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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

OBSERVATIONS

ON THE

GROUND WATERS OF RIO GRANDE VALLEY

BY

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WASHINGTON

GOVERNMENT PRINTING OFFICE

1905

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ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
RECLAMATION SERVICE,
Washington, D. C., January 12, 1905.

SIR: I transmit herewith a manuscript by Prof. Chas. S. Slichter, entitled "Observations on the Ground Waters of Rio Grande Valley," and request that it be published as one of the series of Water-Supply and Irrigation Papers. This report contains results of recent investigations in connection with the underground-water problems of Rio Grande Valley, and it is believed that the facts made available will be of general interest and value.

Very respectfully,

F. H. NEWELL, *Chief Engineer.*

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

OBSERVATIONS ON THE GROUND WATERS OF RIO GRANDE VALLEY.

By Charles S. Slichter.

CHAPTER I.

INVESTIGATION OF THE UNDERFLOW AT THE NARROWS OF THE RIO GRANDE NEAR EL PASO, TEX.

An investigation of the underflow of the Rio Grande was begun in the latter part of August, 1904, at the narrows of the Rio Grande, a few miles above El Paso, Tex., where the stream flows through a narrow gorge of limestone. At this place is the site of the proposed Mexican-American international dam. At the surface of the water the distance between the walls of the gorge is less than 400 feet. The dam site has been investigated by the International (Water) Boundary Commission, organized by the joint action of the American and Mexican Governments, and maps and reports concerning the proposed dam will be found in the Proceedings of the International (Water) Boundary Commission, vol. 2, page 277.

A brief reconnaissance at the site of the proposed international dam indicated that there could be no underflow of any magnitude at this point. The distance between the walls of the gorge is less than 400 feet, and the test borings made by the Mexican commission in 1897 seemed to indicate that the maximum depth to bed rock is 86 feet. A cross section of the gorge, based upon the Mexican borings, is shown in fig. 2. In this diagram the vertical and horizontal scale are the same. A cross section of less than 40,000 square feet could not transmit a large volume of ground water even if other conditions were favorable. The highest velocity ever determined for ground water is about 100 feet in twenty-four hours, and assuming this maximum velocity at the above cross section, and a porosity of one-third in the water-bearing sands and gravel, the daily discharge would be 1,333,000 cubic feet, or 15½ cubic feet per second. The gradient of the water plane at the narrows is but $3\frac{8}{10}$ feet to the mile, and all other indications point to a low rather than a high velocity.

None of the usual indications of an underflow were found at this point. If there was a true underflow a stream undoubtedly would flow perennially in the narrowest part of the gorge. Some miles above the site of the dam the valley broadens and is 2 to 5 miles in width, the sides gradually converging as the gorge is approached. The diminishing cross section would cause any underflow waters in the

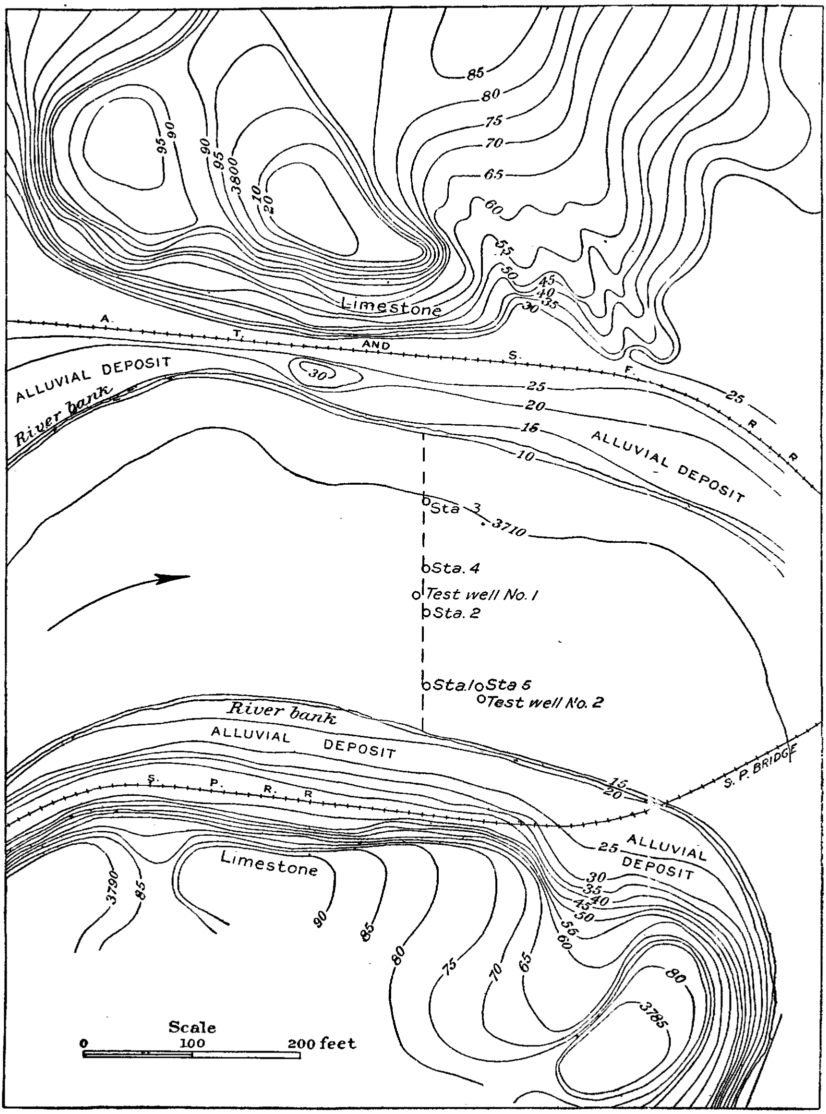
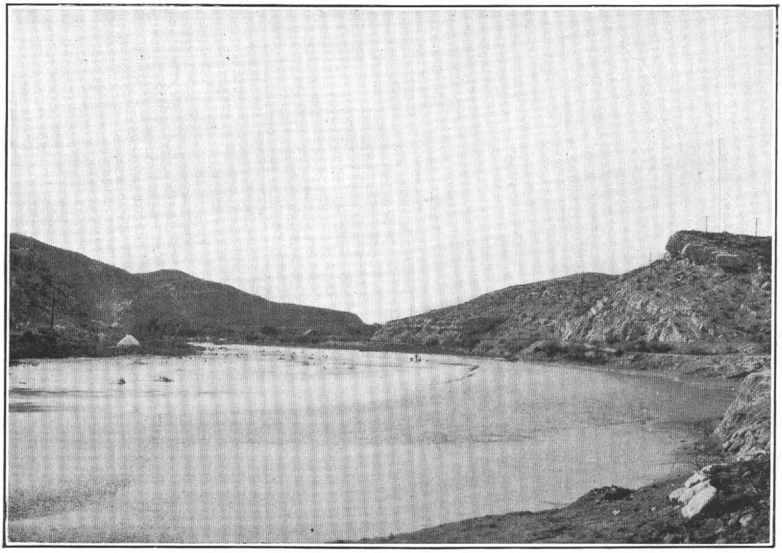
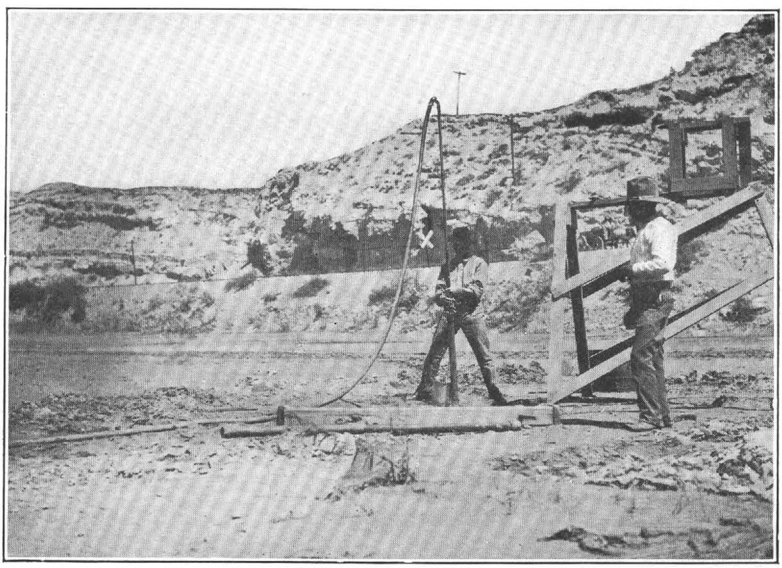


FIG. 1.—Topographic map of the gorge of the Rio Grande above El Paso Tex., where the underflow measurements were made.

valley above the narrows to seek relief at the surface in the narrow gorge and form a perennial flowing stream. Instead of this being the case the river is perfectly dry at the gorge when it ceases to flow above



A. GORGE OF THE RIO GRANDE ABOVE EL PASO, TEX.



B. WASHING DOWN TEST PIPE AT THE GORGE OF THE RIO GRANDE.

the pass. It was dry during several months of 1904. In addition to a perennial surface flow through the narrowest portion of and above the gorge and near its converging sides, the ground waters should have a slightly artesian character. None of these common indications of an underflow were found.

Notwithstanding the above considerations, actual determinations of the rate of underflow were begun, largely on account of a local popular belief that there is an enormous underflow at this point. The results of the investigation are in accordance with general considerations above indicated.

The material in the river bed at the site of the proposed international dam consists of sand and fine gravel with occasional layers of silt. No bowlders were encountered in sinking the test wells and the borings were made with great ease. The ground waters in the sands of the gorge were found to contain a large amount of dissolved solids.

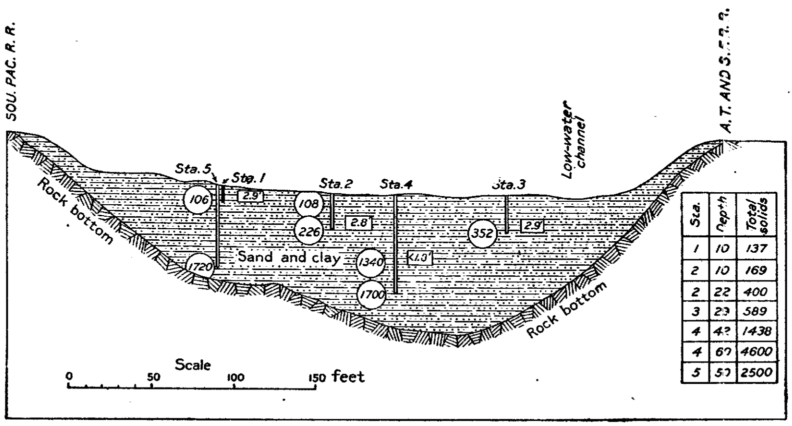


FIG. 2.—Cross section of the gorge of the Rio Grande, above El Paso, Tex., at the site of the proposed international dam.

The numbers inclosed in the rectangles give the velocity of the ground water in feet per twenty-four hours. The numbers inclosed in circles give the amount of common salt in parts per 100,000 dissolved in the ground water. The table at the right gives the depths of the test wells and the amount of total solids found in the water. The supposed rock bottom is given as determined by the Mexican borings, the vertical and horizontal scales being alike.

At a depth of 10 feet the waters contained about 100 parts per 100,000 of common salt, and the quantity became larger as distance from the surface increased. Below a depth of 32 feet so much salt was present that it was very difficult to determine the rate of motion of the ground waters. At a depth of 42 feet the common salt in solution amounted to 1,340 parts per 100,000; at 60 feet it reached 1,700 parts per 100,000; in a 50-foot test hole it amounted to 1,720 parts per 100,000. The total solids dissolved in the ground water were proportionately as large as the amount of common salt, so that at a depth of 40 feet the water was about half as strong as sea water, and at a depth of 60 feet it was about 30 per cent stronger than ordinary sea water. In fig. 2 the positions of the principal test wells are shown.

The velocities as found at stations 1, 2, and 3 were very uniform, being 2.9 feet per twenty-four hours at station 1, 2.8 feet per twenty-four hours at station 2, and 2.9 feet per twenty-four hours at station 3. The greatest depth at which it was practicable to make a determination of the rate of flow was 42 feet, where the common salt in solution amounted to about 1,400 parts per 100,000. In order to increase the conductivity of this water, it was necessary to make use of a stronger electrolyte than ammonium chloride. For this purpose a quantity of ammonium chloride was saturated with a gallon and a half of hydrochloric acid. This mixture was used to salt the upstream well used for determining the rate of the underflow. From the way the apparatus worked it was evident that it is possible to determine the rate of movement of ground waters as strong in salt as the water of the Rio Grande

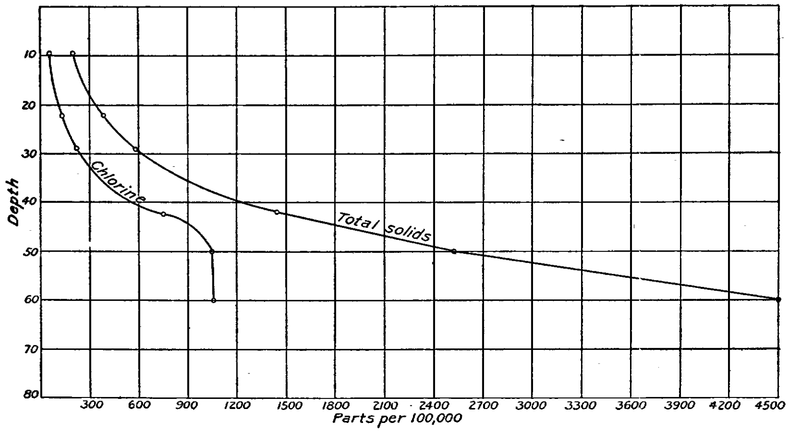


FIG. 3.—Diagram showing the variation with depth of the total solids and chlorine in the ground water at the gorge or narrows of the Rio Grande above El Paso.
The rapid rate of increase in the dissolved solids at a depth of about 40 feet indicates that the water below such depth is stagnant or without appreciable movement.

at a depth of 42 feet; as a matter of fact, however, the water at this depth is either stationary or moves much slower than at higher levels. After waiting three days none of the electrolytes had reached the downstream wells, and it was concluded that there was practically no motion of the ground water at this depth. A few of the test wells were driven to a greater depth, in order to secure samples of the water and to note the amount of contained solids, but no measurements of the rate of motion of the waters were attempted. Fig. 3 represents by curves the variation of the chlorine,[a] and total solids with the depth as determined from the various test wells. This diagram suggests that the water below the 35- or 40-foot level is not moving. The

[a] The amount of common salt is proportional to the chlorine.

increase in total solids is not uniform, but becomes greater below the 35-foot line. The amount of chlorine shows a similar jump at about the same depth, but after increasing suddenly it seems to remain stationary. This may be due to the fact that the common salt in solution originates above the gorge, and has been slowly concentrated during a long time. The total solids, on the contrary, include the dissolved salts of lime, which can become almost indefinitely concentrated from the limestone débris in the gravels of the gorge itself.

