	do	1 N.	5 E.	33		do	33	32	Yes	Yes		do	1,213	1,181	
153	Robert Hornbeck	Mesa	1 N.	5 E.	33	1890	do	33		Yes	Yes	Yes	do	1,214		Do.
154	do	do	1 N.	5 E.	33	1902	do	33	32	Yes	Yes	Yes	do	1,215	1,183	
155	do	do	1 N.	5 E.	33	1896	do	30					do	1,215		Do.
156	E. Pomeroy	do	1 N.	5 E.	33	1901	do	32	31	Yes	Yes		do	1,215	1,184	
157	do	do	1 N.	5 E.	33	1900	do	34	32	Yes	Yes	Yes	do	1,215	1,183	
158	do	do	1 N.	5 E.	33	1899	do	34	32	Yes	Yes	Yes	do	1,215	1,183	
159	J. D. Hibbert	do	1 N.	5 E.	33	1902	do	26					do	1,206		Do.
16	H. E. Dana	do	1 N.	5 E.	33	1888	do	35						1,216		Do.
17	Theresa Martinez	do	1 N.	5 E.	33	1894	do	35						1,215		Do.
18	George Scott	do	1 N.	5 E.	33	1896	do	30	27	Yes	Yes	Yes	Diminished	1,210	1,183	
19	do	do	1 N.	5 E.	33	1890	do	35						1,210		Do.
20	do	do	1 N.	5 E.	33	1890	do	34	33	Yes	Yes	Yes	Diminished			
59	S. Bacca	do	1 N.	5 E.	34		do	30	28				do	1,213	1,185	
2	H. D. Evans	do	1 N.	5 E.	35	1898	do	52	52	Yes	Yes		do	1,221	1,169	
6	R. M. Moore	do	1 N.	5 E.	35	1892	do	44	43	Yes	Yes		do	1,214	1,171	
8	P. B. Hughes	do	1 N.	5 E.	35	1892	do	30						1,220		Do.

Tabulation of shallow wells—Continued.

TOWNSHIP 1 NORTH, RANGE 6 EAST.

[Records obtained by Robert Muldrow.]

Number.	Owner.	Post-office.	Location.			Completed.	How put down.	Depth of well.	Depth to water.	Does water vary at different times of year?	Is water easily lowered?	Did water rise when struck?	Has the volume of water increased or diminished?	Elevation of surface.	Elevation of water.	Remarks.
			Township.	Range.	Section.											
								Feet.	Feet.					Feet.	Feet.	
1	N. H. Wallace	Mesa	1 N.	6 E.	19	1893	Dug	57	55	Yes	Yes	Yes	Neither	1,231	1,196	
3	Doctor Toney	Phoenix	1 N.	6 E.	30	1893	do	60	57	Yes	Yes	No	Diminished	1,251	1,194	
4	Fred Weeks	Mesa	1 N.	6 E.	30	1900	do	45	44	Yes	Yes	No	do	1,239	1,195	
5	E. W. Wilbur	do	1 N.	6 E.	31	1900	do	50	47	No	No	No	Neither	1,237	1,193	
6	Wm. Eruirn	do	1 N.	6 E.	31	1898	do	50	48	Yes	Yes	No	Diminished	1,243	1,195	
7	Dorman Bros	do	1 N.	6 E.	33	1898	do	100	70	Yes	No	Yes	Neither	1,267	1,197	

TOWNSHIP 2 NORTH, RANGE 5 EAST.

Number.	Owner.	Post-office.	Township.	Range.	Section.	Completed.	How put down.	Depth of well.	Depth to water.	Does water vary at different times of year?	Is water easily lowered?	Did water rise when struck?	Has the volume of water increased or diminished?	Elevation of surface.	Elevation of water.	Remarks.
5	F. L. Warner	Phoenix	2 N.	5 E.	8	1903	Drilled	120	100			Yes		1,199	1,099	
1	Indian	Mesa	2 N.	5 E.	21		Dug	61	60					1,263	1,203	
9	Church	Lehi	2 N.	5 E.	29		do	45	43					1,243	1,200	
12	Indian	do	2 N.	5 E.	31		do	37	36					1,231	1,195	
368	do	do	2 N.	5 E.	31		do	31	30					1,221	1,191	
3	do	Mesa	2 N.	5 E.	32		do	33	32					1,226	1,194	
10	do	Lehi	2 N.	5 E.	32		do	36	35					1,230	1,195	
11	do	do	2 N.	5 E.	32		do	39	38					1,233	1,195	
	Indian school	do	2 N.	5 E.	32	1899	do	30	29	Yes	No	No	Diminished	1,220	1,191	Constantly lowered.
	Indian mission	do	2 N.	5 E.	32		do	32	30	Yes	No	No	do	1,220	1,190	
	Indian	do	2 N.	5 E.	32		do	27	26	Yes	No		do	1,218	1,192	
	do	do	2 N.	5 E.	32		do	29	28					1,217	1,189	

367	.....do..............	Lehi.......	2 N.	5 E.	32	....	Dug	29	28	....	....	....	....	1,220	1,192	
2	.....do..............	.....do.....	2 N.	5 E.	33	....	....do...	40	38	....	....	....	....	1,235	1,197	
4	.....do..............	.....do.....	2 N.	5 E.	33	....	....do...	40	39	....	....	....	....	1,238	1,199	
5	.....do..............	.....do.....	2 N.	5 E.	35	....	....do...	38	37	....	....	....	....	1,237	1,200	
6	.....do..............	.....do.....	2 N.	5 E.	35	....	....do...	40	37	....	....	....	....	1,240	1,203	
	.....do..............	.....do.....	2 N.	5 E.	35	....	....do...	36	35	Yes...	No....	No....	Diminished ..	1,233	1,198	
7	Day school.........	.....do.....	2 N.	5 E.	36	....	....do...	44	42	....	....	....	....	1,242	1,200	
8	Mission	.....do.....	2 N.	5 E.	36	....	....do...	45	44	....	....	....	....	1,245	1,201	

TOWNSHIP 1 SOUTH, RANGE 5 EAST.

	M. Barclay..........	Mesa	1 S.	5 E.	1	1890	Dug	36	....	....	....	....	....	1,227	....	Dry.
	Highland school....	.....do.....	1 S.	5 E.	2	1899	....do...	53	52	Yes...	Yes...	No....	Diminished ..	1,221	1,169	
	Wm. Newell	.....do.....	1 S.	5 E.	3	1900	....do...	30	26	Yes...	Yes...	....	.....do........	1,212	1,186	
	C. W. Davisson......	.....do.....	1 S.	5 E.	3	....	....do...	35	25	....	....	....	....	1,208	1,183	
	S. Hall	.....do.....	1 S.	5 E.	3	1899	....do...	26	25	....	....	....	Diminished ..	1,211	1,186	
	Michael Fricker	.....do.....	1 S.	5 E.	4	1899	....do...	24	....	Yes...	Yes...	Yes...	.....do........	1,206	....	Do.
	G. A. Dobson........	.....do.....	1 S.	5 E.	5	1888	....do...	27	25	Yes...	Yes...	....	.....do........	1,203	1,178	
	.....do..............	.....do.....	1 S.	5 E.	5	1897	....do...	27	23	Yes...	Yes...	Yes...	Neither.......	1,202	1,179	
	Andrew Housten....	.....do.....	1 S.	5 E.	5	....	....do...	25	24	Yes...	Yes...	....	Diminished ..	1,200	1,176	
	Thos. Argue.........	Tempe	1 S.	5 E.	6	1890	....do...	19	....	....	....	....	.....do........	1,198	....	Do.
	.....do..............	.....do.....	1 S.	5 E.	6	1893	....do...	23	22	Yes...	No....	No....	.....do........	1,197	1,175	
	.....do..............	.....do.....	1 S.	5 E.	6	1890	....do...	21	20	Yes...	No....	No....	.....do........	1,196	1,176	
	G. S. Johnson	.....do.....	1 S.	5 E.	6	1898	....do...	22	21	Yes...	Yes...	Yes...	.....do........	1,194	1,173	
	Chas. Pine	Mesa	1 S.	5 E.	12	1893	....do...	45	43	No....	No....	Yes...	Neither.......	1,230	1,187	Very salty.

TEMPE TOWNSHIP (T. 1 N., R. 4 E.).

5	F. L. Warner	Tempe.....	1 N.	4 E.	8	1903	Drilled .	120	100	....	....	....	....	1,199	1,099	
6	....	....	1 N.	4 E.	9	....	....do...	125	42	....	....	....	....	1,173	1,131	
2	J. D. Cooper	Tempe.....	1 N.	4 E.	9	1900	Dug	22	18	....	....	No....	....	1,158	1,140	
370	Indian	....	1 N.	4 E.	12	....	....do...	15	12	....	....	....	....	1,185	1,173	
1	T. J. Parry	Tempe.....	1 N.	4 E.	14	1902	....do...	21	17	....	....	No....	....	1,170	1,153	
4	J. H. Commings	.....do.....	1 N.	4 E.	15	1902	....do...	17	16	....	....	No....	....	1,150	1,134	

Tabulation of shallow wells—Continued.

TEMPE TOWNSHIP (T. 1 N., R. 4 E.)—Continued.

Number.	Owner.	Post-office.	Location.			Completed.	How put down.	Depth of well.	Depth to water.	Does water vary at different times of year?	Is water easily lowered?	Did water rise when struck?	Has the volume of water increased or diminished?	Elevation of surface.	Elevation of water.	Remarks.
			Township.	Range.	Section.											
								Feet.	Feet.					Feet.	Feet.	
3	J. D. Cooper	Tempe	1 N.	4 E.	16	1899	Dug	19	18					1,155	1,137	
9	J. Sturgeon	do	1 N.	4 E.	16	1892	do	13	8			No		1,152	1,144	
	Francisco Peralta	do	1 N.	4 E.	16	1894	do	28	25			No		1,153	1,128	
11	Sisto Valdez	do	1 N.	4 E.	16	1901	do	18	16			No		1,150	1,134	
12	G. Mindose	do	1 N.	4 E.	16	1901	do	16	14			No		1,152	1,138	
14			1 N.	4 E.	16	1899	do	16	15			No		1,152	1,137	
15	R. Veltron	Tempe	1 N.	4 E.	16	1892	do	18	16			No		1,152	1,136	
16	——— Gonzalles	do	1 N.	4 E.	16	1898	do	28	18			No		1,155	1,137	
17	Francisco Vajeco	do	1 N.	4 E.	16	1891	do	20	18			No		1,148	1,130	
18	Mrs. Jones	do	1 N.	4 E.	17	1898	do	18	16			No		1,144	1,128	
19	J. T. Priest	do	1 N.	4 E.	20	1889	do	14	12			No		1,144	1,132	
	A. R. Jenkins	do	1 N.	4 E.	20		do		10							
231	Frankenburg Bros	do	1 N.	4 E.	25	1901	do	24	20	Yes	No	Yes	Diminished	1,193	1,173	
232	C. G. Jones	do	1 N.	4 E.	25	1901	do	24	23	Yes	Yes	No	do	1,196	1,173	
	J. W. Johnson	do	1 N.	4 E.	27	1902	Drilled	25								
	Niels Peterson	do	1 N.	4 E.	28		Dug		18							
	do	do	1 N.	4 E.	29	1893	do	25	20			No		1,138	1,118	
	J. P. Jensen	do	1 N.	4 E.	29		do	31	26			No		1,139	1,113	
20	A. H. Brown	do	1 N.	4 E.	31	1899	do	52	49			Yes		1,175	1,126	
	Byron Carr	do	1 N.	4 E.	31		do		32							
	——— Tobin	do	1 N.	4 E.	32				29					1,152	1,123	

21	George W. Nichols	Tempe	1 N.	4 E.	34	1897	Dug	15	8			No		1,178	1,170
165	C. M. Mullen	do	1 N.	4 E.	36	1890	do	22	20	Yes	Yes		Diminished	1,194	1,174
166	do	do	1 N.	4 E.	36	1901	do	22	20	Yes	Yes	Yes	do	1,194	1,174
167			1 N.	4 E.	36		do	13	10					1,194	1,184

TOWNSHIP 2 NORTH, RANGE 4 EAST.

[Records obtained by R. W. Hawley.)

7	F. F. Titus	Tempe	2 N.	4 E.	2	1895	Dug	31	29			No		1,215	1,186
8	H. L. Underhill	Scottsdale	2 N.	4 E.	22	1897	do	75	66			No		1,261	1,195
9	E. M. Toleman	do	2 N.	4 E.	22	1903	do	75	67			Yes		1,262	1,194
10	Chaplin Scott	do	2 N.	4 E.	23		do	67	65			No		1,260	1,195
11			2 N.	4 E.	24		do	69	69			No		1,253	1,184
	W. J. Murphey	Phoenix	2 N.	4 E.	27		do	67	56			No		1,250	1,194
12	do	do	2 N.	4 E.	30	1894	Drilled	98	66			Yes		1,214	1,148
	Thos. Murphey	do	2 N.	4 E.	30	1902	do	325	72			Yes		1,197	1,125
1	Mary Showers	Scottsdale	2 N.	4 E.	36	1901	Dug	40	38			No		1,229	1,191
2	do	do	2 N.	4 E.	36	1900	do	38	37			No		1,227	1,190
3	Wilfred Hayden	Phoenix	2 N.	4 E.	36	1894	do	38	37			No		1,226	1,189
4	Frank Titus		2 N.	4 E.	36	1901	do	60	50			Yes		1,224	1,174
5	Poor ranch	Phoenix	2 N.	4 E.	36	1898	do	40	39			No		1,232	1,192
6			2 N.	4 E.	36		do	26	25			No		1,215	1,190
13	S. W. Ney	Scottsdale	2 N.	4 E.	36	1897	do	38	36			No		1,227	1,191
14	do	do	2 N.	4 E.	36	1903	do	38	36			No		1,227	1,191

Throughout the Mesa region, wherever special inquiry was made, it was found that the surface of the underground water has been continually lowering for years. Wells which were formerly productive throughout the year are now dry for a part or all of the year. With few exceptions the wells have been lowered in order to obtain sufficient water. This lowering of the water has been progressive and wells have been deepened repeatedly. In the vicinity of Tempe the water has lowered about 7 feet. Near Mesa it has lowered much more. According to Code's[a] measurement in 1901, the normal water level at the Murphy-McQueen pumping plant was 22.5 feet below the land surface (see fig. 2, p. 14). On January 19, 1904, this level was found at the same place to be 34 feet below the land surface. At certain places the lowering is reported as 20 feet or even more.

While the underground water supply of the valley has been decreasing for a number of years, there are yearly variations depending more or less directly upon the abundance of surface waters. Certain wells are dry during the dry seasons and contain water during the seasons of more abundant supply. The term "rainy season" is purposely avoided, the seasons of more abundant surface waters being those in which an increased supply enters the valley in streams. The rains in the valley itself are so slight that they have no effect that can be detected in the wells.

THE PHOENIX REGION.

PHOENIX WATER COMPANY'S WELLS.

Previous to 1902 the city of Phoenix was supplied with water from two dug wells, 42 feet deep, which had, when measured, 10 feet of water. During the exceptionally dry season of 1902 the water in these wells failed and three 12-inch double-steel-cased wells were drilled to a depth of 208 feet. An abundant water supply was found at a depth of 55 feet, and thence downward to 208 feet were continuous water-bearing gravels and bowlders. The water from the open wells comes from the upper gravels indicated in the log, and that from the drilled wells comes from the lower gravels. At the time of my visit to the plant water from one open well and one drilled well was supplying the city at the rate of about 1,750 gallons per minute. It is said that one of the drilled wells alone has yielded water at this rate.

Log of well of Phoenix Water Company, near Phoenix.

	Feet.
Soil	13
Gravel and bowlders, water bearing	36
Clay and cement	7
Gravel and bowlders, water bearing	153

[a] Code, W. H., Report of irrigation investigations for 1901, No. 1: U. S. Dept. Agric., Bull. 119, 1902, p. 67.

Unfortunately there was no opportunity of obtaining satisfactory pumping tests at this plant. The amount named, 1,750 gallons per minute, is estimated from the time it takes to fill the standpipe.

As in the case of the well at the asylum and other wells to be described later there is no marked difference between the upper and lower water bodies, although the two are separated by 7 feet of clay and cement. No. 3, in the table below, is an analysis of water from the upper water body and No. 4 from the lower body. The samples were taken directly from the wells at a time when the pumps were in operation.

Much interest is taken by the water users of the valley in the supposed improvement in the quality of the water as the wells are used. Reference has been made to such an improvement in case of the Chandler wells and others. Four analyses of the Phoenix city supply have been made, as indicated below. The three analyses representing the shallow wells extend over a period of about 5.5 years. Since this water supplies the city the draft on the wells is constant, and if use will materially improve the quality of wells, this water should show an improvement. On the contrary, the latest analyses indicate a marked increase in the quantity of soluble salts.

Analyses of water from the Phoenix Water Company's wells.

	1. Dug well, Sept. 18, 1898.	2. Dug well, May 9, 1902.	3. Dug well, May 14, 1903.	4. Drilled well, May 14, 1903.
Quantitative (parts in 100,000):				
Total solids soluble at 110° C.	116.8	102.4	136.00	132.00
Chlorine in terms of NaCl (common salt)	72.5	54.6	80.80	77.60
Hardness in terms of $CaSO_4$ (sulphate of lime)	Strong.	8.98	6.53	5.44
Alkalinity in terms of Na_2CO_3 (black alkali)	....	....	.00	.00
Nitrogen in the form of nitrates	.10	.16	.25	.25
Nitrogen in the form of nitrites	.0007	.0045	.02	Very faint.
Qualitative:				
Sulphates	....	Very strong.	Pronounced.	Pronounced.
Magnesia	....	Very strong.	Pronounced.	Pronounced.
Lime	....	Very strong.	Strong.	Strong.
Bicarbonates	....	....	Strong.	Very strong.

PHOENIX LIGHT AND FUEL COMPANY'S WELL.

This company has a single 12-inch double-steel-cased well at the power house in Phoenix. The well is 194 feet deep, with water at a depth of 31 feet. Below a depth of 46 feet, 16 feet of clay and cement occur. Otherwise, throughout the entire depth of the water-bearing portion, the material is coarse and wholly unconsolidated.

Log of Phoenix Light and Fuel Company's well.

	Feet.
Soil	15
Gravel, water in the lower part	31
Cement	2
Clay	11
Cement	3
Quicksand	3
Sand, gravel, and bowlders, water bearing	129

A shaft has been sunk to near water level and cemented to exclude any moisture from without. At the bottom of this shaft is placed the centrifugal pump and 50-horsepower electric motor. The water is used for condensing steam in the power house, after which it is used for irrigation.

A careful pumping test was made at this plant under the direction of Mr. D. W. Beldon, the engineer in charge, with results given below. It will be noted that in this case a single 12-inch well is yielding 1,995 gallons of water per minute continuously, with a local depression of the water table of little more than 16 feet.

Report of test on electrically driven centrifugal pump for irrigation.[a]

[Test made January 10, 1904, by D. W. Beldon, electrical engineer.]

Motor (3 phase; 350 volt; 60 cycle) speed	r. p. m.	720
Pump (direct-connected centrifugal; 10-inch suction; 8-inch discharge) r. p. m		720
Height; pump center above water (still)	feet	5⅓
Vacuum; pump running	inches	20
Water lowered by pump running (22 feet − 5⅓ feet)	feet	16⅔
Head above vacuum gauge	do	19
Total head (less friction and velocity of discharge)	do	41
Water pumped per minute	cubic feet	266
Total power absorbed by motor	kilowatts	38.6
Kilowatt hours required per acre-foot		105+
Cost of power per acre-foot (2 cents per kilowatt hour)		$2.10
Cost of power per acre-foot (per foot of lift)		$0.0512

PERKINS WELL (SEC. 23, T. 2 N., R. 3 E.).

Mr. C. W. Perkins has a 10-inch drilled well 155 feet deep. The water surface is 83 feet below the surface of the ground. The well is

[a] This report did not reach the writer in time to be included in the computations of cost described in the following chapters. The cost does not differ materially from that of other well-equipped pumping plants.

situated at Mr. Perkins's olive-oil factory, and the water is used for irrigating his olive and orange orchards during dry times when ditch water can not be obtained. The distance through which the water must be raised (a minimum of 83 feet) prohibits its economic use except as a last resort. Before the well was put down the lack of water in the irrigation canals at critical times caused serious damage to the fruit and even the death of a large number of trees. Costly as it is to pump from such a depth, water at a critical time is worth much more than it costs in saving valuable crops that might otherwise be injured or wholly destroyed. The well yields about 200 gallons per minute. The water is lifted by means of a deep-well pump, operated by a gasoline engine.

Analysis of water from C. W. Perkins's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	83.60
Chlorine in terms of NaCl (common salt)	30.80
Hardness in terms of $CaSO_4$	8.30
Alkalinity in terms of Na_2CO_3	.00
Nitrogen in the form of nitrates	.53
Nitrogen in the form of nitrites	.871
Qualitative:	
Sulphates	Very strong.
Magnesia	Strong.
Lime	Strong.

PHOENIX MACHINE AND COLD STORAGE COMPANY'S WELL.

The well is located at the company's factory in Phoenix, and was put down in December, 1903. It is a 12-inch double-steel-cased well 125 feet deep. Only 5 feet of fine material was encountered at the surface, all below this being entirely loose sand, gravel, and bowlders. Water is raised by means of a deep-well cylinder pump, but since no great supply is required the capacity of the well is not known.

Log of Phoenix Machine and Cold Storage Company's well.

	Feet.
Soil	5
Sand and bowlders slightly cemented	12
Sand, gravel, and bowlders, water bearing	118

BARTLETT-HEARD LAND AND CATTLE COMPANY'S WELLS (SEC. 30, T. 1 N., R. 4 E.).

An extensive pumping plant has been planned for this company for the purpose of obtaining an auxiliary water supply for a large tract of land lying south of Phoenix. A battery of six 15-inch double-steel-cased wells has been established, but the machinery is not installed at this writing. A depth of 28 feet of soil was penetrated, and water-bearing bowlders were encountered to a depth of 90 feet. The bowlders are underlain by granitic wash, 10 feet of which was penetrated. The water-bearing material is coarse and unconsolidated. Numerous quartzite bowlders up to 1 foot in diameter were taken from the well in drilling. The water is under no pressure and its surface does not even reach the top of the gravel bed, resting at a depth of 32.5 feet. On account of the limited thickness of the gravel bed drilling was suspended after the completion of the second well and a preliminary pumping test was made under the direction of Mr. Fuller, the engineer in charge, in order to determine whether the available quantity of water would justify the establishment of the plant at this place.

Log of Bartlett-Heard Land and Cattle Company's well No. 3.

	Feet.
Sand and soil	28
Gravel and bowlders, water bearing	62
Granite wash	10

The perforated areas of the wells differed in the proportion of 3 to 5, and the one having the smaller perforation area was tested, on the assumption that if it proved satisfactory there could be no question regarding those having better perforations. A shaft was dug to water level and a small centrifugal pump placed at the bottom and belted to an 18-horsepower traction engine at the surface. The pump was operated 2.5 hours and readings were taken every ten minutes. It discharged an average of 78.8 miner's inches of water (886 gallons per minute) and lowered the water in the well 19 feet and 8 inches (fig. 10). The water in the second well, 15 feet from the one tested, was lowered only 2 feet. Within thirty seconds after the pump stopped the water rose to the normal level. A lighter demand makes correspondingly less depression of the water table and therefore a lower lift. The same effect is also obtained by better perforation of the casing. The present lift of 53 feet can probably be materially lessened and the desired quantity of water can be still obtained by sinking a number of properly perforated wells.

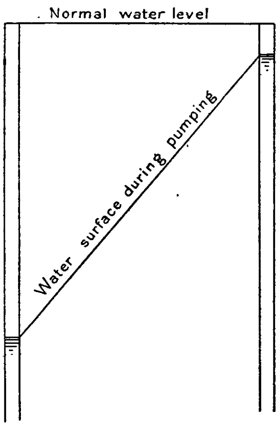


FIG. 10.—Depression of water table during pumping test of the Bartlett-Heard well.

Analysis of water from the Bartlett-Heard Land and Cattle Company's well.

[Sample taken during the pumping test, February 4, 1904.]

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	194.0
Chlorine in terms of NaCl (common salt)	126.0
Hardness in terms of $CaSO_4$ (sulphate of lime)	5.44
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Nitrogen	None.

Qualitative:

Sulphates	Strong.
Magnesia	Strong.
Lime	Strong.
Bicarbonates	Very strong.

WELL AT THE TERRITORIAL ASYLUM FOR THE INSANE (SEC. 2, T. 1 N., R. 3 E.).

The asylum is situated about 3 miles east of Phoenix on the Phoenix-Tempe road. A shaft 12 by 14 feet and 22.5 feet deep is tightly bricked and cemented to shut out any surface water which might seep in. From the bottom of this shaft a 12-inch well was sunk 87.5 feet, or 110 feet below the surface of the ground. At a depth of 57 feet the water-bearing gravel was struck, but the supply of water is not as great as in other wells entering what is presumably the same gravel bed. This may possibly be due to imperfections of construction; only the lower 24 feet of the pipe are perforated, and these perforations were made before the casing was forced into the well. After the pipe was in place the well was "shot." This increased the available supply to a quantity sufficient for the present needs of the asylum, but the yield is not yet as great as might reasonably be expected.

Log of asylum well, near Phoenix.

	Feet.
Soil	12
Gravel, water bearing	16
Clay and cement	9
Gravel and bowlders, water bearing	53

A steam pump is located at the bottom of the shaft and a suction pipe 24 feet long extends into the well. The engine is usually run at a rate which lifts 95 gallons per minute, and depresses the water surface 5 feet. This has been found to be practically the capacity of the well.

There are two water-bearing horizons in this well separated by 9 feet of clay and cement. Since the casing is perforated only near the bottom, the upper water is shut off, and analysis 1 of the following table is from water of the lower gravels. Analysis 2 is from water of a well 42 feet deep and therefore from the upper body. The great similarity of the analyses indicates that the two water bodies are probably connected.

Analyses of water from the asylum well, near Phoenix.

	No. 1.	No. 2.
Quantitative (parts in 100,000):		
Total solids soluble at 110° C	126.40	120.40
Chlorine in terms of NaCl (common salt)	78.80	79.20
Hardness in terms of $CaSO_4$ (sulphate of lime)	13.60	8.20
Alkalinity in terms of Na_2CO_3 (black alkali)	None.	None.
Nitrogen in the form of nitrates	Faint.	Faint.
Nitrogen in the form of nitrites	Faint.	Faint.
Qualitative:		
Sulphates	Very strong.	Very strong.
Magnesia	Strong.	Very strong.
Lime	Strong.	Very strong.
Bicarbonates	....	....

PHOENIX INDIAN SCHOOL WELLS (SEC. 20, T. 1 N., R. 3 E.).

There are three deep wells at the Indian School, one at the power house and two, designed for irrigation, some distance from the school buildings. The well at the power house is 193 feet deep and 6 inches in diameter. The water is used to supply the school buildings and lawns and is pumped at the rate of about 60 gallons per minute.

The first irrigation well is dug to a depth of 56 feet. From the bottom of this pit two 6-inch holes have been drilled, the first 145 feet and the second 338 feet in depth. The water stands 36 feet beneath the surface. It was the original plan to cut the well casing at the bottom of the open part and allow the water to flow from the drilled wells into the open well, from which it was to be lifted by a bucket pump.

Log of Phoenix Indian School irrigation well No. 1.

	Feet.
Soil and cement	40
Sand, cemented in places	40
Hard, white cement	15
Quicksand	6
Sandy clay	66
Sand, water bearing	26
Alternating beds of sand, clay, and cement (no definite record)	62
Cement	20
Cemented sand	24
Granite wash, water bearing	12
Sand and gravel	12
Cemented sand	8
Sand and gravel, water bearing	9
Gravel and bowlders, water bearing	3

The material passed through gave promise of comparatively little water. A gravel bed was encountered at the depth of 335 feet, but since the casing was not extended to the bottom no headway could be made in the loose gravels, and the drilling was abandoned for a time. The gravel bed at the bottom is promising, but its thickness and character are unknown. At a preliminary pumping test only 10 inches of water was obtained.

The well is supplied temporarily with a bucket pump operated by an electric motor. When running at ordinary speed, the pump discharges about 200 gallons of water per minute and soon drains the open well. A discharge of about 100 gallons per minute maintains the water level at 52 feet, a depression of 16 feet, thus indicating the practical capacity of the well. During the time that the water surface was held at a depth of 52 feet the water flowed from the top of the drilled wells into the open part, but without any great force. The rate of discharge is slow, and the outlook for an underground supply is not encouraging.

A good example of the depression of the water table is found at this place. In the year 1895 a well at the Indian School encountered water at a depth of 16 feet. The same well, deepened as the water surface lowered, in January, 1904, contained water at a depth of 38 feet—a depression of 22 feet in about eight years.

Log of Phoenix Indian School irrigation well No. 2.

	Feet.
Soil, sand, and cement	85
Sand, water bearing	14
Cemented sand	40
Putty clay	30
Sand	10
Putty clay	16
Sand and gravel	30
Red sandstone	3

A third well has been put down on the Indian School farm 1 mile east of the school. It is a 6-inch drilled well 228 feet deep. An incident occurred in drilling this well which has an important bearing on the quantity of water to be expected in this vicinity. Water was found at a depth of about 51 feet and rose 15 feet, keeping the well filled until a sand stratum was encountered at a depth of about 170 feet. The water from above entered this sand and lowered the surface of the water in the well to about 100 feet—a depression of about 64 feet. This level was maintained, the sand absorbing the entire flow from the higher water horizons until the leakage was stopped by clay pounded into the loose sand by the action of the drill.

This well is slightly more promising than No. 1, but no test has been made. The red sandstone at the bottom is probably the breccia exposed at the surface farther to the east and north.

Analyses of water from wells at the Phoenix Indian School.

	No. 1 (45 feet).	No. 2 (145 feet).	No. 3 (15 feet).	No. 4 (60 feet).
Quantitative (parts in 100,000):				
Total solids soluble at 110° C	245.20	250.00	222.00	362.30
Chlorine in terms of NaCl (common salt)	160.80	145.00	141.00	258.00
Hardness in terms of $CaSO_4$ (sulphate of lime)	21.80	65.80	None.	Strong.
Alkalinity in terms of Na_2CO_3 (black alkali)	None.	None.	33.36	None.
Nitrogen in the form of nitrates	.40	.25	Faint.	.30
Nitrogen in the form of nitrites	Faint traces.	.00	.0008	.0028
Qualitative:				
Sulphates			Very strong.	Very strong.
Magnesia			Very strong.	Very strong.
Lime			Very strong.	Very strong.
Bicarbonates			Strong.	Strong.

G. W. SMITH'S WELL (SEC. 10, T. 1 N., R. 3 E.).

This well is dug 20 by 40 feet, 38 feet deep, and has 8 feet of water. The lower half of the well is in coarse sand, gravel, and bowlders, and required careful timbering to keep the sides from caving in. It was the material from this well which was used in the experiment described later under the caption of "practical porosity." The water is raised by means of a 12-horsepower gasoline engine and 6-inch horizontal centrifugal pump, at the rate of about 50 inches (564 gallons) per minute. The water is used for irrigation.

THE KUNZ WELL (SEC. 18, T. 1 N., R. 3 E.).

The well of Dr. R. E. Kuntze and L. Kunz & Sons is 6 by 6 feet, 24 feet deep, and has 6 feet of water. It was begun in 1899 and has since been lowered, but the water is now gradually rising. It is used for irrigating a botanical garden containing various kinds of shrubs, trees, and flowers. Since 1899 the garden has been irrigated with no other water.

The pump is a novel invention of one of the owners of the place and has comparatively high efficiency. The essential part of the mechanism is a light walking beam about 12 feet long hinged at the center, with its extremities traveling over a sinuous track. Near the center of the walking beam is placed a system of levers which operate two suction pumps. A mule is hitched to the pump in the ordinary manner, and when properly blindfolded works without a driver. As the machine is turned the walking beam is made to oscillate in a vertical plane by means of the sinuous track, and thus works the pumps.

The comparative ease with which water is raised by this machine and the claim that horsepower is cheaper than gasoline or steam led to a careful measurement of the amount pumped and the computation of cost as given below. The value of the mules employed is probably exaggerated; more valuable animals would do correspondingly more work. The pasturage is counted at $1.50 per month for each animal and feed at $1.30 per month.

Cost of pumping by mule power at the Kunz gard.

Cost of well and pump	$200.00
Two mules at $25	$50.00
Interest on investment at 7 per cent per annum for 3.6 days	$0.17
Depreciation at 10 per cent per annum for 3.6 days	$0.24
Average amount pumped per minute, in gallons	62
Days required to pump 1 acre-foot	3.6
Pasture and feed for 2 mules at 19 cents per day for 3.6 days	$0.68
Oil and incidentals (estimated)	$0.05
Total cost per acre-foot	$1.14
Lift, in feet	18
Average cost per foot in raising 1 acre-foot of water	$0.063

Analysis of water from the Kunz well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	223.00
Chlorine in terms of NaCl (common salt)	146.80
Hardness in terms of $CaSO_4$ (sulphate of lime)	53.70
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Qualitative:	
Sulphates	Very strong.
Magnesia	Strong.
Lime	Very strong.
Bicarbonates	Very strong.

EAST LAKE PARK WELL.

This well supplies water for a natatorium, for an artificial lake, and for general park use. It is 7 by 10 feet, 42 feet deep, and has 9 feet of water. Water is raised by a bucket pump operated by an electric motor. At the time of my visit to this plant the pump was discharging water at the rate of 210 gallons per minute, and this seemed to be the maximum capacity of the well.

WAGNER WELL (SEC. 16, T. 1 N., R. 3 E.).

Mr. Frank Wagner has a dug well 7 by 7 feet and 35 feet deep, from which he pumps water for the irrigation of his gardens and nursery. The well is provided with bucket pump and horsepower, by means of which water is raised at the rate of about 12 inches (135 gallons) per minute.

WETZLER WELL (SEC. 11, T. 1 N., R. 3 E.).

Lewis Wetzler's well is dug 8 by 8 feet and 40 feet deep, and contains 15 feet of water. Water is raised by means of a bucket pump and a 5-horsepower gasoline engine at the rate of about 35 inches (396 gallons) per minute. This water has been used since 1900 in raising garden produce.

Analysis of water from Lewis Wetzler's well, near Phoenix.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	144.00
Chlorine in terms of NaCl (common salt)	86.00
Hardness in terms of $CaSO_4$ (sulphate of lime)	23.90
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Qualitative:	
Sulphates	Pronounced.
Magnesia	Very faint.
Lime	Strong.

M'CALLUM WELL (SEC. 24, T. 1 N., R. 2 E.).

N. P. McCallum's well is situated on the southern bank of Salt River about 4 miles southwest of Phoenix. It is a dug well 9 feet in diameter and 31 feet deep, walled with brick for the lower 15 feet. Spaces are left in the brick wall to allow the seepage water to enter from the side. The well is dug in the sands and gravels of the river deposit a few feet from the southernmost channel of the river. This channel serves at present as a seepage ditch carrying a small amount of water. This water is led by a subterranean passage into the well and adds materially to the amount available for pumping.

The water stands normally 14 feet below the surface. An 8-inch Byron Jackson centrifugal pump is placed a few feet above the normal water level and operated by a 40-horsepower traction engine. The amount of water pumped at present is estimated at 1,100 gallons per minute. With this yield the water in the well is lowered 12.5 feet, and remains stationary. A heavier demand drains the well.

Mr. McCallum's ditch is arranged to take flood water from the river whenever such water is available. The pump water is discharged into the same ditch. A subway from the pump to the ditch is cut 9.5 feet below the surface. The water is therefore lifted only 17 feet when the pump is discharging 1,100 gallons per minute.

A 12-inch double-steel-cased drilled well has recently been put down at this point. It is 124 feet deep and penetrates nothing but unconsolidated sand, gravels, and bowlders. A preliminary test gave 175 inches of water (1,970 gallons per minute).

Log of N. P. McCallum's drilled well, near Phoenix.

	Feet.
River sand	10
Gravel and bowlders, water bearing	114

COLLINS WELL (SEC. 15, T. 1 N., R. 2 E.).

Mr. George U. Collins's well is situated about 3 miles southwest of Phoenix. It is a large seepage well 100 feet long by 60 feet wide and 29 feet deep. The material encountered for the upper 10 feet is sandy soil and for the remaining 19 feet river gravel and bowlders. When the pump is not running the water rises to within 19 feet of the surface of the ground. The water is raised by a 60-horsepower steam engine and a horizontal centrifugal pump which furnishes a continuous supply day and night of 190 to 200 inches, or about 2,200 gallons per minute. When pumped at this rate the water in the well is lowered 6 feet, at which level the inflow equals the amount pumped and the surface remains stationary. When a greater amount is pumped, the surface of the water is proportionately lowered. (See Pl. V, *B*.)

The bed of gravel and bowlders in which the well is sunk has evidently a somewhat free connection with the underflow of the river. At the time of my first visit to the well the pump had not been in operation for several days, and the water was standing at normal level. There was a distinct current in the well caused obviously by the passage of the underflow through it. The inflowing current was stronger at one end than at the other, resulting in a slow eddying movement of the water bearing the floating material in an endless journey about the well.

Mr. Collins was kind enough to give some figures and facts gleaned from his long experience which may be of benefit to those thinking of constructing similar plants. The cost of digging and casing the well was $11,900—probably more than a similar well would cost in some places. The looseness of the gravel and bowlders and the abundance of water in them make excavation a costly process; it should be noted, however, that easier digging due to more consolidated gravels is likely to be accompanied by a smaller water supply.

The plant has been in operation for three years, and land which is irrigated from it is producing as good, and in some cases better, crops than the neighboring land irrigated with ditch water. This may be due to the fact that pumped water can be applied when needed while ditch water must be used at stated times. While the water is derived wholly from the underflow, the quantity and kinds of salts contained in it are not such as to warrant the doubt of its utility that exists in the minds of many people in the valley. It will be noted from the following analysis that the total of contained salts is comparatively low and that the greatly feared black alkali is absent.

Analysis of water from George U. Collins's well, near Phoenix

Quantitative parts in 100,000:	
Total solids soluble at 110° C	150.00
Chlorine in terms of NaCl (common salt)	94.80
Hardness in terms of $CaSO_4$ (sulphate of lime)	17.40
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Qualitative:	
Sulphates	Strong.
Magnesia	Strong.
Lime	Strong.
Bicarbonates	Strong.

Measurements were made at the Collins well for the purpose of computing the cost of pumping. The water was measured in a temporary weir and the quantity given (190 inches) is approximately correct. Leakage at several points occasioned some loss.

Cost of pumping water at the Collins pumping plant.

Cost of well	$11,900.00
Cost of pump and engine	$3,100.00
Interest on $15,000 at 7 per cent per annum for 2.6 hours	$0.31
Depreciation at 10 per cent per annum for 2.6 hours	$0.44
Average discharge of water in inches	190
Average discharge of water in second-feet	4.75
Hours to pump 1 acre-foot	2.6
1.5 cords of wood lasts 14 hours (average).	
Cost of wood for 2.6 hours, at $1.50 per cord[a]	$0.48
Oil and incidentals (estimated)	$0.05
Engineer, 2.6 hours, at 25 cents per hour	$0.65
Total cost per acre-foot	$1.93
Total lift in feet	22
Average cost per foot of raising 1 acre-foot	$0.07
With wood, reckoned at $4 per cord:[a]	
Total cost per acre-foot	$2.75
Average cost per foot of raising 1 acre-foot[a]	$0.124

NELSON & McILWAINE WELLS (SEC. 15, T. 1 N., R. 2 E.).

These wells are located near the river, about 3 miles southwest of Phoenix. There are two, 7 feet in diameter and 26 feet deep, dug side by side and communicating. The water is raised by a 20-horse-

[a] Wood is reckoned at $1.50 per cord; this is its cost of cutting and hauling and not its purchase price. Since fuel is the principal item of expense the purchase price of wood should be counted in order to compare the cost of water at this point with the cost where fuel is purchased in the open market. Four dollars per cord may be considered an average price for the wood used at this plant. This would raise the cost of fuel for 1 acre-foot of water to $1.28 instead of 48 cents and make the total cost per acre-foot $2.75 and the average cost per foot of raising 1 acre-foot of water 12.4 cents in place of 7 cents.

power-"Model" gasoline engine and an 8-inch centrifugal pump at the rate of 900 gallons per minute. The water surface is 16 feet below the surface of the ground at present, but varies with the water in the river. At the time of my visit the water was abundant in the river, and the water in the wells was lowered only 5 feet by pumping. During dry seasons, when there is little water in the river, the water stands at a lower level in the wells and the pump lowers it more easily, and even drains the wells. The quantity of water is also affected by the irrigation of lands in the vicinity, being noticeably more abundant in the wells during times of extensive or continued irrigation. The supply drawn from by this pumping plant is therefore due to seepage, partly from the underflow of the river and partly from the return waters from irrigated lands.

The well water is found to be very useful in the cultivation of crops which grow on or near the ground, such as strawberries, melons, etc. Ditch water is used at certain times for all crops on the ranch, but the well water is used at times when muddy ditch water would be detrimental to the crops. The river water, especially in times of flood, contains large quantities of silt, and during dry times the supply may fail altogether. The well water, being free from silt, is used, not only in times of drought, when river water is scarce, but also in flood times, when the use of silty water would injure the crops.

This pumping plant offered favorable opportunity for computing the cost of raising water by means of the gasoline and centrifugal pump. The measurements of the water were made by means of a temporary weir constructed for the purpose, and the quantity of gasoline used is based on an average of many runs. The pump is used ordinarily not more than one hour at a time, but some runs of several hours have been made. Long runs took proportionately less gasoline. Since nearly all the runs in the present case were short ones the computed cost of an acre-foot is greater than it would be if the plant were in continuous operation. The quantity of gasoline consumed in the longest runs, while not accurately measured, was enough less to warrant the assumption that this plant could raise water 21 feet at a cost not exceeding $2.50 per acre-foot.