It would be interesting to know whether the depth of the most sudden increase in the dissolved salts (say 35 feet) corresponds to the depth of the maximum scour of the river at the gorge.

The velocities of the ground water in the tests described above are undoubtedly the maximum velocities in the narrows of the gorge, since pains were taken to make the tests in the coarsest strata encountered in the borings. Layers of fine silt were frequently met with in putting down the test wells, which probably accounts for the stagnant condition of the water below the 35-foot level. These layers of silt are undoubtedly imbricated in such a way that movement of the deeper ground waters is impossible.

The total cross section in which the ground waters move is about 35 feet in depth and 325 feet in width and has an area of 11,200 square feet. If it is assumed that the porosity of the material is one-third and the maximum velocity of the ground water is 3 feet per day, the total discharge through the gorge does not exceed 11,200 cubic feet per twenty-four hours, or about 0.132 cubic foot per second, or about 50 gallons a minute. This amount of underflow is entirely insignificant. It is obvious that on account of the enormous quantity of dissolved solids the underflow would be worthless, no matter what its magnitude might be.

CHAPTER II.

GROUND WATERS BELOW EL PASO, TEX.

The Rio Grande Valley below El Paso has been studied with reference to possibility of obtaining a ground-water supply from wells. East and north of El Paso is a very level strip of country known as the "Lanoria Mesa." This mesa lies between 4,000 and 5,000 feet above the sea level, and extends as a nearly unbroken plain between two north-south ranges of mountains. On the west the mesa is limited by the Franklin, Organ, and San Andres mountains, to the east it is bordered by the Hueco Mountains, and farther north by the Sacramento Mountains. At the southern end the east and west extent of the mesa is about 20 miles, and at the north it is almost unbroken for 100 miles. The north end of the mesa is interesting on account of several very unusual topographic features. A number of miles west and north of Alamogordo, N. Mex., are depressions which are said to be the channels of an ancient river. A great overflow of lava covers the northern portion of the mesa, and apparently hides the bank of the ancient river channel. About 18 miles north and west of Alamogordo are found the famous "white sands" of New Mexico, which consist of wind-blown hillocks of granular grains of gypsum. The white sands belt has, east to west, a width of 5 to 18 miles, a length north to south of about 40 miles, and an area of nearly 600 square miles.

In the northern portion of the Lanoria Mesa good wells are very rare, and at many places are quite unknown. The ground waters for the most part are highly alkaline and unsatisfactory for use. Running water can be noticed in many places flowing beneath the lava bed, forming a subterranean stream locally called the "Lost River."

In the southern portion of the mesa within 20 miles of the Rio Grande is a very fine-grained, water-bearing sand at a depth of about 230 feet. The water-bearing stratum is between 30 and 60 feet thick where it has been found and the contained water is of an excellent quality. The strongly alkaline waters common in the northern part of the mesa seem to be entirely absent from this portion. The water-bearing sand, however, is too fine grained to furnish wells of large capacity. The origin of ground water in this sand stratum is difficult

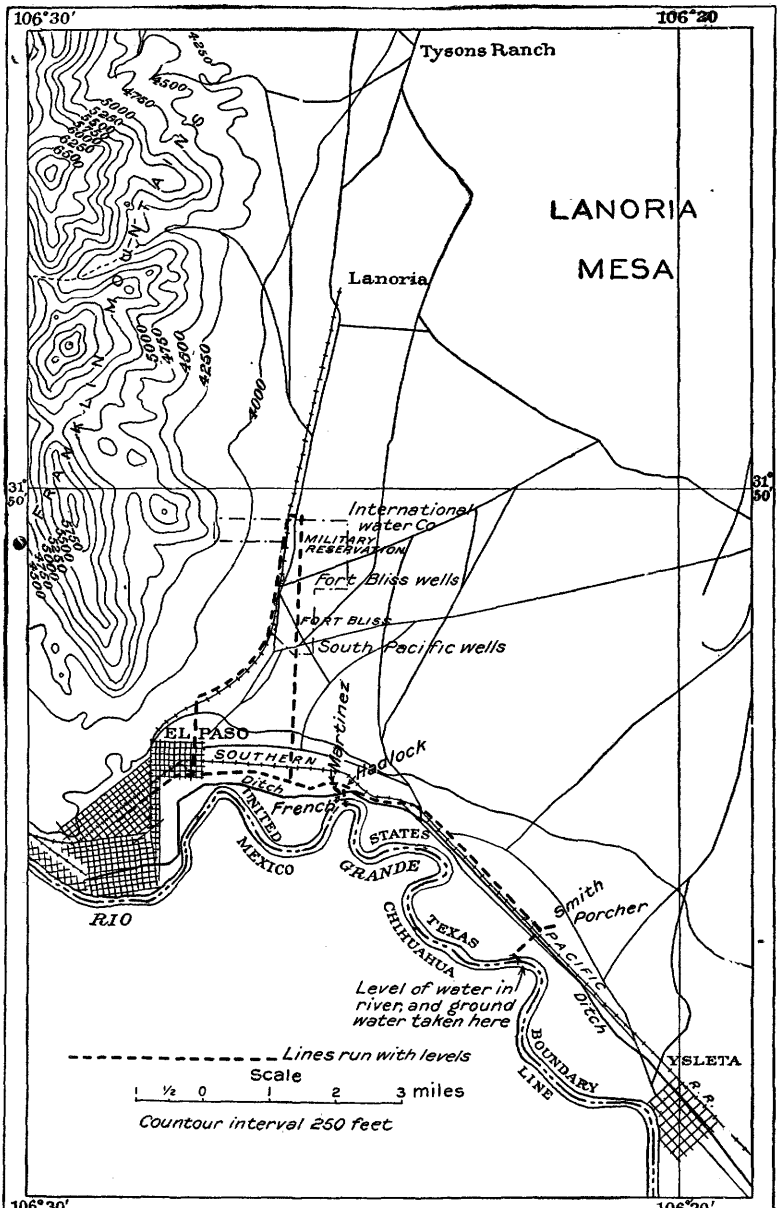


FIG. 4.—Map showing location of wells and pumping plants in the valley and on the mesa east of El Paso. The lines run with level are shown.

to trace. Nearly everywhere in the southern part of the mesa there is within a few feet of the surface from 3 to 6 feet of "caliche," a cemented calcareous impervious conglomerate that prevents the seepage of ground water. The deposit of "caliche" seems to be the result

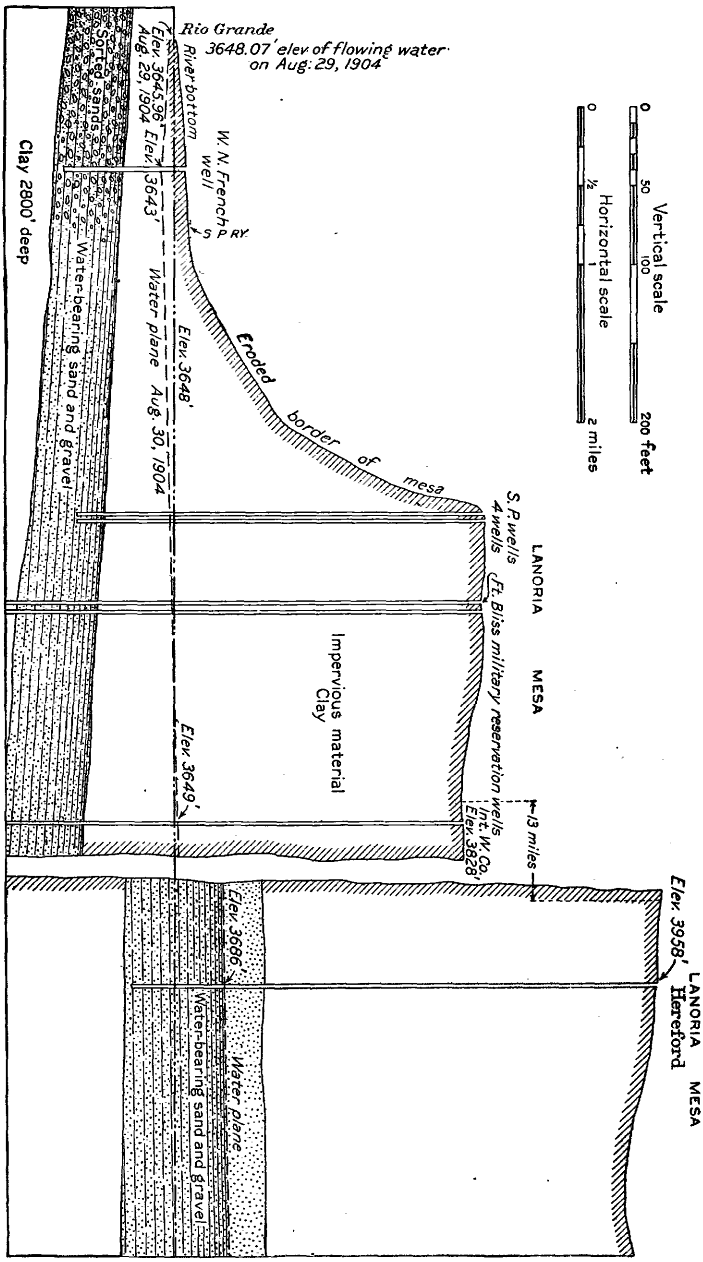
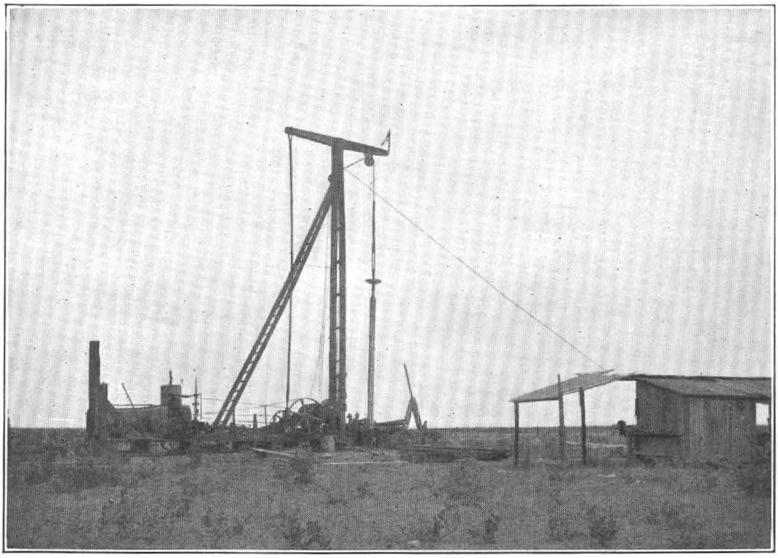
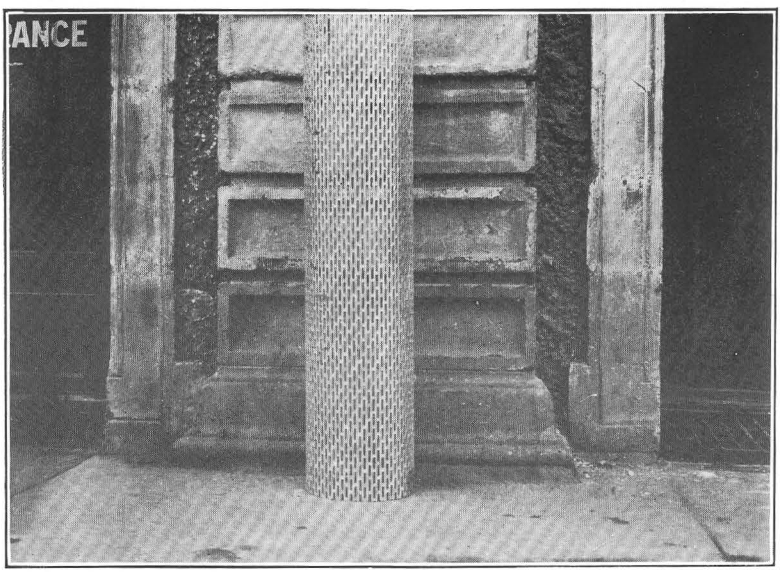


FIG. 5.—Section through Lanoria Mesa near El Paso, from Hereford to French's pumping plant, showing water-bearing sands and position of the water plane.

of the evaporation of the ground water near the surface of the mesa. Whenever this "caliche" is present the rainfall is undoubtedly unable



A. CALIFORNIA WELL RIG.



B. PORCHER STRAINER.

to penetrate the ground for a distance of more than a few feet. The annual precipitation is so slight, not exceeding a total of 9 inches, that the portion that sinks into the ground must soon be evaporated by the intense heat of the sun wherever the "caliche" is present.

It is difficult to believe that the ground water in the stratum of sand referred to above is derived from the run-off from the north-south mountain ranges. These mountain ranges consist very largely of limestone; and the small canyon streams run high in calcium, but the waters found in the sand stratum are very soft and show no indication of having originated in a calcareous catchment area. The most probable source of the water of the sand stratum of the mesa is the rainfall on the mesa itself, especially on limited portions located between 12 and 25 miles north of the Rio Grande. Part of the surface material on the mesa near Hereford is very sandy and is fairly well adapted to receive and absorb a considerable part of the light rainfall. The railroad wells drilled at this point indicate that only a fractional part of the sand stratum is saturated with water, while in the lower part of the mesa in the neighborhood of Fort Bliss, near the valley of the Rio Grande, the water in the sand is found under an artesian head. These facts are brought out in fig. 5. As will be seen by inspection of this diagram, the source of the ground water found in the deep-lying sands and gravels should be sought in the neighborhood of Hereford. The ground water certainly can not have had its source near Fort Bliss, as is proved by its artesian character. North of Hereford a point is reached at which the ground waters are very strongly alkaline, and it is evident that water can not have originated so far north. The contrast between the strong waters in the north and the soft waters in the southern part of the mesa suggests that the waters of the one portion of the mesa must be cut off geologically from those of the other part.

Within a few miles of the southern edge of the mesa several deep wells have been sunk to obtain water from the above-mentioned sand and gravel. Near the southern edge of the mesa the Southern Pacific Railroad has a group of wells designed to obtain ground water for railroad purposes. The wells are 8 inches in diameter and about 270 feet deep, and each contains at the bottom a No. 6 Cook strainer, 7 inches by 20 feet in dimensions. The quality of the water is excellent, but the quantity is very limited. The four wells, each supplied with a Downey double-acting deep-well pump, are able to secure no more than 150,000 gallons in twenty-four hours. About one-half mile north of the Southern Pacific wells two wells have been sunk to obtain water for the use of Fort Bliss Military Reservation. The two wells are about 20 feet apart, the depth of the eastern well being 313 feet and that of the western 319 feet. The wells have a diameter of 8 inches, contain 6-inch suction pipes, and carry at the bottom a No. 6 Cook strainer, $5\frac{3}{4}$ inches in diameter and 8 feet long.

They are pumped by two Cook deep-well pumps, which lift from 52,000 to 86,000 gallons in twenty-four hours. About 200 feet north of the military reservation at Fort Bliss the International Water Supply Company, of El Paso, Tex., has sunk seven 12-inch California stovepipe wells for the purpose of securing a municipal water supply for the city of El Paso. In one of these wells, which ended at the depth of 2,800 feet in a bed of dry clay, no water-bearing stratum was found below the sand referred to above. The yield of the International wells had not been determined, but it was evident from samples of material that it could not be much greater than that at the Southern Pacific or the military reservation wells. A yield of 100,000 gallons per twenty-four hours for each of the seven wells of the International Water Supply Company is probably a large estimate.

At the southern boundary of the mesa the Rio Grande is about 40 feet higher than the top of the water-bearing sand mentioned above (see fig. 5). There is every indication that at the time the river eroded the gorge above the city to the depth of 86 feet it also cut into this deposit of sand and resorted and redeposited the material, carrying away the finer portions. For this reason good wells can be had along the edge of the mesa wherever the river has done its work, except in a few places where the river has carried away all of the sand and left a local deposit of clay and mud. The water in the resorted gravels is very good, but not nearly as soft as the water of the wells on the mesa proper. In these resorted sands and gravels are located the wells used for irrigation in the bottom lands of the Rio Grande. The water found in the sands in the neighborhood of these pumping plants is probably in large part contributed by the Rio Grande. The accompanying table gives partial analyses of water taken from the mesa wells and from the wells in the bottom lands of the river. Furthermore, as shown by fig. 5, on the mesa the water plane slopes very gently toward the Rio Grande and near the irrigation pumping plants it slopes at a higher angle away from the river channel. As can be seen from fig. 5, the water planes on August 29, 1904, at the wells of W. N. French, about 3 miles east of El Paso, sloped away from the river at a gradient of 2 feet to the mile, while the slope from the mesa to French's well was two-thirds foot to the mile. On that date the water plane in the channel of the river stood about 2 feet lower than the surface of the stream. This indicates that the river probably does not furnish very much water to the sand on account of the deposits of silt in the river bed, except at times of flood, when the scour of the river extends to a considerable depth. At such times it is probable that the sands take up and store a considerable quantity of river water, which ultimately finds it way to the pumping plants.

Conditions similar to those mentioned were found about 8 miles east of El Paso, at the pumping plants of J. A. Smith and J. S. Porcher. Fig. 7 shows the slope of the water plane between the river channel

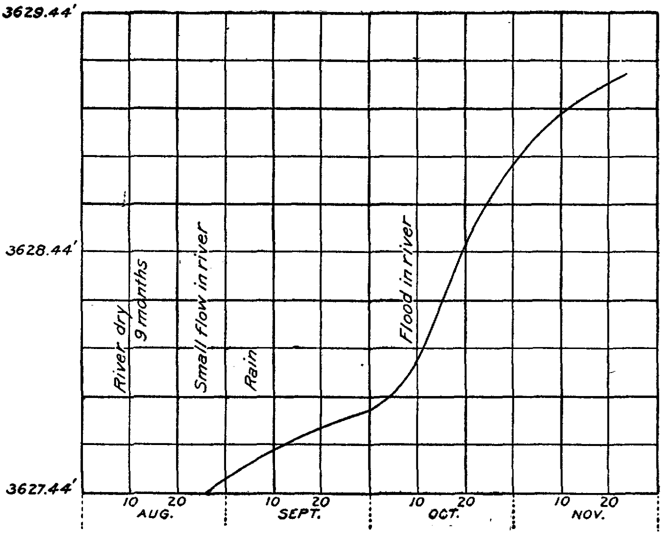


FIG. 6.—Elevation of water plane at Porcher's well No. 1.

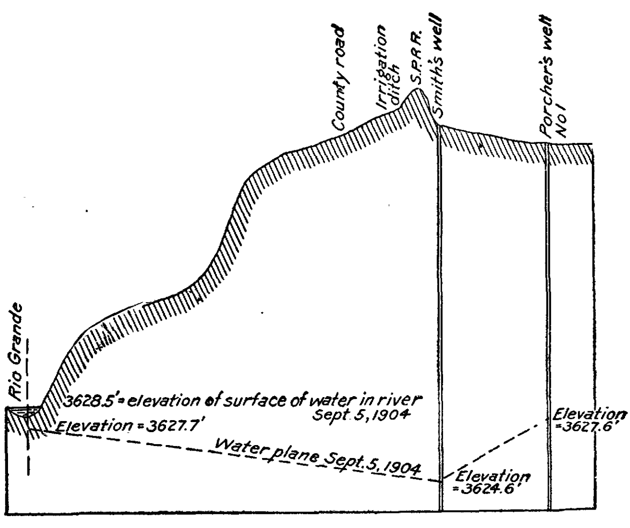


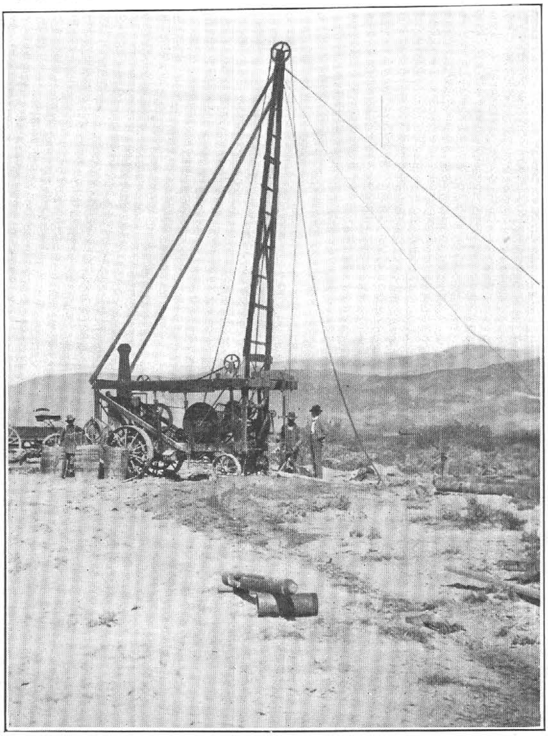
FIG. 7.—Water plane between Porcher's and Smith's pumping plants and the Rio Grande on September, 5, 1904.

and the wells of Smith and Porcher, as determined on September 5, 1904.

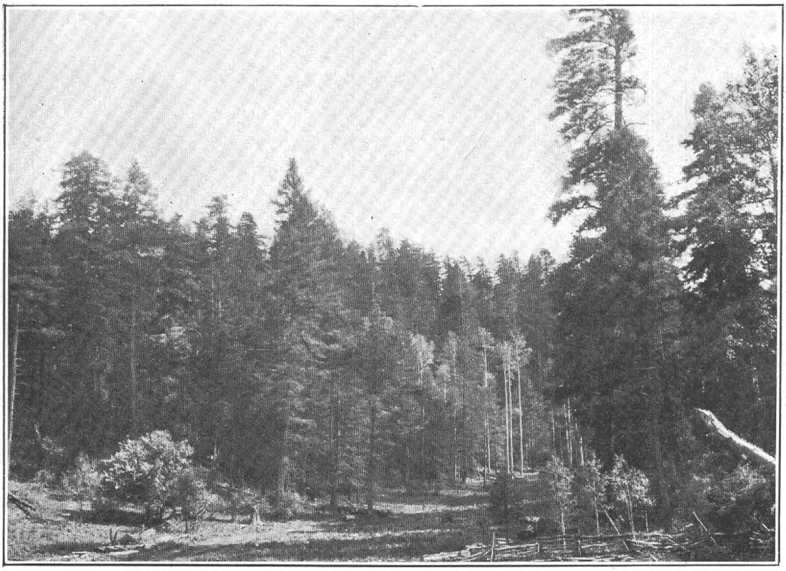
Partial analyses of samples of water from the Rio Grande Valley, Texas and New Mexico.

[In parts per 100,000.]

Name of well.	Depth of well.	Total solids.	Chlorine.	Hardness as $CaCO_3$.	Alkalinity as $CaCO_3$.
Samples taken near El Paso, Tex.:	*Feet.*				
City water, El Paso, Tex	....	127	54.0	70.4	20.0
El Paso Brewery	58	72	21.4	30.0	21.2
Felix Martinez	68	62	13.7	29.6	19.1
E. J. Hadlock	30	104	31.5	47.7	27.7
W. N. French	78	55	11.0	25.0	17.7
J. S. Porcher	60	110	22.6	73.5	25.3
J. A. Smith No. 1	62	174	55.6	67.0	23.0
J. A. Smith No. 2	60	90	18.1	40.8	20.6
Southern Pacific wells	270	42	2.13	11.1	17.5
Fort Bliss Military Reservation	315	29	1.95	10.5	16.4
El Paso and Northeastern at Fort Bliss	250 410	46	2.38	11.3	20.0
International Water Co	260	22	1.48	7.25	11.5
Samples taken near Berino, N. Mex.:					
Horaco Ranch Co. No. 2	53	126	30.9	45.8	29.6
Horaco Ranch Co. No. 1	75	170	54.2	62.8	37.0
Horaco Ranch Co. No. 3	62	203	63.9	59.5	52.5
Samples taken near Las Cruces, N. Mex.:					
G. H. Totten	62	99	19.6	59.8	29.5
T. Roualt	48	76	11.2	47.3	19.4
W. N. Hager	63	71	13.8	50.8	23.6
A. L. Hines	59	73	10.8	47.5	28.5
F. C. Barker	48	96	15.8	58.1	28.7
Mrs. E. M. Boyer	52	57	7.5	38.6	25.1
J. C. Carrera	58	83	11.2	54.2	27.3
Samples taken at the gorge near El Paso:					
River water	....	128	9.6	55.8	11.7
Station No. 2	10	169	63	95	23.0
Do	22	400	137	100	18.6
Station No. 3	29	589	213	139	20.9
Test well No. 1	10	137	65.7	63.6	19.7
Station No. 4	42	1,438	845	245.0	31.4
Do	60	4,600	1,033	224	35.9
Station No. 5	50	2,500	1,040	224	31.4



A. SMALL RIG FOR DRILLING WELLS FOR STOCK.



B. TIMBER ON SACRAMENTO MOUNTAINS.

During nine months ending August 25, 1904, there was no water in the river channel below El Paso. During this time the water plane at the Porcher well No. 1 (an unused well 100 feet from the well of the new pumping plant) fell a total distance of 2 feet, or to an elevation of 3,627.44 above mean sea level. By September 5, 1904, after four days' rain the water in this well had risen 0.15 foot. The record of the week of rain is given in the table below. By October 2 the water plane had risen 0.37 foot (to 3,627.81 feet). On November 20, 1904, it was within 0.3 foot of the elevation before the 2-foot loss noted above, and was still rising at the rate of about one-fifth inch per 24 hours. On March 7, 1905, the water in the well had reached an elevation of 3,630.79, or a total rise of 3.35 feet in seven months. There was water in the Rio Grande during all of this period.

These observations show clearly that the principal source of the ground water near Smith's and Porcher's ranches is seepage from the Rio Grande. A heavy flood about October 9 greatly accelerated the rate of rise of the water plane, as is shown by fig. 6, where the changes in level at Porcher's well No. 1 are represented by a curve.

Rainfall, in inches, at El Paso, Tex., September 1 to 10, 1904, as reported by the United States Weather Bureau.

September 1	0.0	September 7	0.09
September 2	.09	September 8	Trace.
September 3	.53	September 9	Trace.
September 4	.62	September 10	.0
September 5	.16		
September 6	.61	Total	2.10

CHAPTER III.

EXAMINATION OF GROUND-WATER SUPPLIES IN THE MESILLA VALLEY.

The valley of the Rio Grande begins to broaden north of the narrows in the neighborhood of El Paso, Tex. Near Las Cruces, N. Mex., the level bottom lands are about 5 miles wide, and irrigation has been extensively carried on for many years. Besides the city of Las Cruces, there are situated in this part of the valley the villages of Mesilla and Mesilla Park. Between old Fort Selden, north of Las Cruces, and the post-offices of Berino and Anthony, about 12,000 acres are under cultivation.

Owing to frequent shortage in the river supply of water, a number of pumping plants have been installed for the purpose of obtaining ground water for irrigation. One of the first wells for this purpose was drilled by the Agricultural College at Mesilla Park. At this place a coarse water-bearing gravel bed about 12 feet thick was found at a depth of 32 feet. This gravel is overlain by quicksand and adobe. The water level in the wells stood originally 16 feet below the surface of the ground. This well was used extensively for experimental purposes, and later a 12-inch well was put down to the same depth in the neighborhood of the 6-inch well. A great many tests of different kinds of pumps and engines were made at these wells, and a careful study was made of the cost of the recovery of the water, as well as of the amount of land in various kinds of crops that could be irrigated with the water recovered. A report on this work was published in 1903 by Professors Vernon and Lester and issued as a bulletin of the agricultural experiment station at Mesilla Park. As a result of the experiments and of the published reports on the wells at the agricultural station, a number of pumping plants have been installed during the present season, and many more are likely to be established in the near future. For that reason it has become important to have accurate information of the source of the ground-water supply in this part of the Rio Grande Valley and to determine the amount available for such use.