Cost of pumping water at Nelson & McIlwaine's pumping plant, near Phoenix.

Cost of well (estimated)	$1,000.00
Cost of engine and pump	$1,200.00
Interest on investment at 7 per cent per annum for 6 hours	$0.11
Depreciation at 10 per cent per annum for 6 hours	$0.16
Average amount of water in gallons per minute	900
Hours to pump 1 acre-foot	6
Average amount of gasoline per minute ... gallons	1.5
Gallons of gasoline to pump 1 acre-foot	9
9 gallons of gasoline at 28 cents	$2.52
Oil, repairs, etc. (estimated)	$0.05

Total cost per acre-foot	$2.88
Lift in feet	21
Average cost per foot in lifting 1 acre-foot	$0.137

PERRY WELL (SEC. 22, T. 1 N., R. 2 E.).

Mr. Wm. H. Perry's well is located north of the river, not far from the Collins well. It is 12 by 16 feet at the top and at present writing is about 20 feet deep; it is not yet complete. Water occurs at a depth of 14 feet and will be raised by centrifugal pump and steam engine having a capacity of about 2,000 gallons per minute.

The well is about three-fourths of a mile from the river, and the elevation of the water in it is influenced by the flow in the river. Three weeks before visiting the well the river was in flood. After the flood had passed, the water in the well gradually rose until at the time of visit the surface was 3 feet higher than it had been three weeks before.

BRADSHAW WELL (SEC. 15, T. 1 N., R. 2 E.).

The well of J. R. and W. W. Bradshaw is 8 by 16 feet and 27 feet deep, and has 8 feet of water. The water is raised by a 6-inch centrifugal pump and 12-horsepower gasoline engine; when in use a stream of 60 inches (675 gallons per minute) is obtained. The plant has not been in use during the present season, 1903, owing to the fact that a satisfactory supply of ditch water was obtained cheaper than water could be pumped.

BROWN WELL (SEC. 13, T. 1 N, R. 2 E.).

J. L. Brown has a dug well, 7 feet in diameter and 19 feet deep, with 6 feet of water. The water, which, until recently, was used for irrigation, was raised by a bucket pump, the power being supplied by 8 horses hitched into a circular arrangement similar to a merry-go-round. A stream of 25 inches (281 gallons per minute) was obtained when the pump was operated. It has not been in use for about two years.

HARRIS WELL (SEC. 6, T. 1 N., R. 2 E.).

J. J. Harris has a 4-inch drilled well 103 feet deep. Water was encountered at a depth of 32 feet, but it contained common salt and alkali in quantities sufficient to render it unfit for use. Again, at a depth of 47 feet, water was encountered so strongly impregnated with salts that it is described as brine. At a depth of 98 feet a gravel bed was encountered, yielding a supply of good water.

Log of J. J. Harris's well.

	Feet.
Soil and clay	32
Sand and gravel, salt water	2
Clay and cement	13
Sand and gravel, brine	3
Clay and gravel	38
Hard cement	10
Gravel and bowlders, water bearing	3

The water from the gravel bed at the bottom of the well rises to within 30 feet of the surface of the ground, 2 feet above the surface of the upper water horizon. The upper saline waters are cased off and the water used is from the lower gravel stratum. The analysis of this water is as follows:

Analysis of water from J. J. Harris's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	268.00
Chlorine in terms of NaCl (common salt)	185.60
Hardness in terms of $CaSO_4$ (sulphate of lime)	34.80
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Nitrogen in the form of nitrates	2.00
Nitrogen in the form of nitrites	Very faint.
Qualitative:	
Sulphates	Strong.
Magnesia	Strong.
Lime	Very strong.
Bicarbonates	Pronounced.

KELLNER WELL (SEC. 6, T. 1 N., R. 1 E.).

Mr. E. F. Kellner's well, which is situated 12 miles west of Phoenix on the Yuma road, is a 7-inch well 554 feet deep. A light flow of water was obtained at 322 feet, which rose to within 18 feet of the surface. The purpose in sinking the well was to obtain if possible a supply of flowing or artesian water. Owing to accidents in the work the well was never completed and has never been used.

In January, 1904, in taking the temperature of the well it was found to be only 324 feet deep, the lower 230 feet having filled with sand. Water was found at a depth beneath the surface of 32 feet, a lowering of 14 feet since the well was drilled. The temperature at the depth of 324 feet is 82.3° F.

OSTRICH RANCH WELL (SEC. 3, T. 1 N., R. 1 E.).

This is a 4-inch drilled well 170 feet deep with 110 feet of water. Water is raised either by windmill or engine as occasion demands. The pumping is intermittent, but the well is known to yield at least 35 gallons per minute. The full capacity is not known. No satisfactory record of the formation penetrated at this place could be obtained.

Analysis of water from Ostrich ranch well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	130.00
Chlorine in terms of NaCl (common salt)	76.00
Hardness in terms of $CaSO_4$ (sulphate of lime)	8.20
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Qualitative:	
Sulplates	Very strong.
Magnesia	Distinct.
Lime	Strong.
Bicarbonates	Strong.

MOORE WELL (SEC. 11, T. 1 N., R. 1 W.).

The well of Mr. W. G. Moore is situated on the western border of the Agua Fria flood plain. It has been in operation since 1894, and irrigates 250 acres. The well is about 60 feet long and 20 feet wide, and has a maximum depth of 16 feet. The water, which is raised by a 6-inch Byron Jackson centrifugal pump, operated by a traction engine, is said to run at present about 110 inches (1,238 gallons per minute) continuously. More vigorous pumping drains the well. The water is the underflow of the Agua Fria, and the available quantity is directly dependent on the condition of this stream. From 1894 to 1902 a depth of 12 feet supplied a satisfactory quantity of water, but in 1902 the water was low, owing to a long drought, and the well was lowered 4 feet to secure the required amount of water. During the first four months of the present year (1903) the water has risen in the well 3.5 feet.

HEATON WELL (SEC. 15, T. 1 N., R. 1 W.).

Mr. John Heaton's well is 45 feet deep; the lower 33 feet is drilled and has a 6-inch casing. The dug part, 12 feet, is walled and cemented, and serves as a small reservoir. At the bottom is a horizontal suction pipe is attached to the well casing, and supplied with 4 common suction cylinders 5 inches in diameter; from each cylinder a small rod extends to an eccentric revolving shaft at the top of the well. The casing is fitted with a check valve to prevent any return of the water from the well reservoir down the casing pipe when the pumps are stopped. It is thus evident that while in operation the suction cylinders are 12 feet under water, and the 4 iron rods attached to the plungers work through this depth of water with considerable friction. The fourfold plunge pump is operated by an 8-horsepower gasoline engine, in which distillate is used in place of gasoline. The engine has a much greater capacity than the work demands, and runs at a proportionate disadvantage.

A careful computation of the cost of raising water in this manner was made and is given below. The depth from which the water is lifted while the pump is in operation could not be measured accurately on account of the peculiar construction of the well. It is thought, however, from the behavior of other wells in the vicinity, that the lift does not vary greatly from the figure given below, 28 feet. Since the engine works automatically, there is no account taken of attendance.

Cost of raising water from John Heaton's well.

Cost of well	$100.00
Cost of engine and pump	$400.00
Interest on investment at 7 per cent per annum for 45 hours	$0.18
Depreciation at 10 per cent per annum for 45 hours	$0.26
Capacity of pump in gallons per minute	120
Number of hours to raise 1 acre-foot	45
Gallons of distillate used in a 10-hour run	13
Gallons of distillate used to pump 1 acre-foot	13.5
13.5 gallons of distillate at 25 cents	$3.38
Oil and repairs (estimated)	$0.05
Total cost per acre-foot	$3.87
Lift in feet	28
Average cost per foot in lifting 1 acre-foot of water	$0.138

Analysis of water from John Heaton's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	28.00
Chlorine in terms of NaCl (common salt)	5.20
Hardness in terms of $CaSO_4$ (sulphate of lime)	1.09
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Qualitative:	
Sulphates	Pronounced.
Magnesia	Pronounced.
Lime	Pronounced.
Bicarbonates	None.

HAYNE WELL (SEC. 1, T. 1 N., R. 1 W.).

L. C. Hayne's well is 11 by 7 feet and 24 feet deep, with 8 feet of water. Water is raised by a small steam engine and a 4-inch centrifugal pump, which is said to supply 50 inches of water (562 gallons per minute).

The well seems to be supplied by seepage from the irrigated area to the east. When irrigation is carried on extensively the water in the well is notably higher.

RICHARDSON DITCH (SEC. 15, T. 1 N., R. 1 W.).

Mr. Richardson has a seepage ditch near the mouth of the Agua Fria. The ditch cuts the water-bearing gravels for about three-fourths of a mile to a maximum depth of 10 feet. The water obtained is estimated at a maximum of 150 inches when the ditch is kept clear. Less than 50 inches were flowing at the time the ditch was visited. The accumulations of sand and algæ cause continuous work in keeping the ditch clear. Mr. Richardson estimates that the constant work of a man and team is required in order to obtain the best results from the ditch.

Analysis of water from Richardson ditch.

	March 5, 1900.	April 21, 1900.
Quantitative (parts in 100,000):		
Total solids soluble at 110° C	30.00	33.4
Chlorine in terms of NaCl (common salt)	6.00	7.4
Hardness in terms of $CaSO_4$ (sulphate of lime)	None.	None.
Alkalinity in terms of Na_2CO_3 (black alkali)	1.17	1.3
Nitrogen in the form of nitrates	.126	.148
Nitrogen in the form of nitrites	.0032	Faint.
Qualitative:		
Sulphates	Very strong.	Strong.
Magnesia	Strong.	Strong.
Lime	Very strong.	Strong.

COOPER WELL (SEC. 16, T. 1 N., R. 4 E.).

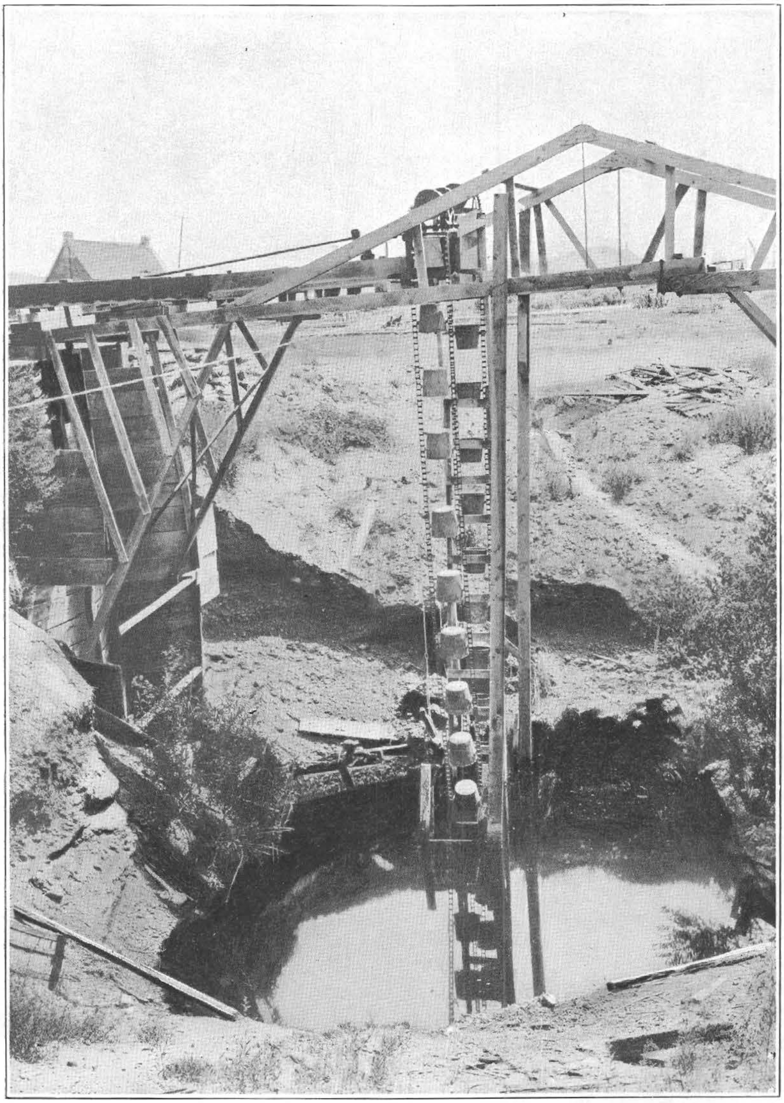
Mr. J. D. Cooper has a small pumping plant north of Tempe. The well is 14 by 20 feet and 22 feet deep, with 4 feet of water. The water is raised by a 4-horsepower gasoline engine and bucket pump, which yields a supply estimated at 20 inches (Pl. VI). The well is in gravels, a few rods from the river bank, and the water comes from the flow of the river, which is here continuous.

THOMAS MURPHY WELL (SEC. 30, T. 2 N., R. 4 E.).

Mr. Thomas Murphy's well is located northeast of Phoenix, west of the Crosscut canal. It is a 6-inch well, 325 feet deep, and is one of the few wells of the region which reach bed rock. The sandstone and conglomerate shown in the log is probably the same as the sedimentary formation which occurs at Camelback Mountain, about 2 miles to the north, and in the buttes just east of the Crosscut canal, and which is described in Chapter II.

Log of Thomas Murphy's well No. 1.

	Feet.
Soil	4
Clay and cement	66
Gravel	3
Cement	5
Gravel, water bearing	37
Clay	27
Gravel	3
Conglomerate	31
Red sandstone	129
Shale	17
Sandstone	3



IRRIGATION BY MEANS OF BUCKETS AT J. D. COOPER'S PUMPING PLANT, NEAR TEMPE.

The conglomerate of this well should not be confused with the water-bearing gravels and bowlders so common in the valley-fill. The valley-fill is here only 140 feet deep; below this depth the material is consolidated red breccia, and can not be expected to yield water so readily as the unconsolidated gravels of the valley-fill.

Analyses have been made from water taken at 4 horizons at this place. The horizons are 78 feet (1), 168 feet (2), 187 feet (3), and 225 feet (4), respectively, below the surface. The water from the upper horizon—that from the 37-foot gravel bed—is strongly charged with sodium carbonate (black alkali), while the waters from the lower horizons are free from the alkali.

Analyses of water from Thomas Murphy's well No. 1.

	No. 1.	No. 2.	No. 3.	No. 4.
Quantitative (parts in 100,000):				
Total solids soluble at 110° C	380.4	303.2	388.0	325.8
Chlorine in terms of NaCl (common salt)	140.0	136.0	105.0	123.4
Hardness in terms of $CaSO_4$ (sulphate of lime)	10.88	None.	None.	32.1
Alkalinity in terms of Na_2CO_3 (black alkali)	None.	2.70	45.16	None.
Nitrogen in the form of nitrates	2.33	.80	1.43	.66
Nitrogen in the form of nitrites	.40	None.	.0666	.0073
Qualitative:				
Sulphates	Very strong.	Very strong.	Very strong.	Very strong.
Magnesia	Very strong.	Very strong.	Very strong.	Very strong.
Lime	Very strong.	Very strong.	Very strong.	Very strong.

Another deep well is in process of construction by Mr. Thomas Murphy at the northern border of this section. At the present time it is 865 feet deep. Very little water-bearing material was encountered, as is shown in the log. It is worthy of note that the well penetrates red sandstone, presumably the red breccia exposed to the east and to the north, and that beneath the sandstones occurs soft clay. Where the red breccia is exposed at the surface it rests upon granite. This does not seem to be the case in the Murphy well. It is possible that the clay at the bottom is nothing more than soft shale, similar to the shale above, and that the drill worked it into a pliant mass not recognizable from unconsolidated clay. On the other hand it is possible that the clay penetrated by the Murphy-McQueen well at Mesa, and by the 705-foot Chandler well occurs at this place and is penetrated by the Thomas Murphy well.

Log of Thomas Murphy's well No. 2.

	Feet.
Cemented wash	160
Red sandstone	38
Shale and clay containing fragments of granite	225
Alternating layers of shale and sandstone	427
Soft clay	15

Since this is the deepest well in the valley—the Murphy-McQueen well having filled with sand for several hundred feet—a series of temperature observations were made, as follows:

Temperature of Thomas Murphy's well No. 2 at various depths.

Depth.	Temperature.	Time thermometer remained in well.	Remarks.
Feet.	*Degrees.*	*Hours.*	
100	74.6+	3	8 feet beneath the water. Temperature probably lowered by surface evaporation.
200	79.1+	3	Suspended in water.
300	79.8+	16	
400	80.0+	7	
500	80.6+	17	
600	81.1+	2	
700	81.9+	2	
800	82.1+	2	
835	83.0+	20	In mud at bottom.

The observations indicate a moderately regular increase in temperature downward, although that increase is not so rapid as might be expected. No variation of temperature is caused here by circulation of water, as the water-bearing strata are cased off at the present time. Since no work has been done at the well for two months or more the recorded temperatures are evidently the true temperatures for the rock at the various depths.

The temperatures taken at intervals of 100 feet indicate an increase downward of 0.2° F. to 0.9° F. per 100 feet. Reckoned, however, from the basis of the average surface temperature, a very different rate is obtained. The average surface temperature at Phoenix, based on seven years' observation, is 69.3° F. There is, therefore, an increase downward of 14.7° F. in 835 feet, or an average increase of 1° F. for every 57 feet.

All things considered, this series of observations gives the most accurate record of the rate of increase of temperature downward of any observations obtained in this region, but since the well is not in the range of free circulation of Salt River underflow the temperature is not included in the table showing the temperature of that underflow, which is given in Chapter IV.

W. J. MURPHY WELL (SEC. 5, T. 2 N., R. 3 E.).

This is a 3-inch drilled well 128 feet deep with 18 feet of water. Water-bearing gravels were encountered at a depth of 110 feet and are at least 18 feet thick.

Log of W. J. Murphy's well.

	Feet.
Alternating sand, clay, and cement	110
Gravel and bowlders, water bearing	18

Analysis of water from W. J. Murphy's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	115.8
Chlorine in terms of NaCl (common salt)	35.6
Hardness in terms of $CaSO_4$ (sulphate of lime)	46.11
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Qualitative:	
Sulphates	Very strong.
Magnesia	Very strong.
Lime	Very strong.

MESSINGER WELL (SEC. 4, T. 2 N., R. 3 E.).

M. W. Messinger's well is drilled 175 feet deep and cased to the bottom, with no perforations. The water is 52 feet deep, having its surface 123 feet below ground surface. The available quantity of water was tested with a 12-horsepower engine and pump. The yield could not be learned, but when the pump was run at the greatest speed possible the water was lowered only 2 feet.

BEET-SUGAR FACTORY WELL (SEC. 8, T. 2 N., R. 2 E.).

A 6-inch well has been drilled at the beet-sugar factory now in process of construction near Glendale. The well is 117 feet deep and is designed only to furnish water for the construction work of the factory. The water is drawn from the gravels at the bottom of the well. It is under very little pressure, as it stands about 100 feet below the surface.

Log of well at beet-sugar factory, Glendale.

	Feet.
Soil	8
Sand and gravel	2
Clay	7
Cemented gravel	2
Clay	29
Cement	8
Cemented bowlders	16
Cement	14
Clay	19
Sand and gravel, water bearing	12

Analyses of water from well at beet-sugar factory, Glendale.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	54.60
Chlorine in the terms of NaCl (common salt)	15.50
Hardness in the terms of $CaSO_4$ (sulphate of lime)	None.
Alkalinity in the terms of Na_2CO_3 (black alkali)	1.99
Nitrogen in the form of nitrates	1.24
Nitrogen in the form of nitrites	.08

Qualitative:

Sulphates	Pronounced.
Magnesia	Faint.
Lime	Pronounced.
Bicarbonates	Strong.

BARTLETT WELL (SEC. 4, T. 2 N., R. 2 E.).

S. C. Bartlett's well, one of the first to be drilled in the region, was completed in 1892. It was 311 feet deep, but was cased with 4-inch pipe to a depth of only 70 feet. No log of the well was preserved, but Mr. A. J. Straw, who was managing the Bartlett ranch at the time the well was put down, stated that the first water struck was at the depth of 120 feet. A second water-bearing stratum was penetrated at a depth of about 185 feet, and a third at the bottom of the well—311 feet.

This well has been of great interest in the community on account of certain indications which lead to the supposition that water is to be found under sufficient pressure to make flowing wells. Mr. Straw, who is himself an experienced well driller, and has put down a large number of the wells near Phoenix, said that at a depth of 311 feet the drill struck a very hard layer, on which the drilling machinery employed was not strong enough to have much effect. After pounding for about two hours the water is said to have suddenly spurted from the well, rising about 7 feet above the top of the casing. The upward rush of the water lifted the drill and operations were stopped. The water flowed from the well for a few moments, then gradually ceased. The next morning the drill was started again and the water is said to have again spurted from the top of the pipe as before, and operations were discontinued, the drilling machinery being inadequate to cope with the difficulty.

Water enough was obtained to supply all needs at the time and nothing further has been done to the well. Since the casing reaches only to a depth of 70 feet, the lower portion of the well soon filled and the water is now derived presumably from the upper or 120-foot horizon.

ALKIRE WELLS (SEC. 21, T. 2 N., R. 2 E.).

Frank Alkire has two drilled wells in this locality. The last one was completed in 1903; it is a 6-inch well 96 feet deep. No water worthy of mention was encountered until the well reached a depth of 96 feet, when a gravel bed was entered, which yields all the water desired. This water was confined by a hard layer of cement.

Log of Frank Alkire's well near Phoenix.

	Feet.
Soil	22
Sand and gravel, dry	6
Clay, sand, and cement	27
Gravel, a little water	10
Cement	1
Bowlders, water bearing	?

Analysis of water from Frank Alkire's well, near Phoenix.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	41.1
Chlorine in terms of NaCl (common salt)	10.0
Hardness in terms of $CaSO_4$ (sulphate of lime)	Strong.
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Nitrogen in the form of nitrates	.0004
Nitrogen in the form of nitrites	1.5

SILVA WELL (SEC. 15, T. 2 N., R. 2 E.).

Mr. Alexander Silva's well is dug 100 feet and drilled 35 feet. The water stands 95 feet below the surface. Some water was found in black sand at a depth of 103 feet, but no satisfactory supply was obtained until gravel was reached at a depth of 110 feet. The water from this gravel bed flows continually from the top of the pipe into the open or dug part of the well and leaks back again in the stratum of sand above.

Log of Alexander Silva's well near Phoenix, Ariz.

	Feet.
Soil	12
Sand and gravel	6
Alternating layers of cement, clay, and sand	72
Quicksand	6
Hard cement	7
Black sand	4
Clay	9
Sand, gravel, and bowlders, water bearing	16

MILLER WELL (SEC. 33, T. 2 N., R. 2 E.).

Edward Miller has a 4-inch drilled well 78 feet deep, with 24 feet of water. A stream of salt water was encountered at a depth of 50 feet. Beneath the salt water a stratum of cement occurs, beneath which is a sand yielding a satisfactory supply of good water. This water is under slight pressure and rose a few feet when struck.

Log of Edward Miller's well near Phoenix, Ariz.

	Feet.
Sandy soil	16
Bowlders, dry	4
Cement, sand, and clay	30
Gravel, salty water	3
Cement	?
Sand, water bearing	?

HOUGH WELL (SEC. 6, T. 2 N., R. 2 E.).

Mr. Samuel Hough has a 6-inch drilled well 105 feet deep, with 15 feet of water. For 95 feet the material is sand, clay, and gravel, more or less cemented; for the lower 10 feet it is uncemented gravel. The material is sufficiently firm to stand without casing, and the well is cased only a few feet from the top. It has been in use since 1899.

A. H. SMITH WELL (SEC. 21, T. 2 N., R. 2 E.).

A. H. Smith's well was dug 96 feet deep and had originally 13 feet of water, probably derived from the gravel bed reached by other wells of the vicinity, though this can not be definitely stated. At a depth of 96 feet the well was in a hard cement which required blasting; after the blast the workman descended but found the water 13 feet deep in the well, and nothing further has ever been done. The water is used only for domestic purposes, but the supply seems to be abundant.

Analysis of water from A. H. Smith's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	130.5
Chlorine in the terms of NaCl (common salt)	40.0
Hardness in the terms of $CaSO_4$ (sulphate of lime)	Strong.
Alkalinity in the terms of Na_2CO_3 (black alkali)	None.
Nitrogen in the form of nitrates	10.0
Nitrogen in the form of nitrites	.012

GLENDALE TOWN WELL (SEC. 8, T. 2 N., R. 2 E.).

This is a 6-inch drilled well 112 feet deep, and contains 12 feet of water. It was put down in 1894 and has yielded a satisfactory supply of water ever since that time.

Analysis of water from the Glendale town well, Glendale, Ariz.

Quantitative (parts in 100,000):	
Total soluble solids at 110° C	79.2
Chlorine in terms of NaCl (common salt)	39.0
Hardness in terms of $CaSO_4$ (sulphate of lime)	Strong.
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Nitrogen in the form of nitrates	None.
Nitrogen in the form of nitrites	.0003

HAMILTON WELL (SEC. 5, T. 2 N., R. 2 E.).

Mr. H. W. Hamilton has a 6-inch drilled well 120 feet deep, with 7 feet of water. Water-bearing gravels were encountered at a depth of 119 feet.

Analysis of water from H. W. Hamilton's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	115.80
Chlorine in terms of NaCl (common salt)	35.60
Hardness in terms of $CaSO_4$ (sulphate of lime)	46.11
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Qualitative:	
Sulphates	Very strong.
Magnesia	Very strong.
Lime	Very strong.
Bicarbonates	No trace.

J. P. ORME WELL (SEC. 25, T. 2 N., R. 1 E.).

Mr. J. P. Orme's well is dug 74 feet deep. At a depth of 44 feet gravels were encountered which yielded a little water, but the supply was not satisfactory and the well was deepened. At a depth of 72 feet a loose gravel bed was found which yielded a large supply, the water rising 26 feet and remaining near that level since the well was dug in 1885. The well is now filled to some extent so that the water does not actually measure 26 feet. The water from the lower gravels is said to be much better in quality than that which comes from higher horizons.

Log of J. P. Orme's well, near Phoenix.

	Feet.
Soil	18
Loose gravel and sand	12
Cement	14
Loose gravel and sand, little water	15
Cement	13
Gravel, water bearing	2

L. B. ORME WELL (SEC. 35, T. 2 N., R. 1 E.).

L. B. Orme has a 4-inch drilled well 102 feet deep. The material to a depth of 76 feet is clay, sand, and cement, yielding no satisfactory water supply. At 76 feet a gravel bed was encountered from which the water rose 14 feet—to within 62 feet of the surface.

Log of L. B. Orme's well, near Phoenix.

	Feet.
Soil	6
Sand and gravel	6
Soil	10
Alternating layers of cement, clay, and sand	54
Gravel and bowlders, water bearing	26

BURROWS WELL (SEC. 35, T. 2 N., R. 1 W.).

Dr. C. Burrows's well, which is 10 feet square and 25 feet deep, is a seepage well in the sands and gravels of the Agua Fria. It was in use from 1896 to 1900. Water was raised by steam power and a centrifugal pump, which furnished a continuous stream of 150 inches (1,680 gallons per minute). No use has been made of the well since 1900.

WIEDER WELL (SEC. 32, T. 3 N., R. 3 E.).

J. A. Wieder's well is drilled 146 feet deep. Near the bottom is a sand stratum that yields the water, which is 17 feet deep and of good supply. The windmill with which the well is supplied has not been able to exhaust the supply even in the strongest winds. The well is not cased, and yet in the six years since it was drilled only 1 foot of sand has accumulated at the bottom, the material through which it is drilled being almost entirely composed of the coarse angular wash from the hills. No waterworn gravels were encountered.

Analysis of water from J. A. Wieder's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	76.1
Chlorine in terms of NaCl (common salt)	31.5
Hardness in terms of $CaSO_4$ (sulphate of lime)	Strong.
Alkalinity in terms of Na_2CO_3 (black alkali)	None.
Nitrogen in the form of nitrates	.70
Nitrogen in the form of nitrites	.0078

FOWLER WELL (SEC. 33, T. 3 N., R. 2 E.).

Mr. B. A. Fowler has a 6-inch drilled well 133 feet deep with 8 feet of water. The well was drilled in 1899. No accurate log of the well was kept, but the presumption is that the water comes from a depth of 133 feet.

Analysis of water from B. A. Fowler's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C	80.9
Chlorine in terms of NaCl (common salt)	13.2
Hardness in terms of $CaSO_4$ (sulphate of lime)	36.5
Alkalinity in terms of Na_2CO_3 (black alkali)	None.

COLE WELL (SEC. 31, T. 3 N., R. 2 E.).

This well is dug 125 feet deep. The material is alternating layers of sand, clay, and cement for 123 feet, when a water-bearing sand is encountered. Two feet deeper a strong flow was struck from which the water rose 19 feet, where it has remained practically constant since 1896, when the well was dug.

Log of N. O. Cole's well, near Phoenix.

	Feet.
Alternating layers of sand, clay, and cement	123
Sand and gravel, water bearing	2

TABULATION OF WELLS FOR PHOENIX REGION.

Many wells in the Phoenix region were visited in addition to those described. In most cases nothing was found worthy of special description, and the measurements were placed directly on the map for construction of the water table. In other cases meager information was obtained, as indicated in following table:

Well records of the Phoenix region.

[Data gathered in part by various members of R. W. Hawley's survey party.]

Number.	Owner.	Post-office.	Location.			Completed.	How put down.	Depth of well.	Depth to water.	Did water rise when struck?	Elevation of surface.	Elevation of water.
			Township.	Range.	Section.			Feet.	Feet.		Feet.	Feet.
	Phoenix Water Co. (2 shallow and 3 drilled wells)	Phoenix	1 N.	3 E.	4	1902	Drilled	208	40	No	1,092	1,052
1	G. W. Barnard	Tempe	1 N.	3 E.	8	1896	Dug	23	21	No	1,143	1,122
	Arizona Laundry Co	Phoenix	1 N.	3 E.	8	1900	do	35	32	No	1,087	1,055
	City Park	do	1 N.	3 E.	9	1902	do	42	31	No	1,092	1,061
	Lewis Wetzler	do	1 N.	3 E.	11	1900	do	40	25	No	1,113	1,088
	Frank Wagner	do	1 N.	3 E.	16	1902	do	35	27	No	1,091	1,064
	L. Kunz	do	1 N.	3 E.	18	1899	do	24	18	No	1,063	1,045
	A. C. Bartlett	do	1 N.	3 E.	27	1901	do	42	34	No	1,103	1,061
	William Christy	do	1 N.	2 E.	1	1902	Drilled	45	37	Yes		
	J. J. Harris	do	1 N.	2 E.	6	1901	do	103	30	Yes	1,046	1,016
	I. L. Brown	do	1 N.	2 E.	13	1901	do	19	13			
	Nelson & McIlwaine	do	1 N.	2 E.	15		Dug	20	14	No	1,048	1,034
	J. R. Bradshaw	do	1 N.	2 E.	15	1900	do	27	19	No		
	George U. Collins	do	1 N.	2 E.	15	1901	do	29	14	No	1,043	1,029
	William H. Perry	do	1 N.	2 E.	22	1903	do		14	No	1,038	1,024
	N. P. McCallum	do	1 N.	2 E.	24	1903	Drilled		14	No	1,051	1,037
24	W. W. Messinger	do	2 N.	3 E.	4	1899	do	175	123	Yes	1,207	1,184
23	F. L. Howard	do	2 N.	3 E.	4	1900	do	175	127	Yes	1,198	1,071
25	Thos. S. Wallin	do	2 N.	3 E.	5	1890	Dug	104	100	No	1,179	1,079
26	Mrs. A. Allen	do	2 N.	3 E.	5	1898	Drilled			No	1,194	
27	W. J. Murphy	do	2 N.	3 E.	5	1897	do	130	110		1,197	1,087
19	—— Barney	Glendale	2 N.	3 E.	6	1897	do	96	95			
29	Harry Thompson	Phoenix	2 N.	3 E.	8	1899	do	104	94	Yes	1,175	1,081
28	J. M. Jamison	do	2 N.	3 E.	8	1897	Dug	125	94		1,173	1,079

Well records of the Phoenix region—Continued.

Number.	Owner.	Post-office.	Location.			Completed.	How put down.	Depth of well.	Depth to water.	Did water rise when struck?	Elevation of surface.	Elevation of water.
			Township.	Range.	Section.							
								Feet.	*Feet.*		*Feet.*	*Feet.*
20	G. F. Houghton	Phoenix	2 N.	3 E.	15	1901	Drilled	98	78	Yes	1,159	1,081
21	Mrs. K. Young	do	2 N.	3 E.	15	1902	Dug	100	95	Yes	1,174	1,079
22	do	do	2 N.	3 E.	15		Drilled	101	88	No	1,159	1,071
	Indian School	do	2 N.	3 E.	20	1903	do	193	36		1,115	1,079
19	Smith & Raney	do	2 N.	3 E.	22	1898	do	90	70	No	1,153	1,083
16	H. H. Munger	do	2 N.	3 E.	23	1899	Dug	83	81	Yes	1,177	1,096
17	C. W. Perkins	do	2 N.	3 E.	23	1901	Drilled	154	82	Yes	1,184	1,102
18	W. D. Bell	do	2 N.	3 E.	23	1902	do				1,171	
8	A. M. Fredrick	do	2 N.	3 E.	27	1883	Dug	56	52	Yes	1,120	1,068
9	B. R. Ellison	do	2 N.	3 E.	27	1901	do	52	50	No	1,123	1,073
7	R. R. Hedgepath	do	2 N.	3 E.	27	1901	do	45	43	Yes	1,117	1,074
13	Elva Hasford	do	2 N.	3 E.	27		do	53	52		1,136	1,084
14	Lee Barnett	do	2 N.	3 E.	27	1901	Drilled	54	37	No	1,133	1,096
15	——— Anderson	do	2 N.	3 E.	27		Dug	58	57	No	1,129	1,071
11	——— McFall	do	2 N.	3 E.	27	1883	do	47	43	No	1,128	1,086
10	J. E. Tounehill	do	2 N.	3 E.	28	1883	do	50	44	No	1,123	1,079
49	L. Perkins	do	2 N.	3 E.	29	1887	do	40	36	No	1,096	1,060
56	Dr. Stone	do	2 N.	3 E.	29	1902	do	53	35	No	1,098	1,063
44	R. B. Quinn	do	2 N.	3 E.	30	1893	Drilled	80	40	No	1,096	1,056
46	——— Warren	do	2 N.	3 E.	30	1888	do	80	40	No	1,105	1,065
48	S. Evans	do	2 N.	3 E.	30	1893	Dug	42	38	No	1,101	1,063
50	C. M. Baum	do	2 N.	3 E.	30	1886	do	43	37	No	1,096	1,059
33	R. H. Green	do	2 N.	3 E.	30	1893	do	50	45	No	1,112	1,067
34	W. T. Cage	do	2 N.	3 E.	30	1902	do	35	33	No	1,112	1,070
36	H. C. Buford	do	2 N.	3 E.	30	1893	do	33	32	No	1,107	1,075
38	C. E. Kirk	do	2 N.	3 E.	30	1900	do	45	41	No	1,105	1,064

51	L. H. Chamler	do	2 N.	3 E.	32	1902	do	37	29	No.	1,089	1,060
52	G. F. Kemper	do	2 N.	3 E.	32	1889	do	46	26	No.	1,088	1,062
53	J. R. Evans	do	2 N.	3 E.	32	1902	do	35	31	No.	1,088	1,057
55	J. P. Orme	do	2 N.	3 E.	32	1884	do	50	30	No.	1,089	1,059
57	W. E. Thomas	do	2 N.	3 E.	32	1890	do	51	30	No.	1,096	1,068
	A. C. Bartlett	do	2 N.	3 E.	32	1900	do	44	28	No.	1,087	959
	D. B. Heard	do	2 N.	3 E.	32	1901	Drilled	42	26	No.	1,092	1,066
2	Thos. Armstrong	do	2 N.	3 E.	33	1902	Dug	44	40	No.	1,110	1,070
3	John Horrineg	do	2 N.	3 E.	34	1886	do	57	53	No.	1,128	1,075
4	Anna Anderson	do	2 N.	3 E.	35	1894	do	50	46	No.	1,128	1,082
5	M. F. White	do	2 N.	3 E.	35	1888	do	54	52	No.	1,124	1,072
18	M. B. Laymon	Glendale	2 N.	2 E.	1	1896	Drilled	104	86			
19	E. Fiscall	do	2 N.	2 E.	1	1897	do	96	89	Yes.	1,210	1,119
	S. C. Bartlett	do	2 N.	2 E.	4	1892	do	311		Yes.	1,180	
	H. W. Hamilton	do	2 N.	2 E.	5	1899	do	120	113		1,176	1,063
13	John Toney	do	2 N.	2 E.	5		do	108	92	Yes.	1,156	1,064
	Saml. Haugh	do	2 N.	2 E.	6	1899	do	105	90	Yes.	1,120	1,030
	E. T. Hawkins	do	2 N.	2 E.	6	1899	do	112	91		1,155	1,064
7	Beet-sugar factory	do	2 N.	2 E.	8	1903	do	117	105	Yes.	1,163	1,058
	Alexander Silva	Phoenix	2 N.	2 E.	15	1899	Dug	135	95	Yes.	1,157	1,062
	A. H. Smith	Alhambra	2 N.	2 E.	21	1897	do	91	82	Yes.	1,138	1,056
	Frank Alkire	Phoenix	2 N.	2 E.	21	1903	Drilled	96			1,135	
	Elliot Evans	do	2 N.	2 E.	25	1902	Dug	68	64	No.	1,109	1,045
	—— Corness	do	2 N.	2 E.	29	1902	do	60	58	No.	1,086	1,028
	J. M. Pike	do	2 N.	2 E.	32	1886	do	64	52	Yes.	1,079	1,027
	Edward Miller	do	2 N.	2 E.	33	1899	Drilled	78	54	Yes.	1,092	1,038
	Jacob Miller	do	2 N.	2 E.	33	1900	do	133	60	Yes.	1,086	1,020
	Chris Miller	do	2 N.	2 E.	34		do	72	47	Yes.	1,093	1,046
11	W. Pope	do	2 N.	1 E.	9	1900	Dug	40	38	Yes.	1,074	1,036
13	—— Young	do	2 N.	1 E.	9	1890	do	40	38	Yes.	1,035	997
4	W. H. Brown	Alhambra	2 N.	1 E.	14	1898	do	80	68	Yes.	1,086	1,018
8	—— Pendergrast	Phoenix	2 N.	1 E.	16	1900	do	50	47	Yes.	1,057	1,010
16	—— Simpson	do	2 N.	1 E.	21	1899	do	63	59	Yes.	1,047	988
17	H. M. Wilburn	do	2 N.	1 E.	22	1903	Drilled	71	56	Yes.	1,064	1,008
7	J. D. Hawkins	Alhambra	2 N.	1 E.	22	1893	Dug	60	56	Yes.	1,069	1,013

Well records of the Phoenix region—Continued.

Number.	Owner.	Post-office.	Location.			Completed.	How put down.	Depth of well.	Depth to water.	Did water rise when struck?	Elevation of surface.	Elevation of water.
			Township.	Range.	Section.			*Feet.*	*Feet.*		*Feet.*	*Feet.*
5	M. S. Rogers	Phoenix	2 N.	1 E.	22	1888	Dug	70	58	Yes	1,074	1,016
3	R. O. Green	....do	2 N.	1 E.	23	1890	....do	76	38	Yes	1,089	1,051
18	W. H. Wilke	Alhambra	2 N.	1 E.	23	1888	....do	68	60	Yes	1,077	1,017
1	——— Green	Phoenix	2 N.	1 E.	25	1896	....do	70	67	Yes	1,087	1,020
	Mrs. Wilke	....do	2 N.	1 E.	25	1896	....do	73	57	Yes	1,091	1,034
	J. P. Orme	....do	2 N.	1 E.	25	1885	....do	74	58	Yes	1,075	1,017
	J. J. Meyer	....do	2 N.	1 E.	26		....do	63	59	No	1,065	1,006
	L. B. Orme	....do	2 N.	1 E.	35	1900	Drilled	102	62	Yes	1,060	998
	J. A. Wieder	....do	3 N.	3 E.	32	1897	....do	146	139	No	1,214	1,075
	W. H. Bartlett	Glendale	3 N.	2 E.	30	1891	Dug	132	116		1,181	1,064
	N. O. Cole	....do	3 N.	2 E.	31	1896	....do	125	106	Yes	1,165	1,059
	B. A. Fowler	Phoenix	3 N.	2 E.	33	1899	Drilled	133	125	No	1,192	1,067
18	——— Woolsey	Peoria	3 N.	1 E.	14	1899	....do	93	85	Yes	1,157	1,072
	A. J. Straw	....do	3 N.	1 E.	25	1898	....do	100	86	Yes	1,157	1,071
1	E. D. Clark	....do	3 N.	1 E.	26	1889	Dug	90	86	Yes	1,141	1,055
2	R. H. Tuckey	....do	3 N.	1 E.	26	1903	Drilled	93	76	No	1,130	1,054
14	R. W. Wagner	Glendale	3 N.	1 E.	36	1895	Dug	97	82	Yes	1,137	1,055

CHAPTER II.

GEOLOGY.

The formations within the area covered by the accompanying geologic map (Pl. VII) are limited in number, owing to the fact that the only map of the region available for use in showing the areal distribution of the geologic formations, was constructed primarily as a map of irrigable lands. In order to obtain a correct conception of the geologic relations of the valley, something of the surrounding hills must be known. For this reason a brief description of the formations occurring near Salt River Valley is included with those represented on the map.

PRE-CAMBRIAN ROCKS.