A reconnaissance near Las Cruces and Mesilla Park indicated that there is probably no underflow in this valley in the true sense in which that term is used. The rainfall upon the catchment area northeast of the valley is very slight and the run-off is correspondingly low. It does not seem possible that the ground waters which are used for irrigation could originate very largely in the rainfall upon the neighboring mesa and the foothills and upon the slopes of the Organ Mountains

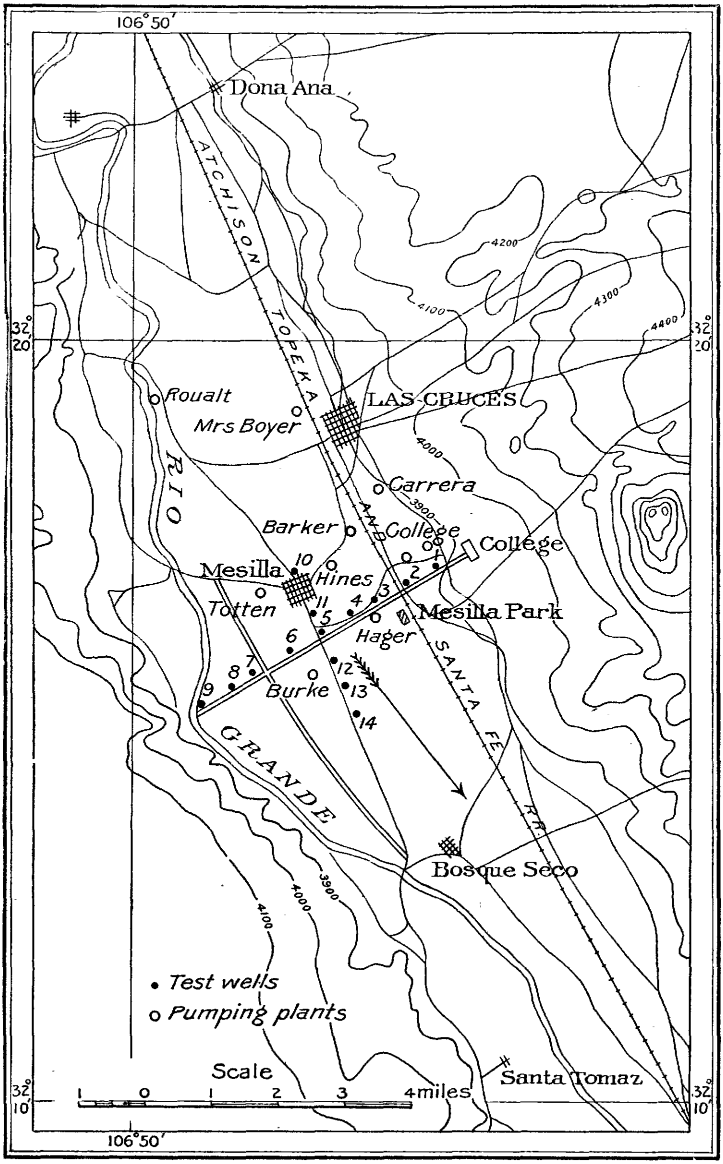


FIG. 8.—Map showing lines of test wells and location of pumping plants near Las Cruces and Mesilla Park, N. Mex.

to the northeast. These mountains are very precipitous, and furnish in all probability a very small amount of run-off to the ground waters of the valley.

TEST WELLS.

For the purpose of determining the source of the ground waters in the Mesilla Valley two lines of test wells were sunk across the valley, one at right angles and the other parallel to the general direction of the river. These test wells were cased with 1½-inch pipe and were provided at the lower end with a common brass jacket well point. They were sunk to such a depth that the strainers would be completely covered with water at all times.

The plan of the test wells is shown in fig. 8. Across the valley are 9 wells on the average of one-half a mile apart. The wells were

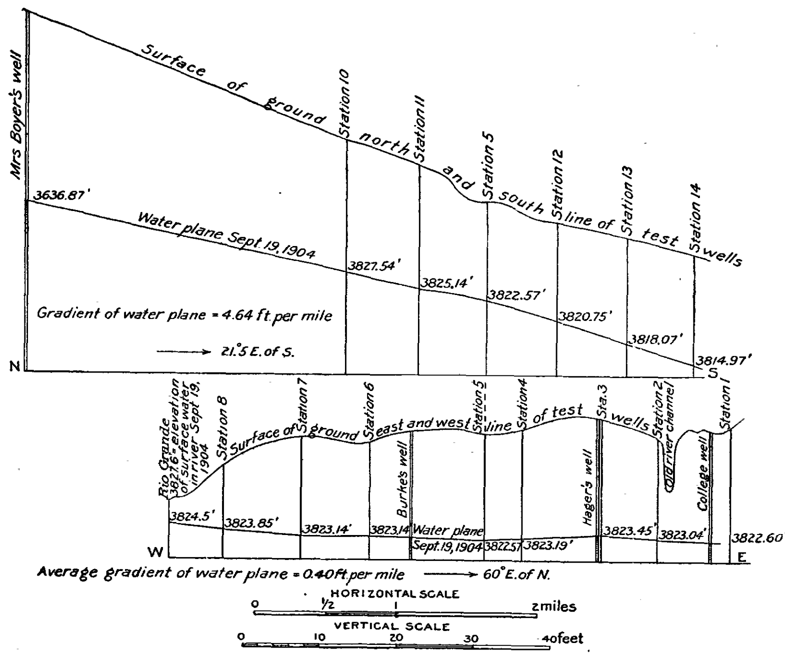


FIG. 9.—Position of the water plane September 19, 1904, in the two lines of test wells shown in fig. 8.

sunk as far as practicable along the public highways, so as to be readily accessible at all times. They were drilled primarily to determine the slope of the water plane in the valley and the changes in the position of the water plane during fluctuations in the level of the flowing water in the Rio Grande. In fig. 9 are shown the results of levels taken on both lines of test wells. In the upper part of the diagram is shown the position of the water plane September 19, 1904, in the wells of the north-south line. The Boyer well, located about 5 miles north of the northernmost 1½-inch test wells, was used as an additional test well, so as to extend the north-south line for a total distance of nearly 6 miles. As will be seen from fig. 9, the gradient of the water plane in the direction of the north-south line of test wells averaged 4.64 feet per mile at the time of the first observation on September 19, 1904. As shown on the lower part of fig. 9 the water plane, in an east-west direction, was nearly horizontal, but near the river it was somewhat higher than at the east end of the line of test wells, although the surface slopes gently in the opposite direction. A slight elevation in this section is seen at station 3. On an average the water plane in the east-west cross section slopes about 0.4 foot per mile toward the east end. It is evident from these cross sections that the ground water must flow in the general direction of the river valley. The direction of maximum slope of the water plane is shown in fig. 8 by the large arrow. This arrow should, therefore, indicate the direction of flow of the ground water. The gradient of the water plane of 4.64 feet per mile is very moderate, and it is probable that the real velocity of the ground water is low. The slight elevation at station 3 indicates that at this point the ground water comes to some extent from the north, and does not move from east to west. If such an east-west movement took place the motion would be uphill for the entire distance from station 1 to station 3.

SOURCE OF THE UNDERFLOW.

When the test wells were sunk it was expected that the position of the water plane in the wells would be observed every week until the time of high water in the Rio Grande, which would naturally be the spring of 1905. The test wells were sunk in cooperation with Prof. J. D. Tinsley, of the Agricultural College of New Mexico, who has made weekly observations of the height of the water plane in them. On October 5, 1904, heavy rains in the Rocky Mountains produced very disastrous floods in the Rio Grande and in nearly all the rivers heading in the Colorado Rocky Mountains. In the neighborhood of Las Cruces the maximum elevation of the river was higher than had been observed at any time in the last ten years. The period of very high water, so soon after the completion of the test wells, furnished an excellent opportunity of observing the effect of the floods in the Rio Grande upon the ground waters of the valley. Instead, therefore, of waiting for the spring floods of 1905, it became possible to determine immediately the essential facts in regard to the effect of the river upon the ground-water level. In Pl. IV the ground-water levels in the east-west line of test wells are given for each month from September 19 to March 26. The first observation taken on October 1 shows that the water had risen 0.4 foot since September 19. On October 9, however, the water at station 8 was 1.6 feet higher than on October 1. This was due to the flood of October 5. The flood raised the ground water at station 8 about 0.7 of a foot more during the next week, but from October 16 to 23 the small rise of 0.1 of a foot indicates that by October 23 the ground-water level at station 8 had temporarily reached its highest position. Therefore, as a result of the flood, the gradient of the water plane immediately adjacent to the river, between stations 8 and 7, increased from 0.7 of a foot per mile to 2.3 feet per mile. The direction of movement of the water in the gravel was therefore undoubtedly downstream, even during times of flood, for while the east-west gradient increased to 2.3 feet to the mile in the immediate neighborhood of the river, the original downstream gradient of 4.64 feet to the mile was not materially affected. The test wells in the north-south line have not shown a departure of more than 0.1 of a foot from the original levels on September 19.

The table contains the observations on both sets of test wells until March 26, 1905. The Rio Grande had water in it continuously during this time. In high stages of the river the water in the wells still further rose, as is shown by the table and fig. 8. The total rise at station 8, located 0.4 mile from the river, was substantially 5 feet. The effect of the river can be traced at least 2 miles from its east bank. The rise at stations 1 and 2 during March, 1905, took place after irrigation had begun and is largely due to that cause.

Elevation of ground water, in feet, above datum,[a] in east-west line of test wells near Mesilla Park, N. Mex.

[Feet above datum.]

Date.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.
1904.								
September 19	22.60	23.03	23.45	23.19	22.57	23.14	23.85	23.85
October 1	22.61	23.10	23.43	23.15	22.85	23.19	23.16	24.25
October 9	22.74	23.21	23.50	23.15	22.85	23.19	23.38	25.85
October 16	22.77	23.23	23.48	23.13	22.86	23.14	23.59	26.18
October 23	22.77	23.23	23.46	23.13	22.83	23.12	23.73	26.22
October 30	22.77	23.21	23.42	23.13	22.86	23.07	23.81	26.28
November 6	22.74	23.18	23.36	23.08	22.84	23.03	23.94	26.36
November 13	22.77	23.20	23.36	23.09	22.86	23.10	24.05	26.38
November 20	22.76	23.16	23.32	23.06	22.83	23.10	24.13	26.34
November 27	22.77	23.18	23.34	23.03	22.83	23.11	24.18	26.42
December 18	22.69	23.08	23.27	23.00	22.84	23.22	24.41	26.59
1905.								
January 15	22.52	22.96	23.10	22.81	22.72	23.25	24.51	26.85
February 5	22.50	22.96	23.05	22.79	22.74	23.48	24.66	26.78
February 26	22.52	22.96	23.01	22.83	22.89	23.73	24.83	27.20
March 12	22.98	23.06	23.01	22.95	23.01	23.82	25.10	28.20
March 26	23.12	23.34	23.12	22.98	23.04	23.97	25.37	28.59

[a] Datum plane 3,800 feet above mean sea level.

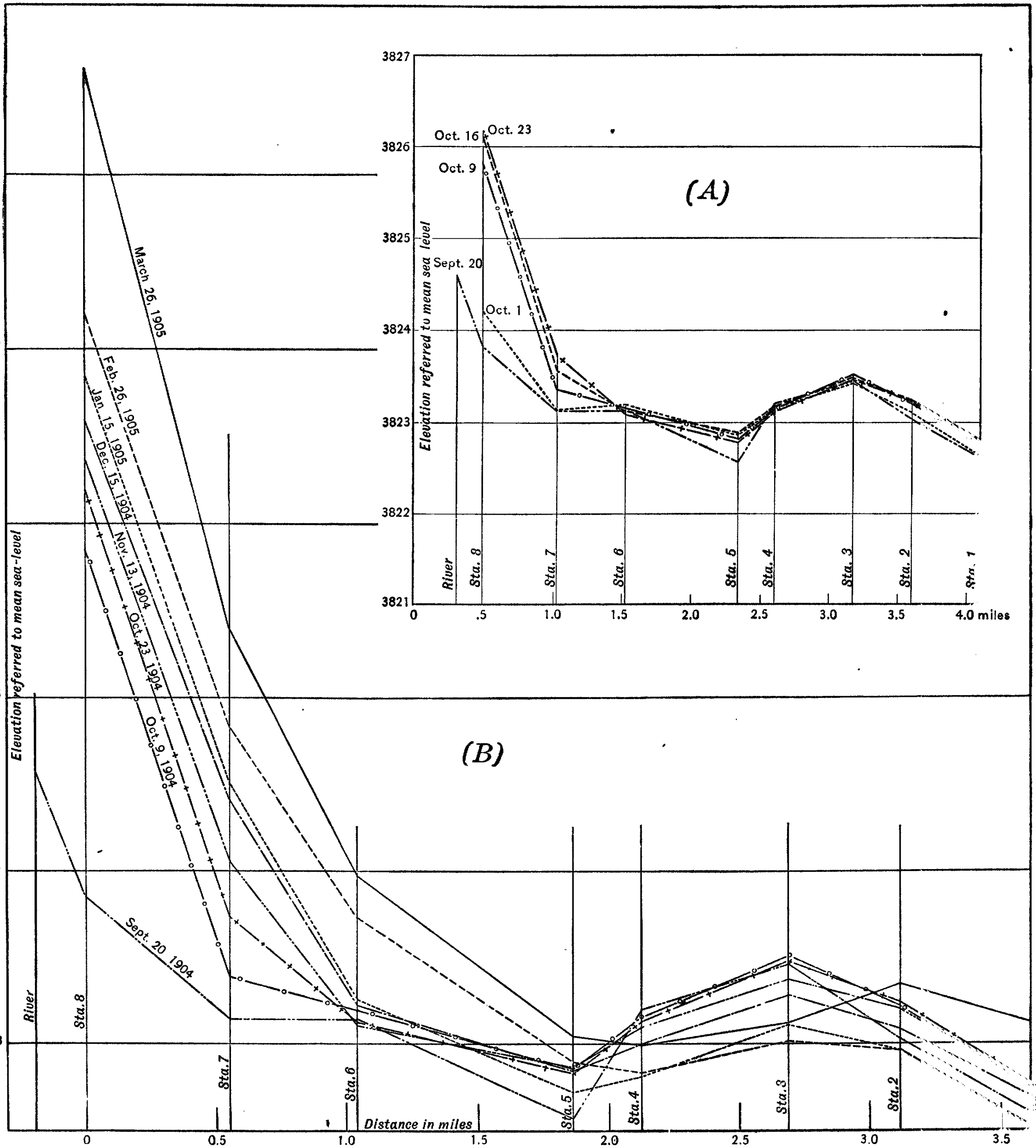


DIAGRAM SHOWING VARIATION IN ELEVATION OF GROUND WATER IN THE EAST-WEST LINE OF TEST WELLS FROM SEPTEMBER 20, 1904, TO MARCH 26, 1905.

Elevation of ground water, in feet, above datum,[a] in north-south line of test wells near Mesilla Park, N. Mex.

[Feet above datum.]

Date.	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.
1904.					
September 20	27.54	25.14	20.75	18.07	14.96
October 1	27.56	25.12	20.65	18.08	14.94
October 9	27.68	25.11	20.71	18.16	15.01
October 16	27.56	25.14	20.71	18.18	15.07
October 23	27.52	25.12	20.70	18.16	15.09
October 30	27.40	25.04	20.63	18.08	15.04
November 6	27.46	25.07	20.65	18.11	15.11
November 13	27.44	25.06	20.64	18.11	15.14
November 20	27.43	25.03	20.63	18.10	15.16
November 27	27.40	25.03	....	....	....
December 18	27.40	25.03	20.64	18.14	15.29
1905.					
January 15	27.25	24.89	20.54	18.05	15.25
February 5	27.29	24.91	20.54	18.18	15.29
February 26	27.46	25.07	20.68	18.50	15.46
March 12	27.59	25.16	20.83	18.59	15.59
March 26	27.59	25.19	20.84	18.58	15.65

[a] Datum plane 3,800 feet above mean sea level.

The observations of the test wells show that the ground waters in the Mesilla Valley originate in the flood waters of the river. During times of low water the river bed is so thoroughly covered with mud that probably only a small amount of water escapes in the sand and gravels of the valley. During the period of flood, when the scour is deep, the contributions of the river to the underflow reach a maximum, as at that time the greatest amount of water is available for this purpose.

The observations of the ground-water level indicate also that a small portion of the underflow reaches the river valley from the mesa and foothills to the north and east of Las Cruces. The changes in the east-west line of water levels reached a maximum at the west end at station 8, with a secondary maximum at the east end at station 1. The high floods in the river were accompanied by rainfall on the mountains and mesa to the north and east of Las Cruces, and a sufficient amount of water penetrated the ground to cause the elevation of the water plane shown at the eastern end of the diagram. It will be observed that the total change in elevation at stations 1 and 2 was 0.2 of a foot. This change took place almost simultaneously with the rise at station 8.

Nevertheless, a slight indication of a lag in the rise of stations 1 and 2 can be observed from the diagram. The table on p. 26 gives the èlevation of the water in the test wells as observed by Professor Tinsley between September 19, 1904, and March 26, 1905.

INDICATIONS OF THE AMOUNT OF GROUND WATER AVAILABLE.

The following table gives the rate at which water was contributed to the underflow at Mesilla Park by the river, and also by the rainfall on the foothills and mountains northeast of the river valley. The total amount contributed by the river during the thirty-three days comprised in the period of observation was 8,900,000 cubic feet of water for each linear mile of the river valley. Of this amount 5,120,000 cubic feet, or more than half, was contributed in eight days, between October 1 and 9, which include the flood beginning October 5. In column 4 of the table is given the rate at which 1 linear mile of the river channel furnished water to the underflow, expressed as a continuous flow in cubic feet of water per second. These same facts are expressed in gallons per minute in column 5. The average rate of contribution for the 33-day period was 3.03 cubic feet per second, or 1,360 gallons a minute. If a plant which pumped continuously 1,360 gallons a minute was installed for each mile of the river valley, all the water contributed by the river would be pumped, and the level of the ground water at the end of the period would be the same as at the beginning. Any greater rate of pumping would have a tendency to lower the water plane below its initial value and make a draft upon the permanent supply stored in the gravels.

In columns 6, 7, and 8 is given the amount contributed to the underflow by the rainfall upon the mesa, northeast of the valley. The total amount contributed during the thirty-three days covered by the table was 1,517,000 cubic feet of water per mile of valley—an average flow of 0.515 cubic foot per second, or 232 gallons a minute. During the last week covered by the table the gravels near the eastern edge of the valley lost water instead of gaining, and the entries in the table for this period are negative. A well pump drawing 232 gallons of water per minute, if operated continuously during the 33-day period, would just consume the seepage from the rainfall contributed by 1 linear mile of the valley.

Amount of water contribution to the underflow of the Rio Grande near Mesilla Park, N. Mex., between September 20 and October 23, 1904.

		Amount of ground water contributed by each mile of the river.			Amount of ground water contributed by rainfall upon mesa east of the valley per mile of river valley.		
1.	2.	3.	4.	5.	6.	7.	8.
Dates.	No. of days.	Cubic feet of water per 24 hours.	Cubic feet per second.	Gallons per minute.	Cubic feet of water per 24 hours.	Cubic feet per second.	Gallons per minute.
September 20 to October 1.....	11	110,500	1.28	575	40,500	0.47	211
October 1 to 9[a]..	8	640,000	7.40	3,330	152,000	1.76	794
October 9 to 16..	7	248,000	2.87	1,290	29,900	.35	155
October 16 to 23.	7	117,200	1.36	745	− 5,950	− .069	− 31
Total.....	33	[b]8,900,000	....	....	[b]1,517,000	....	....
Average per day.	......	270,000	3.03	1,360	45,800	.515	232

[a] Heavy flood on October 5, 1904.
[b] Total amount contributed for each mile of the valley in thirty-three days. Converting cubic feet into acre-feet we find that the river lost 204 acre-feet of water to the gravels of the underflow in thirty-three days, and 34.8 acre-feet were contributed by the rainfall in the same period. These amounts are for each mile of the valley.

NECESSITY FOR DEEP WELLS.

The examination of the underflow of the Mesilla Valley was confined exclusively to the zone of ground waters, in which are all of the irrigation wells of the valley. These wells have a depth of from 48 to 63 feet, and contain no more than 12 linear feet of strainer at the bottom. In some cases quicksand or silt was encountered at the bottom of the water-bearing gravels, but in other cases the drill was stopped while still in good material. There are no deep wells in the valley, but there is no indication that good gravels will not be met with at greater depths than those known at present. There seems to be a reasonable expectation of increasing enormously the specific capacities of the wells, and consequently the amount of ground water available for irrigation by drilling wells to greater depths. There is great need of an experimental well several hundred feet in depth that will test satisfactorily the ultimate possibilities of ground-water supply.

OBSERVATIONS AT BERINO, N. MEX.

Berino is situated in the Rio Grande Valley 15 miles south of Las Cruces. The ground water in this part of the valley lies for the most

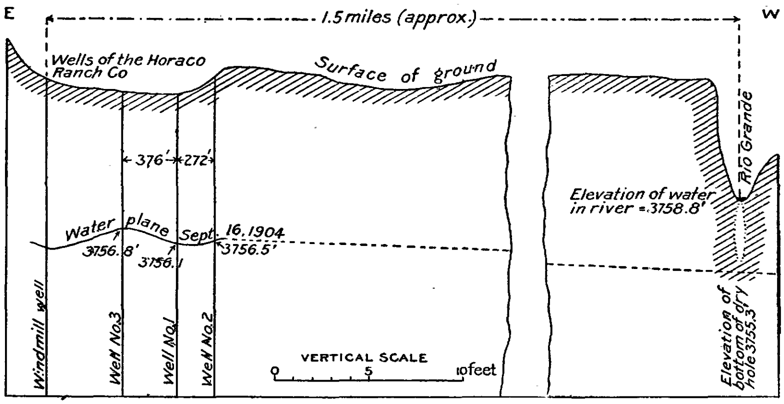


FIG. 10.—Cross section of part of Rio Grande Valley at Berino, N. Mex., showing position of the water plane on September 16, 1904. Water could not be found in a hole excavated 3½ feet below the level of running water at the edge of channel of the Rio Grande.

part within 8 or 9 feet of the surface. There is much "bosque," or lowland, which is covered with dense growth of timber, and in which the water plane is even nearer the surface.

A line of levels was run across the bottom lands of the valley at this point and the wells of the Horaco Ranch Company used to determine the position of the water plane. As shown on fig. 10, the water plane is nearly level in section A at right angles to the river valley, in which respect the situation at Mesilla Park is practically duplicated. A hole excavated to a depth of 3.47 feet below the surface of the running water in the river was dry at the bottom. The water plane is therefore some distance below the running water at low stages of the river, as at Mesilla Park and at points below El Paso. The losses of the river to the sands and gravels of its channel are undoubtedly small during low stages of water when the silt is heavily deposited. The principal contribution of the river to the underflow must take place during flood when the scour is deep.

In addition to the heavy autumn floods described above, very heavy floods came down the Rio Grande Valley during the spring of 1905. There was a good run of water during the entire winter. On this account the ground water at Berino in May, 1905, had risen about 4 feet above the level shown at the pumping plants in fig. 10.

CHAPTER IV.

SUMMARY OF TESTS OF PUMPING PLANTS IN SOUTHERN NEW MEXICO AND TRANS-PECOS TEXAS.

The table on pp. 34–35 shows the results of tests of a number of pumping plants used for irrigation in the valley of the Rio Grande in southern New Mexico and trans-Pecos Texas. Most of the headings in the table explain themselves. Under the heading "Location" is given the post-office nearest to the ranch on which the pumping plant is located. The first three pumping plants, those of Felix Martinez, W. N. French, and E. J. Hadlock, are located about 3 miles east of El Paso, Tex. The plants of J. A. Smith and J. S. Porcher are situated in the valley of the Rio Grande about 8 miles east of El Paso, Tex. The plants of Barker, Boyer, Burke, Carrera, Hager, Hines, Roualt, Totten, and the Agricultural College are located in the valley of the Rio Grande in the neighborhood of Las Cruces, N. Mex. The pumping plants of the Horaco Ranch Company are located near the post-office of Berino, N. Mex., which is situated 24 miles north of El Paso and 17 miles south of Las Cruces.

The fuel used in most of these pumping plants is gasoline, which term as here used includes the "distillate" manufactured from Texas crude oil, which is extensively used for fuel purposes. Its calorific value is somewhat less than that of the gasoline used in the Eastern States.

DETERMINATION OF VACUUM.

In all of the plants, except the one of E. J. Hadlock, water is raised by means of centrifugal pumps, which are usually coupled directly to the top of the well casings. In order to determine the suction of the pumps it was necessary to drill a hole in the goose neck of the centrifugal pumps and insert the vacuum gage. The measurements to determine the distance the pumps were obliged to lift the water were made from this vacuum-gage tap as datum in all cases. In column 6 is given the distance the pump is required to lift the water above the vacuum-gage tap. In column 7 the vacuum reading is given in feet of water. The total lift of the pump can, therefore, be found in each case by adding the corresponding numbers in columns 6 and 7. In column 8 is given the distance that the water in the well is lowered during pumping. If the vacuum gage had been placed at the exact level of the undisturbed ground water, the readings in column 8 would be identical to those in column 7. The numbers in column 8 are less than those in column 7, because in all cases the vacuum gage stood some distance above the natural level of the water in the well.

The vacuum gage was carefully calibrated against a mercury column at an altitude of 3,720 feet above mean sea level, and the corrected readings are tabulated in all cases. In cases in which there were no foot valves in the suction pipe, the depth of the well and the position of the water plane could be determined by sounding through the quarter-inch hole drilled for the vacuum gage.

SPECIFIC CAPACITY.

The numbers in column 11 express the readiness with which the well furnishes water to the pump. In each case the result was obtained by dividing the numbers in column 10 by the corresponding numbers in column 8; column 11, therefore, expresses the amount of water the wells would furnish if the water level in them was lowered but one foot. These numbers constitute what is known as the "specific capacity" of the well, and are large in case of a good well and small in case of a poor well. This subject is more fully discussed in Water-Supply Paper No. 140, Chap. VII.

In column 12 are given the same magnitudes as in column 11, reduced in each case to 1 square foot of well strainer. The numbers in this column, therefore, express the amount of water in gallons per minute furnished by 1 square foot of well strainer under a head of 1 foot of water. They are a numerical expression of the degree of coarseness of the material in which the well is placed.

COST AND OPERATING EXPENSES.

In column 13 are given the costs of the plants expressed in round numbers. They are nearly equivalent in most cases to $100 per horsepower for the total cost of engine, pump, and wells. In a few special cases the cost was higher. In estimating the expense of operation, an allowance of 10 per cent has been made for the depreciation and repairs and of 8 per cent for interest. It is difficult to make an accurate estimate of the proportion of cost that should be charged up to the water recovered by an irrigation plant, on account of the presence of several unknown factors. If the plants were in operation every day in the year it would be relatively easy to make an accurate estimate of these factors in the operating expense. As it is, the plants are in operation for a longer or shorter period, depending on circumstances which vary from year to year. Most of the plants are used merely as auxiliaries to the supply of ditch water. In making the estimate of the charge for interest and depreciation it has been assumed that the plants are in operation for two thousand hours each season. This corresponds to a continuous use of three months of twenty-four hours daily, or two hundred days of ten hours each. It probably represents a fair average of the actual conditions.

In column 15 there is given a charge for labor and such other incidental expense—including oil and batteries—as is not properly included under the head of depreciation. The operation of the gasoline plants can be easily put in charge of unskilled labor, and for the smaller plants full time is not required of such labor.

FUEL COST.

That part of the operating expenses which is properly chargeable to fuel cost can be accurately determined. Column 16 expresses the cost for fuel per hour. Column 18 expresses the cost per acre-foot of water recovered. In column 17 are given the costs of fuel for lifting 1,000 gallons of water through a distance of 1 foot. For the purpose of comparison these results are expressed in fractional parts of a cent.

In column 5 is given the price of fuel. The price of gasoline is given in cents per gallon in barrel lots. The price of electricity is given in cents per kilowatt hour. Cost of wood at the ranch of T. Roualt is that of cottonwood per cord. The price of wood at the Agricultural College of $2.25 per cord is the rate for small Tornillo wood, which has a higher calorific value than the cottonwood used by Roualt.

Principal data derived from tests of Rio Grande pumping plants.

Name of plant.	Location.	Horse-power.	Fuel used.	Price of fuel.	Lift above vacuum.	Vacuum in feet of water.	Amount water is lowered.	Total lift.	Yield, gallons per minute.	Specific capacity.
1	2	3	4	5	6	7	8	9	10	11
					Feet.		*Feet.*	*Feet.*		*Gals. per min.*
Felix Martinez	El Paso, Tex	10	Electricity	$0.05	16.77	25.50	22.16	38.93	378	17.50
W. N. French	do	8	Gasoline	.14	12.65	18.05	13.35	30.70	269	20.20
E. J. Hadlock	do	5½	do	.14	5.20	22.60	13.03	27.80	258	19.80
J. A. Smith No. 1	do	28	Crude oil	.03	14.00	22.70	16.24	36.70	938	57.40
J. A. Smith No. 2	do	22	Gasoline	.14	15.45	26.10	21.00	41.45	1,325	63.20
J. S. Porcher	do	15	do	.14	12.80	23.07	20.59	35.87	658	32.00
F. C. Barker	Las Cruces, N. Mex	5	do	.17	20.18	25.40	22.48	45.58	131	5.83
Mrs. E. M. Boyer	do	12	do	.17	17.60	22.70	19.76	40.30	658	33.30
F. Burke	Mesilla, N. Mex	21	do	.17	14.85	25.60	22.85	40.45	725	31.75
J. C. Carrera	Mesilla Park, N. Mex	8	do	.17	12.65	14.20	8.48	26.85	648	74.60
W. N. Hager	do	12	do	.17	17.17	17.60	15.20	34.77	325	22.30
A. L. Hines	Mesilla, N. Mex	8	do	.17	19.05	17.00	14.08	36.05	271	19.20
T. Roualt	Las Cruces, N. Mex	10	Wood	2.00	8.66	25.50	23.86	34.16	351	16.00
G. H. Totten	Mesilla, N. Mex	28	Gasoline	.17	16.95	26.40	22.50	43.35	464	20.60
Agricultural College	Mesilla Park, N. Mex	20	Wood	2.25	17.10	12.45	11.37	29.55	1,000	88.00
Horaco Ranch Company No. 1.	Berino, N. Mex	12	Gasoline	.17	9.71	14.18	13.75	23.89	837	60.80
Horaco Ranch Company No. 2.	do	12	do	.17	10.36	24.90	23.64	35.26	191	8.10
Horaco Ranch Company No. 3.	do	12	do	.17	11.56	20.80	18.55	32.36	750	40.40

Principal data derived from tests of Rio Grande pumping plants—Continued.