A small area of the Archean complex is included in the region shown on the map north of Tempe and in Camelback Mountain. The rock is mainly granite and gneiss, intersected in numerous places by dikes, most of which are highly decomposed. Outside the valley the granites are extensively exposed in the surrounding hills. In the Salt River Mountains, south of Phoenix, a fine-grained biotite-granite occurs, which is being used successfully as an ornamental stone. Granite occurs in large masses in the Sacaton Mountains, southeast of Salt River Valley and in the mountains to the east and the north. The granites, particularly to the east, are very coarse grained, the feldspars often attaining a diameter of 2 inches. The rock disintegrates in the arid climate of Arizona to a coarse-grained arkose, commonly known in this region as granitic wash.

Three samples of rock, so chosen that they are representative of the granites in and about Salt River Valley, have been described by J. E. Spurr, of the United States Geological Survey, as follows:

No. 1. Mountains south of Salt River and east of Mesa, Ariz., coarse, siliceous biotite-granite. Structure—hypidiomorphic, granular, with a tendency to idiomorphism, suggesting at times a micro-pegmatitic structure. This rock contains abundant quartz; orthoclase containing a great deal of sericite, probably a decomposition product; microline; and an undetermined finely striated feldspar, which is very likely albite. There is also frequent biotite, almost entirely altered to chlorite and epidote, with abundant titanite, and considerable original magnetite. The whole rock shows the effects of weathering markedly, but is not profoundly decomposed.

No. 2. Same locality as No. 1. Siliceous granite, similar to No. 1. Structure—coarse, hypidiomorphic; contains orthoclase, including much sericite, probably secondary; quartz contemporaneous in general with the feldspar, but largely segregated in veinlike bodies; abundant epidote and chlorite. Titanite is relatively abundant. The rock shows the effect of weathering to a considerable extent.

No. 3. From head-gate of Consolidated canal. Siliceous biotite-granite. Structure—irregular, coarse to fine, hypidiomorphic, granular, in part poikilitic; contains orthoclase, partly kaolinized; microline slightly decomposed to sericite and kaolinic decomposition products, and a striated feldspar whose optical properties show it to be very siliceous, probably anorthoclase. The abundant biotite is fairly fresh; quartz is present in large quantity; fine muscovite occurring in the orthoclase in flakes may be secondary, but is probably original; original magnetite is present; titanite is in large and abundant crystals.

This rock, although a different facies from Nos. 1 and 2, is of the same petrographic character, and all can very easily belong to a single rock mass or intrusion. The condition of this rock is fairly fresh.

In addition to the granites there are extensive series of gneisses in the hills surrounding the valley. The granites pass into the gneisses by imperceptible gradations. Rocks occur in which the feldspars are but slightly deformed, while others reveal a highly gneissoid structure. Bands of gneiss were noted in several places in the midst of granites which show little or no gneissoid structure, probably where movement has occurred along lines of least resistance, while the more resistant masses remained unchanged.

In the Phoenix Mountains, immediately north of the city of Phoenix, occurs an extensive series of metamorphosed sediments, many thousands of feet in thickness (Pl. VIII, *A* and *B*). The layers rest in a nearly vertical position. The quartzite which makes up a large proportion of this series has probably furnished many of the quartzite bowlders of the valley fill, which are described later.

In the Tonto basin east of Salt River Valley an extensive series of quartzites, argillites, etc., occur, which, although they are pre-Cambrian are much less disturbed and less altered than the sedimentaries of Phoenix Mountains (Pl. IX). The pre-Cambrian series of Tonto basin is probably the Apache group of Ransome.[a] Dr. Charles D. Walcott refers this formation to the Algonkian. He writes regarding the relations at the Tonto dam site:

The Carboniferous limestones rest directly and unconformably upon the quartzites and argillites of the Algonkian.[b]

The formation is composed throughout of extremely resistant rock, forming an escarpment in which the strata are nearly horizontal, as in the Sierra Ancha (Pl. IX, *B*), overlooking the Tonto basin, or forming a ridge where the strata are tilted, as in the ridge through which Salt River has cut its gorge at the Tonto dam site (Pl. IX, *A*, and fig. 11).

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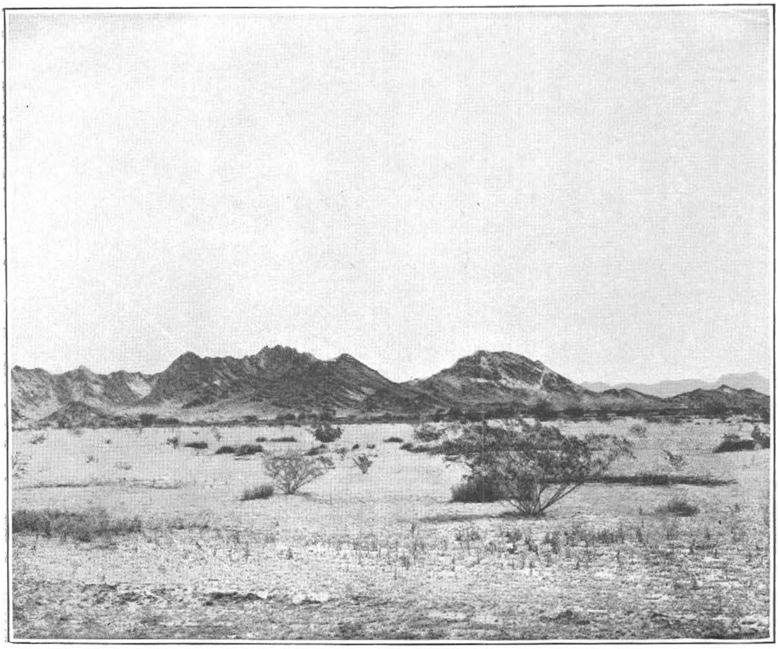
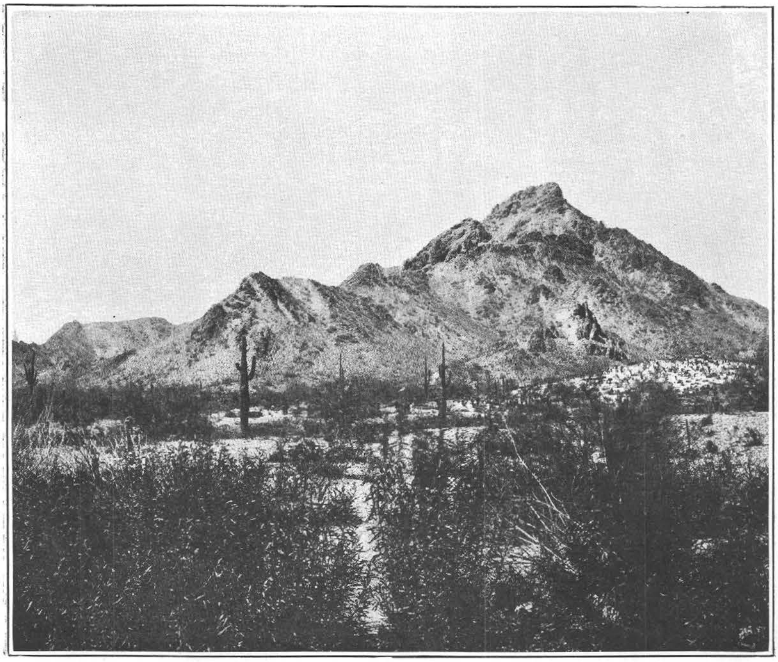
[a] Ransome, F. L., Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903, pp. 28-39. Geology of Globe quadrangle: Geologic Atlas U. S., folio 111, U. S. Geol. Survey, 1904.

[b] Personal communication.



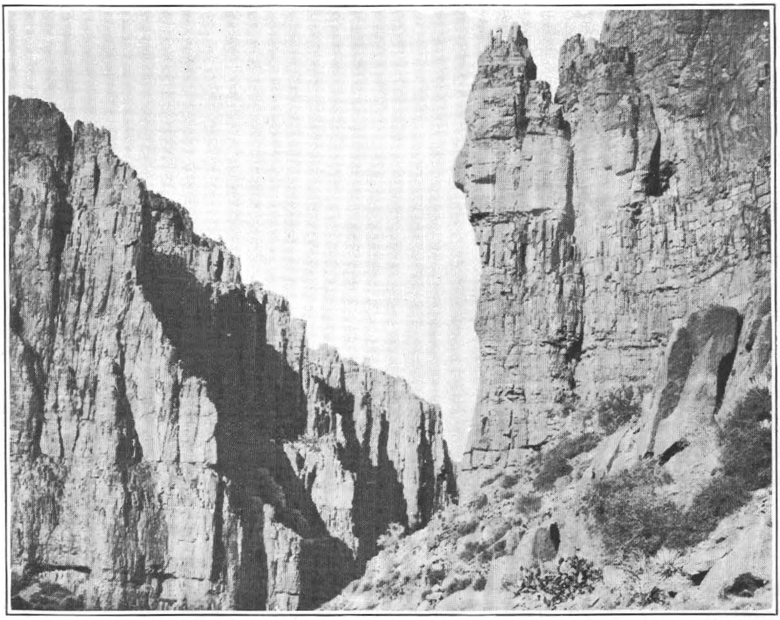
A. TILTED PRE-CAMBRIAN QUARTZITES AND ARGILLITES IN THE PHOENIX MOUNTAINS.



B. PHOENIX PEAK, NORTH OF PHOENIX.

A. SALT RIVER DAM SITE, LOOKING UPSTREAM INTO TONTO BASIN.

The rock is Algonkian quartzites and argillites dipping upstream. Photograph by Walter Lubkin.



B. SIDE CANYON IN TONTO BASIN.

Showing the nature of the quartzites and argillites of the Algonkian strata of the Sierra Ancha.

The thickness of this formation as exposed in this gorge is about 1,800 feet. In the Sierra Ancha the same formation is seen and seems to be much thicker. It is extensively exposed along Salt

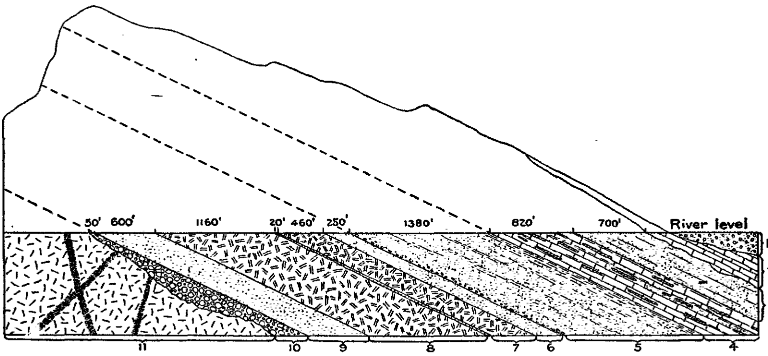


FIG. 11.—Section through Salt River gorge at the Tonto dam site.

River, east of Tonto basin, and has probably furnished the greater portion of the gravel and bowlders of the valley fill of Salt River Valley.

CARBONIFEROUS ROCKS.

The formation next younger than the Apache, so far as known in the vicinity of Salt River Valley, is the lower Carboniferous. Fossiliferous limestones rest upon the Apache group in the Tonto basin, and have yielded the following fossil forms:

Fossils from limestone at Tonto basin dam site.

Zaphrentis sp.
Menophyllum excavatum.
Syringopora surcularia.
S. aculeata.
Leptopora typa.
Rhipidomella sp.
Schuchertella inæqualis.
Productus lævicosta.
Spirifer centronatus.
Spirifer sp.
Camarotœchia metallica.
Platyceras sp.
Bellerophon sp.
Fish tooth.

Fossils from limestones near Tonto basin dam site.

Zaphrentis sp.
Menophyllum excavatum.
Cyathophyllum sp.
Syringopora surcularia.
Leptopora typa.
Rhipidomella sp.
Schuchertella inæqualis.
Spirifer centronatus.

Fossils from limestone at Windy Hill, Tonto basin.

Menophyllum excavatum.
Cyathophyllum sp.
Syringopora aculeata.
Leptopora typa.
Crinoidal fragments.
Spirifer centronatus.
Seminula humilis ?

These fossils were identified by George H. Girty, paleontologist of the United States Geological Survey, who refers the formation to the Lower Carboniferous. The fossils are identical with those found in the Redwall limestone of the Grand Canyon section. In writing of the fauna, Mr. Girty says:

The opinion is expressed with considerable confidence that the faunas represent the earlier half of Mississippian time. The fauna is that which has a wide range throughout the West, having been found in almost every State east of the Sierra Nevadas. It characterizes the Madison limestones of Wyoming and Montana, the Ouray limestones of Colorado (in its upper portion), the lower part of the Wasatch limestones of Utah, etc. The fauna resembles that of the Kinderhook and Osage divisions of the Mississippi Valley section.

TERTIARY (?) DEPOSITS.

SEDIMENTARY ROCKS.

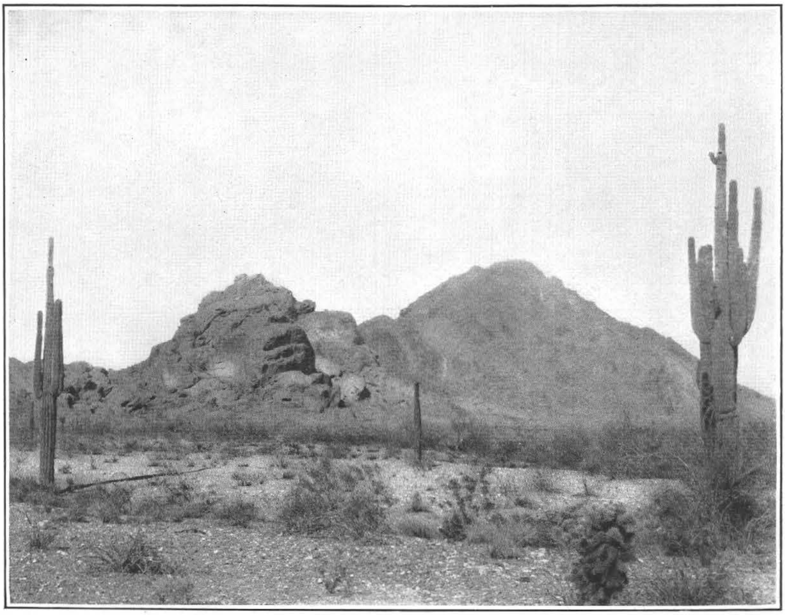
It is not certainly known that any Mesozoic strata are represented in or near Salt River Valley. Near Tempe occur several isolated exposures of red sandstones, conglomerates, and breccias, of which a thickness of about 200 feet is exposed at Tempe Butte. The base is a massive sandstone, used in the valley for building purposes. The sands become more and more argillaceous toward the top, where red shale underlies the lava capping the butte. These strata dip 55° to the southeast and strike N. 60° E.

North of the river at Tempe occurs a series of red sandstones passing downward through a coarse arkose to a granitic breccia at the base. The formation is apparently a continuation of the sandstones of Tempe Butte, although it dips southwest 65° (strike N. 40° W.), nearly at right angles to the direction of dip at the Butte. This formation apparently extends little more than a mile north of the river, although this can not be confidently stated on account of the fragmental débris which covers the greater part of the surface. A well about 1.5 miles northwest of Tempe is in sandstone to the depth of about 200 feet, while a well 2.5 miles northwest of Tempe is entirely in granite to the depth of 110 feet. The attitude of the sandstones both north and south of the river is best explained by faulting, but the fault planes are entirely obscured by surface débris. The sandstone is shown in Pl. XII. Nothing has been found to indicate its age.

In the buttes north of Tempe (Pl. XI, *B*) and on the western slope of Camelback Mountain (Pl. XI, *A*) occurs a formation composed of arkose sandstone, breccia, and conglomerate. It is coarse and massive and indicates only the roughest kind of bedding. It rests upon an uneven surface of granite and the base is composed wholly of fragmental granite. Higher in the series other constituents enter. Quartz, quartzite, jasper, and a number of species of igneous rocks were noted. In places the pebbles are well rounded, forming a conglomerate,

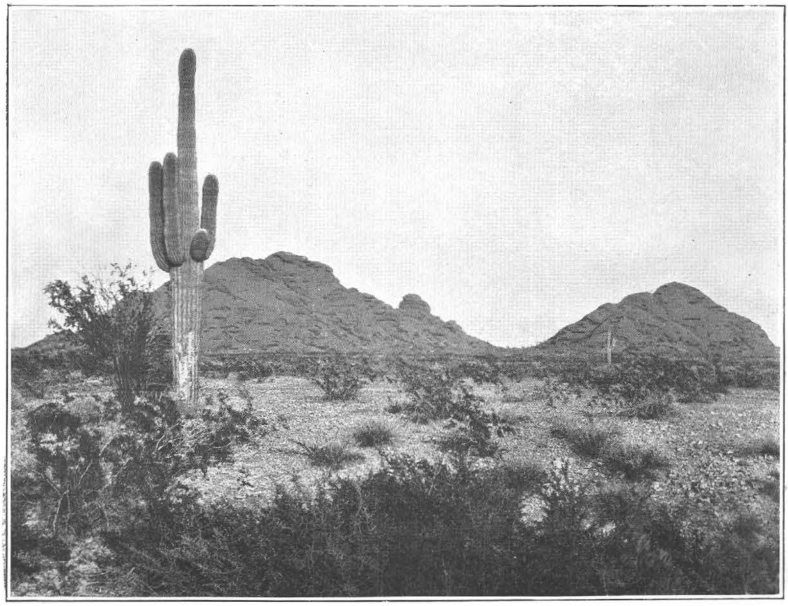
TILTED FORMATIONS AT UPPER END OF TONTO BASIN.

Looking up Salt River from dam site of power canal.



A. CAMELBACK MOUNTAIN, NEAR PHOENIX.

Showing breccia at the left, resting on the flank of a granite mountain.



B. BUTTES NORTH OF TEMPE.

but on the whole the material is sharply angular. The base is not well defined. The massive granite gives place to a granitic agglomerate scarcely separable from the unbroken granite beneath, and this agglomerate passes upward into conglomerate, breccia, and arkose sands according to locality. In Pl. XI, *A*, granite is shown at the right, and massive granoclastics at the left, passing upward to stratified breccia.

The sandstone and breccia of the Tempe region are similar in being red, arkose, and devoid of fossil forms. It is possible that they form a single series passing from the granoclastic mass at the base through the breccias and sandstones to the shale at the top. They are not found in actual contact, and are apparently unconformable. The breccia seems to lie across the upturned sandstone, and upon the granite beyond. It is probable that the sandstone, together with the granite against which it rests, was upturned and deeply eroded previous to the deposition of the breccia.

Owing, no doubt, to their resemblance in color and texture to the Triassic sandstones occurring elsewhere, these two formations have been referred to the Trias. Professor Blake[a] refers to them briefly as follows:

> Formations of the Mesozoic are not absent in southern Arizona. The massive red sandstones north of Phoenix, of Tempe, and of Mesa in Salt River Valley are referred to the Trias.

In fig. 17 I have attempted to show in a general way the relation of Salt River Valley to the great continental plateau. It is probable that the sedimentary formations (pre-Cambrian and Carboniferous) forming the escarpment, and the mountain ridge at the Tonto dam site, formerly extended over Salt River Valley, and were carried away by erosion after the elevation of the plateau. In that case a formation resting in contact with the pre-Cambrian formations of the valley can scarcely be of Triassic age. The well-known Triassic of Arizona is found on the top of the plateau, being thus elevated when the plateau was raised. If the supposition is correct that the low-lying area beyond the edge of the plateau, of which Salt River Valley is a part, is in large measure due to degradation subsequent to the elevation of the plateau, any formation resting on that degraded surface must be later than the period of degradation. The elevation of the plateau began, so far as known, at the end of the Cretaceous period. A long period of erosion must have elapsed subsequent to the elevation of the plateau before the sandstone and breccia were laid down. For these reasons the breccia is thought to be not older than late Tertiary, and may indeed be equivalent to the Gila conglomerate, which Gilbert regards as early Quaternary. Beyond the suggestion that the sand-

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[a] Blake, William P., Some salient features in the geology of Arizona with evidences of shallow seas in Paleozoic times: Am. Geol., March, 1901, p. 166.

stone and breccia may be phases of a single accumulation, the age of the sandstone must remain an open question.

Judging from the character of the breccia and its relation to older rocks, there is little doubt that it is due to upland accumulations. The size of some of the granite blocks—many of them several feet in diameter—indicates that action was violent and granite highlands not far distant when the breccia was formed. In general character the breccia closely resembles the Gila conglomerate of Gilbert. On the other hand it is evident from the remnants left in the valley that this breccia formerly had a wide areal distribution and that the greater part of it has been carried away. All things considered it seems preferable to refer the formations exposed at Tempe tentatively to late Tertiary.

TERTIARY LAVAS.

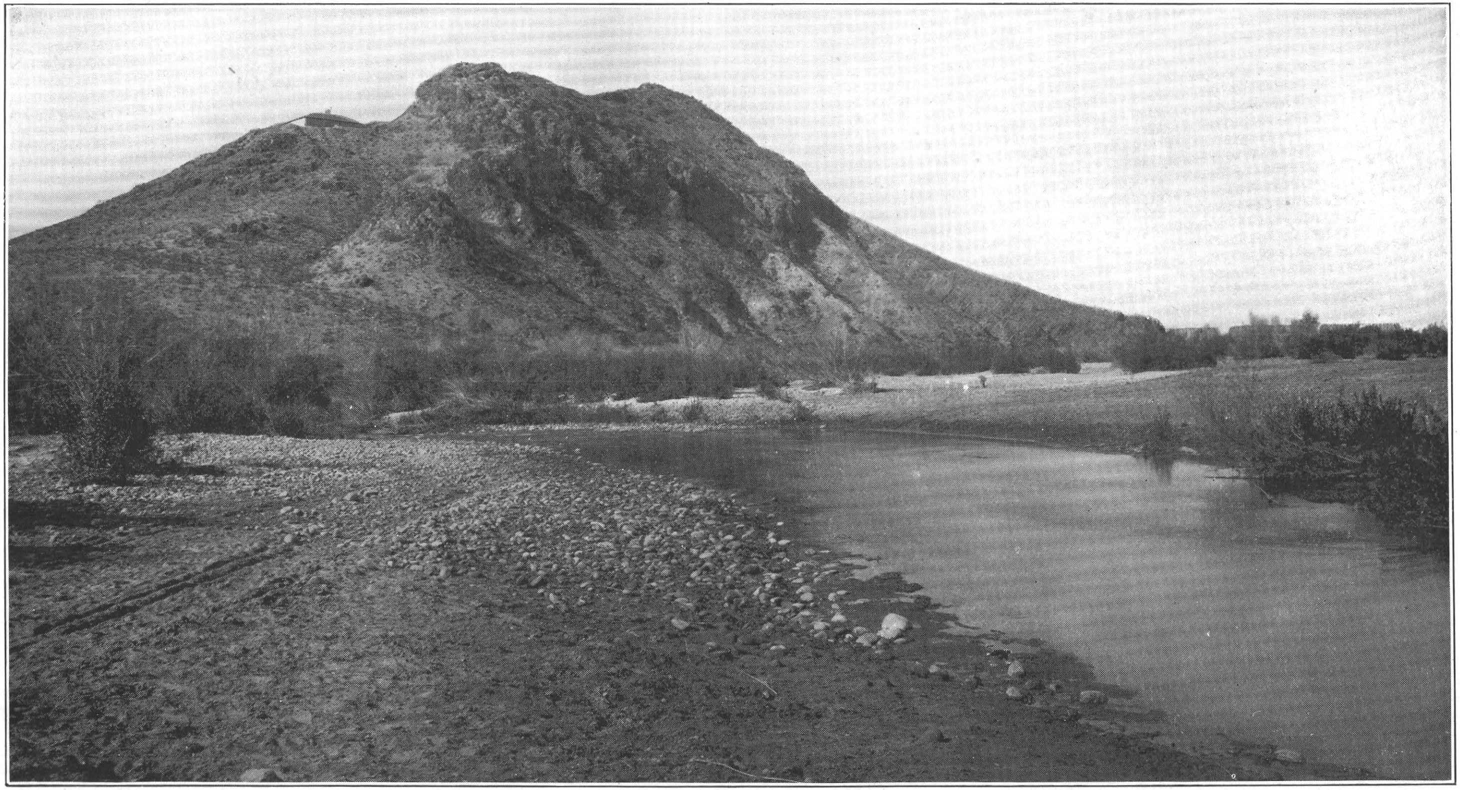
Eruptive rocks occur within Salt River Valley in Bell Butte (see Pl. XIII, *A*), Tempe Butte, and a line of small buttes north of Tempe. The rock from Bell Butte is described by J. E. Spurr as follows:

> Butte southwest of Tempe, Ariz.: Hornblende-pyroxene-andesite, fine grained. Structure—fine porphyritic. Phenocrysts of pale-brown basaltic hornblende, altered along the edges to calcite and iron; pseudomorphs of calcite and iron oxide after pyroxene; and turbid feldspars which are altered chiefly to calcite, indicating their belonging to the soda-lime group. The groundmass is glassy, in part microlithic, and shows altered feldspars, etc. This rock is highly altered.

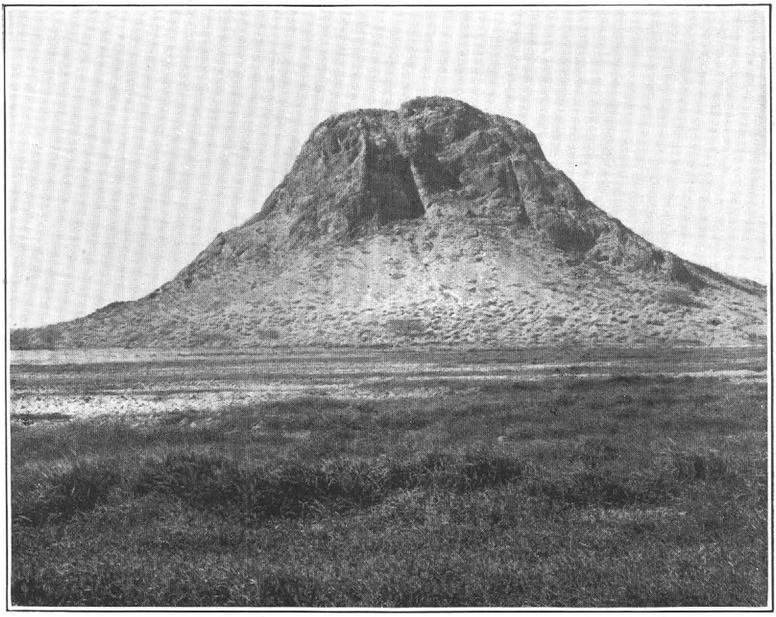
In the hills surrounding the valley occur extensive masses of eruptive rock, consisting of rhyolite, andesite, basalt, volcanic glass, pearlite, ash, scoria, etc. The most extensive mass in the immediate environs of the valley is found in the Superstition Mountains, east of Salt River Valley, where rhyolitic flows and beds of white tuff and ash occur to an aggregate thickness of several thousand feet. The igneous rocks form a nearly vertical escarpment rising something over 5,000 feet above the valley floor (Pl. XIII, *B*).

QUATERNARY FORMATIONS.

The greater part of the area represented in the accompanying geologic map is occupied by débris which is here designated "valley fill." It is unconsolidated material, accumulated in the valleys and on the gentler slopes of the hills. Since it is in this valley fill that the underground water occurs, it is, so far as this report is concerned, the formation of prime importance in the region. An understanding of processes of accumulation now in operation is necessary for an adequate understanding of certain features in the structure of the valley fill. For this reason much that properly belongs in the chapter on physiography is given in this connection.

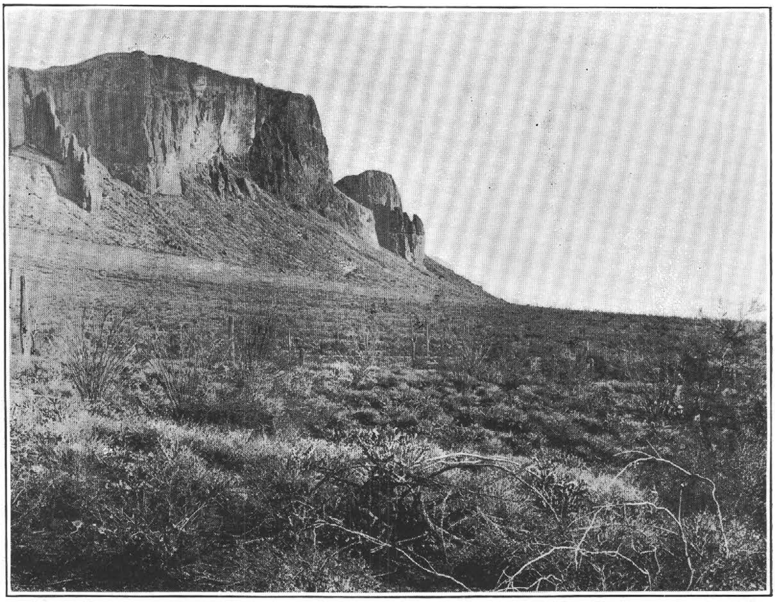


TEMPE BUTTE, SHOWING TILTED SANDSTONE AT THE RIGHT, OVERLAIN BY ANDESITE.



A. BELL BUTTE, NEAR TEMPE.

A lava butte partly buried by valley fill.



B. NORTH END OF SUPERSTITION MOUNTAINS.

A lava promontory rising above the detrital plain of Salt River Valley.

VALLEY FILL.

At Mount McDowell Salt River emerges from the narrow canyon by which it passes through the Superstition Mountains and enters the broad bottom lands known as Salt River Valley. (Mount McDowell stands at the head of what is termed the "valley" in this paper.) Some time ago it was proposed to construct a dam across the Verde River near its junction with Salt River at Mount McDowell, and a series of borings was made across the canyon to ascertain the depth to bed rock. From the records of these borings a cross section of the

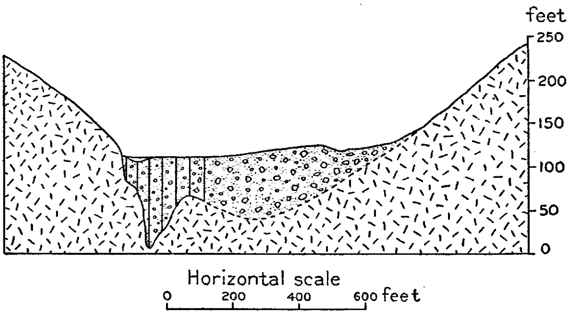


FIG. 12.—Cross section of Verde Valley near Mount McDowell, Arizona.

ancient or filled canyon of the Verde is constructed (fig. 12), showing that the valley has been filled to a depth of at least 90 feet. This valley fill is composed of waterworn material, similar to that found in the river bed and throughout the valley at the present time. This section may be taken as illustrative of the general structure of Salt River Valley. The valley, very much deeper in past ages than it is now, has been filled to its present level by fragmentary material.

STRUCTURE.

The region known as the Mesa is at the eastern extremity of the valley, lying about 25 feet higher than the bed of the river. The bluffs forming the edge of the Mesa are composed of river gravels and bowlders similar to those found in the present river bed (see Pl. IV, *A*). It is evident that the Mesa gravels were deposited by Salt River, and that because of some subsequent change in the abrasive force of the river, caused perhaps by a slight elevation of the surface, the river has cut into its former deposit to a depth of at least 25 feet near Mesa. How much deeper it cut remains unknown. The well at the creamery near Tempe, described in the former chapter, seems to be entirely in the recent material, though this can not be confidently stated. This degradation occurred over a strip 1 to 2 miles wide. The degraded area was again covered with débris forming the lowlands found along the river in the Mesa region. No deep wells have penetrated the more recent deposits of the lowlands in the Mesa region in localities suitable to indicate the depth of these deposits. Shallow wells dug to a depth of about 50 feet seem to be wholly in the recent deposits, indicating that the erosion which formed the Mesa bluffs must have lowered the river bed at least 50 feet beneath its present elevation.

The two gravel terranes differ but slightly. Their constituents are the same, but the younger accumulations are notably less cemented. Wells sunk in them are the most productive wells in the region because of the readiness of movement of their ground waters. In the Mesa region the younger gravels are easily distinguished from the older on account of the former being confined between bluffs of the older material. But at Tempe and throughout the Phoenix region the younger gravels cover the older and their distribution can be judged only from the well records. The relations of the two series of accumulations are shown in sections AB and CD of Pl. XIX, and in the cross section near Phoenix (Pl. XXI).

MATERIAL.

The valley fill is composed of more or less irregular lenses of clay, silt, sand, gravel, wash, and bowlders. These are arranged in a most erratic manner, the character of the beds changing rapidly both vertically and horizontally, as indicated by the well records.

This material may be divided for convenience of description into (1) river débris, (2) sheet wash, and (3) chemical precipitate.

RIVER DÉBRIS.

In the present river bed are found bowlders and gravel of quartzite, quartz, chert, granite, gneiss, and various kinds of eruptive rock. The quartzose materials greatly predominate, owing, no doubt, to their enduring character. Bowlders occur with a maximum diameter of about 2 feet. A comparison of the material found in the river bed at the present time with the older material found in the exposed bluffs along the river and in the numerous wells throughout the valley indicates that for the most part the valley fill was derived from the same sources from which the present river gravels are derived, namely, the formations along the upper reaches of Salt River.

SHEET WASH.

The term wash is used in this region with at least four meanings, more or less separate and distinct:

(1) The stream courses occupied by water only in times of heavy rainfall, called arroyos in other parts of the West, are here called washes.

(2) Many of the dry stream courses having their origin in the mountains are well defined for a greater or less distance after emer-

ging from the mountains, but finally disappear on the plain, leaving no trace of a definite course. During times of flood the waters spread in a broad, thin sheet over the plain. The largest floods gradually find their way to the rivers, not by way of channels, for there are none, but by a broad wash over the even surface of the gently sloping plain. In most cases, however, the waters never reach the river, but are absorbed by the sands and gravels of the valley floor and disappear completely from the surface. The broad sheet of water thus sweeping over the surface is called a sheet wash.

(3) The material brought from the hills by the streams, many of them of considerable size—as, for example, Queen Creek and Cave Creek—is deposited as a broad fan, so broad and low, in fact, that it is scarcely separable from the general valley floor. Queen Creek has a well-defined course for about 50 miles, and Cave Creek one somewhat longer. During floods a large amount of débris is deposited along these stream courses and is locally known as wash. The material in which wells have been sunk is sometimes described as "Queen wash" or "Cave wash," etc.

(4) A fourth meaning of the term is closely allied with the third, and yet distinct enough to demand separate mention. The sudden heavy showers so characteristic of Arizona are too well known to require explanation. If a so-called cloud-burst occurs in the hills near the edge of the valley the small stream courses, flooded to overflowing, discharge their débris-charged waters upon the gentler slope of the valley floor, where all definite stream courses disappear. Should a channel by chance become established, the checked velocity of the water on the gentler slopes of the valley floor soon causes it to become choked and to be deflected and join that of the neighboring streams. The result is that flood waters from the hills move more or less in a sheet over the valley floor until they disappear beneath the surface. The loose material from the hillsides is thus brought to the valley and distributed somewhat evenly over the surface. Cloud-bursts which take place over the valley produce the sheet floods on a smaller scale. The material thus brought from the hills and distributed over the valley is called also sheet wash.

The term wash, therefore, applies (1) to a dry stream course, (2) to water moving in the form of a thin sheet over the plain, (3) to the material deposited by an intermittent stream near the base of the mountains in the form of a fan or dry delta, and (4) to the accumulations of detrital material working slowly from the hillsides, as a more or less evenly distributed sheet.

It is not difficult to understand how the washes can cause large quantities of débris to accumulate near the hills. But in the midst of the plain, miles from the hills, the sheet flood, as a geologic agent, might seem so unimportant as to be negligible. The heavy showers occur but seldom and affect a very limited area at any one time. It is probable that scores of years may intervene between two showers sufficiently heavy to produce sheet floods at any given point, and yet the writer is of the opinion that the sheet flood is a factor which can not be neglected in the adequate explanation either of the valley fill or of the underground water contained in this fill.

As the arkose works its way down the mountain slopes and spreads over the surface of the plain, the coarse material naturally accumulates near the foot of the parent mountain, while the finer material is carried farther out. The sorting, however, is not carried on to anything like the extent observed in the case of regular streams. In many cases, indeed, the floods are so tumultuous that coarse and fine materials alike are carried forward and piled in confusion. In the less violent floods the coarse material accumulates near the hills. This fact is of the utmost importance in furnishing an explanation of certain phenomena connected with the underground waters of the valley.

The sheet wash is apt to differ from the stream-carried débris in bearing less evidence of the recognized action of running water. The water wear and sorting are at a minimum. When there is water enough to move any of the material of the wash, there is likely to be enough to move coarse and fine alike. The result is an accumulation of silt, clay, sand, and gravel commingled in every conceivable proportion. The gravels are usually angular, although some are slightly water worn. Near the granite hills the wash is composed of the coarse, angular products of the partial decomposition of the granite, previously described. When the feldspars are decomposed to such an extent that they do not easily retain their original form, the material is locally known as "talc" or "soapstone" (not to be confused with true talc and soapstone).

At Desert well the wash covering the surface is at least 180 feet thick, and no other material except a few feet of sand is found throughout that thickness. The 348-foot well of the Valley Seedless Grape Company, near the eastern end of the Salt River Mountains, is in granitic wash throughout most of its depth and at the bottom penetrates solid granite. In many places the wash from the hills gives character to the topography over wide areas. Southwest of the Superstition Mountains the surface of the desert over an area of something like 300 square miles is composed of wash from these mountains. The small stream courses from the mountains soon disappear in a regularly inclined desert surface which is practically wanting in even the smallest stream courses.

Queen Creek, which may be taken as a type of the streams that enter the valley from the neighboring mountains and disappear on the valley floor, illustrates the manner of accumulation of wash. It has a drainage area of about 143 square miles in the mountainous district northeast of Florence, and its course is traceable in a distinct channel for a distance of over 40 miles, but on entering the valley the waters soon sink from view into the sands and gravels of the floor, leaving the bed dry except in times of flood. A few miles below the dam site at Whitlow's ranch the creek emerges from the hills upon the sloping plain of the valley, and thence to the end of its course follows no well-defined depression or valley. From Whitlow's ranch to the end of the course near Andrada well the creek bed has a fall of about 665 feet, making an average gradient of 28 feet to the mile, which above the ranch is still higher. With such a gradient it is evident that during times of flood great quantities of débris must be swept from the hills. The floods are in part checked as they enter the plain and in part lost by sinking into the gravels, and the débris is deposited, building up the course of the stream. The result is that numerous channels occur side by side, more or less connected by crosscuts forming a network of interlacing courses. A second result is that along the lower reaches of its course, Queen Creek has built up a fan or dry delta above the surface of the surrounding plain. A similar fan has been built by Cave Creek, the lower reaches of which are within the area covered by the detailed topographic map of Salt River Valley. The deflection of the contours south of Cave Creek, as shown on this map, is due to the general elevation of the land surface in that region caused by the Cave Creek fan. North of Sacaton Mountains Queen Creek branches into numerous forks or distributaries and is eventually lost in the general surface of the plain. From this point to the Gila River, a distance of about 15 miles, there is no stream channel. Floods large enough and lasting enough to reach the Gila pass over this last 15 miles as sheet washes. These washes are said to vary from a few inches to 2 feet in depth and the water is so loaded with silt and floating vegetation that it works its way slowly over the plain without excavating channels even where the slope is comparatively steep.

It is seldom, however, that floods occur of sufficient size and duration to reach the Gila, being more often lost in the valley fill long before reaching that river. The amount of water which thus sinks beneath the surface, together with the intermittent character of the flow, is well shown in the accompanying table and diagram (fig. 13) taken from the paper on Irrigation near Phoenix, Ariz., by A. P. Davis.[a]

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

Estimated monthly discharge of Queen Creek, Whitlow's ranch, Arizona, in 1896.

[Drainage area, 143 square miles.]

Month.	Discharge.			Total for month in acre-feet.
	Maximum in second-feet.	Minimum in second-feet.	Mean in second-feet.	
January	2	2.0	2.0	123
February	2	2.0	2.0	115
March	2	2.0	2.0	123
April	2	1.0	1.5	87
May	1	1.0	1.0	61
June	1	1.0	1.0	60
July	9,000	....	121.6	7,480
August	1,433	.6	13.1	805
September	3,428	.5	17.1	1,016
October	1,188	.5	13.3	820
November	80	.6	1.3	80
December	207	.6	2.0	120
Total	9,000	....	15.0	10,890

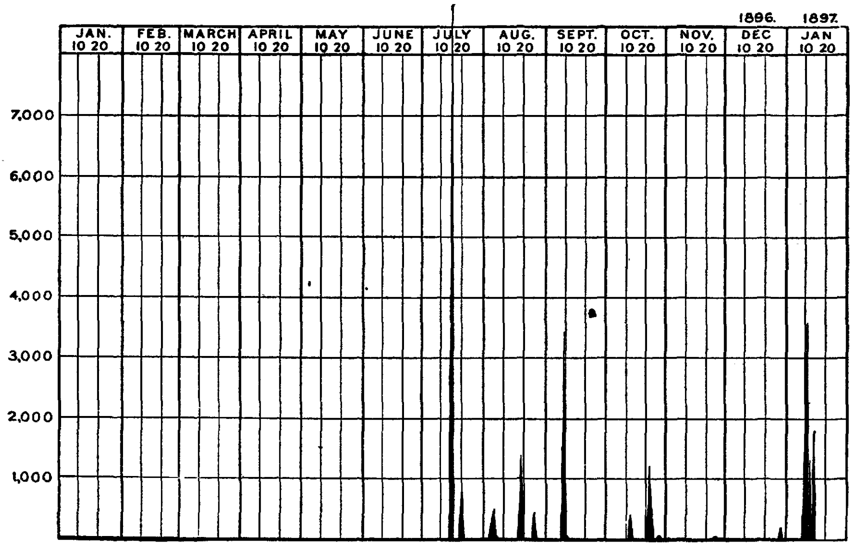


FIG. 13.—Daily discharge of Queen Creek.