Name of plant.	Location.	Horse-power.	Fuel used.	Specific capacity per square foot strainer.	Cost of plant.	Interest and depreciation.	Labor and other cost.	Fuel cost per hour.	Fuel cost 1,000 foot-gallons.	Fuel cost per acre-foot.	Total cost per acre-foot.
1	2	3	4	12	13	14	15	16	17	18	19
				Gals. per min.		*Per hour.*	*Per hour.*		*Cents.*		
Felix Martinez	El Paso, Tex	10	Electricity	1.21	$1,200	$0.108	$0.050	$0.243	$\frac{1}{27}$	$3.43	$5.75
W. N. French	do	8	Gasoline	1.37	800	.072	.120	.112	$\frac{1}{44}$	2.26	6.13
E. J. Hadlock	do	5½	do	.792	800	.072	.140	.074	$\frac{1}{58}$	1.58	6.02
J. A. Smith No. 1	do	28	Crude oil	1.01	3,000	.270	.180	.0975	$\frac{1}{171}$	.70	3.17
J. A. Smith No. 2	do	22	Gasoline	1.37	2,200	.198	.150	.35	$\frac{1}{94}$	1.43	2.79
J. S. Porcher	do	15	do	1.28	1,500	.135	.150	.21	$\frac{1}{67}$	1.73	4.10
F. C. Barker	Las Cruces, N. Mex	5	do	.337	1,200	.108	.120	.09	$\frac{1}{40}$	3.73	13.20
Mrs. E. M. Boyer	do	12	do	1.969	1,200	.108	.150	.163	$\frac{1}{98}$	1.34	3.47
F. Burke	Mesilla, N. Mex	21	do	.930	1,800	.162	.150	.34	$\frac{1}{52}$	2.52	4.87
J. C. Carrera	Mesilla Park, N. Mex	8	do	3.530	900	.081	.120	.177	$\frac{1}{59}$	1.48	3.16
W. N. Hager	do	12	do	.760	1,200	.108	.150	.31	$\frac{1}{22}$	5.14	9.57
A. L. Hines	Mesilla, N. Mex	8	do	1.790	800	.072	.120	.255	$\frac{1}{23}$	5.10	8.95
T. Roualt	Las Cruces, N. Mex	10	Wood	.62	1,200	.108	.180	.223	$\frac{1}{32}$	3.47	7.91
G. H. Totten	Mesilla, N. Mex	28	Gasoline	.760	2,000	.180	.150	.37	$\frac{1}{33}$	4.34	8.19
Agricultural College	Mesilla Park, N. Mex	20	Wood	2.32	1,600	.144	.200	.52	$\frac{1}{34}$	2.83	4.70
Horaco Ranch Company No. 1.	Berino, N. Mex	12	Gasoline	1.690	992	.090	.090	.16	$\frac{1}{75}$	1.04	2.21
Horaco Ranch Company No. 2.	do	12	do	.173	992	.090	.090	.204	$\frac{1}{20}$	5.80	10.90
Horaco Ranch Company No. 3.	do	12	do	.892	992	.090	.090	.16	$\frac{1}{89}$	1.16	2.46

COMMENTS ON THE RIO GRANDE PUMPING PLANTS.

The pumping plants of Martinez, French, Hadlock, Smith, and Porcher are all located in the bottom lands of the Rio Grande, from 3 to 8 miles east of El Paso, Tex. Column 12 of the table shows that the specific capacity per square foot of well strainer is nearly the same at the plants of Martinez, French, Smith No. 2, and Porcher, ranging from between 1.21 gallons a minute at Martinez's well to 1.37 gallons at French's well. These numbers, it should be remembered, represent the amount of water furnished by each square foot of well strainer for 1 foot head of water, and express, therefore, the degree of coarseness of the material in which the strainer is placed, provided, of course, that the well strainers themselves offer little or no resistance to the admission of water to the well. The specific capacity per square foot of strainer at the Smith plant No. 1 and at the Hadlock plant is much smaller than at the others. In the case of the Hadlock well, the low specific capacity is no doubt due to the fact that three of the Hadlock wells obtain water from above a clay which overlies the sand and gravel from which the fourth well and the neighboring wells of Martinez and French draw their supply. Furthermore, the strainers on the three Hadlock wells consist of nothing but common pipe perforated with round holes. This poor form of strainer is sufficient in itself to cut down very materially the specific capacity of the wells.

The low specific capacity at Smith's plant No. 1 is probably due chiefly to a local deposit of fine-sized water-bearing sand. There is no covering layer of clay over the water-bearing sands and gravels at these wells. The sands contain so little coarse material that fine sand is constantly being drawn into the wells by the pumps. This draft on the sand deposit at the easternmost of the three wells at Smith's plant No. 1 is so great that several wagon loads of gravel have been placed in the pit of the east well to replace the sand removed by the pumps.

The tests of the 9 wells in Rio Grande Valley near Las Cruces, N. Mex., form an interesting study. The relative locations of these 9 wells are shown in fig. 8. The rank of these wells in order of specific capacities per square foot of well strainer is as follows:

Specific capacity, in gallons per minute, of wells near Las Cruces, N. Mex., per square foot of strainer.

	Gals. per min.
Carrera	3.530
Agricultural College	2.320
Mrs. Boyer	1.969
Hines	1.790
Burke	.930
Hager	.760
Totten	.760
Roualt	.627
Barker	.337

The first three of these wells are located near the eastern edge of the river valley, and their high specific capacity is undoubtedly due to coarse mountain débris that has been deposited along the eroded edge of the mesa. The high specific capacity at Hines's plant seems to be an exception to the general lower average prevailing in the intermediate district between the border of the mesa and the river channel, as at the plants of Hager, Totten, Burke, and Barker. The low specific capacity of the Barker well is due in part to its small diameter, and it is to be classed, therefore, with the Burke, Totten, and Hager wells rather than with the Roualt well. This last well is close to the river channel. Its low specific capacity is an indication of the progressive fineness of the deposits as the river is approached.

The specific capacities should be considered exceptionally high in the first wells in the above list, rather than exceptionally low in the others. Even the specific capacity of the Roualt well—over one-third of a gallon a minute per square foot of well strainer—would be regarded as high in many parts of the country.

The specific capacity of the three wells on the Horaco ranch near Berino, N. Mex., present an interesting study. These plants are located but a few hundred feet apart and are identical in all respects except in the depth of the wells. Nos. 2 and 3 are 9⅝ inches in diameter, and No. 1 is 7⅝ inches in diameter. Each has 18 linear feet of well strainer at the bottom, formed by drilling 1½-inch holes in the casing and wrapping the casing with No. 9 galvanized iron wire, leaving one-eighth inch space between. The enormous difference in the specific capacities of these wells is entirely due to the fact that No. 1 is 75 feet deep, No. 2 is 53 feet deep, and No. 3 is 62 feet deep. The small expense necessary to sink well No. 2 from a depth of 53 feet to a depth of 75 feet should change the cost of the water recovered from $10.90 per acre-foot to $2.21 per acre-foot.

Most of the pumping plants near Las Cruces have been very recently constructed, and changes will undoubtedly be made in many of them as the result of the experience of the present irrigation season. The wells at the Agricultural College were the first ones sunk in this part of the valley, and an excellent report on the tests of these wells, by Professors Vernon and Lester, was issued in April, 1903. The very high specific capacity of the college wells has influenced the construction of the other plants. With a few exceptions, it may be said that at the pumping plants in Mesilla Valley the engines and pumps are entirely too large for the wells, or the wells are too small for the pumps and engines. By comparing the high lifts recorded in column nine of the table with the amount of lowering of the water in the well, which is recorded in column eight, it will be seen that the lift of many of the plants can be considerably decreased by increasing the amount of strainer surface in the wells. In most cases this will make necessary the sinking of additional wells, as the strainer surface can not be otherwise sufficiently increased. The necessity of keeping the lift of the pump down to a minimum is greatly emphasized in irrigation plants, and large strainer surface is the first requisite.

The efficiency of the smaller plants can also be increased by the construction of storage reservoirs or ponds for the accumulation of water before it is used for irrigation. In this way the duty of the water can be considerably increased. Barker's plant is the only one having such reservoirs. For plants that yield over a second-foot of water the reservoir is undoubtedly of little additional value.

The investigation showed that generally the speed of the centrifugal pumps had not been properly adjusted, and in nearly all cases was too high. This was undoubtedly due to the fact that the vacuum had never been determined, so that the total lift of the pumps was unknown. A table of observed and of correct speeds follows:

Sizes and speeds (in revolutions per minute) of centrifugal pumps used in the Rio Grande pumping plants.

Name of plant.	Kind of pump.	Actual speed.	Correct speed.
Martinez	Byron Jackson No. 5	1,028	565
French	Byron Jackson No. 4	938	890
Smith No. 1	Fairbanks Morse No. 6		
Smith No. 2	Byron Jackson No. 7	585	592
Porcher	Byron Jackson No. 5	712	629
Barker	Byron Jackson No. 3	1,110	1,244
Mrs. Boyer	Byron Jackson No. 5	730	665
Burke	Byron Jackson No. 6	733	585
Carrera	Byron Jackson No. 5	560	527
Hager	do	668	619
Hines	Rumsey No. 4	594	558
Roualt	Van Wie No. 3	525	
Totten	Byron Jackson No. 6	692	606
Horaco No. 1	Byron Jackson No. 5	695	513
Horaco No. 2	do	700	624
Horaco No. 3	do	692	598

CHAPTER V.

DETAILS OF TESTS OF PUMPING PLANTS.

The following pages contain detailed accounts with diagrams of the various pumping plants discussed in general terms in the preceding chapter of this report. The location of the various plants is marked in figs. 4 and 8.

PLANTS NEAR EL PASO, TEX.

PLANT OF E. J. HADLOCK.

The plant of E. J. Hadlock is located near the main country road near El Paso, Tex., about 400 feet east of the pumping plant of Felix Martinez. Water is pumped by a 5½-horsepower horizontal Otto gasoline engine geared to a horizontal double-acting piston pump. The wells consist of four 4-inch wells, arranged as shown in figs. 11 and 12. Three of the wells, Nos. 1, 2, and 3 in fig. 10, draw surface water from

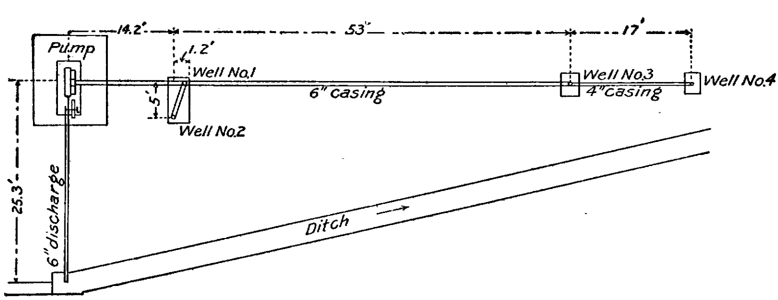


FIG. 11.—Plan showing arrangement of wells at Hadlock's pumping plant.

above a clay stratum. The fourth well, which is 54.35 feet deep and penetrates the surface water and clay, obtains very good water from a deposit of sand and gravel below the clay.

Wells Nos. 1, 2, and 3 are about 30 feet deep. Each of these has 6 feet of perforated iron pipe on the bottom, while well No. 4 has a 6-foot strainer constructed of perforated galvanized iron. During the test the engine made 210 revolutions and 81 explosions per minute. The pump made 69 strokes per minute. The vacuum gage attached to the suction pipe fluctuated very erratically, showing that the pump valves were badly worn. One end of the pump seemed to be working very well and showed a vacuum of 22 inches, which is equivalent, when corrected for altitude, to 20 inches of mercury or 22.6 feet of water. The lift of the pump above the vacuum gage was 5.2 feet, making a total lift of 27.8 feet. The distance from the vacuum-gage tap to the water plane was 9.75 feet. The water in the well was lowered 13.03 feet during pumping.

The discharge of the pump was determined by means of a fully contracted weir, which was placed in the main irrigating ditch. The width of the crest was 1.01 feet, height of water on the crest was 0.313 feet, and the discharge was 258 gallons per minute. The pump cylinders were 9½ by 14 inches. With the speed noted above the pump should discharge, if no allowance be made for slip, 507 gallons per minute. It is seen that the slip of the pump was 49 per cent, which shows that the valves at one end of the pump were doing practically no work at all.

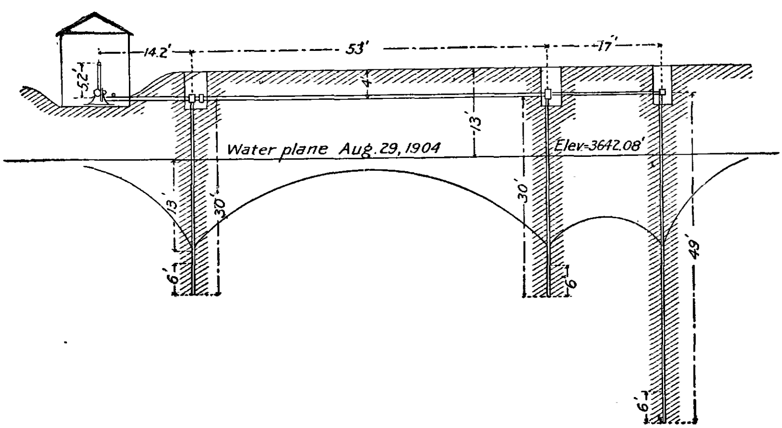


FIG. 12.—Elevation of wells at Hadlock's pumping plant near El Paso, Tex.

At well No. 4 the elevation above mean sea level of the water plane on August 29, 1904, was 3,642.08 feet, that of the top of tee on casing of this well and of the vacuum-gage tap was 3,651.652 feet, and that of the surface was 3,656 feet.

From the discharge (258 gallons per minute) and the amount that the water level in the well was lowered during pumping (13.03 feet), it is estimated that the specific capacity of the group of four wells is 19.8 gallons per minute. As the combined area of well-strainer surface in all of the wells is 25 square feet, the specific capacity per square foot of strainer is 0.792 gallons per minute.