Robert Bowen, who owns a ranch about 6 miles east of Harrington well, on Queen Creek, pointed out to me certain fields which were flooded a few months previous to my visit. There are 6 channels at this point, varying from a few feet to about 100 feet in width. In order to flood the fields in question the water in these channels must have had a depth of at least 5 feet. Mr. Bowen states that at the Harrington ranch, 6 miles downstream, there was not enough water to fill certain irrigation ditches which had been prepared for the diversion of flood waters. Here then is a specific case of a flood of somewhat notable volume that sank into the sands and gravels of the valley fill within a distance of about 6 miles.

CHEMICAL PRECIPITATES.

Caliche.—In nearly every well of the valley a substance is encountered, in greater or less quantity, which is commonly known as cement or hardpan. This material is also known, though less generally, as caliche, and has been described by Prof. W. P. Blake,[a] of the University of Arizona, who says:

In southern Arizona and in Mexico the word caliche is in general use to denote a calcareous formation of considerable thickness and volume found a few inches, or a few feet, beneath the surface soil, upon the broad, dry, gravelly plains and mesas. * * *

Caliche has a wide distribution in the regions of Arizona and Mexico. It is usually hidden from view by a slight covering of soil, but it is easily found by digging, and is often revealed by a flow of water during heavy rains. It is practically a continuous sheet, from 3 to 15 feet thick, of earthy limestone or travertine, through which the smaller plant roots find their way with difficulty. * * *

The top of the caliche is more dense and solid than the lower portions. The surface of this crust, or layer, is comparatively smooth, though undulating, while the lower portions, under the crust, are irregular, cavernous, earthy, and very porous, blending gradually with the materials of the sandy and gravelly beds, from which they are divided by no sharply defined plane of stratification or separation. The caliche invests, surrounds, and includes sand grains, gravels, and more or less earthy material, but seems to have had the power, especially in its upper crust, of extruding the coarse materials of the soil to a great extent.

The deposit does not form a regular horizontal bed conformable with the rude stratification of the gravels and sands, but conforms roughly with the general surface, rising and falling with the undulations of the mesa. There are, in places, repetitions of the compact layers, separated by a few inches of the amorphous and more earthy deposit. * * *

Close observation detects, in some places, small perforations, like pin holes, at the top, which enlarge gradually below and penetrate the entire compact crust, becoming lost in the irregular amorphous granular mass. * * *

The caliche is an example of deposition independent of the influence of organic agencies. * * *

In chemical composition the caliche is essentially a lime carbonate, but contains some calcium, magnesium, and aluminum silicates, as more fully shown by the result of an analysis made by my assistant, Mr. J. S. Mann, in the laboratory of the Arizona School of Mines:

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[a] Blake, William P., The caliche of southern Arizona: Trans. Am. Inst. Min. Eng., vol. 31, 1901, p. 220.

Analysis of Arizona caliche.

Calcium carbonate ($CaCO_3$)	72.28
Magnesium carbonate ($MgCO_3$)	2.13
Calcium silicate ($CaSiO_3$)	5.57
Aluminum silicate ($AlSiO_5$)	7.37
Ferric oxide (Fe_2O_3)	1.88
Moisture (H_2O)	1.20
Total	96.43

This caliche, unlike the deposits of travertine formed in the open air, is not sufficiently compact and solid to be useful in construction, as was the travertine of ancient Rome. When calcined it yields good caustic lime, which, tempered with sand, makes a strong, quick-setting mortar or cement. It is quarried and used for this purpose in some places. Occurring as it does in mixture with gravel and sand, it has the appearance of an artificial mixture. * * *

After describing local conditions and giving the analyses of water from 7 wells near Tucson, which indicate that the underground waters contain the principal elements found in caliche, Professor Blake adds:

There has been much speculation in regard to the origin of the caliche. It has been generally assumed to be a deposition from some ancient lake, or body of water, once covering the area in which it is found. But such a theory is untenable when all the phenomena are considered. The formation is clearly the result of the upward capillary flow of calcareous water, induced by constant and rapid evaporation at the surface in a comparatively rainless region.

With a constant supply of phreatic calcareous water, the second great essential factor in the formation of caliche is the continued desiccating atmosphere—a condition which prevails, with only short and temporary exceptions, through the year. The desert and semidesert regions of Arizona are characterized meteorologically by the unusual dryness of the air and its capacity for the absorption of moisture and by the maintenance of continued evaporation from the soil, which determines a constant upward movement of the phreatic water. The occasional rains in midsummer and midwinter do not penetrate to great depths, but are sufficient to leach out the soil to the depth of a few inches or feet, turning the calcareous solution back and downward and producing the denser upper crust, where it meets the upward flow.

Such I conceive to be the origin of the caliche. It may be called a subterranean deposit of travertine; but it is not the result of a flow from springs or from any source at the surface, or from the lateral movement of water. Unlike ordinary travertine, it is the result not of descending but of ascending currents. The ordinary conditions of vadose circulation are reversed. The caliche is a fine example of the formation of extensive calcareous strata in the midst of preexistent beds, not by metasomatic processes, but by precipitaton from sources below.

To Professor Blake's description I would add that caliche occurs in varying degrees of purity and that any consolidated layer is locally known as cement. When caliche is not mixed with a considerable amount of foreign material it may become very compact, resembling a fine-grained limestone, and sometimes causes much difficulty in sinking wells through it. Several cases are on record where wells were abandoned because the casing caught on a cement layer and could be forced no farther.

A sand or gravel bed cemented with this material often becomes impervious to water. The confining strata above the water in nearly all the wells of Salt River Valley, where water is found under pressure, contain more or less caliche in the form of a cementing material.

It will be noted that according to Professor Blake's interpretation the caliche is due to the deposition of compounds gathered from some outside source and brought in solution, through underground passages, to the region where they are deposited through the agency of surface evaporation. Applying this explanation to the origin of the caliche layers in the valley fill of Salt River Valley, it is evident from the analyses of waters already given and from the rocks previously described, which furnish by their decomposition the elements brought into the valley by the waters, that all elements necessary for the formation of caliche are present. The prevalence of caliche at or near the surface strengthens the postulate that the surface is its natural place of formation. Since the valley fill, as explained elsewhere, is due to the gradual filling of the valley by débris shed from the hills, each horizon throughout its depth has at some former time been the surface. Hence the presence of caliche bands at all horizons.

It should be noted, however, that bicarbonates are present in nearly all the waters of the valley. A relief of pressure alone is sufficient under certain conditions for the escape of carbon dioxide, which causes the bicarbonates to change to the comparatively insoluble carbonates, which are then readily deposited. It is entirely possible, therefore, that the deposition of caliche may take place at some depth beneath the surface, in fact at any depth where the pressure upon water containing bicarbonates in solution is sufficiently relieved and opportunity given for the escape of the gas.

The postulate that caliche is in some cases at least deposited without the influence of surface evaporation, is strengthened by the observation of uneven porous structures on the under side of caliche layers. This strongly suggests the deposition of caliche beneath, after the impervious layer had been formed. A lowering of the water table during dry cycles, such as are known to occur, would naturally leave beneath a caliche layer which had been formed near the surface a space occupied by loose gravels, no longer filled with water as before. The caliche layer would prevent any great amount of evaporation, but probably would not prevent relief of pressure upon the water in the gravels beneath. A relief of pressure might cause a loss of carbon dioxide and result in deposition of the insoluble carbonates.

A case in hand is found at the Murphy-McQueen pumping plant (see p. 12). Beneath the 13 feet of soil at the surface coarse gravels and bowlders occur to a depth of 34 feet. The material in the upper 13 feet is free from any notable amount of caliche, while the loose gravels and bowlders are more or less cemented. The bowlders are encased somewhat uniformly in a white crust of caliche, often thick enough to unite them into resistant masses; the cementing is irregular, however, uncemented portions being found throughout the mass. Accepting the postulate of surface formation of caliche through the agency of evaporation, the soil above should be cemented. This is not the case. On the other hand, accepting the postulate of deposition of this caliche at some former time when the bowlders were at the surface, it is inconceivable that the caliche should be as irregularly distributed as it is. It is known that there has been a lowering of 12 feet in the underground water at this place in the last four years. There is every reason for believing that at some time the underground waters filled the gravels up to the bottom of the soil layer, and that a subsequent fall of these waters from the soil layer left a bed of loose gravel above the surface of the underground waters where these waters were not only under no pressure but were lifted to some extent among the loose gravels by capillary action, where they would naturally deposit their contained minerals on the surface of the gravels. Cyclic oscillations of the underground water would distribute this action through a considerable depth.

On the other hand, caliche is present on the hillsides far above the reach of any permanent supply of underground water. It is found generally along the slopes of the hills and over dry plains such as that in the vicinity of Desert well, where no underground water is found within hundreds of feet of the surface. (Water is found at a depth of 212 feet at Desert well and 284 feet in the Kleinman well.) Caliche found at the surface of this dry plain and on the barren hillsides can scarcely be due to the evaporation of water which can in any sense be called an underground supply as postulated by Professor Blake.

A somewhat different view is held by Prof. R. H. Forbes, director and chemist of the agricultural experiment station of Arizona, who has given the subject considerable study from a chemical standpoint. At the writer's request he has furnished the following statement of his opinion:

My view of the formation of caliche is that in this region of scanty rainfall, which penetrates the ground from a few inches to a maximum of a very few feet—say 3 or 4—the rain water, containing a small amount of carbon dioxide, percolating from the surface to this maximum depth of, say, 3 feet, dissolves small portions of calcium and magnesium bicarbonates in the form of normal carbonates, leaving in course of time a layer of limy hardpan at the depths to which it penetrates. The large amount of siliceous material found in caliche layers indicates also that colloidal clayey materials are carried down mechanically by percolating rainfall, the result being the mixture of siliceous calcareous materials, together with portions of original soil in situ, which are found to constitute nearly all of our caliche layers. The different layers found at different depths below the surface mark the various levels which for geologic reasons remained constant for a long enough period of time to permit the formation of a layer of caliche just below the surface of that time. I have noticed also that igneous rocks at the base of hills containing calcareous materials are often coated with a thin layer of calcareous materials, evidently carried in solution in carbonated waters from higher levels and deposited upon these rocks, over which this drainage percolated, through the agency of evaporation, aeration, or heat.

It should be noted that while the two hypotheses attribute the origin of caliche to the deposit by evaporation of salts held in solution, they differ in this: Blake's postulate assumes a more or less definite underground flow bringing the materials from a distance, while Forbes's postulate assumes that the materials are taken into solution at the surface through the agency of carbonated rain water, held in solution but a short time near the surface, and deposited by evaporation at no great distance from the place of their origin. Each postulate seems satisfactory in certain cases and unsatisfactory in other cases. It seems probable that many of the caliche layers of Salt River Valley have been formed from the carbonates and other salts held in solution in the underground flow, as postulated by Blake. It seems equally evident that the caliche of the hillsides and the dry plains has been formed in some such manner as that described by Forbes.

There are still other cases where deposition of caliche evidently takes place in subterranean cavities where evaporation can have little influence, either because of relief of pressure, as previously suggested, or from some other cause not yet recognized.

Salts.—In addition to the caliche considerable quantities of the various salts found in solution in all of the waters of the valley have been deposited in the valley fill. While they are quantitatively unimportant from a geologic standpoint, they are of the greatest importance in influencing the character of the water. The principal salts are sodium chloride (common salt), calcium and magnesium sulphates (hardness), and calcium carbonate (lime). The salts are irregularly diffused through the materials composing the valley fill, and their amount, kind, distribution, etc., will be described more in detail in connection with the chemical character of the waters.

AGE OF THE VALLEY FILL.

The physiographic relations of the valley fill indicate that it is comparatively young, but no fossil forms have been found in any of the deposits. As already indicated, there are at least two periods of accumulation represented at the surface. During the accumulation of over 1,300 feet of the detrital material it is possible that there were more than two such periods. Good exposures are wanting in Salt River Valley, but similar deposits are widely distributed over western Arizona, and a comparison with regions where the recent deposits are better exposed seems to throw light on the question of age. A similarity in the succession of events recorded indicates that certain surface movements have been somewhat general over a large portion of western Arizona.

The Colorado River probably furnishes the best index available to the general surface movements of the Southwest. In an examination of northwestern Arizona, described elsewhere, the author noted at numerous points a series of tilted and partly consolidated conglomerates and breccias, overlain by more recent and unconsolidated sands and gravels, which were in turn dissected and overlain by a third series now accumulating to form the present lowlands along the Colorado River. The older series is extensive both in thickness and areal distribution. Its original thickness must have been at least 2,500 feet, remnants being now found 2,300 feet above the river, and it extends downward to some unknown depth beneath its bed. The next younger deposits are less extensive, and the youngest form the present flood plain.

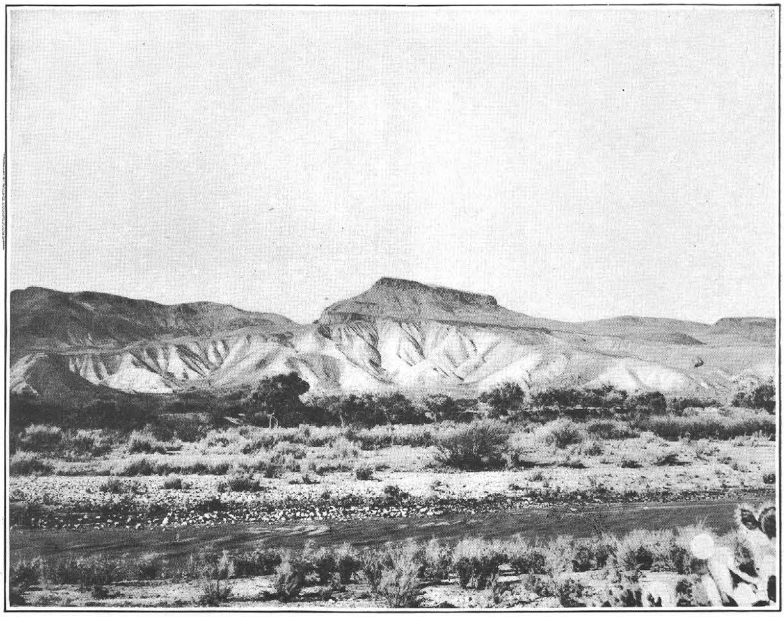
The succession of events recorded in these deposits as well as in those of Salt River Valley and elsewhere is indicated in fig. 14. The original valley (A) was filled with the oldest débris (B), and this in turn was eroded (C) and again filled with the second accumulation (D). A third stage of erosion excavated the present valley (E), and the deposits now accumulating are represented in stage F.

A similar succession of events has been noted at several points in Arizona, notably along San Pedro, Santa Cruz, and upper Gila rivers, and in Tonto basin, as well as in a number of places in northwestern Arizona. Near Benson, in San Pedro Valley, wells have penetrated the valley fill to a depth of about 800 feet without reaching bed rock.

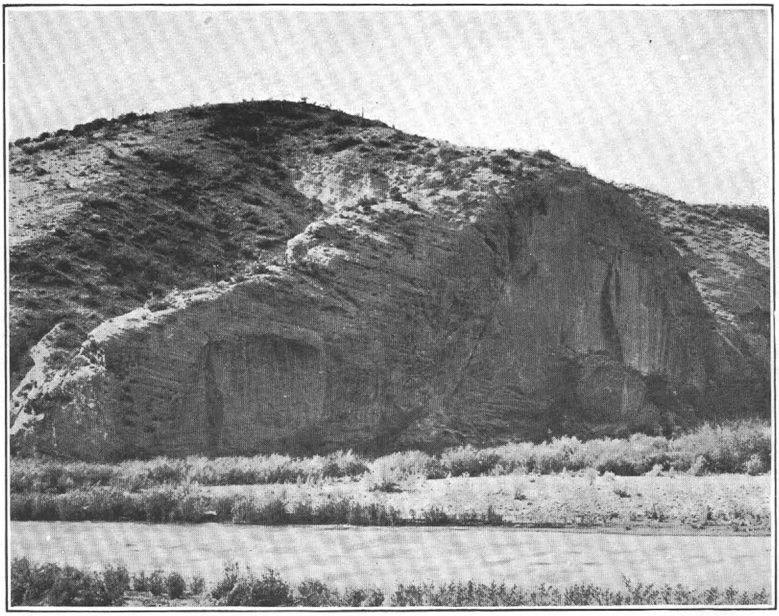
In the Tonto basin upland deposits of at least two periods of accumulation are exposed. The older is a coarse breccia, moderately well consolidated and more or less tilted in places (Pl. XIV, *B*). This breccia rests upon the eroded surface of the older formations and is deeply dissected in places. Against this tilted breccia rest nearly horizontal beds of more recent sediments, which are in turn dissected, large portions of them having been carried away by the more recent action of the river (Pl. XIV, *A*). Nothing was found to indicate the geologic age of either deposit, but the older is regarded as probably representing the base of the Quaternary.[a]

There have been, then, since the original formation of Tonto basin at least 5 separate stages: (1) The period of erosion, which, in part at least, formed the basin, corresponding with stage A of fig. 14; (2) a period of accumulation, during which the breccia just described was deposited, this period corresponding to stage B; (3) a period of

[a] Gilbert, G. K., Report on the geology of portions of New Mexico and Arizona: U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, p. 540.
Ransome, F. L., Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903, p. 57.



A. CLAY BANK IN TONTO BASIN, FROM WHICH CLAY WILL BE OBTAINED FOR CEMENT IN THE CONSTRUCTION OF SALT RIVER DAM.



B. TILTED BRECCIA IN TONTO BASIN.

Accumulation represented by stage B.

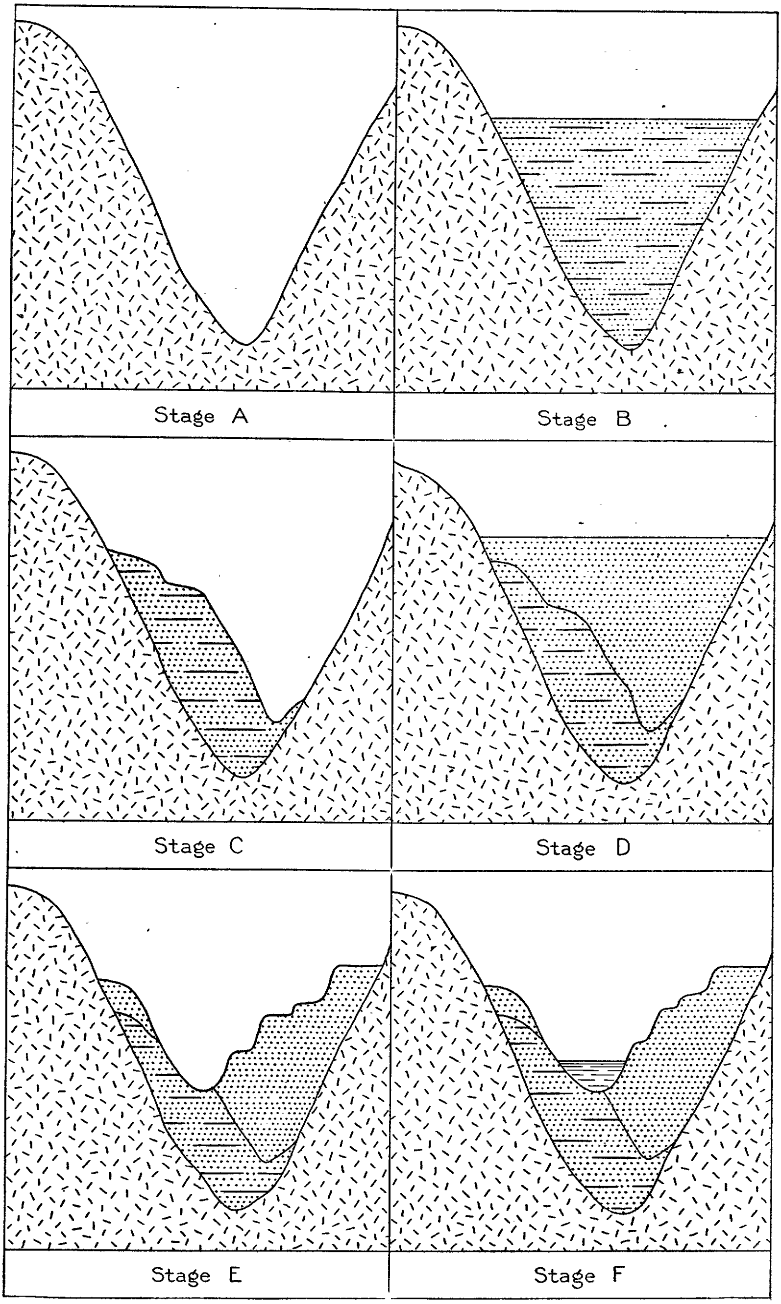


FIG. 14.—Diagrammatic illustration of valley filling and erosion in central and western Arizona.

erosion, probably inaugurated by uplift and tilting, in which the breccia was dissected, this period corresponding to stage C; (4) a period of accumulation, in which the younger sediments of the basin were deposited on or against the dissected breccia—stage D; (5) a period of erosion, the present stage of the river, during which the present valley has been excavated—stage E.

Since the same succession of events is shown to the west of Salt River Valley along the Colorado, to the east in Tonto basin, to the southeast in San Pedro Valley, etc., it is possible that the various stages are due to far-reaching causes affecting Salt River Valley in common with the other localities named.

The older mesa gravels of Salt River Valley may represent stage B, while the younger gravels represent stage D and the present river channel, stage E. There are no accumulations in Salt River Valley, except the gravels of the broad bed of the river, which can be compared to the accumulation of stage F. The similar succession of events in widely separated localities is suggestive of common causes, but no definite correlation is possible at the present time. This much, however, can be stated with reasonable confidence—the valley fill is not the result of continuous aggradation. Periods of erosion have alternated with periods of accumulation.

It is worthy of note that in the three deepest wells of the valley—the Murphy-McQueen well, 1,305 feet; the Chandler well, 705 feet; and the Thomas Murphy well, 865 feet—a considerable thickness of clay or other fine material occurs beneath the coarse detritus. In the Murphy-McQueen well this material is described as "chalk rock" and "talc." The writer has seen a small portion of the material taken from the 1,305-foot level. It consisted of clay containing a few quartz pebbles. The clay from the bottom of the Thomas Murphy well is very plastic and contains no fragments of foreign material. The clay apparently lies underneath the breccia. Little more is known of the lower horizons of the valley fill. The material of the upper horizons, so far as known, is evidently due to upland accumulation. For this reason, and because of the want of definite information concerning the lower horizons, the whole thickness of the valley fill has been assumed to originate in the same way. What little is known of the lower horizons suggests the possibility of lacustrine origin. The occurrence of the clay underneath the breccia near Phoenix suggests that the clay beds encountered in the Mesa region may be notably older than the detrital material above. In that case the lower part of the valley fill may be of Tertiary age, and a thickness of only a few hundred feet at the top may belong to the Quaternary.

SURFACE MOVEMENTS.

There is abundant evidence that changes in surface elevation have taken place in and about Salt River Valley in comparatively recent times.

(1) The immense deposits of upland accumulation in this region are best explained as due to subsidence of the surface. The general occurrence of upland accumulations of débris throughout western Arizona and southern California suggests that the same cause affected wide areas. It is probable that these accumulations are in part due to desiccation of the climate. There is abundant evidence that in former ages streams of considerable size occupied valleys which are now dry. However much desiccation of the climate may have caused a diminution of streams and consequent deposition of débris in valleys which were formerly swept clear by these streams, it can not wholly account for this accumulation.

The present surface elevation at Mesa is about 1,200 feet. The deep well at Mesa—1,305 feet—extends about 100 feet below sea level and does not reach bed rock. It is obvious that at this point the surface must have been at a greater elevation when the valley was formed, since the river could not excavate the valley below sea level. Similar thicknesses of the upland débris occur elsewhere—800 feet in San Pedro Valley; 1,000 feet in Sacramento Valley at Yucca, Ariz., and about 2,400 feet exposed in the bluffs of the Colorado River. In none of these places, however, is bed rock reached. The evidence points to a general subsidence as the initial cause of the upland deposits.

(2) Local movements. The sandstones and the breccia near Tempe and at Mount McDowell, near the head of the valley, are highly inclined. The attitude of the sediments in Tonto basin indicates faulting and tilting to a notable extent, and Ransome[a] describes an area of intense faulting and movement east of Salt River Valley. Faulting and block tilting are not easily recognized in crystalline formations such as those immediately surrounding the valley, and the covering of detrital matter renders the location of possible fault lines doubtful. Reasoning, however, from analogy it is probable that faulting and block tilting have played a considerable part in bringing about present relations in and near Salt River Valley.

The most conspicuous example of a tilted block within the valley is found in Tempe Butte, where the sandstone and its overlying sheet of andesite are tilted steeply to the south. The movement which brought this butte to its present position was very recent. Waterworn bowl-

[a] Ransome, F. L., Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903.

ders, such as compose a large part of the valley fill, are found on the sides of the butte above the level of the valley floor, and although they

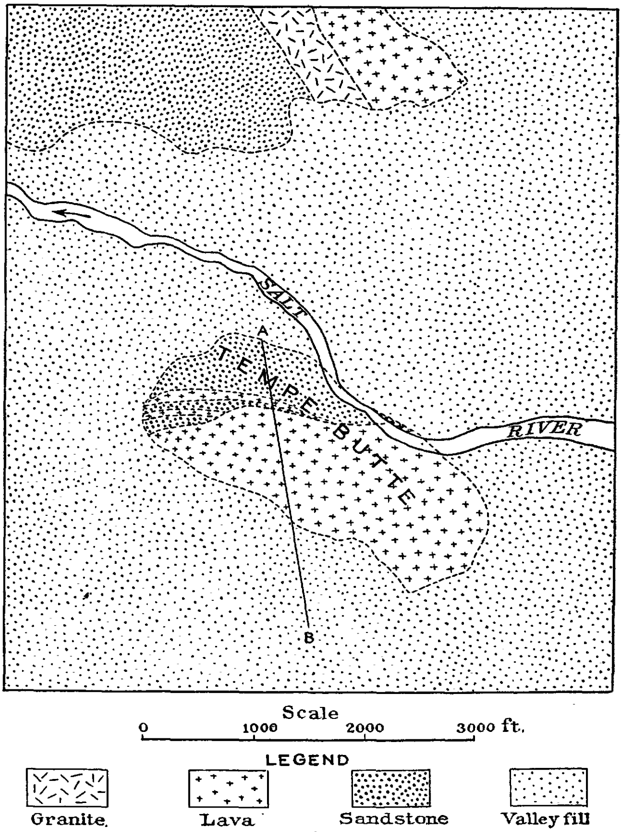


FIG. 15.—Geologic map of Tempe Butte.

lie loose on the steep sides, sufficient time has not elapsed since their elevation to allow of their finding their way back to the river which

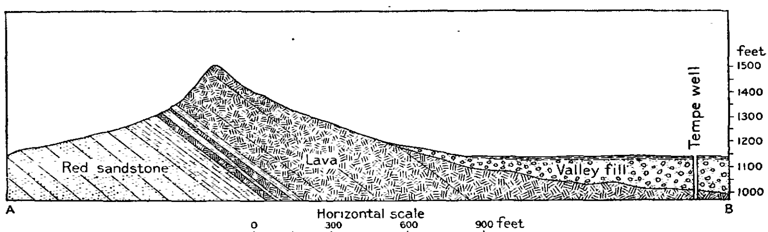


FIG. 16.—Section through Tempe Butte and Tempe well.

flows at the foot of the butte. The attitude of the formations and their relations to each other are indicated in figs. 15 and 16.

CHAPTER III.

PHYSIOGRAPHY.

MOUNTAIN AND PLAIN.

The so-called valleys of Salt and Gila rivers are but parts of a broad plain occupying a large portion of southwestern Arizona. The valleys are in part surrounded by mountainous areas, and they themselves in turn surround isolated peaks and groups of mountains which rise abruptly from their surface. To the north and east the country becomes more and more mountainous to the edge of the high plateau, which within a distance of something like 80 miles rises to an elevation of about 7,500 feet, as indicated in the sketch profile fig. 17. The escarpment bordering the great western plateau passes through this region. The surface of the plateau slopes northward, while the drainage from its face—the edge of the Mogollon Mesa—together with that from the broken country to the southwest of the escarpment forms Salt and Verde rivers, thus furnishing the water which supplies Salt River Valley. In a general way the aggraded

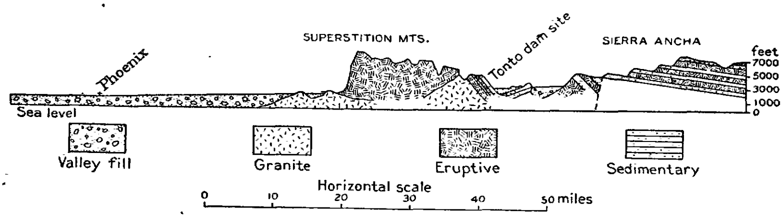


Fig. 17.—Sketch profile from the Agua Fria, through Tonto basin and the Sierra Ancha.

plain of which Salt River Valley is a part lies at the foot of the escarpment bordering the plateau, and has been filled and graded principally by material shed from the edge of this plateau. Between the escarpment proper and the aggraded plain there is much broken country of which little is known. Toward the south and west of the escarpment the mountain masses stand out as more or less isolated groups, separated by stretches of fairly level plains, as, for example, the Salt River and Sacaton mountains.

The plain from which these comparatively small mountain groups rise has a regular and moderately uniform slope corresponding to the gradients of the streams. In some cases the transition from mountain to plain is marked by a series of partly buried hills, which were originally outlying remnants of erosion and which have since been surrounded by débris shed from the mountain slope. This is illustrated in a small way south of the Phoenix Mountains (Pl. XV). In a larger way the groups of mountains, such as Salt River Mountains, Sacaton Mountains, etc., are also remnants of erosion partly buried by débris. In other cases the mountains rise from the graded plain or valley floor with the utmost abruptness, as in the case of Bell Butte (Pl. XIII, *A*), and Camelback Mountain (Pl. XVI, *A*). Probably the most notable physiographic feature of the region is the abrupt transition from mountain to plain.

In the views, previously referred to, of Tempe Butte, Bell Butte, etc., the aggraded plain shown in the foreground extends to the abrupt rocky slopes with little or no transition. Irrigable lands extend to the foot of the slopes, as indicated in Pl. XVII, which is a view from the top of Tempe Butte. The explanation of these relations is found in the study of the material and structure of the valley floor. The old valley has been flooded with débris and the outlying peaks and spurs partly or wholly submerged.

THE MESA REGION.

The Mesa gravels, or older gravel accumulations, were deposited to an elevation 25 feet or more above the present river bed. Later these gravels were cut by the river to a depth of at least 75 feet, and this

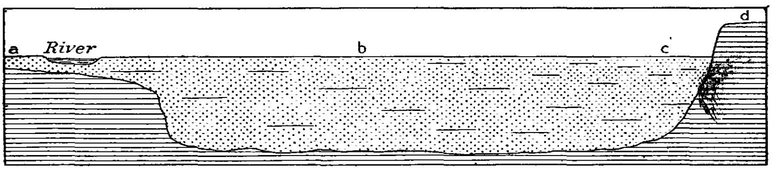
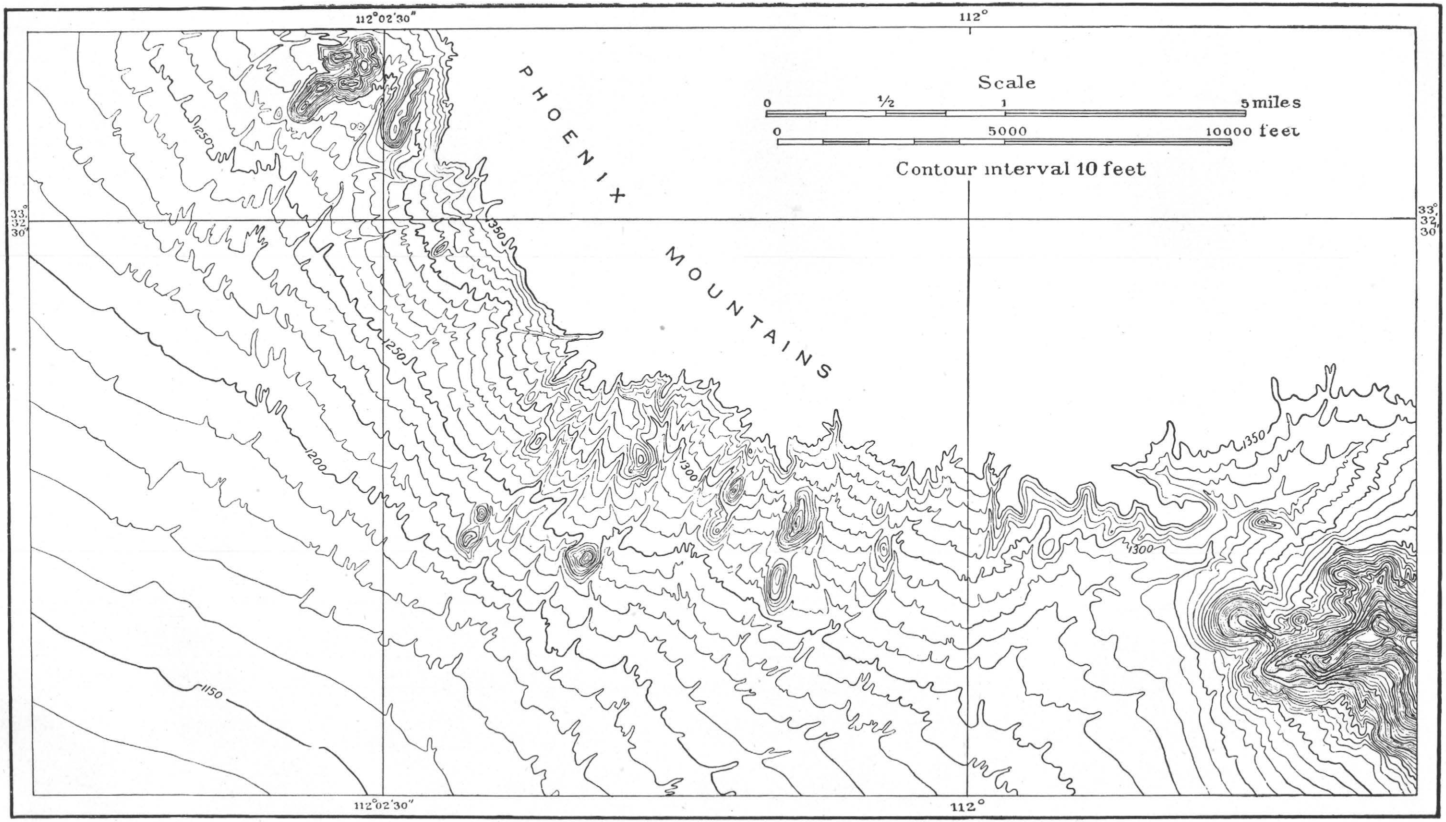
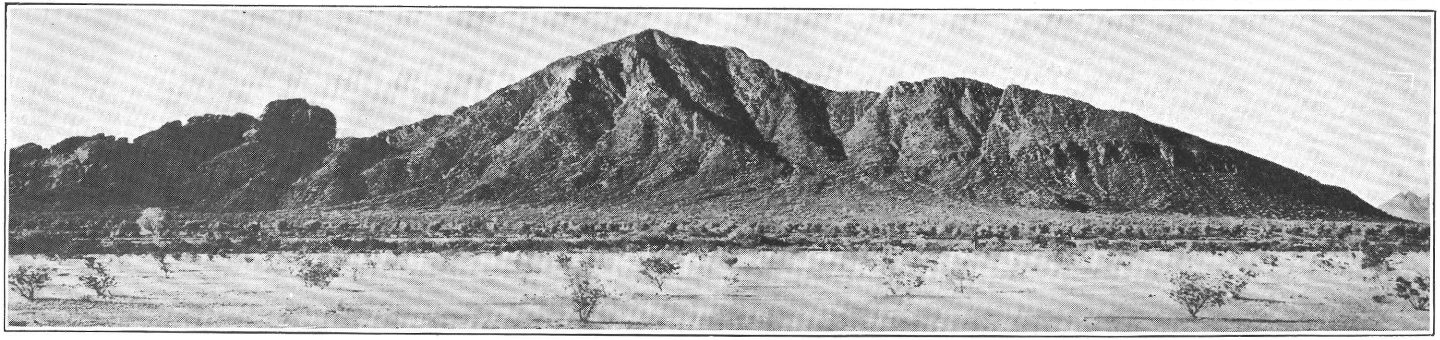


FIG. 18.—Sketch section illustrating the restricted area of water-bearing gravels due to underground structure. The older accumulation (stage B) was dissected (stage C) and the valley filled (stage D).

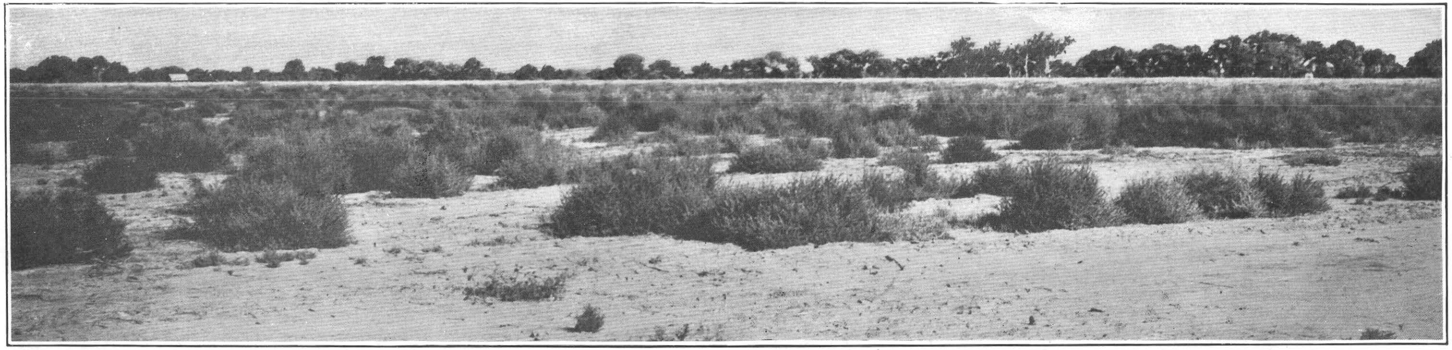
depression widened several miles. Later still this degraded area was partly filled. There is, then, an old valley filled with débris in which a younger valley was excavated, to be, in turn, itself filled with débris. It may be best explained, in this connection, why certain wells are productive while others in seemingly as good positions fail. If the old valley fill—the Mesa gravels—had become impervious by the deposit of silt or caliche, or from any other cause, and the present river gravels had remained unconsolidated, a water-bearing stratum of restricted distribution would occur, corresponding in extent to the recent gravels. If the recent gravels had filled the secondary valley and spread over the older accumulations, wells sunk in the strip covered by the recent gravels would be productive while wells outside of this strip would be unproductive. This is illustrated graphically in fig. 18.



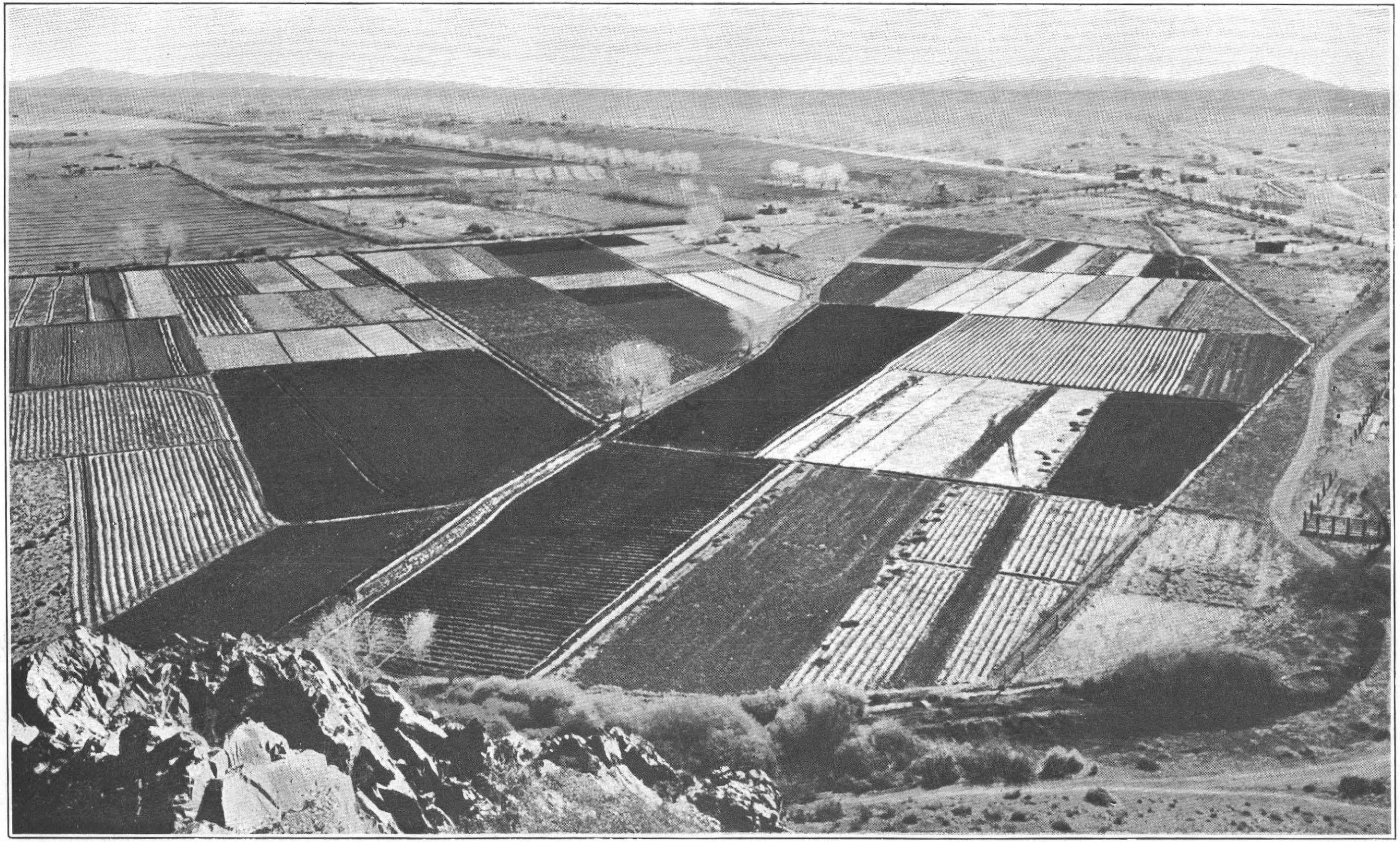
MAP OF BASE OF PHOENIX MOUNTAINS, SHOWING SMALL OUTLYING POINTS PARTLY SUBMERGED IN DÉBRIS.



A. CAMELBACK MOUNTAIN FROM NEAR POWER HOUSE ON ARIZONA CANAL. RISING ABRUPTLY FROM DETRITAL PLAIN.



B. SEEPAGE LAND NEAR TEMPE.



VIEW EASTWARD FROM TEMPE BUTTE.

The valley thus filled with débris may or may not correspond with the present course of the river. Changes in the river's course over an aggrading area are the rule rather than the exception. Old channels, therefore, which do not correspond with the present river's course are to be expected in the valley fill, and incidentally these old channels are likely to give the most productive wells. The old débris-filled channels may be narrow like the present channel of Salt River near the upper end of the valley, or may be miles in width according to circumstances.

In the accompanying sketch (fig. 18) the lined area represents the older gravels and the dotted area the younger. If both be pervious, wells will yield water whether put down in the ancient or the recent gravels. If, on the other hand, the older gravels be consolidated by the deposition of caliche or otherwise and thus made impervious to water, a well at *c* would yield water while a well at *d* would yield none. At *a* the well would strike water near the surface but would soon enter nonproductive material. Examples similar to these are familiar in the construction of wells throughout the valley.

WATER TABLE.

Mesa Township was selected as being the most favorable, all things considered, for testing the regularity of the water table and its relation to the land surface. Every well was measured and the data were tabulated and placed on the map. From these data the water table of Mesa Township has been constructed in contour, and appears on the map (Pl. XVIII).

Several special features are to be noted in connection with the water table. As indicated by the sections the line representing the water table and passing through the town at right angles to the river (CC) is horizontal and at the level of the water in the river. The lines representing the water table drawn parallel to the river (AA and BB) indicate a uniform slope downstream, but the gradient of the water table is lower than the gradient of the river, and the water table approaches the surface downstream as far as Tempe, where a break occurs which is described later. On the other hand going upstream the water table becomes progressively farther beneath the surface.

From this township as a center the investigation was pushed in every direction and from the data furnished by well records given in part in Chapter I the water table has been constructed in contour for the greater part of Salt River Valley (Pl. XX).

By an inspection of the tables and of the maps constructed from these tables it is seen that the surface of the underground water is a comparatively regular plain, sloping in general with the grade of the river, the rate of fall averaging about 10 feet per mile. The cross sections of Mesa Township (Pl. XVIII), where the wells are numerous, indicate that a line projected across the water surfaces in the wells in any direction is practically a straight line, and furthermore that the water level in any well is practically the level of the river bed at the point nearest that well. This is modified in certain cases near the river, which are described later. So regular is the surface of the underground water that the depth to water at any point of known elevation can usually be foreseen with considerable accuracy.

The water table as here described is not necessarily the same as the water-bearing stratum. For example, the water table at some particular point may be 30 feet beneath the surface. Water may or may not be found at that depth, but if found at a depth of 40 feet it will rise 10 feet in the well, and if found at 100 feet it will rise 70 feet in the well.

The shallow wells have an annual and a cyclic variation. During the dry summer season the water lowers more or less, and the shallower wells become dry. During seasons of more abundant rainfall the water level rises again. There are several facts connected with this annual variation which are worthy of note:

(1) The stage of lowest water is not coincident with the driest season, but is reached some time after the rains begin.

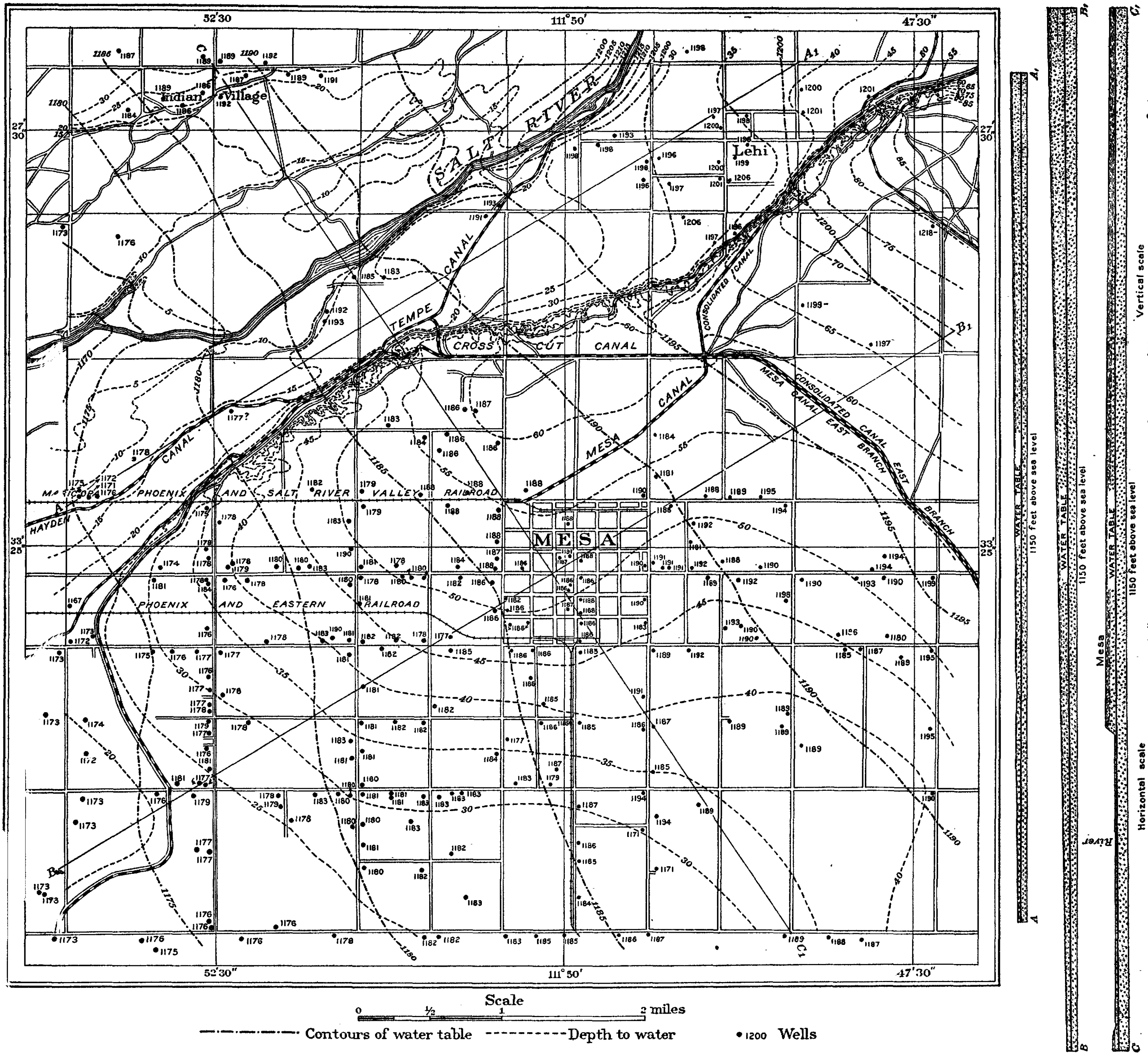
(2) The water in the wells seems to stand at its maximum height far into the dry season.

(3) The variations in water level can not be due to rainfall in the valley for the obvious reason that not enough rain falls to supply the quantity of water represented by the variations, even if it all joined the underground water.

As a matter of fact very little of the water falling as rain in the valley can enter the wells, except in certain localities where wells are obviously fed by surface water. The impervious layers of caliche common throughout the valley would prevent a great amount of surface water from joining the underflow, even if evaporation allowed an appreciable amount to remain permanently in the soil.

The only supply of water that is quantitatively adequate to explain the phenomena is that from the river and from the flood waters entering the valley from the surrounding hills. Waters move through sand and gravel very slowly, and a greater or less time, differing according to circumstances, must elapse after the floods enter the valley before their influence can be felt in the wells. Theoretically, there should be a retardation, or lagging of effect, and such is found to be the case in the variations of the water level.

The cyclic variations may be explained in the same way, but less accurate knowledge is obtainable than in the case of the annual variations. During the past few years the shallow wells throughout the valley have been lowered repeatedly. South of Tempe, where the



MAP AND SECTIONS OF MESA TOWNSHIP, SALT RIVER VALLEY, SHOWING POSITION OF WATER TABLE.

water level is said to have been formerly within 2 feet of the surface, it is now 8 feet. At Mesa it has lowered 12 feet in four years; at the Phoenix Indian School it has lowered 20 feet in ten years. This is commonly attributed to the drought which has prevailed during the past few years. It may be partly due also to the increasing number of wells in use. The quantity of ground water is not unlimited and the operation of a large number of pumps must in time affect the supply.

The deep wells which draw their water from the lower water horizons vary to some extent, but little is yet known of them. The water level in Mr. Olsen's well rose 2 feet in less than three months, February 1 to April 14, 1903. The water in Desert well has been rising for the past eight years—during the time when the shallower wells of the valley were being repeatedly lowered to obtain water. The deeper water-bearing beds naturally draw their supply from points farther out toward the borders of the valley and the waters may have a greater distance to travel through the valley fill than those of the surface flow. It is possible also that the zigzag course which the water may follow in the valley fill is a matter of much importance. If the ideal section given in fig. 3 represents actual conditions, water from the river would pass laterally six times partly across the valley before reaching the lowest gravels. At the rate of flow as described later on it might take many years for water to make such a journey. The waters of any particular flood may not reach the deep wells until several years after the flood occurs.

It is likely, however, that the water level in a particular well would be affected by a flood long before the waters of that flood actually arrived at the well. Much as a wave may travel faster than the water composing the wave, so there may be waves or pulsations in the underflow due to the entrance of flood waters. The smaller pulsations—the annual ones—might and probably do appear in the shallow wells. These smaller pulsations may become imperceptible where they travel far, and may merge into cyclic pulsations, which alone affect wells far from the source of supply—for example, the Desert well.

On account of these variations of the water table certain allowances must be made in applying the accompanying maps which indicate by contours the elevation of the water table and the depth of this table beneath the surface. At a certain point, for example, the depth to water was 20 feet when the map was constructed. At some future time the depth may be greater or less than 20 feet according as the volume of underground water may have increased or diminished.

THE RIVER AND THE UNDERFLOW.

The river is considered the most important source of the underflow. There is a permanent water supply in it from the head of the valley to the Tempe canal, north of Mesa. Below the head-gates of the Tempe canal a short space occurs in which the river is practically dry for the greater part of the year. Farther downstream underground water returns to the river bed; that is, the river cuts beneath the water table and the underflow returns in part, making a surface flow of something like 35 second-feet. It is evident, therefore, that from the head of the valley to the Tempe canal the surface flow of the river is at a higher level than the general surface of the underground water on either side. Wells sunk near the river indicate that the depression

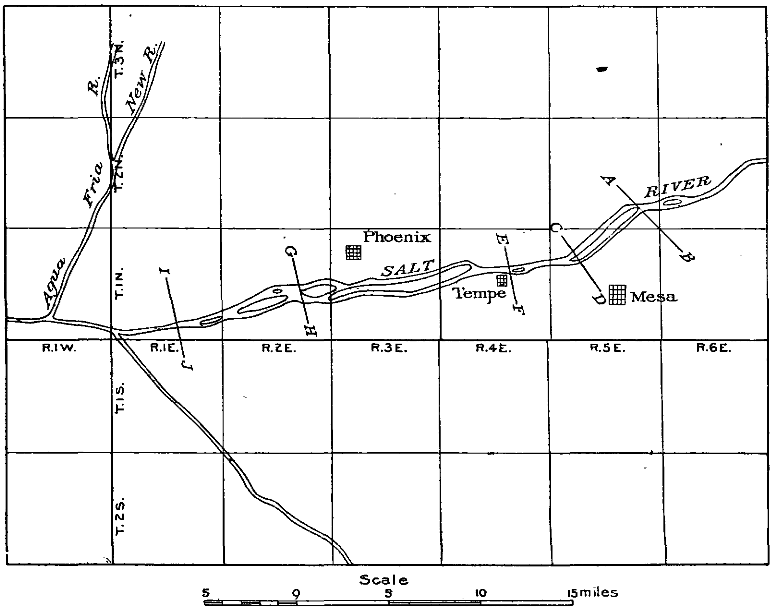
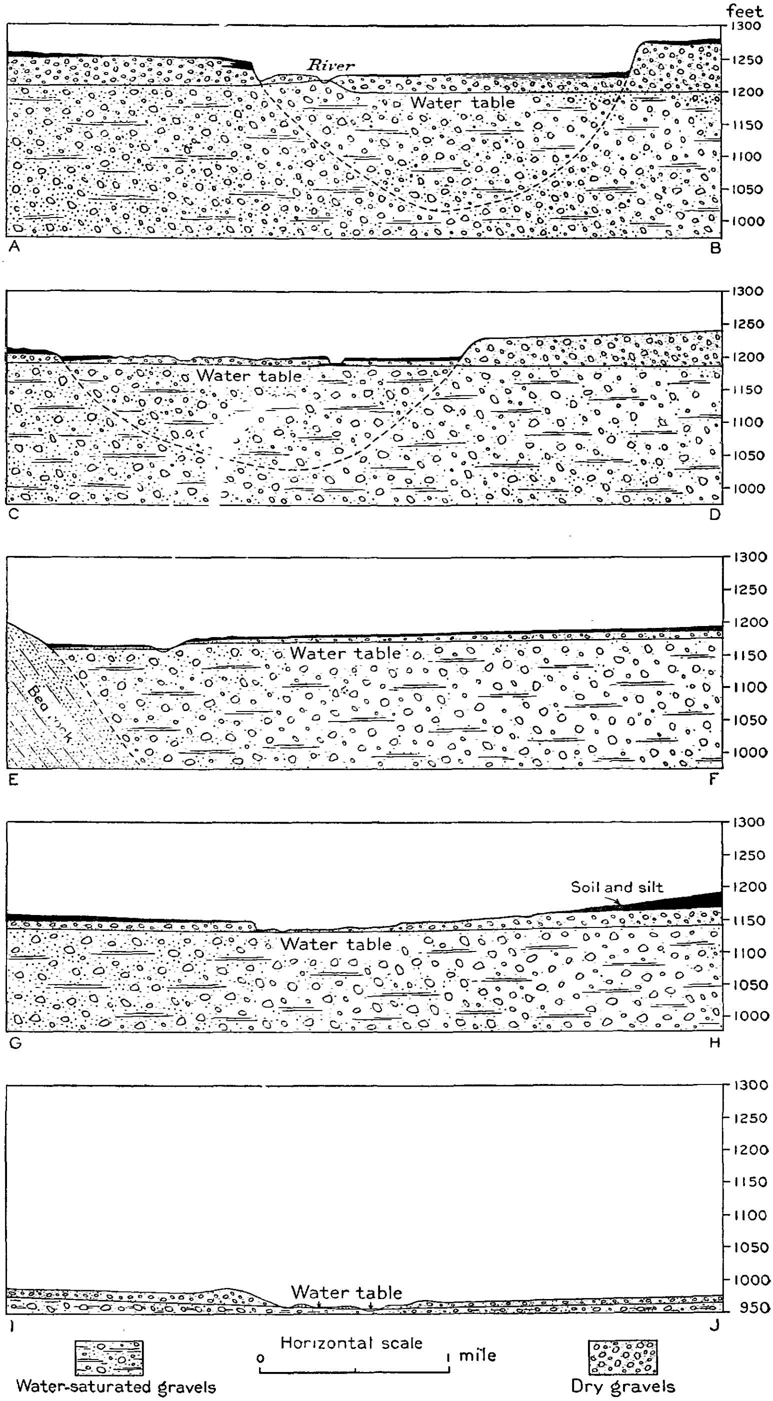


FIG. 19.—Index map of Salt River Valley, locating the sections shown in Pl. XIX.

of the water table from the river laterally is very abrupt. This is indicated by the contours of the water table as given on the map, Pl. XX, and in the sections of Pl. XIX. The fact that a permanent flow of water exists in the river at the upper end of the valley at an elevation higher than the surface of the underground water of the valley in general is of prime importance in understanding how the water enters the valley fill.

North of Mesa the river bed is at the same elevation as the water table, while at Tempe the river bed is below the water table. This explains the return of the underflow to the surface, making a perennial stream at Tempe, while the river bed both east and west of Tempe is dry. The reason for the approach of the water table to the surface near Tempe requires further explanation.



SECTIONS INDICATING RELATION OF WATER TABLE TO RIVER AND LAND SURFACES.

COURSES OF THE UNDERFLOW.

At Tempe the river flows practically on bed rock. The andesite and the red sandstones of the butte are exposed down to the water's edge. The river passes through a narrow channel between Tempe Butte and the conglomerate hills to the north. From Tempe northward to the Phoenix Mountains bed rock appears at the surface for the greater part of the distance. Where it is not exposed it is encountered in wells at no great depth. A glance at the contours of the water table of the township north of Tempe (T. 2 N., R. 4 E.) will reveal the fact that this table is 90 feet higher east of the buttes than it is about 2 miles farther west. There is then no free passage for the underflow north of Tempe except through the gravels in the immediate channel of the river.

Southwest of Tempe, Bell Butte rises from the level valley floor about midway between Tempe Butte and the Salt River Mountains. No deep wells have been drilled between Tempe and Bell Butte to indicate the underground conditions, the nearest being that of H. L. Chandler, one mile south of Tempe. This well indicates that loose gravels and bowlders extend to a depth of at least 186 feet. This would seem to indicate a free passage for the underflow between Tempe and Bell buttes. On the other hand, there is a sharp decline of the water table to the west in this region. North of Bell Butte a depression of the water table of 16 feet within half a mile was observed. South of Bell Butte a still sharper decline occurs, depressing the water table 10 feet in less than a quarter of a mile. The line along which this depression of the water table takes place is one passing from Tempe Butte through Bell Butte to Salt River Mountains.

As previously described in D. B. Heard's well, situated at the southwest corner of section 30, bowlders were encountered to a depth of 90 feet, beneath which granite wash occurs, probably from the mountains at the south. The wells at the Valley Seedless Grape Company's vineyard, 4 miles south of Tempe, and the two wells drilled in the same region by Mr. Heard indicate that the water-bearing bowlder bed hardly reaches that point. It is evident, all things considered, that the underflow so voluminous and extensive in the Mesa region does not find free passage to the Phoenix region past Tempe.

In explanation of this, there is a belief somewhat widespread in the valley that the passage is obstructed by a subterranean dam formed either by volcanic activity or by the formation of a cement reef across the valley. After what has been said of the formation of caliche, or cement, it seems evident that the continuous passage of the underflow would prevent any cement from forming across the valley which could in any sense act as a dam, and this postulate may be dismissed without further comment. The suggestion of a volcanic dam finds some confirmation in the presence of the andesite of Tempe and Bell buttes. As previously described, the uplift of Tempe Butte occurred in comparatively recent time, but whether the formations of the lava of Tempe and Bell buttes and the subsequent local movements occurred after the excavation of the valley or had anything to do with the obstruction of the underflow remains a matter of conjecture. In the mind of the writer, the phenomena about Tempe find most rational explanation in the change of the course of the river described below.

In order to place pumping plants where they will be most productive, it is a matter of prime importance to know the nature and course of

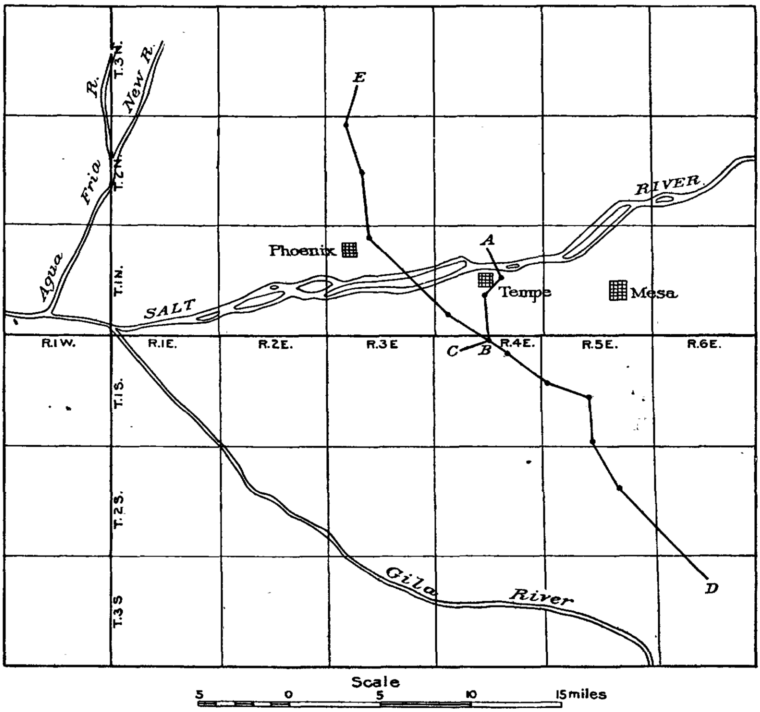


FIG. 20.—Index map of Salt River Valley, locating the sections shown in Pl. XXI.

the underflow. It is believed by some that the water is virtually stagnant and held in the gravels as water is held in a sponge: The "underground lake" is a familiar expression in the valley. A still more common expression is "the underground river." It is scarcely necessary, after what has been written, to explain that no underground lake and no underground river, taken in the popular sense, exist. There is, however, a slow movement of the underground water down the valley, which is designated as the underflow. Whether the underflow is as wide and as deep as the valley fill, or whether there are certain restrictions both laterally and vertically, directing the flow in certain courses, depends entirely upon the structure of the valley fill.

There is also to be considered the possibility that the ancient course of the river was not the same as the present course. Enough has been written to indicate that there are restrictions, and that the great volume of the underflow passes through a comparatively narrow space. The valley, filled as it has been both by wash from the hills and by sands and gravels brought down the river, would naturally yield abundant water only where the valley fill is sufficiently open to allow a free passage of water. The wash from the hills along the outer portions of the valley, while coarse enough to allow free passage of water in places, is very frequently cemented to a practically impervious mass. Some wells obtain a good supply from this wash, but there are many that have failed because they were in the wash. The most productive wells are in the beds of river gravel and bowlders.

ANCIENT RIVER CHANNELS.

Since it is always the river that is making the deposits of gravel and bowlders through which water passes most readily, it naturally follows that the bowlder beds mark the ancient courses of the river. It furthermore follows that the present course of the underflow is in general the course of the ancient river that deposited the gravels and bowlders in which the underflow occurs. It remains, then, to determine the old courses as accurately as possible in order to place the pumping plants in the most advantageous localities. At first thought this course should be in general down the valley, parallel to the river. But a little reflection indicates that this is not necessarily the case. As the floor of the valley was raised by the deposition of débris, the river shifted from side to side of the valley. When the level of the rising valley floor reached the saddle of some spur or divide the river might pass over this divide, leaving its former course at one side. This is probably what Salt River has done in comparatively recent times. On this point the following facts are to be noted:

(1) In the Mesa region water-bearing gravels occur to a depth of at least 620 feet (Murphy-McQueen well) and extend at least as far south as the Chandler well No. 5, 12 miles south of Mesa.

(2) It is in these gravels that some of the best producing wells of the valley are located.

(3) There is an obstruction of some kind, as previously described, preventing a free passage of the underflow downstream at Tempe. Such well records as are available indicate that the gravel-filled valley near Tempe may be comparatively shallow.

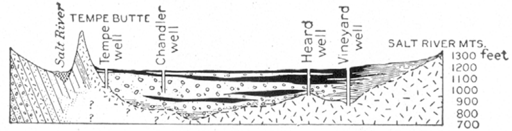
(4) Between Salt River Mountains and Sacaton Mountains is a broad and nearly level plain extending without interruption from the Mesa region to Gila River. It is an aggraded plain underlain by water-bearing gravels and connecting with the water-bearing gravels of the Gila, described in a previous paper by the writer.[a]

[a] Lee, W. T., Underground waters of Gila Valley, Arizona: Water-Sup. and Irr. Paper No. 104, U. S. Geol. Survey, 1904.

(5) At a point in Gila Valley where the waters passing as underflow through the gravels between the two groups of mountains just mentioned would naturally be expected to appear underground water returns to the surface in considerable quantity. At this point there is the somewhat novel phenomenon of a perpetual lake in the midst of a desert where evaporation is about ten times greater than the rainfall. This lake is not fed by Gila River, as is evident from the fact that the river is dry for a distance of about 50 miles above the lake during the greater part of the year. It is not fed from flood waters, since floods are seldom of sufficient volume to enter it. There is furthermore a constant and regular discharge of water from the lake. The only obvious source of supply is the underflow of Gila and Salt rivers.

An attempt has been made to show graphically the underground conditions across the valley at Tempe (Pl. XXI, *A*) and across the space between the Salt River Mountains and the Sacaton Mountains (Pl. XXI, *C*), so far as those conditions are known or can be reasonably inferred from the data at hand. It should be explained in this connection that these sections are so chosen as to pass through such deep wells as are known, thus making a section along a broken line. The depth of water-bearing gravels there indicated should not be interpreted as the depth of the passage open to the underflow. The crest of the subterranean ridge which is thought to exist is probably about a mile west of the line represented in section A, as indicated by the shallowness of the gravels at Heard's well and the sharp depression of the water table already described.

The evidence at hand leads clearly to the inference that in former ages Salt River joined the Gila east of the Salt River Mountains instead of occupying its present course north of those mountains. It has been argued with some degree of plausibility that the chemical character of the water throws doubt upon this hypothesis. The waters of the Salt River underflow as represented in the Olsen and Hansen wells, contain much greater quantities of salts than do the waters of the Gila underflow. It has been argued that waters so saline could not feed in any great measure an underflow such as that of Gila Valley. It should be noted, however, that the water from the Chandler wells farther to the east is less saline. For convenience of comparison there are placed, below, the analyses of four samples of the Gila underflow. (All water in this part of Gila Valley at ordinary times comes from the underflow.) In the same table are included the analyses of waters from the Salt River underflow, so selected as to give as wide a range as possible within the region which presumably feeds the Gila underflow. It appears from a comparison of these analyses that although the waters from the Hansen and Olsen wells are much more saline than the Gila underflow, those from the Chandler wells are



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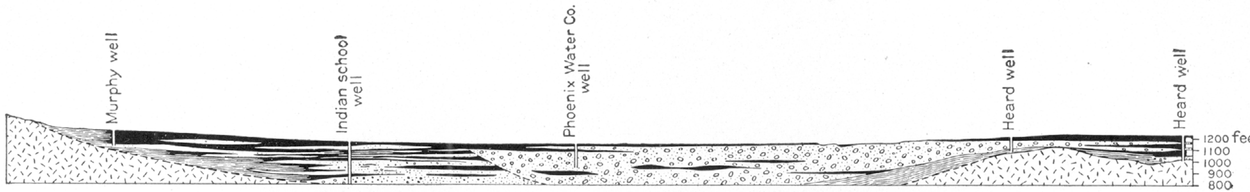

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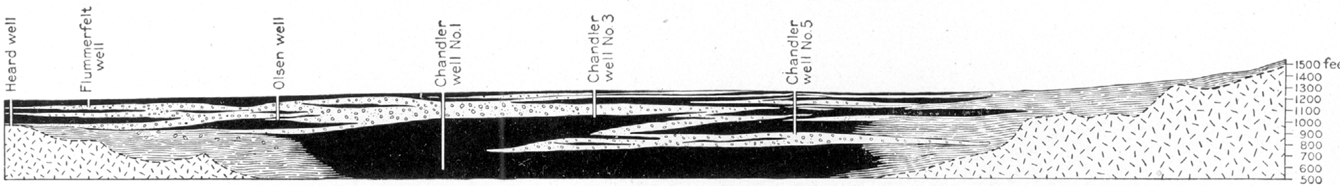

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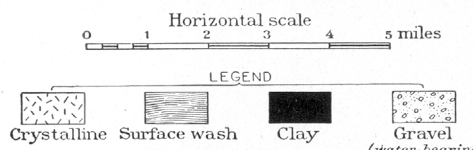


A. SECTION THROUGH TEMPE BUTTE TO SALT RIVER MOUNTAINS, ALONG THE BROKEN LINE A-B-C, FIG. 20.

B. SECTION ACROSS SALT RIVER VALLEY NEAR PHOENIX, LINE B-E, FIG. 20.

C. SECTION FROM SALT RIVER MOUNTAINS TO SACATON MOUNTAINS, LINE B-D, FIG. 20.

practically the same as the Gila underflow. It is entirely possible that the Chandler wells are in or near the course of freest flow where salts have either failed to find lodgment or if deposited in former times have been carried away by the comparatively free sweep of the waters, while the Olsen and Hansen wells may draw from water which, for some reason, is comparatively sluggish and therefore more saline, since the gravels in which it is held are not freely washed by a constant inflow of water.

Analysis of water from the underflow of Salt and Gila rivers, Arizona.

FROM GILA VALLEY.

	Lake in Gila Valley.	Cooperative Co.'s ditch, Gila Valley.	Gila River seepage.	Well at Presbyterian mission, Gila crossing.
Quantitative (parts in 100,000):				
Total solids soluble at 110° C	107.0	106.0	127.0	160.0
Chlorine in terms of NaCl (common salt)	61.2	62.8	76.4	110.8
Hardness in terms of $CaSO_4$ (sulphate of lime)	2.72	13.1	12.5	28.4
Alkalinity in terms of Na_2CO_3 (black alkali)	....	....	....	....
Nitrogen in the form of nitrates	....	....	....	....
Nitrogen in the form of nitrites	....	....	....	....
Qualitative:				
Sulphates	Very strong.	Strong.	Very strong.	Very strong.
Magnesia	Strong.	Strong.	Strong.	Strong.
Lime	Strong.	Strong.	Strong.	Strong.
Bicarbonates	Strong.	Strong.	Pronounced.	Strong.

FROM SALT RIVER VALLEY.

	Chandler well No. 1 (after 15 months' pumping).	Chandler well No. 1 (after 24 months' pumping).	Chandler well No. 3 (after thorough pumping).	Olsen well.	Hansen well (after several months of constant pumping).
Quantitative (parts in 100,000):					
Total solids soluble at 110° C	127.4	179.0	84.8	381.0	442.0
Chlorine in terms of NaCl (common salt)	75.6	116.8	44.6	235.2	311.0
Hardness in terms of $CaSO_4$ (sulphate of lime)	23.1	53.3	18.5	59.84	151.2
Alkalinity in terms of Na_2CO_3 (black alkali)	None.	None.	None.	None.	None.
Nitrogen in the form of nitrates	.07	Trace.	.266	2.0	Trace.
Nitrogen in the form of nitrites	Traces.	None.	Traces.	Faint.	.01
Qualitative:					
Sulphates	Strong.	Very strong.	Strong.	Very strong.	Very strong.
Magnesia	Distinct.	Strong.	Distinct.	Strong.	Strong.
Lime	Pronounced.	Strong.	Strong.	Very strong.	Very strong.
Bicarbonates	Strong.	Strong.	Very strong.	Very strong.	Distinct.

PRINCIPAL COURSES OF UNDERFLOW.

While it is not probable that the underflow in this region follows a channel that is in any sense well defined, there are without doubt courses along which the flow has a maximum velocity, and others along which it has a minimum velocity. It is entirely conceivable, also, that there are places where the water is virtually stagnant. The underflow may be compared with the water of a swamp. It is one body of water, but communications between various localities are not equally free as in the case of a lake. Nor is the flow conceived to be as nearly uniform as in the case of a river. The water finds its way through the gravels along paths of least resistance, sometimes straight and sometimes circuitous. It should not be inferred, therefore, from reference to the principal course of the underflow, that anything like a definite channel is meant.

From a consideration of all available data it seems clear that the ancient course of the river and the present course of a large part of the underflow are east of the Salt River Mountains. It is probable that at a comparatively late stage in the course of the accumulation of the valley fill the gradually rising floor of the valley reached the level of the saddle between the Salt River Mountains and the Phoenix Mountains and found a shorter and easier passage than the circuitous route around the former. As the valley floor was still farther raised by the deposition of débris, and as the river passed its aggrading and degrading stages previously described, its course may have changed repeatedly, sometimes north of the Salt River Mountains and sometimes east and south of them. While the débris accumulating along its course is deemed the chief cause of the lateral migrations of the river, certain changes may have been caused by volcanic action and local movements in the vicinity of Tempe, as previously suggested.

This postulate explains in a rational and natural way the peculiarities near Tempe already described. There is probably a subterranean dam across the present valley at Tempe, which prevents the passage of the principal part of the underflow. It is not a dam thrown across a previously existing valley, but one which was formerly a ridge at the side of the valley and which was buried by débris as the valley was filled. It is probable that only the waters from the upper horizons of the gravels of the Mesa region find their way over the top of this submerged ridge into the underflow of the Phoenix region.

SOURCES OF THE UNDERFLOW.

One of the most notable features about the valley fill in the Mesa region is the thick bowlder bed covered with impervious clay. It occurs in the center of the valley, while toward the sides the bowlders give place to the finer material. The water in the bowlder bed is under considerable pressure, while above the clay which confines it occur water bodies of limited extent, forming what is locally known as the surface flow. In certain places the surface flow is under slight pressure, while in others it is under no pressure, but the underflow and the surface flow form a single water body, as evidenced by the definite water table. The questions naturally arise: How are the waters connected? whence do they come? and how do they get into the ground?

There are several possible sources—(1) rainfall soaking into the ground; (2) underground water in the form of springs or artesian flow entering the valley from foreign regions; (3) streams and sheet washes entering the valley from the surrounding hills during times of abnormal precipitation.

(1) The rainfall is so slight—an average of little over 7 inches per year in the valley—that it could supply but a very small part of the underground water known to exist, even if it did not evaporate before entering the soil to any great depth. It is probable, however, that little if any of the water from rains in the valley finds its way to the underflow. At best it could only join the surface waters owing to impervious clay and cement layers separating these waters from those beneath.

(2) The hills surrounding the valley are composed principally of crystalline rock. There is no known possibility of water entering the valley in any form of artesian flow, and springs from the hillsides are so small that they may be disregarded.

(3) The only source which is quantitatively adequate to supply the known amount consists of the streams, chief among which is the Salt River system. There seems to be little doubt that the underflow is connected directly with the river.

In order to understand clearly how the waters enter the underflow it is necessary to know how the valley fill was deposited. In former ages Salt River Valley was a broad, deep valley of erosion, at least 1,305 feet deeper than it is at present. How much deeper, is impossible to say, for no well has penetrated beyond that depth. By some change in the altitude of the land or change of climate, perhaps both, the streams were changed from degrading to aggrading streams. The water could no longer carry all of its load. River débris accumulated as it is still accumulating. The coarser material was dropped in the channel, while the clay and silt accumulated on the floodplain, and cement formed near its surface. As the channel became choked with gravels and bowlders the stream shifted gradually, covering the clay and cement already deposited, while these materials in turn slowly accumulated over the gravels and bowlders of the abandoned stream courses. As the river swung from side to side of the valley, gravel and bowlder beds were always left in its wake; furthermore—and this is the key to the problem—wherever a bowlder bed was formed a bowlder train filling the old channel connected and probably still connects this bed with the mouth of Salt River Canyon, whence the water, together with its débris, issued then as it does now.

While Salt River was the main factor in the formation of the valley fill the tributary streams and sheet washes played some part. Each stream, no matter how small, left a train of gravel leading into the valley fill, and in a small way migrated from side to side, as did the river. Permanent streams, no matter how small, kept a constant connection with the river, and their ancient gravel trains probably still form comparatively free subterranean passages for water into the general underflow. But nowadays the small stream courses, even streams as large as Queen and Cave creeks, do not reach the river but are lost in the valley fill. Judging the past by the present, similar relations may have obtained then. Such streams as Queen and Cave creeks might form their valley trains from the hills into the main valley for a considerable distance, and perhaps form a considerable bed of loose material through which water would flow readily, but the connection with the bowlder beds of the main stream might be cut off by impervious beds of clay or cement. Such beds might form water pockets in the valley fill, and under certain conditions yield flowing wells. However, no water pockets have been found in Salt River Valley yielding flowing water.

At the present time, while the streams are depositing their débris in the bottoms of the valleys, the granitic hills about the valley are forming granitic sand which slowly works its way down to meet the advancing accumulation of the river fill. Judging the past by the present, the outer edge of the valley fill is composed largely of granitic sand or arkose. This material is more or less pervious, and the waters shed from the hillsides sometimes sink quickly into it. Since it is only on the old flood plains that impervious clay layers were formed, these layers, so potent in the middle of the valley, where they are penetrated by the wells, do not exist near the edges of the valley, where both clays and gravel beds pass laterally into the accumulations of arkose. Thus the water, whether from the river, or from a tributary stream, or from a sheet wash from the hillside, finds its way always downstream into and through the valley fill underneath the impervious layers or wherever the trains or sheets of gravel lead.

The gravel trains thus form a network through the valley fill, connecting the principal bowlder beds, and leading back in every case to the stream which formed them. It is evident, therefore, that the underflow, although seemingly divided by impervious layers, is one body of water, although the avenues of communication may be extremely tortuous and complicated. It thus results that the water of the underflow, whether from an upper or an under stratum, rises to a definite level which forms a comparatively uniform "water table," the gradient and local variations of the table being due to the varying resistance offered by the gravels to the passage of the water.

THE PHOENIX REGION.

The physical features of the Phoenix region differ in but few important respects from those of the Mesa region, and need be described only in so far as they differ in some essential manner. The principal part of this area consists of a broad plain, sloping gently southward to Salt River. Cave Creek enters the region from the north, and is lost upon the plain in a manner resembling that of Queen Creek in the Mesa region. At the western border of the region the Agua Fria and New River have definite channels extending over the plain to join the Gila.

DISTRIBUTION OF MATERIAL.

At the eastern border of the region granites, lavas, and the older sediments occur, as described in Chapter II. From Tempe westward to the Crosscut canal and thence northward and westward the valley fill abuts more or less abruptly against the older formations. The asylum well penetrates gravels to the depth of 110 feet without reaching bed rock, while 2 miles to the east bed rock appears at the surface. In the Murphy well, 325 feet deep, 115 feet of valley fill is penetrated, below which the breccia is encountered. Two miles to the east the breccia emerges from the surface to form the buttes north of Tempe.

In the southern portions of the region near the river the valley fill, as indicated by the well records, is composed mainly of river gravels and bowlders. It appears, from the occurrence of gravels in the Heard and McCallum wells, that the bowlder bed continues well southward toward the mountains. This southward extension is in harmony with the southward trend of the streams at the present time, as well as the southward trend of the ancient river, as indicated by the bowlder beds and the underflow of the Mesa region. While it is always unsafe to make predictions in matters so uncertain as underground conditions, the indications so far as known point to more favorable conditions for pumping south of Salt River than north of it.

A study of the well records in the light of what has already been said respecting surface oscillations, and the resulting stages of degradation and aggradation, leads to the belief that the bowlder bed underlying Phoenix is somewhat abruptly terminated at the north, as indicated in the section, Pl. XXI, *B*. The several wells in the vicinity of Phoenix enter bowlder beds differing in no essential manner from those in the Mesa region except that they are, so far as known, comparatively free from cement. Three miles north of the Phoenix waterworks, the Indian School wells penetrate no bowlder beds nor any material that could not rationally be attributed to the action of small streams from the north and to wash from the hills. At some point, therefore, in the 3 miles intervening between the Phoenix well and the Indian School there is a transition from the bowlder bed to comparatively fine material. This transition has been shown in the section as abrupt, since the bowlder bed is regarded as equivalent to the younger beds of the Mesa region, while the finer material corresponds in age to the older Mesa gravels. During the stage of degradation intervening between the two periods of accumulation it is thought that a broad valley was cut in the older deposits similar to that described in the Mesa region, and that during the later accumulation this valley was not only filled, but the bordering bluffs were buried by the younger accumulation.

North and west of Phoenix gravel beds are few, and sand, cement, and wash make up the principal part of the valley fill. While there are a great many drilled wells in this region, there are few for which definite records were kept. The meager data obtainable are noted in Chapter I. Several wells reach gravel beds, but the extent of such gravels is unknown. Since, with few exceptions, the wells are small, being intended only for domestic use, they do not penetrate through the gravel beds. A few wells, such as the Bartlett well, the Kellner well, and the Indian School wells, have been sunk deep enough to indicate that the bowlder beds of the southern part of the Phoenix region do not extend far to the north. No accurate record of either the Bartlett well or the Kellner well is obtainable. It is thought, however, that had bowlder beds been encountered, their presence would be known, if for no other reason, because drilling machinery such as was employed in constructing these wells has proved inadequate to go through bowlders such as are found in the southern part of the region. It is probable that gravel beds of considerable volume occur, but they seem to be more or less separated. If water pockets are to be found in Salt River Valley with water under pressure sufficient to produce flowing wells, it would appear from theoretical considerations that the northern part of the Phoenix region is the place where they might reasonably be expected; but while many shallow wells have been sunk in this region, no well has yet penetrated to a sufficient depth to test this possibility. The Bartlett well, 311 feet deep, is the deepest well put down, and, according to the best account to be obtained, water under considerable pressure was encountered.