At the time of the test, on August 16, 1904, the Hadlock pumping plant had been in continuous operation day and night for several months. The quantity of gasoline used was determined from the amount required to fill the tank to standard depth after one hour's run. As 2.1 quarts of gasoline were consumed per hour, the hourly cost for fuel, with gasoline at 14 cents per gallon, is $0.0735. The yield of water in one hour was 15,500 gallons, so that the fuel cost was $0.00475 per 1,000 gallons, $1.58 per acre-foot, and $0.000171, or one fifty-eighth of a cent per 1,000 foot-gallons (1,000 gallons raised one foot).

PLANT OF W. N. FRENCH.

At the pumping plant of W. N. French (see fig. 13) water is obtained from an 8-inch well, 66 feet deep, which has a 7-inch by 8-foot perforated galvanized iron strainer at the bottom. The water is raised by a No. 4 Byron Jackson horizontal-shaft centrifugal pump driven by a 10-horsepower Charter gasoline engine. The engine made 189 revolutions and 95 explosions a minute, no explosions being missed. The diameter of the driven pulley on the pump was 6 inches; that of the driving pulley on the engine was 30 inches. The speed of the pump was 938 revolutions a minute. The top of flange on the well casing is 12.65 feet below the top of the 5-inch discharge pipe, which rises from the pump at an angle of 45°. Before pumping, the water stood 4.7 feet below top of flange on the well casing. After one-half hour's pumping it was 18.05 feet below top of flange, showing that it was lowered 13.35 feet by pumping. The lift of the pump above the top flange of the well was 12.65 feet, making a total lift of 30.70 feet. The elevation of the water plane in the French well on August 29, 1904, was 3,642.969 feet; on September 8, after several days of rain, it was 3,643.07 feet. Between August 29 and September 8 it rained every day, and the neighboring pumping plant of Mr. Hadlock had not been in use. The elevation of the top of the delivery pipe at the French well was 3,658.884 feet.

The discharge was measured both by integrating with a Price acoustic current meter in a rectangular flume and by means of a fully contracted weir placed in the main ditch not far from the pumping plant. The cross section selected for the meter measurement had an average depth of 0.857 foot, an average width of 0.885 foot, and an area of 0.76 square foot. The average velocity of the water was 0.82 foot per second, giving a discharge of 0.596 second-foot, or 269 gallons, per minute.

The same discharge was also measured by a fully contracted weir. The length of the crest was 1.01 feet and the height of the water on the crest was 0.30 foot. The velocity of approach was about one-half foot per second. Using the weir formula,

$$q=c. \tfrac{2}{3} \sqrt{2g}\, b\, (\mathrm{H}+1.4\mathrm{h})^{3/2}$$

and substituting the coefficient 0.608 for the number c in the formula (Table 23, Merriman's Hydraulics, 1903) we obtain,

$$q=0.608 \times \tfrac{2}{3} \times 8.025 \times 1.01\ (3.06)^{3/2}$$
$$=0.555 \text{ second-foot}$$
$$=250 \text{ gallons per minute.}$$

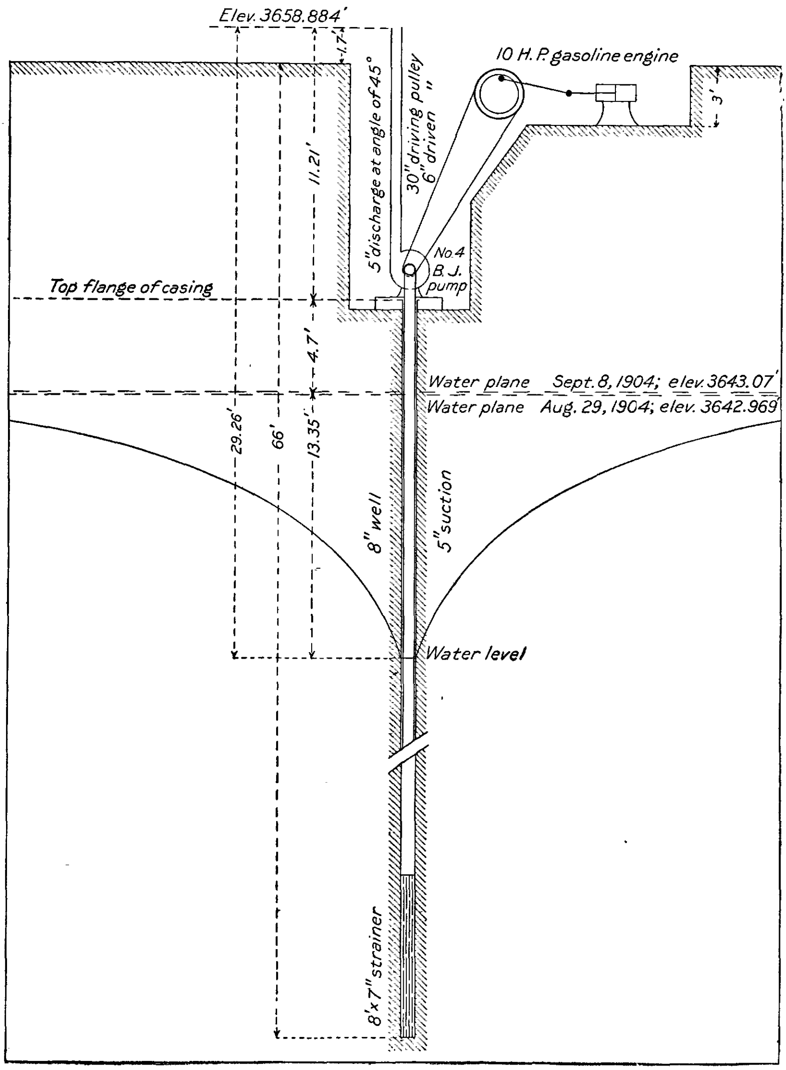


FIG. 13.—Diagram of pumping plant of W. N. French, near El Paso, Tex.

The discharge as determined by the current meter has been used in the following estimates:

The specific capacity of the well is 20.2 gallons a minute. As the strainer has an area of 14.7 square feet, the specific capacity for each square foot of strainer is 1.375 gallons per minute.

In the French test 8 gallons of gasoline were used in ten hours. With gasoline at 14 cents per gallon the cost of fuel is 11.2 cents per hour. As 16,150 gallons of water were obtained in one hour the fuel cost per 1,000 gallons was $0.00695, or $2.26 per acre-foot. The total lift being 30.7 feet the cost per 1,000 foot-gallons was $0.000226, or one forty-fourth of a cent.

PLANT OF FELIX MARTINEZ.

The plant of Felix Martinez is located about 3 miles east of the court-house of El Paso, Tex., near the main country road (see fig. 4). It consists of a No. 5 Byron Jackson horizontal-shaft centrifugal pump run by General Electric 10-horsepower direct-current motor, type C. E., class 4. The pump is located in a pit and is connected to a 6-inch well. The well is 68 feet deep and has 10 feet of perforated or slotted galvanized iron strainer at the bottom. The gravels, which were reached at a depth of 56 feet are fairly large, but contain a great quantity of fine sand. The pump is connected with the well by a 5-inch suction pipe and discharges through a vertical and horizontal 5-inch pipe into a rectangular flume. The discharge was measured by integrating with a Price acoustic current meter in the rectangular flume. The cross section of flume where measurements were taken had an average depth of 0.475 foot, an average width of 0.992 foot, and an area of 0.470 foot. The mean velocity was 1.78 feet per second, giving a total discharge of 0.838 cubic foot per second, or 378 gallons per minute.

The vacuum gage was attached to the goose neck of the centrifugal pump. After a few minutes pumping the vacuum was 18 inches, but it gradually fell to 24½ inches at the close of the first half hour, where it remained constant during the next hour. The vacuum, when corrected for altitude, is equivalent to 22.5 inches of mercury, or 25.5 feet of water.

On August 29, 1904, the elevation above sea level of the water plane was 3,643.13 feet; that of the vacuum-gage tap was 3,646.47 feet, and that of the top of discharge pipe was 3,659.90 feet. As the water level in the well was lowered 22.15 feet by pumping, the total lift was, therefore, 38.93 feet. The specific capacity of the well is 17.5 gallons per minute. As the area of the well strainer is 14.4 square feet, the specific capacity for each square foot of well screen was 1.21 gallons per minute.

The amount of electric current used during the pumping was determined by means of a Westinghouse watt meter. The current used in one hour's test (average speed of motor 1,485 revolutions a minute) was 4,950 watts. Speed of the pump was 1,028 revolutions a minute. The diameters of the pulleys are as follows: Pulley on motor, 7½ inches; driven pulley on countershaft, 24 inches; driving pulley on countershaft, 14 inches; pulley on pump shaft, 6 inches.

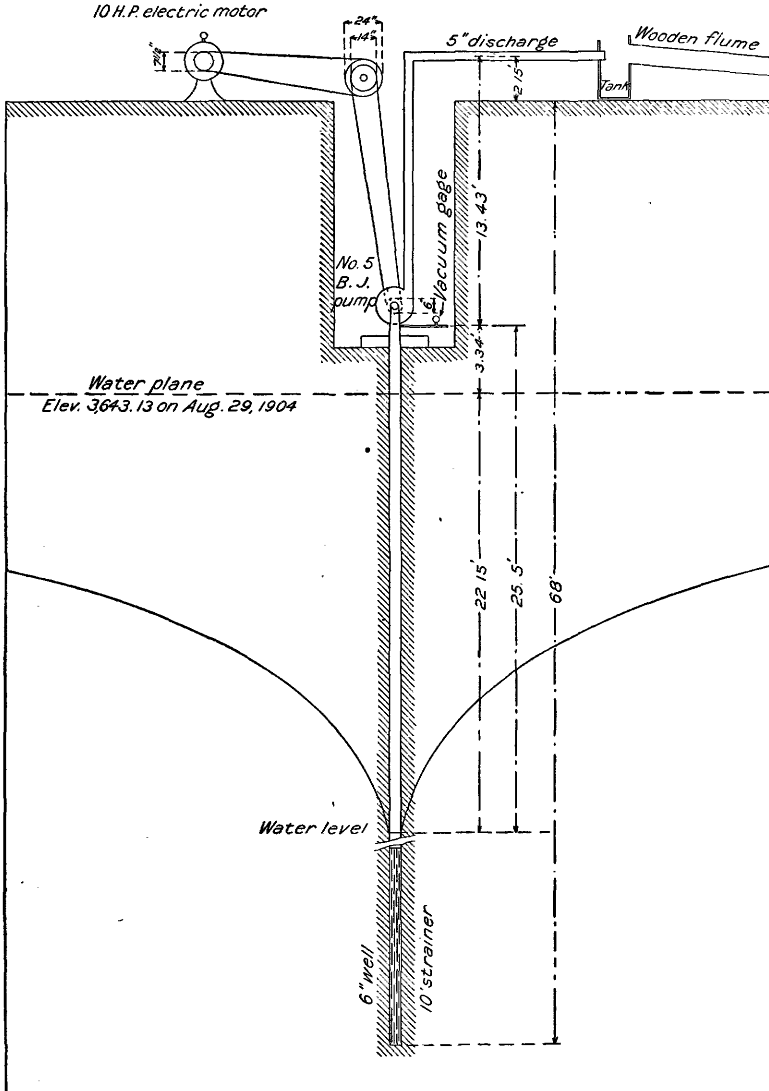


FIG. 14.—Diagram of pumping plant of Felix Martinez, near El Paso, Tex.

The power actually used at the plant is the equivalent of 4,950 watts, or 6.64 horsepower. The power represented by the discharge of 0.838 second-feet of water lifted 38.93 feet is equivalent to 2,030 foot-pounds per second, which is equal to 3.7 effective horsepower. If the applied horsepower, 6.64, is compared with the effective horsepower, 3.7, the total efficiency of the plant is found to be 55.5 per cent. The duty of the plant can be found by comparing 4,950 watts, the electrical energy consumed in one hour, with 655,200 foot-gallons, the work done by the pump in one hour. The resulting duty is 132,400 foot-gallons of water per kilowatt hour of electric current.

PLANTS OF J. A. SMITH.

The plants of J. A. Smith are located 8 miles east of El Paso, Tex., near the right of way of the Southern Pacific Railroad. There

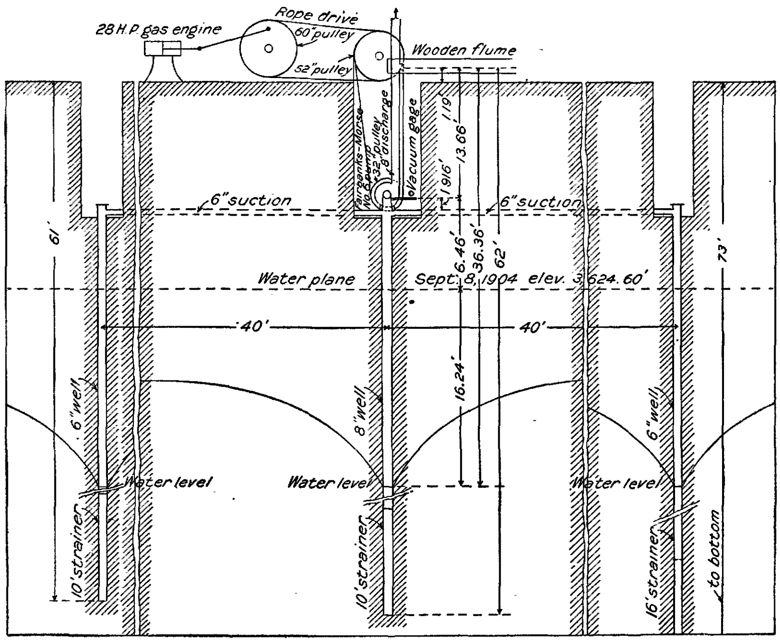


FIG. 15.—Diagram of J. A. Smith's pumping plant No. 1, near El Paso, Tex.

are two pumping plants on the same ranch. At the first or older plant there are three wells, 40 feet apart, in a row. The pump pit is over the middle well, which is 8 inches in diameter and 62 feet deep, measured from the surface. Fine sand and quicksand were passed through to a depth of 50 feet, then 12 feet of coarse gravel containing much fine material was encountered. A 10-foot slotted galvanized-iron strainer of the Porcher pattern was placed at the bottom of this well. The east well is 6 inches in diameter and 73 feet deep. The gravel at this point is 22 feet deep. A 16-foot Porcher strainer was used. The west well is 6 inches in diameter and 61 feet deep. The gravel was 11 feet deep, and a 10-foot Porcher strainer was used. All of the strainers have $\frac{3}{16}$ by $1\frac{1}{2}$ inch slots or perforations. The horizontal 8-inch suction pipe, which extends from the central well to the east and west wells, is 14 feet below the surface.