GEOGRAPHIC CHANGES.

On account of the great importance of this subject to those who may consider the construction of wells for irrigation purposes, emphasis is put on it at the risk of repetition. During stage B (see fig. 14) a thickness of more than 1,300 feet of débris was deposited in the Mesa region, closing with the great bowlder beds. During the greater part of this time, and perhaps until the close of stage B, Salt River flowed east of Salt River Mountains. The Phoenix region in the meantime was without the controlling influences of Salt River. Its aggradation was due to wash from the hills and to the débris of comparatively small streams. The material thus brought into the valley was comparatively fine; some of the larger streams formed gravel beds, but no great accumulation of bowlders took place. During stage C Salt River was flowing in or near its present course north of Salt River Mountains, and was cutting away the deposits previously laid down, and at the same time was deepening a passage through the rock ridge near Tempe. This passage is narrow, as would naturally be expected, on account of the hardness of the rock.

During the second period of accumulation (D) the new channel, or secondary valley, was filled, as was the case in the Mesa region, and since this secondary valley in the Phoenix region was now the course of the river, it was filled principally with coarse material, and to an extent sufficient to bury the bluffs, obliterating from the surface all evidence of such a valley. The recent river accumulations of the Mesa region and the bowlder beds of the Phoenix region are regarded as equivalent and directly connected through the comparatively narrow passage at Tempe.

WATER TABLE.

From what has been written it appears that the water table of the Phoenix region assumes neither the definiteness nor the importance of the water table in the Mesa region, where there is free communication between the water-bearing formations. At certain points in the Phoenix region communication seems to be wanting, as is shown in the Indian School well; at other places communication is poor. The water supply in the northern part of the Phoenix region is comparatively limited, and yet there is an inclination of the water table in places of 20 feet or more to the mile. Such a gradient could scarcely be maintained unless the passages through which the water finds exit presented formidable obstructions.

EXTENT OF BOWLDER BEDS.

The northern boundary of the bowlder bed west of Phoenix is not known. The Harris well is 7 miles west of Phoenix and 5 miles north of the river; the ostrich-farm well is 9 miles west of Phoenix and 5 miles north of the river; and the Kellner well is 14 miles west of Phoenix. The bowlder bed of the southern part of the Phoenix region was not encountered in either of these wells. It is probable that the bowlder bed will not be found much, if any, north of the Salt River canal. Thence northward the chances of finding water sufficient for successful pumping plants grow progressively less, (1) because of the increasing depth to water; (2) because of the scarcity of water-bearing material; (3) because of the limited supply of water; and (4) because of the evident want of easy communication between the various beds of water-bearing material. So far as known the underground water throughout the Phoenix region is amply sufficient for domestic use. Certain wells would probably yield a moderate supply for irrigation for a time. It is evident, however, that a pumping plant to be permanently successful must be in such a position as to draw freely from the underflow of the river, the only permanent and adequate supply. Extensive pumping would soon exhaust the limited supply from the north. If my interpretation of the underground conditions, as indicated in the history of the valley fill and presented graphically in the section across the valley (Pl. XXI), be correct, it is probable that pumping on an extensive scale would not be permanently successful anywhere north of an east-west line passing 1 or 2 miles north of Phoenix.

South of this line, however, there is every indication that pumping plants could be successfully operated. The known volume of the bowlder bed near Phoenix indicates that a similar volume is to be expected downstream. The great productiveness of the pumping plants now in operation near Phoenix, described in Chapter I, indicates an abundant water supply wherever the bowlder bed is found. The readiness of movement evidenced by the large output, and the rapidity with which the water regains its normal level in the wells when the pumps stop, indicate conditions most favorable for profitable pumping. The return of the underflow to the surface a few miles west of Phoenix and thence westward, making a surface flow of considerable volume in the Buckeye region, indicates a volume of underflow which promises permanency of supply.

CHAPTER IV.

ECONOMICS.

It remains to inquire into the practical application of the information presented in the preceding chapters. The end in view is the determination of the quantity of underground water available for irrigation, its adaptability for use in irrigation, and the best means of obtaining it. To this end I shall consider the area in which the underflow occurs, the chemical character of the waters, the volume of the underflow, the cost of pumping, and the location of pumping stations.

AREA OF PROFITABLE PUMPING.

The utility of pumping plants is determined largely by two considerations: First, the lift; and, second, the freedom of movement of the

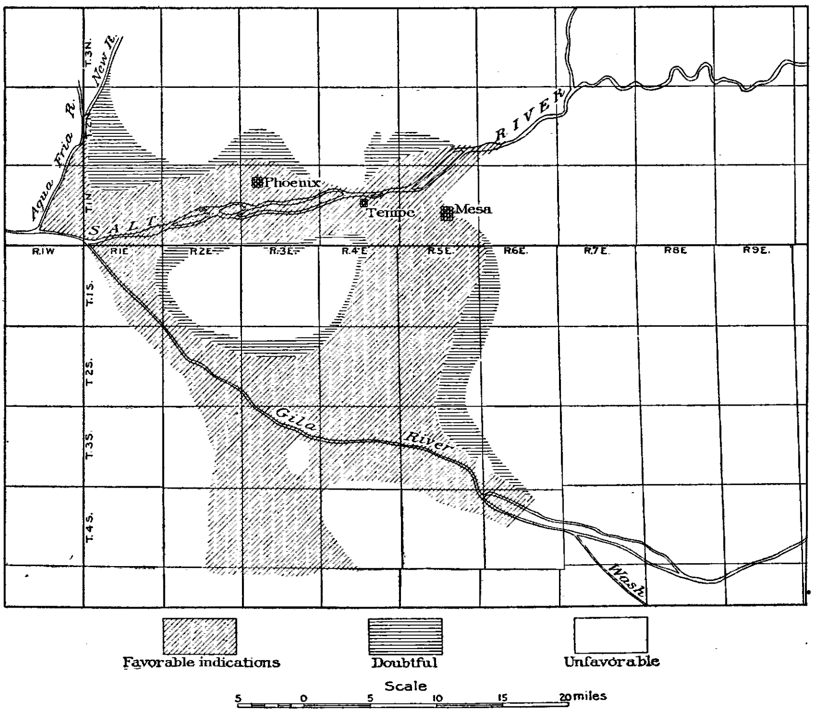


FIG. 21.—Map of Salt River Valley, showing area beneath which water is 50 feet or less below surface.

underground waters. The limit of lift, or total height to which the water may be profitably raised, can only be determined by the cost of pumping and the value of the water obtained. With certain crops water yields larger returns than with others. On the other hand, there are localities in the valley, as shown in the last chapter, where pumping plants can not secure water from the gravels rapidly enough to make their operation profitable. The underground conditions are so variable that the selection of sites for pumping plants must depend largely on experiment in each case. In fig. 21 is indicated the area where pumping plants would probably be profitable and the area where their success would be doubtful. The line of demarcation can not be accurately drawn at present and the map should not be interpreted in this regard too literally.

The delimitations dependent on the lift can be drawn with more accuracy. Assuming a lift of 65 feet as the maximum for economic pumping, and assuming 15 feet as the average local depression of the water table in the wells through the action of the pumps, it follows that the boundary of the area thus denoted is the contour indicating a depth of 50 feet to water. The contour maps now available do not cover the southern portion of the area indicated. The boundaries are taken from the contour maps as far south as the base line; south of that line the boundaries are approximately correct. The outline of the area in Gila Valley indicating an approximate depth of 50 feet to water is also appended. This outline is taken from a map included in a former paper by the writer on the underground waters of Gila Valley.[a]

CHEMICAL CHARACTER OF GROUND WATER.

The water analyses quoted in this paper were made for the most part at the chemical laboratory of the Arizona Experiment Station at Tucson, by Prof. R. H. Forbes and W. W. Skinner. In addition Mr. Thos. H. Means, formerly of the United States Department of Agriculture, has kindly furnished a table of analyses made by himself some years ago. In so far as the analyses apply to the waters of Salt River Valley they are gathered into the following tables, arranged according to the methods of analysis:

[a] Lee, W. T., Underground waters of Gila Valley, Arizona: Water-Sup. and Irr. Paper No. 104, U. S. Geol. Survey, 1904.

Chemical analyses of waters in or near Salt River Valley, Arizona.[a]

[Parts in 100,000.]

Number.	Owner.	Location.			Date.	Depth of well.	Total solids soluble at 110° C.	Chlorine, NaCl (common salt).	Hardness, $CaSO_4$ (sulphate of lime).	Alkalinity, Na_2CO_3 (black alkali).	Nitrogen in the form of nitrites.	Nitrogen in the form of nitrates.	Qualitative.		
		Township.	Range.	Section.									Sulphates.	Magnesia.	Lime.
						Feet.									
2815	Perry Williams, Maricopa				Mar. 19, 1902	35	1[illegible]0.0	50.0	24.48		Faint.	0.20	Very strong.	Very strong.	Strong.
2816	Railroad Co., 1$\frac{3}{4}$ miles west Maricopa				do		39.8	6.4	5.41		Very faint.	.104	Strong.	Strong.	Faint.
2082	Alhambra town well	2 N.	2 E.	26	Sept. 16, 1898	50	116.3	56.0		34.13		.05			
2083	A. H. Smith	2 N.	2 E.	21	do	95	130.5	40.0	Strong.		0.012	10.0			
2084	Frank Alkire	2 N.	2 E.	21	do	96	41.1	10.0	Strong.		.0004	1.5			
2085	—— Barkley	2 N.	2 E.	17	do	90	340.8	68.0	Strong.		.0084	16.0			
2086	—— Boyer				do	80	234.5	149.0	Strong.			.60			
2087	W. S. McClain	2 N.	2 E.	18	do	80	117.6	29.0	Strong.		.016	7.0			
2088	Town well, Glendale	2 N.	2 E.	5	do	90	79.2	39.0	Strong.		.0003				
2089	—— Bartlett	3 N.	2 E.	30	do	140	53.1	17.0	Strong.			.80			
2090	—— Mosher	2 N.	2 E.	9	do	70	346.4	112.0	Very strong.			1.0			
2091	G. B. Morgan	2 N.	1 E.	5	do	40	46.2	10.0	Strong.		.0028	.40			
2150	B. A. Fowler	3 N.	2 E.	33	June 30, 1899		80.9	13.2	36.5						
2619	W. J. Murphy				June 8, 1901		115.8	35.6	46.11				Very strong.	Very strong.	
2620	J. B. Doner				do		143.6	44.8	53.2				Very strong.	Very strong.	Very strong.
2621	H. B. Lehman	2 N.	2 E.	6	do		91.2	30.8	35.8				Strong.	Very strong.	Strong.
2622	A. J. Straw	3 N.	1 E.	25	do		188.6	81.0							
2623	A. W. Bennet				do		31.0	5.6		.32			Faint.	Faint.	Faint.
2624	E. E. Jack				do		57.9	9.6		4.35			Pronounced.	Faint.	Pronounced.
	MESA.														
1506	H. L. Chandler				Nov. 24, 1896		103.6	Very strong.					Strong.		
1515	A. J. Chandler				Feb. 1, 1897		166.6	Very strong.					Faint.		Faint.
1517	do				do		179.4	Very strong.					Strong.		Strong.

[a] Taken from tables in The Underground Waters of Arizona, by W. W. Skinner, Ariz. Agric. Exp. Sta. Bull. 46.

Chemical analyses of waters in or near Salt River Valley, Arizona—Continued.

Number.	Owner.	Location.			Date.	Depth of well.	Total solids soluble at 110° C.	Chlorine, NaCl (common salt).	Hardness, $CaSO_4$ (sulphate of lime).	Alkalinity, Na_2CO_3 (black alkali).	Nitrogen in the form of nitrites.	Nitrogen in the form of nitrates.	Qualitative.		
		Township.	Range.	Section.									Sulphates.	Magnesia.	Lime.
	MESA—Continued.					*Feet.*									
2615	Murphy-McQueen	1 N.	5 E.	34	May 17, 1901	1,305	133.2	82.0	11.15		0.0067	0.43	Very strong.	Very strong.	Very strong.
2724	A. J. Chandler	1 S.	5 E.	22	Aug. 27, 1901	150	174.2	110.7	47.02		Slight trace.	.07	Strong.	Very strong.	Strong.
2775	....do	1 S.	5 E.	22	Dec. 5, 1901		176.2	111.1	42.6		None.	.02	Very strong.	Very strong.	Very strong.
2804	....do	1 S.	5 E.	23	Jan. 28, 1902	54	103.2	48.8		7.63	.0094	.21	Strong.	Faint.	Faint.
2818	....do	1 S.	5 E.	22	Mar. 9, 1902	705	157.4	104.0	39.3		Very faint.	.12	Very strong.	Very strong.	Very strong.
2819	....do	1 S.	5 E.	22	....do	146	172.2	110.0	45.3		Very faint.	.12	Very strong.	Very strong.	Very strong.
2820	....do	1 S.	5 E.	22	....do	236	163.8	104.4	44.5		Very faint.	.12	Very strong.	Very strong.	Very strong.
2977	....do	1 S.	5 E.	22	Feb. 6, 1903	240	299.6	154.8	20.9		.0105	.29	Very strong.	Strong.	Strong.
2983	....do	1 S.	5 E.	34	Mar. 7, 1903	260	162.4	80.4	52.2		.0061	.27	Very strong.	Strong.	Very strong.
3157	....do	1 S.	5 E.	22	June 13, 1903	236	127.4	75.6	23.1		Faint.	.17	Strong.	Faint.	Pronounced.
3158	....do	1 S.	5 E.	34	....do		84.8	44.6	18.5		Faint.	.26	Strong.	Faint.	Strong.
3138	Desert well	1 S.	7 E.	11	May 14, 1903	212	32.0	5.2		4.66	Very faint.	.49	Faint.	Very faint.	Faint.
3141	E. Olsen	1 S.	5 E.	18	....do	212	381.0	235.2	59.8		Faint.	2.0	Very strong.	Strong.	Very strong.
3144	P. Mets	1 N.	5 E.	22	....do	56	167.8	108.0		9.33	Very faint.	.38	Strong.	Faint.	Strong.
3145	Alhambra Hotel	1 N.	5 E.	22	....do	51	152.0	89.6		5.51	Very faint.	.33	Strong.	Faint.	Strong.
3146	Dorman Bros.	1 N.	6 E.	33	....do	100	114.0	74.0					Strong.	Very faint.	Strong.
	PHOENIX.														
1819	Fowler Bros	1 N.	1 E.	1	Apr. 30, 1897		399.3	Very strong.					Very strong.	Strong.	Faint.
2017	Mrs. W. J. Murphy				Aug. 15, 1898		334.3	107.0			.05	10.0	34.3	3.64	10.5
2067	North Central Avenue				Sept. 15, 1898		117.7	66.5			None.	.20			
2068	School, Central Avenue	1 N.	3 E.	5	....do		216.1	150.0				.20			
2069	Indian School	2 N.	3 E.	20	....do	15	222.0	141.0		33.36	.0008	Faint.			
2070	....do	2 N.	3 E.	20	....do	60	362.3	258.0	Strong.		.0028	.30			

2981	do	2 N.	3 E.	20	Mar. 7, 1903	45	245.2	160.8	21.8		Faint.	.40	Very strong.	Very strong.	Very strong.
2982	do	2 N.	3 E.	20	do	145	250.0	145.6	65.8		.004	.25	Very strong.	Very strong.	Very strong.
2071	Ida E. Lawrence	2 N.	3 E.	20	Sept. 15, 1898	30	413.1	285.0	Strong.			.60			
2073	——— Cawthorn	2 N.	3 E.	29(?)	do	65	97.6	61.0	Strong.		.0006	.40			
2074	Orangewood	2 N.	3 E.	4(?)	do	105	44.9	16.0	Strong.		.0016	.80			
2075	J. A. Wieder	3 N.	3 E.	32	do	146	76.1	31.5	Strong.		.0078	.70			
2076	W. R. Beshier	2 N.	3 E.	20(?)	do	36	126.9	43.0		39.2		.10			
2077	——— Churchill	2 N.	3 E.	20(?)	do	92	284.6	103.0	Strong.		.0004	.80			
2078	do	2 N.	3 E.	20(?)	do	70	531.8	179.5	Strong.		.043	2.10			
2079	M. Morrison	2 N.	3 E.	32(?)	do	28	287.5	203.0	Strong.		.0002	.80			
2080	Wm. Christy	1 N.	2 E.	1	do	22	150.6	84.0	Strong.			.05			
2081	G. R. Brewster	2 N.	2 E.	36	do	35	122.5	44.5		33.63	.0004	.40			
2095	Phoenix city supply	1 N.	3 E.	4	Sept. 18, 1898	42	116.8	72.5	Strong.		.0007	.10			
2840	do	1 N.	3 E.	4	May 9, 1902	42	102.4	54.6	8.98		.0045	.16	Very strong.	Very strong.	Very strong.
3139	do	1 N.	3 E.	4	May 14, 1903	208	132.0	77.6	5.4		Very faint.	.25	Pronounced.	Pronounced.	Strong.
3140	do	1 N.	3 E.	4	do	42	136.0	80.8	6.5		.021	.25	Pronounced.	Pronounced.	Strong.
2143	G. R. Brewster	2 N.	2 E.	36(?)	June 30, 1899		103.4	36.5		34.87	.0006	.02			
2215	Dr. Duffield				Oct. 24, 1899		75.3	35.0		2.3			Strong.	None.	Faint.
2216	do				do		68.8	32.0		4.0					
1612	C. W. Perkins	2 N.	3 E.	23	May 10, 1901	155	83.6	30.8	8.3		.0871	.53	Very strong.	Strong.	Strong.
2625	W. J. Murphy				June 8, 1901		28.2	3.1		2.12			Faint.	Pronounced.	Faint.
2696	do				July 3, 1901		27.6	3.1		2.42	Faint.	.47	Very faint.	Faint.	Faint.
2774	B. Smith				Oct. 14, 1901	25	235.8	153.5	12.10		.0029	.31	Very strong.	Very strong.	Very strong.
2837	Thomas Murphy	2 N.	4 E.	30	Apr. 22, 1902	187	380.4	140.0	10.88		.40	2.33	Very strong.	Very strong.	Very strong.
2838	do	2 N.	4 E.	30	do	168	303.2	136.0	26.65		.80	2.70	Very strong.	Very strong.	Very strong.
2839	do	2 N.	4 E.	30	do	78	388.0	105.0		45.16	.0666	1.43	Very strong.	Very strong.	Very strong.
2842	do	2 N.	4 E.	30	May 9, 1902	325	325.8	123.4	32.1		.0073	.66	Very strong.	Very strong.	Very strong.
2845	J. Miller	2 N.	2 E.	33	May 27, 1902		239.0	89.8					Very strong.	Very strong.	Very strong.
2849	Asylum	1 N.	3 E.	2	June 12, 1902	42	120.4	79.2	8.2		Faint.	Faint.	Very strong.	Very strong.	Very strong.
2949	do	1 N.	3 E.	2	Oct. 31, 1902	90	126.4	78.8	13.6		Very faint.	Very faint.	Very strong.	Strong.	Strong
2960	Soap Springs, 50 miles north				Jan. 5, 1903		272.2	52.4		144.6			Strong.	Faint.	Faint.
2970	A. C. Bartlett	2 N.	3 E.	32	Jan. 2, 1903	60	164.0	102.8	6.8		Faint.	.66	Very strong.	Very strong.	Strong.
2342	J. J. Harris	1 N.	2 E.	6	May 14, 1903	103	268.0	185.0	34.8		Very faint.	2.0	Strong.	Strong.	Very strong.

Chemical analyses of waters in or near Salt River Valley, Arizona—Continued.

Number.	Owner.	Location.			Date.	Depth of well.	Total solids soluble at 110° C.	Chlorine, NaCl (common salt).	Hardness, $CaSO_4$ (sulphate of lime).	Alkalinity. Na_2CO_3 (black alkali).	Nitrogen in the form of nitrites.	Nitrogen in the form of nitrates.	Qualitative.		
		Township.	Range.	Section.									Sulphates.	Magnesia.	Lime.
	PHOENIX—Cont'd.					*Feet.*									
3143	H. Thompson	2 N.	3 E.	8	May 14, 1903	104	26.0	4.0	....	4.88	0.126	0.33	Faint.	Very faint.	Very faint.
3187	Mission (Presbyterian), Gila Crossing	......	......	......	Aug. 25, 1903	......	160.0	110.8	28.4	.0	....	....	Very strong.	Strong.	Strong.
3184	Lake near Gila Crossing	......	......	......	do	......	107.0	61.2	2.72	.0	....	....	Very strong.	Strong.	Strong.
3185	Cooperative ditch, Gila Crossing	......	......	......	do	......	106.0	62.8	13.1	.0	....	....	Strong.	Strong.	Strong.
3186	Gila River at Gila Crossing (seepage)	......	......	......	do	......	127.0	76.4	12.5	.0	....	....	Very strong.	Strong.	Strong.
3204	S. W. Nigh	2 N.	4 E.	36	Sept. 19, 1903	......	110.0	60.0	....	....	....	....	Pronounced.	Very faint.	Pronounced.
3203	N. J. Murphy	2 N.	4 E.	30	do	......	193.0	74.0	....	....	....	....	Very strong.	Very faint.	Very faint.
3202	——— Underhill	2 N.	4 E.	22	do	......	189.4	93.0	....	....	....	....	Very strong.	Pronounced.	Strong.
3201	——— Warner	2 N.	4 E.	8	do	120	52.0	17.0	....	....	....	....	Pronounced.	Very faint.	Pronounced.
	Geo. U. Collins	1 N.	2 E.	15	Aug. 25, 1903	29	150.0	94.8	17.40	.0	....	....	Strong.	Strong.	Strong.
	L. Kunz	1 N.	3 E.	18	do	24	223.0	146.8	53.7	.0	....	....	Very strong.	Strong.	Very strong.
	J. Heaton	1 N.	1 W.	15	do	45	28.0	5.2	1.09	.0	....	....	Pronounced.	Pronounced.	Pronounced.
2092	H. L. Underhill	2 N.	4 E.	22	Sept. 17, 1898	61	84.4	50.0	Strong.	....	....	.15	....	....	....
2093	Geo. Blont	2 N.	4 E.	26	do	40	159.4	90.0	....	....	....	.40	....	....	....
2795	Winfield Scott	2 N.	4 E.	23	Jan. 9, 1902	67	167.4	100.8	42.7	....	.001	.50	Very strong.	Very strong.	Very strong.
2796	Paradise Valley	......	......	......	do	......	25.6	5.72	1.6	....	.0049	.35	Faint.	Pronounced.	Pronounced.
2961	Winfield Scott	2 N.	4 E.	23	Dec. 5, 1902	60	171.4	91.2	21.22	....	....	....	Very strong.	Very strong.	Strong.
	TEMPE.														
1525	J. W. Johnson	1 N.	4 E.	27	Mar. 15, 1897	11	79.2	Strong.	....	....	....	....	Faint.	....	....
2110	Hough's creamery	1 N.	4 E.	28	Dec. 2, 1898	......	103.0	67.0	Strong.	....	....	....	....	....	....

2111	Hough's ranch				Dec. 2, 1898	8	188.5	109.0	Strong.		.0004	.30			
2113	J. W. Wolf	1 N.	4 E.	23	do	15	160.0	94.0	Strong.		.0012	.20			
2114	J. B. Mullen	1 N.	4 E.	35	do	13	287.6	192.0	Strong.		.0004	.25			
2115	W. T. Fowler				do	12	163.1	88.5		26.82	.0028	.30			
2116	Niels Peterson	1 N.	4 E.	29	do	20	221.8	141.5		24.91	.0004	.20			
2118	A. P. McKern	1 N.	3 E.	6	do		171.5	110.0	6.8		.0004	.05			
2303	Wolf & Jones				Mar. 28, 1900		128.8	80.8	12.0		.0006	.30			
2304	do				do		190.4	120.0	6.1			.25			
2339	Hotel Casa Loma	1 N.	4 E.	15	May 7, 1900		169.8	105.8	12.9		.0027	.18	Very strong.	Pronounced.	Very strong.
2748	Geo. Kinney				Oct. 17, 1901	40	202.6	130.5	8.16		None.	.25	Strong.	Very strong.	Strong.
2766	Normal School	1 N.	4 E.	22	Nov. 19, 1901	30	219.2	133.6	15.78		None.	.51	Very strong.	Very strong.	Very strong.
2966	A. R. Jenkins	1 N.	4 E.	19	Jan. 2, 1903	50	217.0	142.4		3.6	.004	.20	Very strong.	Strong.	Strong.
2967	do	1 N.	4 E.	19	do	50	223.0	171.2		3.4			Very strong.	Strong.	Strong.
2968	A. J. Hansen	1 S.	4 E.	35	do	156	509.0	355.0	60.9				Very strong.	Very strong.	Very strong.
2980	do	1 S.	4 E.	35	do	156	446.8	307.0	135.4		Faint.	Faint.	Very strong.	Very strong.	Very strong.
2969	H. L. Chandler	1 N.	4 E.	21	do	180	224.0	146.0		2.12			Very strong.	Very strong.	Strong.
2973	Tempe city supply				Jan. 8, 1903	200	103.0	58.8	9.52		None.	.17	Strong.	Strong.	Strong.
3118	Valley Seedless Grape Co	1 S.	4 E.	4	Mar. 19, 1903	200	115.2	78.6	11.4				Strong.	Pronounced.	Strong.
3119	do	1 S.	4 E.	4	do	300	155.8	105.4	21.8				Strong.	Pronounced.	Strong.
2226	Salt River				Nov. 17, 1899		134.5	81.8			.04	.10			
2251	A. R. Jenkins ditch	1 N.	4 E.	20	Dec. 26, 1899		189.4	136.0		8.4			Very strong.	Strong.	Very strong.
2252	do	1 N.	4 E.	20	do		216.4	142.9		7.7			Strong.	Strong.	Strong.
2285	Buckeye canal				Mar. 5, 1900		182.0	119.2	23.1		.0032	.126	Very strong.	Strong.	Very strong.
2286	Richardson ditch	1 N.	1 W.	(?)	do		30.0	6.0		1.17	.004	.16	Strong.	Strong.	Strong.
2340	do	1 N.	1 W.	(?)	May 21, 1900		33.4	7.4		1.3	Faint.	.148	Strong.	Strong.	Strong.
2287	Salt River seepage, Phoenix				Mar. 5, 1900		130.0	86.4		.32	.0064	.30	Strong.	Strong.	Very strong.
2288	Salt River at Tempe				Mar. 5, 1900		118.0	79.6	10.2		.008	.22	Strong.	Strong.	Very strong.
2289	Salt River at Arizona dam				do		102.2	68.4	.62			.20	Strong.	Strong.	Strong.
2293	Agua Fria underflow, Buckeye				Mar. 6, 1900		78.4	32.2	1.50		Faint.	.08			
2341	Buckeye canal				May 21, 1900		185.0	121.8	23.4		Faint.	.165	Very strong.	Very strong.	Very strong.
	Lewis Wetzler	1 N.	3 E.	11	Sept. 19, 1903	40	144.0	86.0	23.9	0.0			Pronounced.	Very faint.	Strong.

Chemical analyses of waters in or near Salt River Valley, Arizona—Continued.

Number.	Owner.	Location.			Date.	Depth of well.	Total solids soluble at 110° C.	Chlorine, NaCl (common salt).	Hardness, $CaSO_4$ (sulphate of lime).	Alkalinity, Na_2CO_3 (black alkali).	Nitrogen in the form of nitrites.	Nitrogen in the form of nitrates.	Qualitative.		
		Township.	Range.	Section.									Sulphates.	Magnesia.	Lime.
	TEMPE—Cont'd.					*Feet.*									
3154	C. T. Sharp, Sacaton.	......	......	......	May 20, 1903	30	132.6	66.8	29.4	......	0.031	0.083	Very strong.	Strong.	Very strong.
3156	Beet-sugar factory..	2 N.	2 E.	8	June 10, 1903	112	54.6	15.6	0.0	1.99	.08	1.24	Pronounced.	Faint.	Pronounced.
3236	Ostrich ranch	1 N.	1 E.	3	Feb. 16, 1904	170	130.0	76.0	8.2	0.00	....	....	Very strong.	Distinct.	Strong.
3230	Bartlett-Heard	1 N.	4 E.	30	Feb. 4, 1904	100	194.0	126.0	5.44	0.0	0.0	0.0	Strong.	Strong.	Strong.
3237	D. B. Heard	......	......	......	Feb. 16, 1904	......	185.0	111.6	13.6	0.0	....	....	Strong.	Strong.	Very strong.
3238	Bristol Flummerfelt	1 S.	4 E.	11	.....do	61	186.0	122.0	13.6	0.0	....	....	Strong.	Strong.	Very strong.
3239	Robert Bowen	2 S.	9 E.	(?)	.....do	212	54.0	24.0	16.3	0.0	....	....	Distinct.	Distinct.	Strong.

Analyses of waters from Salt River Valley.[a]

[Parts in 100,000.]

Owner of well.	Location.			Depth of well.	Total salts in solution.	Calcium sulphate.	Calcium and magnesium carbonates.	Chlorine reckoned as common salt.	Sodium carbonate.	Sodium nitrate.	Qualitative.
	Township.	Range.	Section.								
				Feet.							
Phoenix city supply	1 N.	3 E.	4	42	116.8	1.0	22.0	72.0	....	1.0	Magnesium sulphate.
A. P. McKern	1 N.	3 E.	6	......	171.46	1.3	32.65	110.0	....	.06	Magnesium chloride and sulphate.
——— Thomas	.....	......	......	30	117.65	1.35	14.60	66.5	....	.2	Do.
School building	1 N.	3 E.	5	......	216.10	5.60	23.05	150.0	Trace.	.2	Magnesium sulphate.
Indian School	2 N.	3 E.	20	15	222.0	....	26.65	141.0	33.36	.....	Sodium, magnesium, and potassium sulphates.
Do	2 N.	3 E.	20	60	362.25	29.95	27.45	258.0	....	.3	Calcium chloride, magnesium chloride and sulphate.
Well south of W. S. Lawrence s places.	.....	......	......	30	413.10	5.45	47.75	285.0	....	.6	Magnesium chloride and sulphate.
Well at middle one of W. S Lawrence's places.	.....	......	......	24	370.80	....	22.15	176.5	23.59	.3	Sodium and potassium sulphates.
——— Cawthorn	2 N.	3 E.	29(?)	65	97.60	1.60	11.35	61.0	....	.4	Sodium and magnesium sulphates.
——— Blaine	2 N.	3 E.	4(?)	105	44.90	1.85	5.35	16.0	....	.8	Magnesium sulphate.
J. A. Wieder	3 N.	3 E.	32	146	76.1	1.20	15.75	31.5	....	.7	Calcium chloride, magnesium chloride and sulphate.
——— Beshier	2 N.	3 E.	20(?)	36	126.90	.26	5.05	43.0	39.22	.1	Sodium and potassium sulphates.
——— Churchill	2 N.	3 E.	20(?)	92	284.60	7.15	21.10	103.0	....	.8	Magnesium sulphate.
M. Morrison	2 N.	3 E.	32(?)	28	287.50	19.30	16.65	203.0	....	.8	Calcium chloride, magnesium chloride and sulphate.
Col. Wm. Christy	1 N.	2 E.	1	22	150.60	2.65	20.45	84.0	....	.05	Magnesium sulphate.
G. R. Brewster	2 N.	2 E.	36	35	122.46	.21	10.60	44.5	33.63	.4	Sodium and potassium sulphates.
Blacksmith shop	2 N.	2 E.	26	50	116.30	.22	9.15	56.0	34.13	.05	Do.
A. H. Smith	2 N.	2 E.	21	95	130.50	6.8	11.65	40.0	....	10.0	Calcium chloride, magnesium chloride and sulphate.
Frank Alkire	2 N.	2 E.	21	96	41.10	2.2	8.7	10.0	....	1.5	Magnesium chloride and sulphate.
——— Barclay	2 N.	2 E.	17	90	340.80	56.90	12.25	68.0	....	16.0	Do.

[a] McClatchie, Alfred J., and Forbes, Robert H., Ariz. Agric. Exp. Station, Bull. 30, 1899.

Analyses of water from Salt River Valley—Continued.

Owner of well.	Location.			Depth of well.	Total salts in solution.	Calcium sulphate.	Calcium and magnesium carbonates.	Chlorine reckoned as common salt.	Sodium carbonate.	Sodium nitrate.	Qualitative.
	Township.	Range.	Section.								
				Feet.							
——— Boyer	2 N.	2 E.	18(?)	80	234.45	21.30	10.85	149.0	....	0.6	Calcium and magnesium chlorides.
W. S. McClain	2 N.	2 E.	18	80	117.55	1.2	11.75	29.0	....	7.0	Sodium and magnesium sulphates.
Glendale town well	2 N.	2 E.	5	90	79.2	2.8	20.0	39.0	....	......	Sodium sulphate, magnesium chloride and sulphate.
——— Bartlett	3 N.	2 E.	30	140	53.05	2.0	6.95	17.0	....	.8	Magnesium chloride and sulphate.
——— Mosher	2 N.	1 E.	9	70	346.40	111.50	13.85	112.0	....	1.0	Sodium and magnesium sulphates.
J. B. Morgan	2 N.	1 E.	5	40	46.20	1.45	15.75	10.0	....	.4	Do.
H. L. Underhill	2 N.	4 E.	22	61	84.4	1.55	12.80	50.0	....	.15	Magnesium chloride and sulphate.
George Blount	2 N.	4 E.	26	40	159.35	20.90	22.40	90.0	....	.4	Sodium and magnesium sulphates.
Arizona Falls canal water, taken Sept. 17, 1898.	......	......	......	......	93.30	1.0	13.60	61.5	....	......	Do.
Arizona Falls water taken Jan. 5 to Jan. 31, 1897.	......	......	......	......	46.4	....	16.3	17.0	....	......	
F. A. Hough	1 N.	4 E.	23	22	103.03	.9	16.35	67.0	....	......	Magnesium chloride and sulphate.
J. W. Woolf	1 N.	4 E.	23	15	159.96	1.90	32.90	94.0	....	.2	Magnesium sulphate.
J. B. Mullen	1 N.	4 E.	35	13	287.56	4.0	40.45	192.0	....	.25	Magnesium chloride and sulphate.
W. T. Trusler	1 N.	4 E.	27	12	163.10	.43	12.0	88.5	26.82	.3	Sodium and potassium sulphates.
Nels Peterson	1 N.	4 E.	29	20	221.80	.66	15.30	141.5	24.91	.2	Do.
Canaigre ranch, 6 miles southeast of Phoenix.	......	......	......	34	171.40	1.60	29.05	108.5	....	.2	Magnesium chloride and sulphate.

Analyses of waters in Salt River Valley by electrical method.

[Data furnished by Thos. H. Means.]

Source of sample.	Location.	Depth to water.	Parts of Na_2CO_3 in 100,000.	Parts of solids in 100,000.
		Feet.		
Tempe ditch	1 mile south of Tempe			105
Jenkins ditch	3/8 mile east of Bell Butte			209
Do	do		5.8	195
Do	do			211
Well	Sec. 33, T. 1 N., R. 4 E., just below canal			258
Canal	do			115
Well	Sec. 3, T. 1 S., R. 4 E., 1/4 mile south of date orchard			251
Do	Sec. 27, T. 1 S., R. 4 E., Harmon's place	5	10.5	160
Do	Sec. 19, T. 1 N., R. 4 E., Reed's place	16		265
Do	Sec. 27, NE. 1/4 NE. 1/4, T. 1 N., R. 4 E., Rice place	9		209
Do	Sec. 35, SE. 1/4 SW 1/4, T. 1 S., R. 4 E	(a)		167
Canal	do			111
Well	Sec. 24, SE. 1/4 SW. 1/4, T. 1 N., R. 5 E	11		179
Do	Sec. 19, NE. 1/4 SE. 1/4, T. 1 N., R. 5 E	30		161
Do	Sec. 2, NW. corner, T. 1 S., R. 5 E	15		213
Canal	Sec. 36, T. 1 N., R. 5 E., Consolidated canal			99
Well	Sec. 12, NE. corner, T. 1 S., R. 5 E	50		436
Do	Pumping plant below Highland canal, east of Mesa	60		92
Springs	Sec. 13, T. 1 N., R. 4 E., springs along Salt River seeping from gravel.			167
Salt River	Sec. 13, T. 1 N., R. 4 E			152
Do	At Tempe Bridge			123
Well	Sec. 13, NE. 1/4 NW. 1/4, T. 1 N., R. 4 E	12		189
Salt River	Above intake of Tempe canal			113
Well	Sec. 9, SW. 1/4 SW. 1/4, T. 1 N., R. 4 E	13		158
Ditch	Sec. 23, T. 1 N., R. 3 E., south side			150
Salt River	Southwest of Phoenix			135
Well	Sec. 6, SW. corner, T. 1 S., R. 6 E	40		184
Do	Sec. 9, SW. 1/4 SW. 1/4, T. 1 N., R. 3 E., brickyard	12		179
Salt River	Sec. 19, SW. corner, T. 1 N., R. 2 E			131
Canal	St. Johns canal, meridian line			144
Well	Sec. 9, T. 1 N., R. 3 E., south of S. P. depot			177
Do	T. 1 N., R. 1 E			305
Do	Sec. 13, NW. 1/4 SW. 1/4, T. 1 N., R. 1 E			277
Draw	Emptying into Gila River 2 miles above Agua Fria			258
Gila River	At initial monument			169
Canal	St. Johns canal			159
Well	3/4 mile north of initial monument			213
Gila River	1/4 mile west of initial monument			158

[a] Rises to surface.

ORIGIN OF SALTS.

SALTS IN WELL WATER.

An inspection of the chemical analyses of well waters and a comparison of them with analyses of the river water given below reveals a remarkable similarity in the salt content. Since the débris contributed by Salt River is the principal source of the valley fill, we naturally look to Salt River as the source of the salts found in the sediment. The accompanying table by Professor Forbes[a] indicates the character

[a] Forbes, R. H., The river irrigating waters of Arizona: University of Arizona Agric. Exp. Sta. Bull. No. 44, 1902, p. 174.

of Salt River water. The salts of the valley fill are regarded as concentrations by evaporation from the river waters. A study of the conditions as they exist in and near the river bed at the present time throws some light upon the manner of concentration.

Composition of the waters of Salt River.

[Samples taken at the Consolidated Canal Company's office, Mesa, Ariz., representing the Arizona Canal dam supply.]

PARTIAL ANALYSES.

	High and low summer waters (average of 4 weekly composites of samples taken daily, Aug. 1–Sept. 1, 1899).	Summer flood water (one weekly composite of daily samples taken Sept. 2–9, 1899).	High and low summer waters (average of 4 weekly composites of daily samples taken Sept. 10–Oct. 9, 1899).	Winter flood water (one composite of daily samples taken Oct. 10–17, 1899).	Low winter water (average of 10 weekly composites of daily samples taken Oct. 18–Dec. 30, 1899).	Low winter water (average of 13 weekly composites of daily samples taken Feb. 17–May 30, 1900).	Very low summer water (average of 8 weekly composites of daily samples taken June 1–Aug. 4, 1900).
Silt, per cent by weight	0.32	0.95	0.096	0.714	0.025	0.024	0.026
Soluble solids, parts in 100,000	72.40	110.00	114.20	95.10	102.64	106.90	139.15
Containing chlorine stated as common salt, NaCl	46.2	52.1	72.9	61.9	67.6	72.2	98.1
Containing alkalinity stated as sodium carbonate, Na_2CO_3	....	1.80	....	....	....	....	....
Containing permanent hardness stated as calcium sulphate, $CaSO_4$	1.59	....	2.79	2.45	2.12	5.43	13.70
Nitrogen, parts in 1,000,000:							
Total nitrogen in silt and water	6.94	26.7	4.36	12.19	1.96	1.48	1.30
Nitrogen in nitrates	1.32	1.2	1.90	1.52	1.21	.67	.78
Nitrogen in nitrites	Traces nearly always.						

COMPLETE ANALYSES OF SOLUBLE SALTS, STATED BY IONS.

[Parts in 100,000 of water.]

Sodium, Na	12.2	18.3	27.45	....	30.99	32.7	40.73
Potassium, K	1.29	1.41	1.09	....	1.53	1.23	1.12
Calcium, Ca	6.79	10.2	7.24	....	4.02	4.37	6.51
Magnesium, Mg	1.74	2.33	2.79	....	2.84	2.92	3.28
Chlorine, Cl	27.99	31.57	44.11	....	40.96	43.75	59.44
Sulphuric, SO_4	9.79	4.81	7.27	....	7.48	7.64	9.19
Carbonic, CO_3	....	15.45	8.02	....	11.71	11.51	13.15
Silicic, SiO_3	2.06	1.11	5.83	....	4.65	5.29	3.55

COMPLETE ANALYSES OF SOLUBLE SALTS CALCULATED TO COMPOUNDS.

[Parts in 100,000 of water.]

Sodium silicate, Na_2SiO_3	3.31	1.79	9.35	....	7.46	8.50	5.69
Sodium chloride, NaCl	27.84	42.80	60.84	....	67.54	72.16	98.04
Sodium sulphate, Na_2SO_4	....	....	....	....	4.97	3.46	.07
Sodium carbonate, Na_2CO_3	....	1.80	....	....	....	....	....
Potassium chloride, KCl	2.45	2.69	2.07	....	....	....	....
Potassium sulphate, K_2SO_4	....	....	....	....	3.40	2.74	2.50
Magnesium chloride, $MgCl_2$	6.88	5.81	8.34	....	....	....	....
Magnesium carbonate, $MgCO_3$	....	3.03	2.37	....	9.93	10.21	11.49
Calcium chloride, $CaCl_2$	7.50	....	....	....	....	....	....
Calcium sulphate, $CaSO_4$	13.87	6.82	10.30	....	3.18	5.37	11.00
Calcium carbonate, $CaCO_3$	....	20.48	10.53	....	7.71	7.00	8.20

In certain localities along the river the surface of the underground water is so near the land surface that evaporation takes place readily. Water from the river directly or from the underflow is continually finding its way into these localities, bearing its burden of soluble salts, and escaping from the surface by evaporation, leaving its load of salts behind. Localities which have been thus affected are found near Tempe (Pl. XXIII, *A*) and in many places in Gila Valley. Floods may remove these deposits of salt or may bury them, according to circumstances. At the present time both results are being accomplished. The constant shifting of the river channel causes a corresponding shifting of degradational and aggradational localities. Where the aggradational processes predominate, a notable amount of the accumulated salts are necessarily buried.

SALTS IN RIVER WATER.

The origin of the salts contained in the river water presents a different problem. It has recently been demonstrated by M. O. Leighton and his assistant, Sheldon Baker,[a] of the United States Geological Survey, that the common salt so abundant in Salt River is probably due to large salt springs. Several springs were found along the upper reaches of Salt River whose water is described as a weak brine. The water is also strong in carbonates, as evidenced by large travertine deposits at the point of issuance. Iron is also abundant in the water and is deposited near the springs as red oxide. The carbonates contained in the waters are probably due in part to the limestones drained by Salt River and its tributaries and in part to the decomposition of the granitic rocks in its basin. The sodium carbonate, or "black alkali," seems to be due to the decomposition of the igneous rocks. It will be noted that the river water is ordinarily lacking in black alkali, but that it is contained occasionally in flood waters. It is the belief that this is due to the fall of rain upon some alkali-charged slope or mesa which is seldom visited by rains in sufficient quantity to carry away the soluble salts. Specific examples are given by Professor Forbes[b] as follows:

> For the period from September 2 to 17, during which a flood occurred, the salts were greater than in the low water preceding and following. The alkali in this water was also distinctly black in character. These circumstances indicate that this flood, which was due to heavy rainfall on the lower half of the Verde River, washed large surface accumulations of salts from a black-alkaline district into the drainage. To a less degree the same holds true of the small flood from August 16 to 22. In most instances, however, during flood time the soluble salts more or less abruptly decrease oppositely to increasing sediments. Mountain rainfall such as was that of August and October, 1899, and May, 1900, is evidently responsible for this freshening of the water. Mountain rainfall in southern Arizona is more abundant than upon the level, lower deserts. The higher watersheds, being better drained, afford

[a] Personal communication.

[b] Forbes, R. H., op. cit, p. 165.

fresher water. The less frequent, though often copious, floods which sweep the lower levels carry much accumulated soluble salt into the drainage, which is often thus rendered strongly saline.

EFFECT OF SALTS ON VEGETATION.

EFFECT IN ARIZONA.

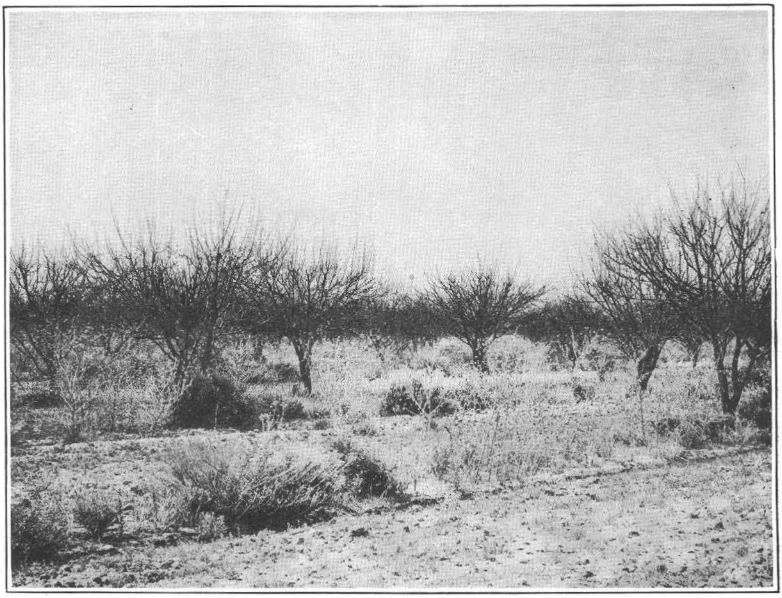
There is a widespread opinion among water users of Salt River Valley that the waters of the underflow are injurious to vegetation. The evidence on this question is conflicting. It is probable that too little is known of determining conditions in Salt River Valley to draw any general conclusion at the present time. The character of the soil, the manner of manipulation, and the kind of crop should be considered as well as the character of the water. Professor Forbes[a] has studied this question and concludes that waters containing more than 100 parts of soluble salts in 100,000 parts of water "are liable in a few years to cause harmful accumulations of alkali."

On the other hand there are many instances of land irrigated with pumped water alone where no detrimental effects can be detected. The Collins well has supplied land entirely with irrigation water containing 150 parts of soluble salts in 100,000 parts of water, for several years, with no detrimental effect that can be detected. Doctor Kunz's garden has had no water for five years other than well water containing 223 parts of salts. The court-house yard in Phoenix has been irrigated for about twenty years with well water alone, containing from 102 to 136 parts of salts. The Indians at the western end of the Pima Reservation have used the seepage water from Salt River, containing about 200 parts of salts, for many years. Land upon which this water has been used continuously at least since the Indians came under the supervision of the white men, about thirty years ago, is at the present time the most productive land on the reservation.

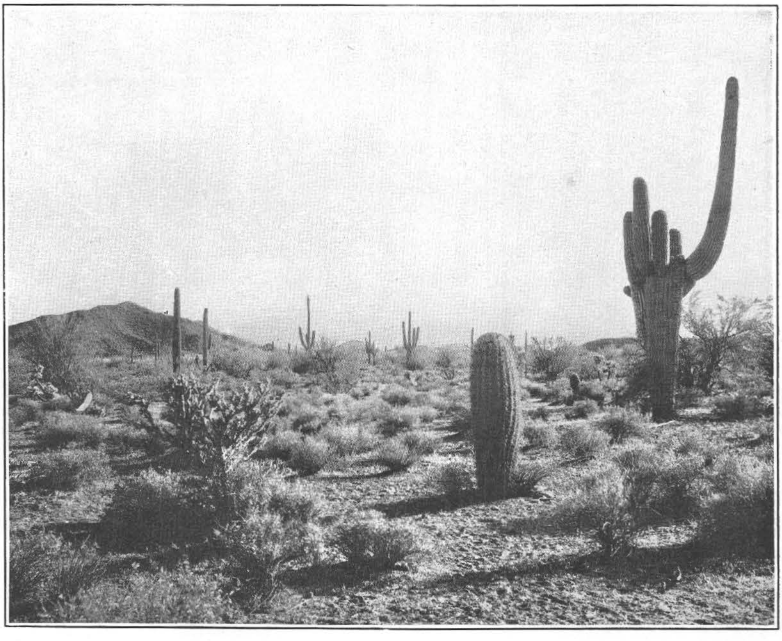
The sodium carbonate (black alkali) is the salt most feared by those who object to the use of pumped water. It will be noted from an inspection of the tables that no sodium carbonate is found in the underflow from which the great proportion of the pumped water is to be secured. The sodium carbonate is found only in the comparatively unimportant surface waters in the Mesa region and in the Phoenix region and is north of the area in which irrigation waters can probably be pumped with profit. It is evident, therefore, that the quantity of this salt which would probably find its way into waters pumped for irrigation is too small to be seriously considered.

The effects of accumulation of salts in the soil is plainly marked in certain parts of the valley. A considerable part of the land south of Tempe is barren in places and covered with white incrustations of salt

[a] Forbes, R. H., op. cit., p. 166.



A. AN ORCHARD NEAR PHOENIX KILLED BY LACK OF WATER.



B. DESERT NEAR TEMPE, SHOWING TYPICAL DESERT VEGETATION.

(Pl. XXIII, A). Some of this land has been under cultivation, and has been abandoned on account of the accumulations of alkali. It is in this region that the Bureau of Soils has leased a tract of land for the purpose of demonstrating the methods of reclaiming alkali land.

EFFECT IN EGYPT.

Waters much more saline than those of Salt River Valley may be used for irrigation if used properly, as is shown by the following extract from a circular by Mr. Means:[a]

During the summer of 1902 a representative of the Bureau of Soils visited the oases of the Oued Rihr country in the Desert of Sahara in eastern Algeria. In these oases artesian waters carrying very large quantities of soluble matter are used successfully for irrigation. From the information gathered there, and from experience in this country, it seems that the amount of soluble matter allowable in an irrigation water has been greatly underestimated by American writers, and that many sources of water which have been condemned can be used with safety and success, provided the proper precautions are taken to prevent the accumulation of the salts. As the precautions are those which should be taken by every irrigator, even if pure water is used, it seems an important matter to bring before the American people the methods in use in the Sahara.

The staple crop grown by the Arabs in the oasis country is the date, the fruit of a palm tree known to be one of the plants most resistant to alkaline or saline conditions of the soil, but in addition to this considerable quantities of the deciduous fruits, garden vegetables, and alfalfa are produced for home consumption.

Some of the vegetables successfully grown are those considered sensitive to alkali, and yet they were being irrigated with water containing in some instances as much as 800 parts of soluble salts to 100,000 parts of water, sometimes as high as 50 per cent of the salts being sodium chloride.

The limit of concentration for irrigation water in the United States, even where only the most resistant field crops are to be grown, has been placed by some authorities at 30 parts sodium chloride (common salt) or sodium carbonate (black alkali), and at from 170 to 300 parts of the less harmful salts, per 100,000 of water.

* * * * * * *

The fact that the Arabs in Algerian oases are actually growing sensitive plants by the aid of irrigation waters containing from 400 to 800 parts of soluble salts, in some instances 50 per cent sodium chloride, shows that the Bureau has been on the conservative side in its estimates and should encourage a more hopeful feeling among the people occupying areas where only alkali water is available for irrigation.

The prerequisite to the use of water of high salt content in irrigation is the knowledge that the methods employed are opposed to the teachings of most American writers on the subject. Those who place the low limit of safety for alkaline irrigation waters have taught that where water was badly alkaline irrigation should be sparing. They have not insisted on thorough drainage, and they have warned irrigators against too frequent irrigation. With such practices the limit of concentration which they set is probably high enough, and even then all except the most sandy soils or those with exceptionally good natural drainage would ultimately be damaged.

The methods in the oases are quite different. The Arab gardens are divided into small plats, about 200 feet square, between which run drainage ditches dug to a depth of about 3 feet. The soils being very light and sandy, this ditching at short intervals

[a] Means, T. H., The use of alkaline and saline waters for irrigation: Bur. Soils Circular No. 10, U. S. Dept. Agric., 1903.

insures the most rapid and thorough drainage. Irrigation is by the check method, and application is made at least once a week, though often two wettings a week are deemed necessary. A large quantity of water is used at each irrigation. Thus a continuous movement of the water downward is maintained, and there is little opportunity for the soil water to become more concentrated than the water as applied, and the interval between irrigations being so short but little accumulation of salt from evaporation at the surface takes place. What concentration or accumulation does occur is quickly corrected by the succeeding irrigation.

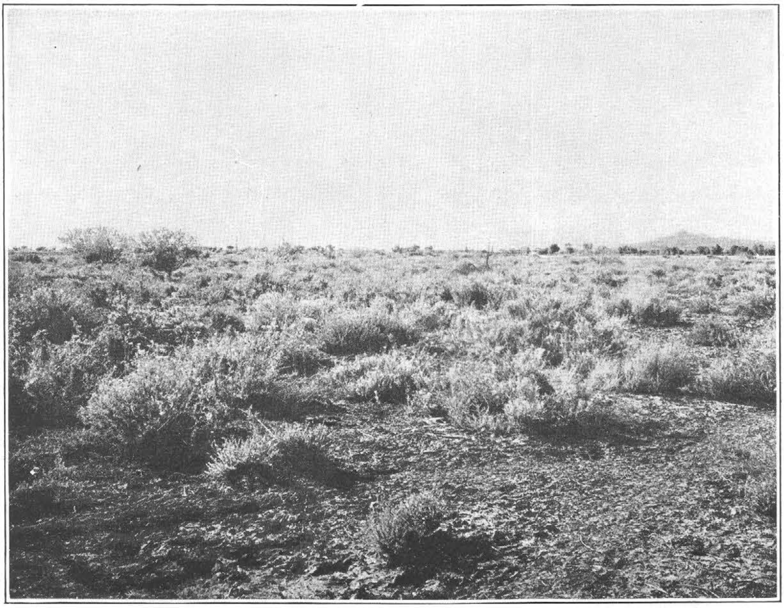
The native gardens are situated in the date palm groves and the vegetables and fruit are grown in the partial shade cast by these trees. The natives not only have the question of very saline irrigation waters to contend with, but the soils originally are often very alkaline. In three years they reclaim land too salty to grow the minor crops, using the saline water for that purpose, following the same plan of drainage and weekly irrigation as where crops are growing. One garden situated on the side of a salt flat and originally very saline was visited. Here alfalfa was in very good condition, and fig, pomegranate, melon, tomato, cabbage, pepper, and other plants were growing luxuriantly. The reclamation of this plat by irrigation twice a week had taken three years.

* * * * * * *

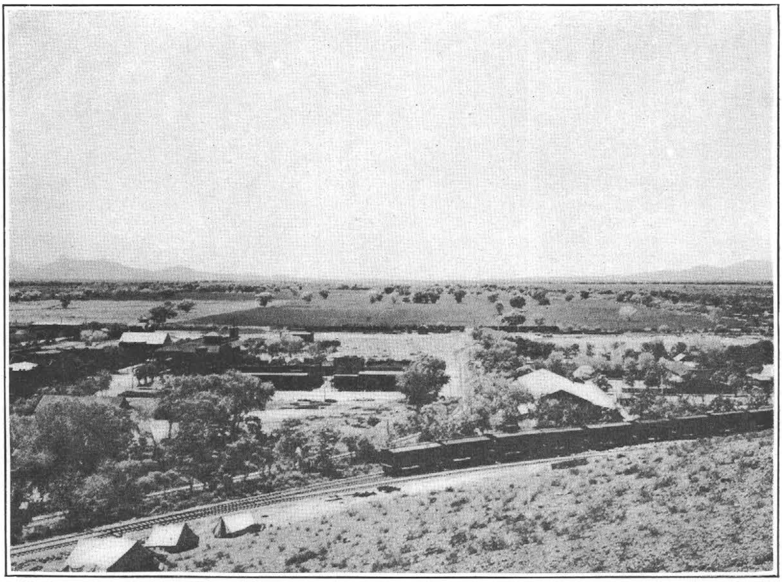
The irrigation water is all drawn from artesian wells. A number of samples were sent in to the laboratory for analysis, the results of which are shown in the following table. These are fair average samples of the irrigation waters in use, and do not represent by any means the maximum of salinity. Field tests showed as high as 816 parts to 100,000 of water in actual use on soils growing vegetables.

Chemical analyses of artesian water used in irrigating gardens in Sahara oases, Algeria.

Constituent.	Well at oasis Tabesbest.	Well at oasis Kudi Asli.	Well at garden of Ben Hadrian.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	9.92	4.19	9.86
Magnesium (Mg)	4.52	6.02	4.26
Sodium (Na)	14.03	20.48	14.18
Potassium (K)	4.27	2.35	2.72
Sulphuric acid (SO_4)	34.38	29.43	17.59
Chlorine (Cl)	28.06	36.21	27.05
Bicarbonic acid (HCO_3)	5.02	1.32	24.34
Conventional combinations:			
Calcium sulphate ($CaSO_4$)	33.04	14.23	24.90
Magnesium sulphate ($MgSO_4$)	13.63	24.29	7.04
Magnesium chloride ($MgCl_2$)	7.23	4.41	16.72
Potassium chloride (KCl)	8.12	4.48	5.19
Sodium bicarbonate ($NaHCO_3$)	6.92	1.81	33.54
Sodium chloride (NaCl)	31.06	50.78	12.61
Total solids in 100,000 parts water	601.50	408.10	571.90



A. SEEPAGE LAND SOUTHEAST OF TEMPE.



B. VIEW SOUTHWARD FROM TEMPE BUTTE.

QUANTITY OF UNDERGROUND WATER.

THE UNDERFLOW.

WATER ENTERING THE VALLEY.

In order to secure a measure of the water entering the valley fill as underflow, it would be necessary to measure all streams, both permanent and intermittent, as well as the occasional waters entering as sheet wash from the surrounding hills. It would be necessary, furthermore, to measure the quantity of surface water escaping from the valley. The greater part of the supply is from Salt River and the total quantity entering from this source is known from the records of the gaging stations on Salt and Verde rivers. The amount taken from the river by the canals is known, but the loss from the valley during times of flood is unknown on account of the want of a gaging station at the outlet of the valley: It is, therefore, obviously impossible to arrive in this way at even an approximate measure of the water entering the underflow. Other methods must be resorted to in order to obtain a quantitative estimate.

RETURN WATER.

The Tempe canal diverts all the surface water of the river north of Mesa. Near Tempe the underground water returns to the surface, making a flow of about 35 second-feet. West of Phoenix the underground water again returns to the surface. It is not possible at present, however, to state what proportion of the seepage water comes from Salt River, since its underflow joins that from Gila River. It is probable, however, as previously stated, that the underflow of the Gila is fed in large measure by the waters from Salt River passing as underflow east of Salt River Mountains. In Gila Valley west of Florence all the waters diverted from the river, except during occasional floods, are seepage waters. The flow in the Gila channel and in the Indian ditches at Gila Crossing was 800 inches when measured on August 17, 1902. Mr. M. M. Murphy estimated the water diverted by the Indian ditches east of the junction of Gila and Salt rivers in January, 1903, as 500 inches, leaving 1,000 inches in the river. The smaller canals of Salt River, between Tempe and the Buckeye, divert water as follows:

Water received by canals west of Phoenix, Ariz.

[Information furnished by M. M. Murphy.]

Canal.	June, 1902.	June, 1903.
	Inches.	*Inches.*
Leon	265	None.
Peninsula	35	234
Lambeye	74	138
Meridian	153	180
Indian	82	72
Total	609	624

The winter flow is about double the above. Available summer flow at the head of St. Johns canal is 400 inches.

Maximum winter flow (not flood) at St. Johns is 800 inches.

Indian ditches on the lower Gila take a minimum of 400 inches.

The amount taken by the Salt River and Maricopa canals—joint head—for June, 1903, averaged 1,344 inches. This is slightly more than usual.

The amount diverted by the Buckeye canal is given by Mr. W. A. Apgar, as follows:

Flow in Buckeye canal.

	Second-feet.
July, 1902	78
July, 1902 [a]	80
May 14, 1903	129
May 23, 1903	133
May 24, 1903	128

Davis[b] says:

The amount of seepage water was measured by Mr. Cyrus C. Babb in June, 1896, and the results showed in one case an increase of over 80 second-feet in a distance of 7 miles.

Code[c] states that "the return flow picked up by the head of the Maricopa and Salt River canals in ordinary years is found to approximate 60 cubic feet per second. This flow has naturally decreased during the past summer owing to the scanty irrigations received by the Mesa, Utah, and Tempe lands above, and to the gradual lowering of the underground supply." He states further that—

at the head of the Buckeye canal, some 24 miles farther down the stream, is again found a volume approximating in ordinary summers 150 cubic feet per second. * * * Some 20 miles below the Buckeye, I am told, another flow of approximately 50 cubic feet per second is to be picked up.

[a] A few days later.

[b] Davis, A. P., Irrigation near Phoenix, Ariz.: Water-Sup. and Irr. Paper No. 2, U. S. Geol. Survey, 1897, p. 43.

[c] Code, W. H., Irrigation in Salt River Valley, in Report of irrigation investigations for 1900, No. 2: U. S. Dept. Agric., Bull. 104, 1901, p. 103.

According to Code's estimate the return water is 210 second-feet, whereas the estimate given above is only 150.

There is no time for which measurements are available for all the canals diverting seepage water. The amount, however, of the seepage water does not vary to any great extent. The average amount, then, according to the best measurements and estimates available is something over 150 second-feet, making a total of more than 100,000 acre-feet per year.

If Code's estimate be accepted the return water east of the Buckeye canal is something over 150,000 acre-feet per year. A small part of this is return water from irrigated lands, but the greater part is from the natural underground flow. A considerable but undetermined part of it is from the Gila underflow, but the greater part is from Salt River.

The seepage waters estimated at 100,000 acre-feet per year are only those returning to the surface east of the Buckeye canal, and take no account of a large quantity of return water diverted by the several canals farther down the river. Furthermore no account is taken of the quantity passing as underflow through the gravels at the lower end of the valley, at the Buckeye head-gates. The 100,000 acre-feet is a measure of the spill from the top of the underflow—water which the valley fill for some reason is unable to hold. The total volume of underflow is therefore something greater than 100,000 acre-feet per year.

MEASURING THE UNDERFLOW.

SLICHTER'S METHOD.

The most elaborate and scientific method of arriving at a quantitative estimate of the underground waters of the valley is obtained from the application of Slichter's[a] method. On account of the great importance of arriving at as accurate an understanding as possible of the underflow and its probable volume, I quote from this paper such portions as apply to the principles and methods of procedure. After a discussion of the principles relating to the movement of underground waters, Professor Slichter proceeds:

Formula.—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

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

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 the table 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 the table, page 155.

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

Temperature.	Coefficient of viscosity μ.	Relative flow.[a]
°F.		
32	0.0178	0.74
35	.0168	.78
40	.0154	.85
45	.0142	.92
50	.0131	1.00
55	.0121	1.08
60	.0113	1.16
65	.0105	1.25
70	.0098	1.34
75	.0092	1.42
80	.0087	1.51
85	.0081	1.62
90	.0077	1.70
95	.0073	1.80
100	.0069	1.90

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

Constants for various porosities of an ideal soil.

Porosity m.	$\frac{1}{K}$	Log. K.	Diff.	Colog. K.
Per cent.				
0.26	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

If t stands for temperature of the water F., 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:

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

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 the table on page 155 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

$$k=0.2012\,\frac{d^2}{\mu K}=Md^2 \quad (5)$$

and the formula for the flow becomes

$$q=k\frac{ps}{h}, \quad (6)$$

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.

Rates of flow.—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. Mr. E. L. Rogers reported to the Denver Society of Civil Engineers 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.

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 on page 158, and for other temperatures by the use of table on page 154.]

1. Diameter of soil grain.	2. Velocity, pressure gradient 1:1.	3. Velocity, pressure gradient 1:1.	4. Velocity, pressure gradient 100 feet to 1 mile.	5. Maximum flow, or transmission constant, *k*.	6. Logarithm of numbers in column 5.	7. Kind of soil.
Mm.	*Inches per minute.*	*Miles per year.*	*Miles per year.*	*Cubic feet per minute.*		
0.01	0.0014	0.0113	0.00026	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	7.3621	
.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	

The table on page [157] 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 the 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.

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.
30	0.81
32	1.00
34	1.22
36	1.47
38	1.76
40	2.09

Maximum flow.—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

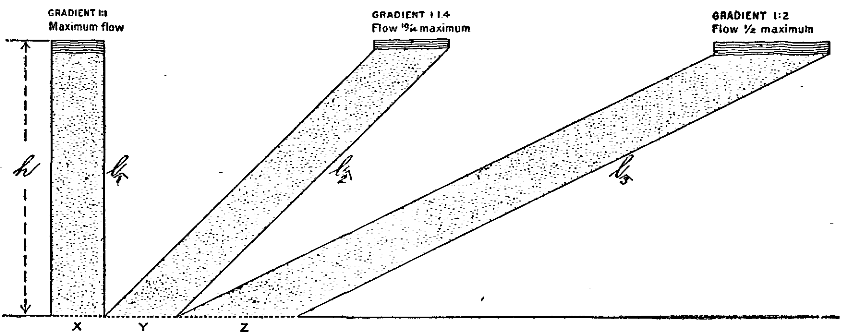


FIG. 22 (7 of Slichter).—Diagram illustrating various pressure gradients and the maximum flow. In these three cases the upper portions of the soil columns are supposed to be supplied with water as fast as it can flow through the columns. The escape at X, Y, Z is supposed to be perfectly free. The head 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.

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. 22. 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. 23, 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.

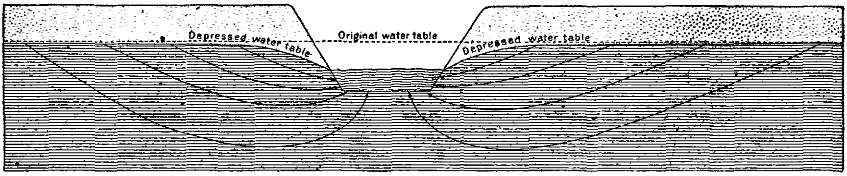


FIG. 23 (8 of Slichter).—Diagram showing lines of flow into a drainage ditch and the shape of the water table in its neighborhood. The head under which the flow takes place is the difference in height of the original water table and the level of the surface of the water in the ditch. This is much less 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 flow.—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, 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 the table on page 157 one should use the numbers in columns 2, 3, or 4 if the 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 per year.	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

Example.—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 on page 157. The flow for one 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.

	Cubic feet per minute.
Fine sand	5.5
Medium sand	22.0
Coarse sand	87.0
Fine gravel	546.0

The estimates in the table on page 157 were based upon a porosity of 32 per cent. For other porosities the results must be changed by the percentages shown in the table on page 158. 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.

FACTORS IN SLICHTER'S METHOD.

In order to apply the principles above quoted it is necessary, in addition to the facts already stated, to know (1) the area of cross section through which the underflow passes; (2) the porosity of the material; and (3) the temperature at the depth at which the flow occurs.

Area of cross section.—On the assumption that the principal source of the underflow is Salt River, and that the underflow passes in part down the present valley past Tempe and in part to the south, east of the Salt River Mountains, it is evident that the open plain between Tempe and the Salt River Mountains and between the Salt River and Sacaton mountains gives a measure of the width of the underflow. Since the principal part of this underflow passes through the bowlder beds and comparatively little through the finer material, the practical width of the underflow is much less than the spaces indicated between the mountains. For all practical purposes the width of the underflow probably does not differ materially from that given in the sections on Pl. XXI, or about 15 miles.

The thickness of the bowlder beds can not be stated with any degree of accuracy, since many of the wells do not reach the bottom of the bowlders. The thickness varies greatly from place to place, but in general is greater near the center of the bed than at the sides, as indicated in the sections just referred to. The wells in the regions near these sections penetrate on the average about 150 feet of gravel and bowlders. Neglecting, then, the finer materials through which a minor quantity of water finds its way, and neglecting the unknown thickness of bowlders which the wells do not penetrate there remains an average depth of 150 feet across a width of 15 miles, or 11,880,000 square feet, as the working area of cross section of the underflow. The actual area of cross section is greater than this, owing to the unknown thickness of the bowlder beds left out of account, but how much greater is not known. In order to keep well on the side of conservatism the figure is made no larger than known facts warrant.

Temperature.—Since the volume of water passing as underflow varies with the temperature, the temperature of several wells was determined, as follows:

Temperature of wells in Salt River Valley, Arizona, in 1904.

Well.	Location.			Depth.	Temperature.	Time.
	Township.	Range.	Section.			
				Feet.	° F.	
Consolidated Canal Co. No. 1	1 S.	5 E.	22	375	84.6	January 19.
Do	1 S.	5 E.	22	150	81.1	Do.
Murphy-McQueen	1 N.	5 E.	34	340	78.1	January 20.
Do	1 N.	5 E.	34	150	77.6	Do.
E. F. Kellner	1 N.	1 E.	6	324	82.3	January 15.
Valley Seedless Grape Co.	1 S.	4 E.	4	319	74.4	December.

With the exception of the Kellner well, the wells in which the temperature was determined are those in active operation. The lowest horizons at which readings were obtained are below the bottom of the bowlder bed. In two wells readings were taken at a depth of 150 feet. The temperature at this depth is the temperature of the water of the underflow, since at that depth the thermometer was in the midst of the bowlder bed.

An inspection of the table indicates a considerable diversity of temperature. In the case of wells in which readings were taken at more than one depth the downward increase in temperature differs materially. In the Consolidated Canal Company well an increase downward is shown of 3.5° F. in 250 feet, while in the Murphy-McQueen well an increase of only 0.5° F. occurred in 190 feet. It is probable that the circulation of the underground water causes the differences in the temperature. Since the waters of the underflow follow the paths of least resistance, a certain quantity of water may be near the surface at one point and in the course of its journey be far beneath the surface at another point. This circulation of the water tends to destroy the regularity in the increase of temperature downward which might otherwise obtain. Variations such as those indicated above are to be expected.

Since there is no uniformity of temperature, the degree chosen to represent the average temperature is a matter of judgment. The average of the temperatures indicated in the table, 79.7° F., is obviously not representative. The Kellner well is not in the direct underflow, so far as known, and the vineyard well, while near the edge of the bowlder bed, is principally in fine material, and the freedom of its connection with the main underflow is a matter of doubt. The two wells from which the first four readings given above were obtained are in the midst of the underflow and are among the most representative wells of the valley. The average of these four readings, 80.3° F., probably represents with some accuracy the average temperature of the underflow. Eighty degrees has, therefore, been chosen as the value of t for substitution in Slichter's formula.

Porosity.—According to the principles laid down by Slichter, the velocity of flow depends upon porosity, and this in turn upon the size of grain. The size of grain is determined as follows:[a]

In order to give expression to the variety of sizes present in a sample, Hazen introduces a number known as the uniformity coefficient. To determine this magnitude, first find the size of sand grain which is such that 60 per cent of the material is of smaller grains and 40 per cent of larger grains. This result, when divided by the effective size of soil grain of the entire sample, gives the uniformity coefficient. Thus, if 60 per cent of a sample be finer than 0.62 mm. and 10 per cent be finer than 0.25 mm., the uniformity coefficient is $\frac{0.62}{0.25}$, or $2\frac{1}{2}$. Hazen concludes from his experimental work that the 10 per cent of small grains in a sample of a natural sand or soil has the same influence on the flow water as the 90 per cent of large grains, provided the uniformity coefficient does not exceed 5.

In order to obtain the porosity of the gravels of Salt River Valley through which the underground waters flow, samples were taken at six localities, as follows:

Derivation of gravels sampled for mechanical analyses.

Name.	Location.			Depth.	Remarks.
	Township.	Range.	Section.		
				Feet.	
River bed	1 N.	3 E.	20	....	South of Phoenix.
Geo. U. Collins	1 N.	2 E.	15	25	Fully half the material was bowlders more than 1 inch in diameter.
One-half mile north of Collins's.	1 N.	2 E.	10	25	
N. P. McCallum	1 N.	2 E.	24	60	Samples taken from sand pump while well was drilling.
D. B. Heard	1 N.	4 E.	30	75	Do.
Murphy-McQueen	1 N.	5 E.	34	34	Samples taken at water level in the open shaft.

[a] Slichter, Charles S., The motions of underground waters: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, p. 22.

An effort was made to select the samples in such a manner that they would be representative of the material from which the best pumping plants draw their supply. It will be noted that the samples are all from the regions previously indicated as containing the bowlder beds. While only one sample is from the Mesa region, it is probable that the material represents the gravels there as faithfully as it does those of the Phoenix region. The samples are taken directly from the native material, as exposed in the sides of the well, and are thought to represent adequately the best water-bearing material of the valley.

In each case the proportion of material more than 1 inch in diameter is estimated as half the sample. Since bowlders occur 2 feet in maximum diameter it is obvious that no account of them can be taken in a small sample. It is certain that in some cases the proportion of large material is greater than half. Pebbles 1 inch or more in diameter were discarded and the remainder passed through standard sieves of sizes indicated in the following table. The work was done at the assay office of J. Q. A. King, of Phoenix, and the weight of the various sizes of material was accurately determined as indicated below:

Mechanical analyses of the water-bearing material of Salt River Valley.

RIVER GRAVELS.

Sieve marked.	Size of separation of the sieve in millimeters.	Quantity held by each sieve in grams.	Quantity passing each sieve in grams.	Per cent of total weight of grains less than 1 inch in diameter.	Per cent of total weight of entire sample.
....	[a]0.158	31.1	....	....	....
120	.152	3.1	31.1	6.3	3.15
100	.182	29.6	34.2	8.9	4.45
80	.235	25.8	63.8	12.8	6.4
60	.320	50.0	89.6	17.9	8.95
50	.390	97.2	139.6	27.9	13.95
40	.460	225.0	236.8	47.3	23.65
20	.930	23.6	461.8	92.6	46.3
10	2.040	3.1	485.4	97.7	48.85
6	3.900	10.4	488.5	97.9	48.95
....	[b]3.900	498.9	510.4	....	52.1
....	....	....	....	[c].21	[c].43

[a] Less than. [b] Larger than. [c] Effective size.

Mechanical analyses of the water-bearing material of Salt River Valley—Continued.

GEORGE U. COLLINS.

Sieve marked.	Size of separation of the sieve, in millimeters.	Quantity held by each sieve, in grams.	Quantity passing each sieve, in grams.	Per cent of total weight of grains less than 1 inch in diameter.	Per cent of total weight of entire sample.
....	a 0.152	20.5	....	....	....
120	.152	.8	20.5	4.1	2.05
100	.182	14.5	21.3	4.2	2.1
80	.235	14.5	35.8	7.2	3.6
60	.320	23.1	50.3	10.6	5.3
50	.390	47.1	73.4	14.7	7.35
40	.460	167.1	120.5	24.1	12.05
20	.930	35.7	287.6	57.5	28.75
10	2.040	17.7	323.3	64.6	32.3
6	3.900	159.5	341.0	68.2	34.1
....	b 3.900	500.5	659.5	....	65.9
....	....	....	....	c .31	c .43

ONE-HALF MILE NORTH OF COLLINS'S.

....	a 0.152	10.5	....	....	....
120	.152	1.0	10.5	2.1	1.05
100	.182	11.3	11.5	2.3	1.15
80	.235	10.7	22.6	4.5	2.25
60	.320	18.6	33.3	6.7	3.35
50	.390	25.7	51.9	13.8	6.9
40	.460	117.5	77.6	15.5	7.75
20	.930	126.5	195.1	39.0	19.50
10	2.040	53.2	321.6	64.5	32.25
6	3.900	124.5	374.8	74.9	37.45
....	b 3.900	499.5	624.5	....	62.6
....	....	....	....	c .35	c .55

a Less than. b Larger than. c Effective size.

Mechanical analyses of the water-bearing material of Salt River Valley—Continued.

N. P. McCALLUM.

Sieve marked.	Size of separation of the sieve, in millimeters.	Quantity held by each sieve, in grams.	Quantity passing each sieve, in grams.	Per cent of total weight of grains less than 1 inch in diameter.	Per cent of total weight of entire sample.
....	[a] 0.152	21.9	....	....	....
120	.152	1.7	21.9	4.4	2.2
100	.182	12.2	23.6	4.7	2.35
80	.235	14.3	41.8	8.4	4.2
60	.320	24.8	56.1	11.2	5.6
50	.390	49.9	80.9	16.2	8.1
40	.460	220.5	130.8	26.2	13.1
20	.930	66.6	351.3	70.4	35.2
10	2.040	17.6	417.9	81.9	40.95
6	3.900	63.5	435.5	87.2	43.60
....	[b] 3.900	499.0	563.5	....	....
....	....	....	....	[c] .29	[c] .42

D. B. HEARD.

Sieve marked.	Size of separation of the sieve, in millimeters.	Quantity held by each sieve, in grams.	Quantity passing each sieve, in grams.	Per cent of total weight of grains less than 1 inch in diameter.	Per cent of total weight of entire sample.
....	[a] 0.152	12.4	....	....	....
120	.152	.9	12.4	2.5	1.25
100	.182	9.4	13.3	2.7	1.35
80	.235	7.7	22.7	4.5	2.25
60	.320	13.7	30.4	6.1	3.05
50	.390	21.7	44.1	8.9	4.45
40	.460	106.0	65.8	13.2	6.6
20	.930	80.0	171.8	34.4	17.2
10	2.040	45.5	251.8	50.5	25.1
6	3.900	201.5	297.3	59.6	29.8
....	[b] 3.900	498.8	701.5	....	....
....	....	....	....	[c] .43	[c] .56

[a] Less than. [b] Larger than. [c] Effective size.

Mechanical analyses of the water-bearing material of Salt River Valley—Continued.

MURPHY-McQUEEN.

Sieve marked.	Size of separation of the sieve, in millimeters.	Quantity held by each sieve, in grams.	Quantity passing each sieve, in grams.	Per cent of total weight of grains less than 1 inch in diameter.	Per cent of total weight of entire sample.
....	[a] 0.152	32.7	....	....	....
120	.152	1.6	32.7	6.5	3.25
100	.182	20.5	34.3	6.9	3.45
80	.235	12.2	54.8	10.9	5.45
60	.320	26.0	67.0	13.5	6.75
50	.390	42.7	93.0	18.7	9.35
40	.460	138.5	135.7	27.7	13.85
20	.950	61.5	274.2	55.1	27.55
10	2.040	32.25	335.7	67.2	33.6
6	3.900	130.0	367.95	73.9	36.8
....	[b] 3.900	497.95	532.25	....	53.3
....	....	....	....	[c] .26	[c] .42

[a] Less than. [b] Larger than. [c] Effective size.

Following the example given by Slichter, the results of the mechanical analyses were tabulated, and the effective sizes determined for each sample, as shown in the following table:

Effective size[a] *and uniformity coefficients of material from Salt River Valley as determined by Hazen's method.*

	Diameters of effective size of total sample, in millimeters.	Diameters of effective size of material less than 1 inch in diameter, in millimeters.	Uniformity coefficient for material less than 1 inch in diameter.
River gravel	0.43	0.21	2.47
Geo. U. Collins	.43	.31	2.84
One-half mile north of Collins's	.55	.35	4.86
N. P. McCallum	.42	.29	2.31
D. B. Heard	.56	.43	9.3
Murphy-McQueen	.42	.26	4.61
Average	.47	.31	....

[a] By *effective size* is meant a diameter of grain such that 10 per cent of the sample is less than that size. It is determined by the intersection of the curve and the 10 per cent line. The effective size differs materially according to the choice of material, as indicated in the foregoing tabulation.

An application of Slichter's formula to the underflow of Salt River Valley, using the effective size thus obtained, gives results which are obviously erroneous, since the quantity of underflow thus indicated is notably less than the quantity known to return to the surface and measured as water actually diverted for irrigation purposes.

A sample of the gravels was sent to Professor Slichter and tested in his apparatus. The sample was taken from George U. Collins's well, and probably represents the water-bearing gravels of the valley as well as any single sample can represent them. The quantity of material rejected as too large to handle was about one-half. The finer material was analyzed by Professor Slichter for porosity and effective size. I quote from his letters as follows:

MADISON, WIS., *March 20, 1904.*

* * * * * * *

I have gone over the samples of gravel you sent with the following results:

Porosity: The porosity of the sample of gravels, after carefully tamping them in the aspirator tube, was found to be 40.3 per cent.

Effective size: The fine portion of the sample that will go through a No 8 sieve was used for the determination. Triplicate determinations give for effective size of this portion of the sample 0.716 mm. The effective size of the actual material you sent is slightly greater, but our aspirator tubes are such that I can not safely introduce large pebbles into the instrument. I shall make an actual test with water of the entire sample as soon as I can do so.

Hazen's 10 per cent is worthless for nearly all western gravels. I have never yet found a sample of heterogeneous gravel that will test to correspond with his 10 per cent. The 50 per cent line is frequently about correct, although even this is often far from the true value.

CHAS. S. SLICHTER.

MADISON, WIS., *April 4, 1904.*

About two weeks ago I sent you results of tests of gravels from Collins's well by aspirator method. I inclose herewith further data.

After picking out the larger pebbles I separated the larger particles by standard sieves, and after each sifting determined porosity and effective size of the gravel passing the sieve. The gravels were packed in the cylinder by tamping while poured in place very slowly, and an effort was made to pack as closely as possible. You will note that the porosity changes greatly, and that the removal of the larger grains has a tendency to lower the effective size of the sample, with one or two notable exceptions.

I believe that the larger grains necessarily omitted from the sample probably would increase the effective size if we could use them. You will note that Hazen's 10 per cent is perfectly useless for all of the samples in the table. The 50 per cent line gives a value of grain nearer the true mean.

Gravel from George U. Collins's well, Salt River Valley, Arizona.

No. of sieve.	Per cent of sample held.	Per cent of sample passed.	Porosity of "pass."	Effective size of "pass," in millimeters.	Transmission constant of "pass" at temperature 80° F., in cubic feet per minute.
2	6.6	93.4	38.1	0.727	0.511
8	....	....	40.0	.716	.602
10	16.3	83.7	38.6	.63	.400
12	17.4	82.6	40.3	.68	.543
14	19.7	80.3	39.5	.63	.428
16	22.0	78.0	39.7	.63	.440
18	23.6	76.4	39.6	.62	.427
20	25.8	74.2	40.6	.71	.597
30	44.1	55.9	41.0	.56	.382
40	67.8	32.4	40.6	.42	.209

CHAS. S. SLICHTER.

APPLICATION OF SLICHTER'S METHOD.

It will be noted from the contours of the water table that the inclination of the table varies from 5 to 20 feet per mile, the inclination on the average being practically the same as that of the land surface. The gradient is practically 10 feet to the mile where the principal underflow occurs. This figure is therefore used in the following computation.

The porosity, as previously stated, may reasonably be assumed as 40 per cent, the effective size as 0.72 mm., and the temperature as 80° F. In order that the quantity of underflow may be expressed in acre-feet per year, the number of minutes in one year is placed above the line and the number of cubic feet in 1 acre-foot of water beneath the line.

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

$$q = \frac{11.3 \times 10 \times \overline{.72}^{2} \times 11880000 \times 525600}{5280 \times 43560 \times 20.318} [1 + .0187(80-32)]$$

acre-feet per year.

Solving this equation we have 148,196 acre-feet per year as the quantitative measure of the underflow of Salt River Valley, or a rate of flow of about 1,360 feet per year. In other words, assuming that the values chosen are correct, a quantity of water sufficient to cover 148,196 acres of land 1 foot deep each year enters the gravels of the valley and works its way at the rate of 1,360 feet per year through the valley fill. This is not a measure of the quantity of water in the gravels at any one time, but a measure of the quantity which passes any given cross section of the valley in one year.

COMPARATIVE DATA FROM OTHER REGIONS.

Owing to the great importance of arriving at an estimate as nearly correct as possible of the quantity of underflow it may be profitable to consider it from different standpoints. There are so many unknown factors and so many varying conditions that no quantitative estimate can be final. Such estimates are, however, of illustrative value in giving a measure of possibilities.

Observations have been made on the rate of movement of underground waters at many localities. L. C. Carpenter has published a paper[a] giving the results of his study on the rapidity of underflow, from which the following quotation is taken:

> Near Montrose, Colo., the velocity was found to be about 1 mile per year. At Fort Morgan, Colo., 15 feet per day, or a little more than 1 mile per year in soil and sand. On the Hoover ditch the velocity is 3.6 feet per day, or 314 feet per year in sand.

In the paper previously quoted, Professor Slichter gives rates of movement of underground water as follows:

> 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, Colo., 2½ miles in ten years, or 1,320 feet per year. King River, California, 4.8, 4.3, and 16 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.

To the above data may be added the observations mentioned in Chapter I, that the underflow is made evident through the Bowen well by the collection at one side of floating bodies, and that in the Collins well floating blocks of wood indicate a current sufficiently swift to be plainly visible to the observer. This was noted on three different occasions each time after the well had been undisturbed for several days. On each occasion the velocity was practically the same and appeared to be affected by nothing except the normal movement of the underflow.

From the above data it appears that the rate of underflow as measured in several localities varies from a minimum of 132 feet per year 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 rate is, for the most part, soil or comparatively fine sand. In no case described is the material so coarse as that occurring in Salt River Valley.

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[a] Carpenter, L. C., Seepage, or return waters, from irrigation: Colo. Agric. Exp. Sta. Bull. No. 33, 1896.

COMPUTATIONS OF VOLUME.

Since the maximum velocity previously quoted is 3.6 miles, or 18,908 feet per year, it seems probable in view of the great freedom of movement of the underground waters in a number of places in Salt River Valley, as shown by pumping tests and otherwise, that the effective size may be much greater in places than 0.72 mm., and the porosity may be greater than 40 per cent with a rate of movement correspondingly greater. It is reasonable to suppose that in material of such varying size as that of Salt River Valley accumulations of the coarse gravel and bowlders in places occur with little sand and silt. Such beds would offer little resistance to the underflow and a velocity even exceeding the maximum quoted above (3.6 miles) might easily occur. It is evident from the quantity of return water—more than 100,000 acre-feet per year—that the underflow of which this return water is a part may easily amount to the 148,196 acre-feet per year indicated by the application of Slichter's formula, and may possibly be much greater. Let it be remembered, however, that the 100,000 acre-feet of return water is from Gila and Salt rivers combined, there being no way at present of separating the two.

It may be useful to compute the volume of underflow for several possible velocities, bearing in mind always that since the actual rate of underflow is unknown, the results are only possibilities and have only illustrative values.

In a former paper[a] on the underground waters of Gila Valley certain estimates of the possible quantity of the Gila underflow were made. Much less is known of that valley than is known of Salt River Valley, and the estimates are less likely to be correct than those for Salt River Valley. Since the two underflows join and their relative values are not determinable, the estimates made in that paper are quoted for comparison with those herein given. The two underflows should be considered together for the reason that the only reliable measure of the quantity of underflow at hand is the return water of Salt and Gila rivers combined.

Quantitative estimates of underflow of Salt and Gila rivers.

	Area of cross section in square feet.	Acre-feet per year at velocity of—			
		1,360 feet per year.	½ mile per year.	1 mile per year.	2 miles per year.
Salt River	11,880,000	148,196	287,760	575,520	1,151,040
Gila River	2,872,320	35,830	69,564	139,128	378,256
Total		184,026	357,324	714,648	1,529,296

[a] Lee, W. T., The underground waters of Gila Valley, Arizona: Water-Sup. and Irr. Paper No. 104, U. S. Geol. Survey, 1904.

It will be observed that with the given cross sections and a porosity of 40 per cent a velocity of one-half mile per year yields a volume of 357,324 acre-feet per year. Considering the great volume of return waters—100,000 acre-feet or more east of the Buckeye canal and a large though unknown volume west of that canal—and considering also the coarseness of the water-bearing material and the freedom of movement evident at many of the pumping plants, it seems probable that the rate of movement may be greater than the computed rate of 1,360 feet per year, and that the average velocity may be more nearly one-half mile per year, making a normal volume of underflow of 287,760 acre-feet per year in Salt River Valley and 69,564 acre-feet per year in Gila Valley, or a total of 357,324 acre-feet of water entering the underflow each year.

THE RESERVE.

The computations thus far have dealt only with the flow—that is, with the volume passing through the assumed cross section during the year; they take no account of the water already in the valley-fill. An estimate of this amount may be instructive.

There are in Salt River Valley, north of the Pima Indian Reservation, about 525 square miles (fig. 21) beneath which underground water occurs less than 50 feet below the surface. About 275 square miles of this area are underlain by bowlder beds. These beds are known to be thicker than 150 feet, but how much thicker can not be stated. They are known to extend beyond the limits of the area indicated in the map, but to what extent remains unknown. Over a considerable part of the 525 square miles the water is only 10 to 20 feet beneath the surface. Assuming the limit of lift for pumping as 65 feet, and allowing 15 feet for the local depression of the water table due to the action of the pump, it is evident that pumps placed in the lower portions of the region might permanently lower the level of underground water 35 feet and still obtain water within the limit of cost. It is furthermore evident from the readiness of movement of the underground waters that pumps placed on the lower grounds might readily draw from the whole region and depress the water table uniformly.

It is thought that water contained in the vast quantities of material beyond the 50-foot contour will much more than compensate for the area in which the finer material predominates, as indicated in fig. 21, and that it is safe to assume a porosity of 40 per cent for the material over an area of 525 square miles as a working basis. In order that the water table shall be permanently lowered 35 feet the gravels must part with the water contained in the spaces, amounting to 40 per cent of the volume over an area of 525 square miles, or 336,000 acres, and 35 feet deep. This amounts to 4,704,000 acre-feet of water.

Viewing the problem from another standpoint, there is available for pumping in the gravels at the present time, provided none escape, water in sufficient quantity to cover the 336,000 acres to a depth of 14 feet. This water if applied to 200,000 acres, the estimated area cultivated in Salt River Valley, would supply the entire area, allowing 4 acre-feet of water per acre per year, for nearly 40 years.

It should be stated in this connection that the immense quantity of water contained in the gravels is continually moving down the valley. While the water table remains constant, the inflow at the head and sides of the valley equals the outflow or discharge at the lower end. The total quantity, therefore, should be considered as a reserve rather than an available supply. The quantity entering the underflow represented by the volume of flow is the maximum amount which can be considered as permanently available for pumping. This amount might be withdrawn continuously if the pumps could be arranged in such a manner as to secure the whole flow. Since this is obviously impossible, something less than the normal flow is permanently available for pumping. A greater draft will draw upon the reserve and continued use of the reserve may lower the water table in time to a horizon too deep for pumping.

From the quantity of the reserve it is evident that pumps might be operated for years before the reserve was exhausted, provided the natural escape of the water from the valley could be prevented. But since this escape is great and constant—more than 100,000 acre-feet per year (besides an unknown quantity passing as underflow in the Buckeye region as previously described)—any great quantity of water extracted by pumps would probably cause a material depression of the water table.

The elevation of the surface where the underflow returns in part, west of Phoenix, is about 200 feet lower than at Mesa. Should the inflow cease the surface of underground water must eventually lower to the level of the point where the water escapes. It is the friction due to passage through the sands and gravels retarding the flow, coupled with the supply from the inflow, that maintains the water gradient. When this balance is disturbed, a disturbance of the water table must result. The practical question is: How much of a disturbance in the way of pumping can be made and still have water within pumping distance?

It is evident that, other things equal, an increase of water entering the valley will raise the water table and a decrease will lower it; an increased draft at the lower end of the valley, whether by escape as seepage or by the demand of pumps, will lower the water table; water withdrawn by pumps at any point in the valley will affect the water table, particularly below the pumps and in general over the whole valley, by disturbing the equilibrium established in nature.

A lowering of the water table of several feet has taken place during the past few years. How much of this lowering, if any, is due to the operation of pumps and how much to the scarcity of water during the past few years, owing to the scant rainfall, is not determinable at present.

The underflow, even though the volume be great, should not be considered as inexhaustible. There is a large quantity of water available; a quantity well worth the necessary expense of pumping plants for securing it. But it is fairly certain that a large number of pumps run continuously will cause a permanent lowering of the water table, and pumps established on high ground may find the lift too great for economic operation after a few years.

Probably the most satisfactory way of utilizing the underground water is to withdraw by pumps no more than the normal flow, leaving the gravels saturated as a reserve to be used in times of need and replaced in times of plenty; in other words, to use the water in the valley fill as a reserve supply rather than to exhaust it quickly in the extension of cultivated land, with the consequent loss of property when the water level falls beyond the reach of the pumps.

PRACTICAL POROSITY.

The proportion of voids given for various diameters of sand grains usually assumes a comparatively uniform size of grain. It is obviously erroneous in heterogenous materials to make computations for any selected size or even for an average size. The finer material packs into the interstices of the coarser. It would be entirely possible to have such materials packed in such a manner as to hold very little water. 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.

It is furthermore obvious that since the sands can not be pumped dry, much water might be held by them which is properly a part of the underflow, but which is not available for pumping. In order to arrive at an approximation of the quantity of water available for pumping in the mixed gravels of the valley, a series of measurements were made by filling a barrel with gravel and sand and measuring the quantity of water which could be poured into it, assuming that this quantity would be a fair measure of the quantity that might be withdrawn by pumping. In order to obtain representative material, the measurements were made at a well east of Phoenix (G. W. Smith's), where the material thrown from the well lies undisturbed. The barrel held 46⅜ gallons—measured by a standard graduate. Such material was first selected as seemed to be a fair average of the water-bearing materials observed throughout the valley. It was sand, pebbles, and bowlders up to 8 inches in diameter. 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 slowly into the material until the barrel was full. It was found that 10½ gallons of water could be poured into the barrel, representing 20.5 per cent of the total space. These gravels might easily be packed more closely in nature than they were in the experiment, and the amount of water that could be pumped from them, leaving them damp since all the water could not be withdrawn, would be something less than 20 per cent of the total bulk.

For a second experiment a place was selected where only coarse gravel and bowlders occurred, varying in size from half an inch to 8 inches in diameter. With this material in the barrel, 16⅝ gallons of water were added to fill the barrel, or 35.8 per cent of the total space. In this case, as in the former one, the percentage of voids in nature would be something less, owing to the closer packing of the gravels. The actual quantity of water available for pumping in this case is something less than 35 per cent of the volume.

Volume of water contained in sands and gravels of different porosity 35 feet deep.

[In acre-feet.]

Valley.	Area in acres.	Porosity.					
		15 per cent.	20 per cent.	25 per cent.	30 per cent.	35 per cent.	40 per cent
Salt River	336,000	1,764,000	2,352,000	2,940,000	3,528,000	4,116,000	4,704,000
Gila River	224,000	1,176,000	1,568,000	1,960,000	2,352,000	2,744,000	3,136,000
Total	560,000	2,940,000	3,920,000	4,900,000	5,880,000	6,860,000	7,840,000

It is evident that the estimated volume of the reserve previously stated as 4,704,000 acre-feet is much greater than the volume which could actually be withdrawn by pumping. In order to have something tangible to consider, the preceding table has been so prepared as to show the volumes of water contained in a given volume of sand and gravel with assumed porosities. The area is chosen to include only the land beneath which water is 50 feet or less below the surface, and where the water level might be lowered 35 feet and still be within pumping distance. Since there is a large area beyond the 50-foot contour beneath which water occurs which is left out of account, it is evident the volumes given in the table are smaller than the actual quantity within reach.

The quantitative estimates for Gila Valley are inserted because of the close association of the two valleys.

It is probable that the practical porosity—that is, the percentage of volume consisting of water actually available for pumping—is somewhere between 15 and 30 per cent.

A pumping plant of average capacity, such as those of the Consolidated Canal Company, throws a continuous stream of about 200 inches. If operated without stop, one pump would raise 3,620 acre-feet of water per year. But since there is always more or less stoppage for repairs, etc., it is assumed, for convenience, that one pump will raise about 3,000 acre-feet per year. The number of pumps required to raise the possible volume of underflow are as follows:

Number of pumps required to raise the water[a] of the underflow.

Number of pumps of 3,000 acre-feet per year capacity.	Volume of underflow in acre-feet.
30	148,196
96	287,760
192	575,520
384	1,151,040

[a] For volume, see tables on pp. 170, 174.

If a volume of underflow of 287,760 acre-feet per year be accepted, as previously suggested, it is evident that 96 pumps would lift the entire flow, provided it could all be secured. It is evident, however, that it could not all be secured. A withdrawal of the supply in any large measure must lower the water table, since the escape of the seepage waters below can not be prevented. The withdrawal of the total supply, if that were possible, would cause a lowering of the water table in time to the level of the outlet, a distance of about 200 feet for the Mesa region. Any depression of the water table due to the loss by seepage at the lower end of the valley will in turn depress the water table in the pumping region. It is therefore evident that, with an inflow of 287,760 acre-feet per year, 96 pumps would soon depress the water table beyond easy reach. In other words, in order to maintain conditions such that the underflow may be permanently and regularly useful, the pumps must be limited, under assumed conditions, to a number notably less than 96.

It is impossible at the present time to give more than a rough estimate of the quantity of water now being withdrawn from the underflow. Few of the pumps run continuously and there are many that run only occasionally to secure irrigation water when other sources fail. The most accurate estimate possible at present (summer of 1904) of the water pumped is 4,000 inches. This amount is pumped only during the summer. Should the pumps now in operation be run continuously at the estimated rate (4,000 inches) they would supply about 54,000 acre-feet of water per year, or more than one-third of the minimum estimated volume of the underflow.

If the reserve be considered as a part of the available supply for pumping, a much greater number of pumps might be operated for some time before the water table was lowered beyond reach. The pumping area described is about 36 miles in length. At the assumed rate of underflow, water entering at the head of the valley above Mesa would require seventy-two years to make the journey to the mouth of the Agua Fria. At this rate of movement water not only to the amount of the inflow but also large quantities of the reserve might be

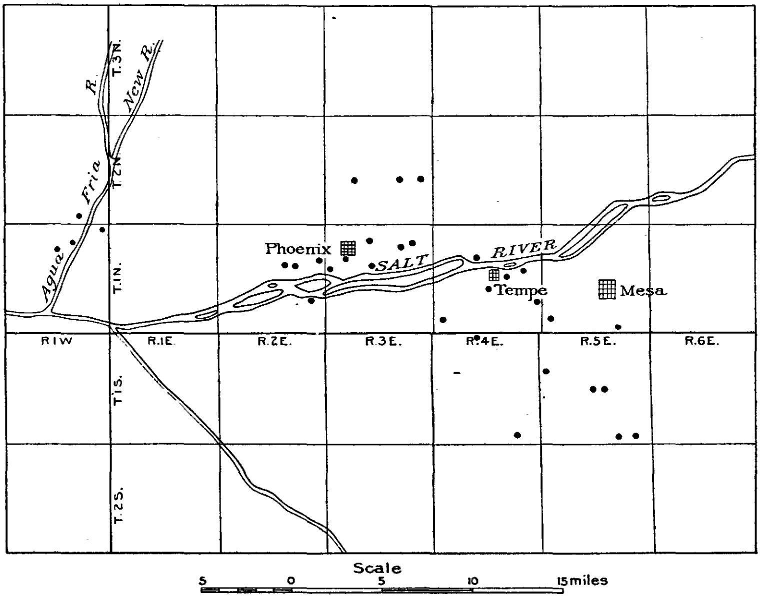

FIG. 24.—Map of Salt River Valley, showing location of pumping plants described.

withdrawn for years before the water table was permanently depressed beyond the limit of lift. Its recovery, however, would be equally slow. If the pumping project is pushed too far, it is inevitable that the more inefficient pumping plants, especially those on higher ground, must be abandoned, owing to increasing lift as the water table is depressed. In this, as in other cases of competition, only the fittest can survive.

If it be objected that the assumed velocity of half a mile per year is too small, and that 1 mile or more per year is the rate of movement, then the volume of flow is correspondingly greater and the number of possible pumping plants will be greatly increased.

COST OF PUMPING WATER.

SALT RIVER VALLEY.

Comparatively little has been known up to the present time of the actual expense of pumping water in Salt River Valley. The pumping tests described in the first chapter and summarized below, deal with conditions as they actually exist. In most cases these conditions are far from ideal. Indeed there are few pumping plants in the valley which are working with the efficiency that could reasonably be expected. There have been no experiments until recently tending to show the most economical method of pumping water, and there is no agreement among those using pumped water as to what kind of pump or what power is best, or even how to construct a well in order that it may give the best permanent results. It is thought that the computations of cost of raising water at the various pumping plants just as they exist with all their imperfections may be of value by way of comparison with guaranteed cost, which is usually based on ideal conditions.

I have excluded from the list all computations except those which I have reason to believe are essentially correct. In some cases certain elements are doubtful; for example, at the Collins well the exact amount of wood used was not obtained. It should be stated also that the test runs upon which the computations are based were short, varying from one to three hours. The figures consequently show the rate irrespective of stoppage for repair or for other cause.

In making the computations I have included in the cost of the acre-foot interest at 7 per cent per annum on the investment, the legal rate of interest in Arizona, and 10 per cent per annum depreciation, the time in each case being the time required for pumping 1 acre-foot of water. No allowance is made for stoppages. In each case the expense for oil and incidentals is estimated at 5 cents per acre-foot.

Records of pumping plants in Salt River Valley, Arizona, on which pumping tests were made.

Name.	Kind of well.	Size.	Total depth.	Depth to water.	Amount of lowering.	Total lift.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Murphy-McQueen	Drilled	1	1,305	23	19	44
Consolidated Canal Co.:						
No. 2	do	1¼	246	36	15	50.65
No. 3	do	1¼	266	37	11	47.56
Valley Seedless Grape Co	do	1	348	30	11.5	47
Tempe waterworks	do	1	152	23	14	249
T. J. Parry	Dug	40 by 60	21	17	1	18
L. Kunz	do	6 by 6	24	18	(?)	18
Geo. U. Collins	do	60 by 100	29	14	6	22
Nelson & McIlwaine	do	7	26	16	5	21
John Heaton	Dug		12	(?)	(?)	28
	Drilled	½	45			

Records of pumping plants in Salt River Valley, Arizona, on which pumping tests were made—Continued.

Name.	Kind of pump.	Power.	Cost of well and pump.	Capacity per minute.	Cost per acre-foot.	Cost per acre-foot per foot of lift.
				Gallons.		
Murphy-McQueen[a]	Centrifugal.	Steam and wood.		3,038	$2.27 2.97	$0.051 .068
Consolidated Canal Co.:						
No. 2	....do	Electric	$8,000	2,223	2.84	.056
No. 3	....do	....do	8,000	2,273	2.69	.054
Valley Seedless Grape Co	....do	Gasoline		518	3.80	.08
Tempe waterworks	Triplex	Electric	3,700	275	14.55	.058
T. J. Parry	Bucket	Gasoline	900	673	2.91	.161
L. Kunz	Plunge	Horse	250	62	1.14	.063
Geo. U. Collins	Centrifugal.	Steam and wood.	1,500	2,200	1.93 2.75	.07 .124
Nelson & McIlwaine	....do	Gasoline	2,200	900	2.88	.137
John Heaton	Plunge	....do	500	120	3.87	.138

[a] Cost does not include interest and depreciation. If this be added, the total cost becomes approximately $2.97 per acre-foot or 6.8 cents per foot per acre-foot.

It has been estimated that electric power can be furnished at a cost not exceeding $50 per horsepower per year. In three of the pumping plants previously described the horsepower consumed at the pumping station is accurately known. Since these three use electric power, direct comparison can be made as in the following table:

Cost of pumping with power furnished at $50 per horsepower per year compared with present cost.

Name.	Horsepower consumed.	Present cost per acre-foot.	Cost per acre-foot with power at $50 per horsepower per year.	Present cost per acre-foot per foot of lift.	Cost per acre-foot per foot of lift with power at $50 per horse-power per year.
Consolidated Canal Co.:					
No. 2	42.88	$2.84	$0.60	$0.056	$0.012
No. 3	42.88	2.69	.59	.054	.0118
Tempe waterworks	31.51	14.55	3.62	.058	.0144

The experiments upon which these costs are based were performed by Engineer P. E. Fuller, and are thought to be very accurate. For irrigation purposes the first two are most reliable, since they are pumping stations established exclusively for irrigation. No allowance has been made for loss of time for repairs. With such an allowance the price per foot per acre-foot with power at $50 per horsepower per year will be slightly more than 1.2 cents. Owing to the careful and painstaking experiments of Mr. Fuller this rate can be stated with considerable confidence.

As previously stated, there are places, for example near Tempe, where the water table is less than 10 feet beneath the surface. Allowing a local depression of 15 feet due to the action of the pump, or a total lift of 25 feet, water can be raised for 30 cents per acre-foot, a price much lower than the present cost of canal water.

The actual cost of canal water in Salt River Valley at present is somewhat difficult to estimate, owing to the manner in which water is sold. The price nominally paid is much less than the actual cost, for the quantity nominally paid for is seldom received. It is probable that the actual cost of canal water at the present time is little, if any, below $1 per acre-foot. With a lift of 65 feet, which has been assumed as the present limit, an acre-foot of water would cost 78 cents. The Consolidated Canal Company finds it profitable to pump water at a cost of $2.84 per acre-foot while others are pumping at a cost as high as $3.87 per acre-foot. At the rate of 1.2 cents per foot, water could be raised with profit from a depth much greater than 65 feet, and the pumping area indicated in the map (fig. 21) could be greatly extended.

COST OF PUMPING IN OTHER REGIONS.

It will be instructive to compare the cost of pumping water in Salt River Valley with the cost as determined elsewhere. The following extract contains some data which may be useful:[a]

COST IN ARIZONA, WISCONSIN, AND CALIFORNIA.

The reports of former years and this report have given meager returns from a few pumping plants, showing the cost of raising water. Mr. Code reports the details of tests made by him, and gives as his general conclusion that with wood at $4 per cord water can be lifted 45 feet for $2.50 per acre-foot, and that with power delivered to the pump at $60 per horsepower per annum water can be lifted 45 feet at a cost of $1 per acre-foot. Both these estimates include the cost of attendance and a fair rate of interest on the investment.

Professor King gives the cost of raising water in Wisconsin. At Madison water was raised 25 feet at a cost of $2.64 per acre-foot, using coal which cost $5 per ton. At Stevens Point water was raised 33 feet at a cost of $3.32 per acre-foot, using a gasoline engine, with gasoline at 11.98 cents per gallon.

Professor Chandler gives the cost of an acre-foot of pumped water in the Tule River Valley at from $5 to $7.40, with a lift of 71 feet and power costing $50 per horsepower per annum.

The following table gives all the data regarding the capacities of various kinds and sizes of pumps which have been included in all the bulletins published by this office:

[a] Report of irrigation investigations for 1901, No. 1: U. S. Dept. Agric. Bull. 119, 1902, p. 34.

Capacity of pumps.

Pump.	Power.	Lift.	Capacity per 24 hours.
		Feet.	*Acre-feet.*
2.5-inch Lawrence centrifugal	5-horsepower gasoline		0.264
5-inch Krogh centrifugal	12-horsepower gasoline	30	1.32
Do	do		.99
5.5 by 8 inch triplex-acting pump.	do	125	.594
8-inch centrifugal			8.80
Do			6.60
Do		19	7.26
Do			7.04
Do		14	8.80
Do	18-horsepower engine (burning wood).		4.40
Do		18	7.70
8-inch Krogh		32	6.60
10-inch centrifugal	80-horsepower engine	39	17.60
12-inch centrifugal		23	15.40
16-inch centrifugal	80-horsepower Frick engine	14.5	35.20
18-inch centrifugal			44.00
20-inch centrifugal		15	44.00
Double-cylinder 6-inch pump	4-horsepower gasoline		.396
Triplex pump, 5.5 by 8 inch plungers.	5-horsepower gasoline		.594
Compound duplex pumping engine.	80-horsepower boiler		132.00
Worthington compound duplex steam pumping engine.	do		176.00

COST OF PUMPING IN NEW MEXICO.

An instructive series of experiments has recently been made at the New Mexico Agricultural Experiment Station calculated to show the comparative merits of several makes of pumps. The most economic speed was determined for each make of pump tested, and the cost determined per acre of irrigating 3 inches deep, using wood for fuel at $2.25 per cord. In order that the table may correspond with those previously given, the figures have been altered to read in cost per acre-foot. Otherwise the figures are those given in the various tables by Vernon and Lester,[a] except those in the last column; there the cost is reduced to unit of lift.

[a] Vernon, John J., and Lester, Francis E., Pumping for irrigation from wells: N. Mex. Agric. Exp. Sta. Bull. No. 45, 1903.

Cost of pumping at New Mexico Agricultural Experiment Station.[a]

Name of pump.	Pump running at most economic speed, in gallons per minute.	Cost per acre-foot.	Lift.		Cost per foot of lift per acre-foot.
			Ft.	*in.*	
Van Wie	600	$2.05	27	10¼	$0.073
R. D. Wood	600	2.59	28	½	.092
Kingsford	824	2.39	34	5½	.069
Bryon Jackson	944	2.46	36	8½	.067
Fairbanks-Morse	824	2.47	35	8¾	.069

[a] Fuel is dry tornillo wood at $2.25 per cord.

COST OF PUMPING IN CALIFORNIA.

The principal expense of pumping is the fuel, and the great cost of fuel is responsible for the high rate of cost of pumping in Salt River Valley. In order to compare this with the cost where fuel is inexpensive, I give the following table of costs from pumping plants in California. The data were furnished by Thomas H. Means, of the Bureau of Soils, having been collected by his assistant, W. H. Knox. It appears from these data that water is pumped with crude oil and distillate as fuel, at a minimum cost of less than 1 cent per foot per acre-foot, as compared with a minimum of 8 cents in Salt River Valley, using distillate, and 5.4 cents, using electric power. It appears, also, that with fuel at the price paid in California, water is pumped cheaper than the estimated cost with electric power at $50 per horsepower per year, the minimum being 1.18 cents for electric power and 0.8 cent for crude oil. It should be stated, however, that allowance is made in the California rates for little besides fuel. It is thought that due allowance for interest, depreciation, etc., would bring the rate up to at least the estimated rate for electric power.

Cost of pumping in California.

[Data collected by W. H. Knox, of the Bureau of Soils of the Department of Agriculture.]

Owner.	Location.	Kind of pump used.	Source of supply.	Total lift.
				Feet.
M. T. Ireland	Fowler, Cal	Burton, 4-inch	Pond	15
J. Vincent	do	Krogh, 5-inch	Well	22
J. S. Brander	do	Krogh, 8-inch		20
John Hartly	Fresno, Cal	Richardson, 5-inch	Well	45
J. H. Marsh	Lone Star, Cal	Krogh, 6-inch	do	25
Aug. Ganfraw	Sanger, Cal	do	Slough	36
L. C. Jolley	Del Rey, Cal	Sampson, 6-inch	Pond	15

Cost of pumping in California—Continued.

Owner.	Capacity in acre-feet per hour.	Fuel used.	Cost of fuel per hour.	Cost per acre-foot per foot of lift.	Remarks.
			Cents.	*Cents.*	
M. T. Ireland	0.115	Distillate	6 to 7.5	4.3	
J. Vincent	.10	do	17	7.7	Plant not yet regulated for best results.
J. S. Brander	[a].75	Crude oil	12.5	.8	Has been operating two years.
John Hartly	.207	Distillate	10	1.1	Distillate costs 10 cents per gallon.
J. H. Marsh	.15	do	6 to 7.5	2	12-horsepower engine—cost of fuel thought to be underrated.
Aug. Ganfraw	.3	Crude oil	[a]10	.9	
L. C. Jolley	.4	Distillate	11	1.8	

[a] Estimated.

COST OF PUMPING IN EGYPT.

It may be of interest to know the cost of well-established pumping plants abroad. Thomas H. Means, of the Bureau of Soils, who is familiar with irrigation operations in Egypt, has kindly furnished the following information for this paper:

Cost of pumping drainage water at Mex, Egypt.

Season.	Acre-feet pumped.	Price of coal per ton.	Cost per acre-foot per foot of lift.
			Cents.
1895–96	141,750		2.42
1896–97	175,800		2.31
1897–98	187,900		2.36
1898–99	230,800	$6.19	1.87
1899–1900	164,430	8.39	2.87
1900–1901	255,960	8.73	2.79

Equipment consists of five Farcot direct-acting centrifugal pumps and two 48-inch centrifugals, with a total maximum capacity of 1,400 cubic feet per second, though the normal output is not intended to exceed 1,125 cubic feet per second; lift about 10 feet. This is one of the largest pumping plants in the world.

Estimated cost of pumping drainage water at Kassasin, Egypt.—Equipment consists of two 30-inch centrifugals and one 20-inch, run by direct-connected double-expansion engines. Total capacity given as 88 cubic feet per second; expenses of plant about $20,000 per year, making cost of lifting about 4.8 cents per acre-foot per foot of lift.

VALUE OF WATER.

Having ascertained the cost of procuring water by pumping, it is well to know what return can reasonably be expected from its use. Prof. Alfred J. McClatchie, of the Arizona Agricultural Experiment Station, has published a paper dealing with this problem.[a] The following table (Table VI of McClatchie's paper) gives the returns realized from the use of water:

Record of principal crops grown on the farm of the Arizona Experiment Station during 1901.

	Amount of water applied previous to planting.	Date of planting.	Date of first irrigation.	Date of last irrigation.	Number of irrigations.	Depth of water applied during growing of crop.	Total amount applied.
	Feet.					*Feet.*	*Feet.*
Wheat sown in moist soil	0.6	Nov. 26	Mar. 4	Apr. 6	3	1.6	2.2
Wheat sown in dry soil	......	....do	Dec. 8	....do	4	2.5	2.5
Wheat sown in moist soil	.6	Dec. 5	Mar. 5	Apr. 11	3	1.5	2.1
Do	.6	Jan. 3	Mar. 7	Apr. 14	3	1.5	2.1
Potatoes	.7	Jan. 9	Mar. 17	May 10	4	1.7	2.4
Do	.7	Feb. 1	Mar. 27	....do	3	1.3	2.0
Do	.7	Feb. 22	....do	....do	3	1.3	2.0
Tomatoes	.6	Feb. 14	Feb. 26	Oct. 28	27	3.7	4.3
Strawberries	.7	Feb. 16	Feb. 16	Dec. 26	36	5.5	6.2
Melons	.7	Mar. 16	Mar. 26	July 8	12	2.6	3.3
Egyptian cotton	.7	Mar. 30	Apr. 11	Oct. 3	13	4.3	5.0
Corn	.6	Aug. 3	Aug. 9	Oct. 7	5	1.5	2.1

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

Record of principal crops grown on the farm of the Arizona Experiment Station during 1901—Continued.

	Date of harvesting.	Yield per acre.	Gross value per acre.	Cost of producing and marketing crop per acre.	Net value per acre.	Net return per foot of water applied.
		Pounds.				
Wheat sown in moist soil	May 22	2,150	$22.55	$10.25	$12.30	$5.60
Wheat sown in dry soil	....do ...	1,850	19.40	9.65	9.15	3.65
Wheat sown in moist soil	May 24	2,120	22.25	10.20	12.05	5.74
Do	May 30	1,920	20.15	9.95	10.20	4.85
Potatoes	....do ...	3,200	80.00	35.00	45.00	18.75
Do	May 25	3,600	85.00	34.50	50.50	25.25
Do	May 30	3,000	70.00	34.50	35.50	17.75
Tomatoes	July 1–Dec. 9	12,300	225.00	75.00	150.00	34.90
Strawberries	Apr. 15–July 15	5,000	500.00	150.00	350.00	56.45
Melons	June 15–July 15	27,000	140.00	26.00	114.00	34.55
Egyptian cotton	Dec. 14	400	68.00	48.00	20.00	4.00
Corn	Dec. 10	1,735	18.00	9.50	8.50	4.05

LOCATION OF PUMPING PLANTS.

From the information previously given it appears that the best places for pumping plants are in the region south of Tempe where water is but a few feet beneath the surface and on the lowlands along the river in the Phoenix region. Unfortunately the lands upon which pumped water would be most useful do not lie at a lower elevation than the areas where that water is most easily obtained. The elevation of the land to be irrigated therefore enters as an important factor. In order to flow water over a certain tract of land it frequently happens that pumps must be placed on comparatively high land back from the river. The farther a well is from the axis of the gravel beds—not necessarily coincident with the present river's course—the more likely it is to encounter unfavorable conditions.

The irregular distribution of materials in the valley fill gives rise to many annoying surprises in constructing wells. Certain wells have entirely failed where every known condition promised success. On the other hand, wells have been successful in localities which gave little promise. It is obviously impossible to foresee in more than a general way what conditions are to be met with in sinking wells. The figures which follow are diagrammatic illustrations explaining conditions known to exist in Salt River Valley. In fig. 25 let A and B represent two wells with the water standing 20 feet below the surface in each well. Assume (1) that the material in which they are put down is all water-bearing gravel with one-third of the space occupied by water; it is plain then that a lowering of 30 feet, for example, will yield water represented by one-third of the space *a b h f*—the space in heavy lining. (2) Assume that *a g c* is impervious clay and *a c f* is water bearing; then a lowering of 30 feet in either well would yield water represented by one-third of the space *a i h f*—the shaded portion of No. 2. (3) Assume that *a g c* is gravel and the rest clay; then a lowering of 30 feet in well A will yield water represented by one-

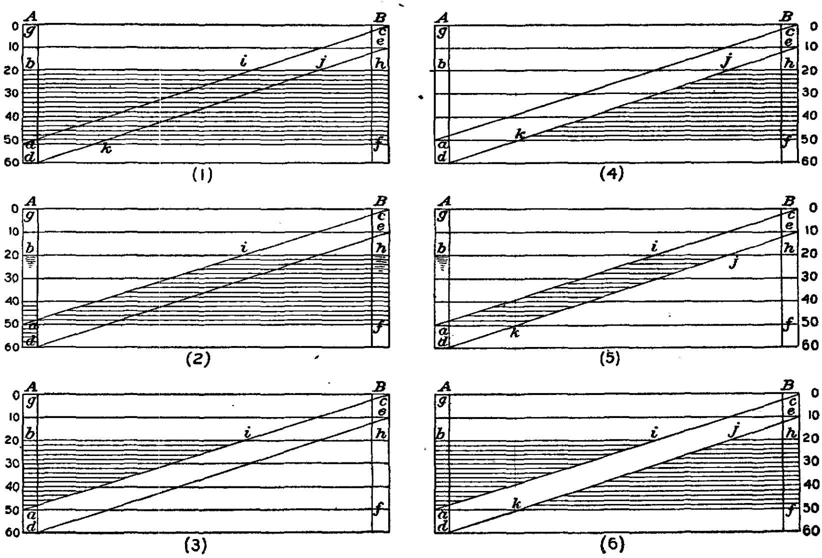

FIG. 25.—Diagrammatic illustrations of underground conditions affecting yield of wells.

third of the space *a b i*, and well B will yield nothing (No. 3). (4) Assume that *d e f* is gravel and the remainder clay; then well A will have no water and well B, in lowering 30 feet, will yield water represented by one-third of the space *k j h f*. (5) Assume that *a c e d* is gravel and the remainder clay; then well B will yield no water and well A only so much as is represented by one-third of the space *a i j k*. (6) Assume that *a c e d* is clay and the remainder gravel; then well A, in lowering 30 feet, will yield water represented by one-third of space *a b i*, while well B will yield water represented by one-third of the space *k j h f;* and the waters may differ in quality as well as quantity.

As a matter of application from the foregoing illustrations it may be stated: (1) That a given set of conditions in one locality will not necessarily be repeated in another, although the two localities are close together; (2) that favorable conditions in one place are not to be interpreted too freely, and, vice versa, that unfavorable conditions in one place are not to be considered entirely discouraging.

RÉSUMÉ.

Some of the more important facts and deductions presented in this paper may be stated as follows:

1. The geological formations which are of most importance in and near Salt River Valley fall naturally in three groups:

(*A*) Pre-Cambrian rocks, consisting of Archean granites and pre-Cambrian quartzites and argillites, in which Salt River Valley was originally formed.

(*B*) Extensive bodies of eruptive rock associated with a limited amount of massive breccia, apparently of Tertiary age.

(*C*) Quaternary and recent formations, consisting of waterworn bowlders, gravel, sand, clay, etc., which partly fill the ancient valley, and are known as the valley fill.

2. The valley fill, at least to a depth of several hundred feet, is regarded as upland or fluviatile accumulation and consists of—

(*A*) River débris, composed principally of waterworn bowlders and gravel of quartzite, quartz, chert, granite, etc.

(*B*) Wash or angular material derived from near-by hillsides.

(*C*) Chemical precipitates, of which caliche is the most important from a geological standpoint. The caliche occurs in more or less impervious layers throughout the valley fill, and serves in many cases to confine the underground water under more or less pressure.

3. The valley fill is not the result of a single period of aggradation. Its accumulation is due to at least two periods of aggradation, perhaps more, separated by a period of degradation.

4. The alternating periods of aggradation and degradation in Salt River Valley correspond with similar periods in other parts of Arizona. Definite correlation of the similar, but widely separated, deposits is impossible at the present time, but uniformity in character and succession over wide areas suggests uniformity of cause.

5. The cause of the accumulation of upland deposits and of the changes from degradational to aggradational condition of streams and vice versa is regarded as due (1) to changes in elevation of the land, and (2) to climatic changes.

6. Salt River Valley is a part of the wide aggraded plain lying southwest of the great continental plateau. Between the plateau and the plain is a mountainous area in which faulting and local crustal movements are numerous. Some of these movements have probably affected Salt River Valley.

7. The isolated peaks and mountain groups in and near Salt River Valley may be due in part to upthrust of crust blocks, but are regarded mainly as remnants of erosion.

8. The plain of which Salt River Valley is a part is due principally to upland accumulations. In the process of accumulation the lowest outlying hills were buried and the higher ones, being only partly buried, are now found rising abruptly from the level plain.

9. The valley fill is saturated with water, and the various beds of gravel are so intimately connected that the water rises to a definite level forming a well-defined water table.

10. During the early part of the accumulation of the valley fill Salt River joined Gila River east of Salt River Mountains, forming in that region the bowlder beds through which the main course of the underflow now finds its way, but at a later stage of the accumulation the river changed to its present course north of Salt River Mountains, forming the uncemented bowlder beds of recent origin, in which the underflow occurs in the Phoenix region.

11. The underground waters are derived mainly from Salt River and to a less extent from the occasional floods entering the valley from the surrounding hills.

12. The valley fill of the Mesa region, to a depth of over 200 feet, consists mainly of river gravels with a subordinate amount of finer material. In the Phoenix region the valley fill consists mainly of fine material with a subordinate amount of river gravels. The river gravels of the Phoenix region occur parallel to the river, and were deposited in a secondary valley, cut in the finer materials of the first period of accumulation.

13. The valley fill is more or less impregnated with various salts derived from the waters of Salt River in former ages and deposited with the detritus.

14. The distribution of the gravel beds and the depth to the water table are such that pumping for irrigation can probably be carried on with profit over an area of 525 square miles.

15. Although some of the underground waters of the valley contain salts in quantities which may be harmful to land under certain conditions, it is probable that with proper manipulation all of the waters can be safely used.

16. The underflow returns in part to the surface in certain places in the valley, making a surface flow estimated as something over 100,000 acre-feet per year.

17. The principal water-bearing horizon is about 15 miles wide in the Mesa region, and extends to a depth of over 200 feet.

18. The quantitative estimate of the underflow, based on experiments, indicates a volume of flow of 148,196 to 287,760 acre-feet per year. At this rate something less than 96 pumping plants of the

average capacity (200 inches) could be operated continuously and retain the water level within pumping distance of the surface.

19. The reserve, or the quantity of water contained in the valley fill at any one time within pumping distance is very much greater than the volume of flow. Conservative estimates place the volume of the reserve of Salt River Valley at from 2,500,000 to 4,000,000 acre-feet.

20. The cost of pumping water in Salt River Valley varies from 5.4 to 13.8 cents per acre-foot per foot of lift, or a cost per acre-foot of pumped water of from $2.50 to something like $5.

21. Since fuel is the great item of cost, the cost could be greatly reduced by the use of electrical power, which might be furnished for about $50 per horsepower per year. At this rate the best pumping plants of Salt River Valley can raise water at a cost of 1.2 cents per acre-foot per foot of lift, or at an average cost per acre-foot of pumped water of something like 75 cents for the present lift.

22. The value of an acre-foot of water applied to irrigation in Salt River Valley varies from $3.65 to $56.45.

23. The volume of underflow is large, but not inexhaustible by the operation of pumps. It is capable of extended development, but there is danger that a greater draft will be made upon it than is consistent with the maintenance of the water level within practicable pumping distance.

INDEX.

O

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 136.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.
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The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the sixty-seventh in Series B, the tenth in Series K, and the thirty-seventh in Series O, the complete lists of which follow (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

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THE DIRECTOR,
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WASHINGTON, D. C.

SEPTEMBER, 1905.

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