The water is pumped by a No. 6 Fairbanks-Morse horizontal-shaft centrifugal pump, connected with rope drive to a 28-horsepower gasoline engine, with crude-oil gas generator attached. The fact that the engine is supplied with gas generated from Texas crude petroleum renders this plant of especial interest. For the amount of water obtained the fuel cost is the lowest I have seen recorded for a small plant. The attached gas generator has been in operation several months, running continuously day and night, except when stopped for cleaning each week or two. When the generator is kept clean there is little trouble from carbon passing from the generator into the cylinder of the engine and cutting out the cylinder and packing. This plant is a decided success, as the further account to be given will show. The engine made 159 and the pump 544 revolutions per minute.

The discharge was measured by integrating with a Price acoustic current meter in a rectangular flume. The selected cross section had an average depth of 0.53 foot, an average width of 1.87 feet, and an effective area of 0.992 square foot. The average velocity was 2.085 feet per second, giving a discharge of 2.075 second-feet, or 934 gallons per minute. This measurement of discharge was made after three months of continuous pumping day and night. The elevation of the vacuum-gage tap, which was 0.917 foot above the top of horizontal suction pipe, was 3,631.06 feet; that of the water plane on September 8, 1904, was 3,624.60 feet, and that of the middle of the 8-inch opening in the tee in the side of vertical discharge pipe, from which the water enters a horizontal wooden flume, was 3,645.06 feet. The vacuum read 22 inches, which, when corrected for altitude, is equivalent to 20 inches of mercury, or 22.7 feet of water. The total lift is, therefore, 36.7 feet. The water is lowered in the wells 16.24 feet by pumping, which gives a specific capacity for the three wells of 57.4 gallons per minute. As the total area of the strainers in all of the wells is 56.7 square feet, the specific capacity for each square foot of strainer is 1.01 gallons per minute.

Several accurate tests have been made of the amount of fuel consumed at this plant. One test was made by the manufacturers of the gas generator, and consequently the consumption of crude oil appears at a minimum. This test lasted seventy-four hours and fifteen minutes. The amount of crude oil consumed was 241 gallons, or 3.24 gallons per hour. With oil at 3 cents per gallon, the cost of fuel will be $2.34 per day of twenty-four hours. The cost of water was, therefore, $1\frac{3}{4}$ mills, or ten fifty-sevenths of a cent per 1,000 gallons, or 57 cents per acre-foot. The lift being 36.7 feet, the cost of 1,000 foot-gallons was one two hundred and tenth of a cent.

Another experimental test of the plant was made when the engine was in charge of the regular help employed on the ranch. No effort was made to save oil or make a record, everything being managed exactly as it was during several months of pumping for irrigation. The test was for forty and one-half hours, extending over four consecutive days of about ten working hours each. The amount of crude oil used was 163.5 gallons, or 97 gallons per twenty-four hours, or 4.03 gallons per hour. This represents, therefore, the actual rate at which oil was consumed during the irrigation season. The cost of fuel is $2.90 per twenty-four hours, 12 cents per hour, ten forty-sixths of a cent per 1,000 gallons, and one one hundred and seventy-first of a cent per 1,000 foot-gallons.

The cost of the water at the same plant, when pumped with gasoline, was also determined. In a test of eleven hours' run with same engine, using gasoline instead of crude oil gas, 40 gallons of gasoline were consumed, or 3.64 gallons per hour. At 14 cents per gallon, the hourly cost for gasoline was $0.51. This makes the fuel cost of water $0.0092 per 1,000 gallons and $0.000236, or one forty-second of a cent per 1,000 foot-gallons.

The above estimates do not represent, of course, the total cost of pumping, as no items have been included to cover interest, depreciation, labor, etc.

The 934 gallons per minute furnished by the above plant amounts to a little over 2 second-feet, or 4 feet per twenty-four hours. The cost of fuel per acre-foot of water was, therefore, 70 cents when using crude oil and $2.95 when using gasoline costing 14 cents a gallon.

J. A. Smith's pumping plant No. 2 is about 1,000 feet north of plant No. 1, which is on the same ranch. There are two 8-inch wells, 40 feet apart, in an east-west line. Each one is 60 feet deep and is equipped with 12 feet of Porcher slotted galvanized iron strainer. The gravel bed is 12 feet thick and is overlain by a thick deposit of clay and hardpan. A No. 7 vertical shaft Byron Jackson centrifugal pump is connected to an 8-inch horizontal suction pipe that is 12.25 feet below surface. The pump is 7 feet from the east well and 33 feet from the west well. It was driven at a speed of 585 revolutions per minute by a 22-horsepower Fairbanks-Morse gasoline engine. The engine made 195 revolutions per minute, the engine being belted to the pump shaft from 36-inch driving pulley to 12-inch driven pulley. The vacuum shown at center of the suction pipe was 25 inches, or 23 inches of mercury when corrected for altitude, corresponding to 26.1 feet of water. The vacuum-gage tap is 14.85 feet below the top of the discharge pipe, above which the discharge jet rises 0.6 foot, so that the total lift is 41.45 feet. A vertical 10-inch pipe delivers the water into a nearly horizontal rectangular flume in which the discharge was measured by integrating with a Price acoustic current meter. The discharge was determined to be 2.945 second-feet, or 1,325 gallons, per minute. As the water in the wells was lowered 21 feet below the

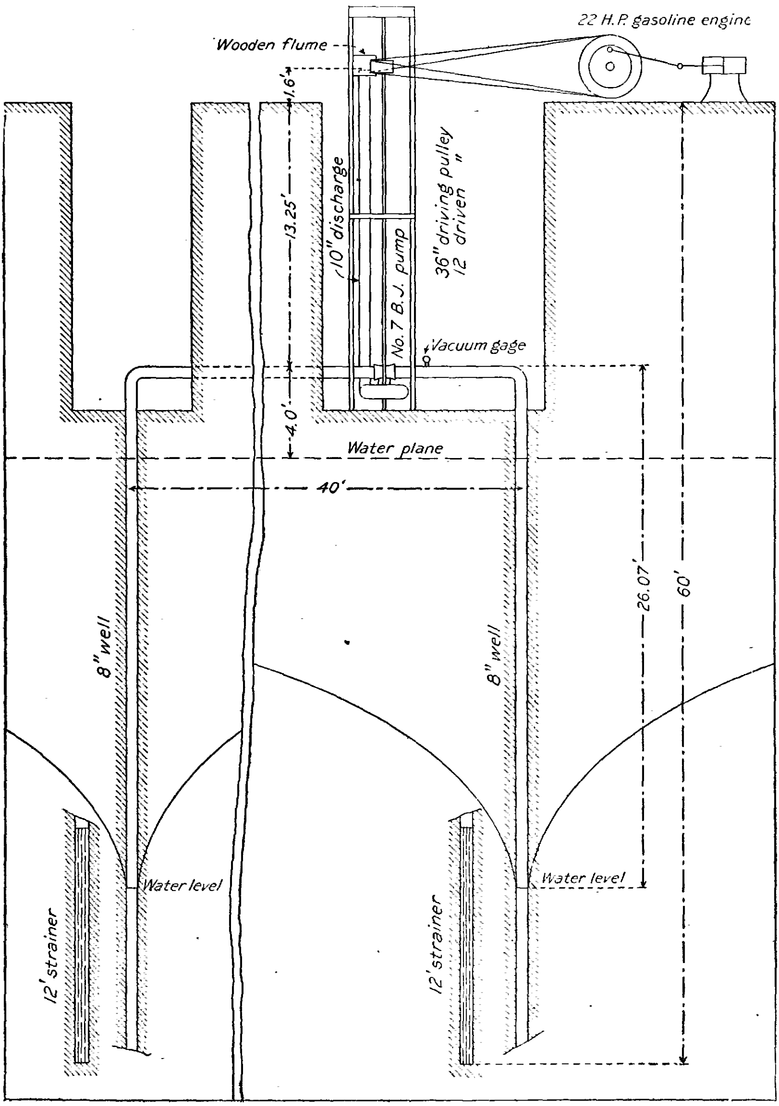


FIG. 16.—Diagram of J. A. Smith's pumping plant No. 2, near El Paso, Tex.

normal water plane by the pumps, the specific capacity of the two wells was 63.2 gallons per minute, or since the total strainer surface is 46 square feet, 1.37 gallons per minute for each square foot of strainer.

The expense of pumping at this plant can readily be estimated as far as the cost of fuel is concerned. The engine, as run in the above test, consumed per hour 2.5 gallons of gasoline or distillate, costing 14 cents per gallon. The fuel cost is, therefore, 35 cents per hour, 0.44 cent per 1,000 gallons, $0.000106, or one ninety-fourth of a cent, per 1,000 foot-gallons, and $1.43 per acre-foot.

PLANT OF J. S. PORCHER.

This pumping plant is located on the ranch of J. S. Porcher, in the Rio Grande Valley, about 8 miles east of El Paso, Tex., and about 1,000 feet east of J. A. Smith's first wells. Water is obtained from a well 8¼ inches in diameter and 60 feet deep. The water-bearing gravel has a thickness of 12½ feet and lies below a layer of quicksand. There is a 12-foot slotted galvanized iron strainer at the bottom of the well. Mr. Porcher first used this type of strainer in the Rio Grande Valley. At the present time this form of strainer is universally used, and is known as the "Porcher" strainer (see Pl. II, *B*). Water is raised by a No. 5 Byron Jackson horizontal-shaft centrifugal pump driven by a 15-horsepower Columbus gasoline engine. The engine made 212 revolutions and 75 explosions per minute. The diameter of driving pulley was 30 inches and that of driven pulley 8 inches. The pump made 712 revolutions per minute. The water is discharged through an 8-inch vertical pipe into a rectangular wooden flume. The discharge from this rectangular flume was measured by integrating with a Price acoustic current meter. The selected cross section had an average depth of 0.1792 foot, a width of 1.92 feet, and an area of 0.344 square foot. The current meter showed that the average velocity was 4.245 feet per second, which gives a discharge of 1.46 second-feet, or 658 gallons per minute. The vacuum gage read 22.4 inches, which, when corrected for altitude, is equivalent to 20.4 inches of mercury, or 23.07 feet of water. The elevation of the ground water at the well on September 5, 1904, was 3,627.59 feet and that of the vacuum-gage tap was 3,630.07 feet, so that the water in the well was lowered 20.59 feet by pumping. As the vacuum-gage tap is 12.8 feet below the top of the discharge pipe the total lift is 35.87 feet.

Since the water level in the well was lowered 20.59 feet, the specific capacity of the well is estimated to be 32 gallons per minute, or 1.28 gallons per minute for each square foot of strainer.

The amount of gasoline used in running the engine was determined in two test runs. During the first test the consumption of gasoline from 6 a. m. to 4 p. m. was ascertained by measurements in the gasoline reservoir. In the ten hours' test there was used 14.3 gallons, or 1.43 gallons per hour. In the second test Mr. Porcher determined the time necessary to consume 5 gallons of gasoline in the engine. At 6.30 a. m. on the day of the test 5 gallons of gasoline were placed in the empty gasoline reservoir. All the gasoline had been used up by 10.20 a. m., so that the consumption was 5 gallons in 3.83 hours, or 1.31 gallons per hour. As the engine was run with considerable care during these

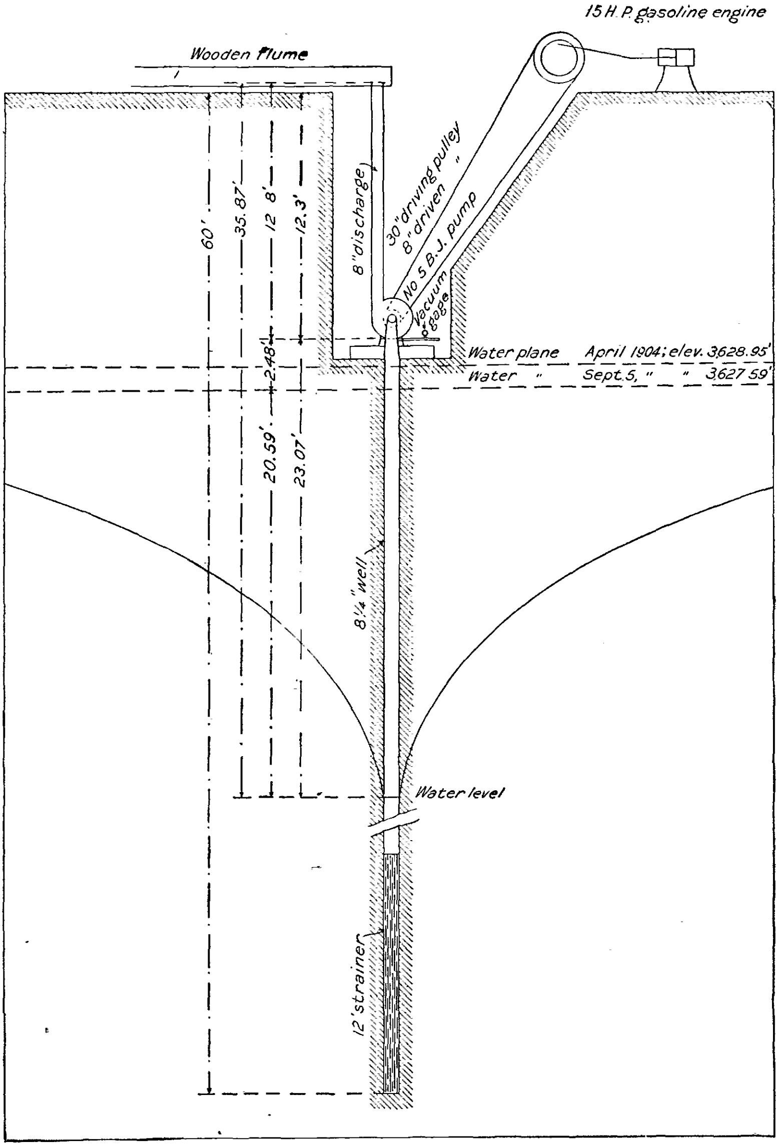


FIG. 17.—Diagram of pumping plant of J. S. Porcher, near El Paso, Tex.

tests, it is probable that the consumption of gasoline normally runs as high as 15 gallons for ten hours. The hourly cost for fuel, with gasoline at 14 cents per gallon, was 21 cents. As 39,500 gallons of water were obtained in one hour, the cost was $0.00531 per 1,000 gallons, $1.73 per acre-foot, and $0.0001, or one sixty-seventh of a cent, per 1,000 foot-gallons.

A 4½-acre field of alfalfa can be irrigated with the pump in from fourteen to nineteen hours. After a rain it was irrigated in fourteen hours, but sixteen hours usually are required. A number of irrigations of the same field have varied from sixteen to eighteen hours each. This field was irrigated every seven days, and the crop taken off at the end of the fourth week, so there were three irrigations to a crop.

With gasoline, or distillate, at 14 cents per gallon, or $2.36 per acre, per crop of alfalfa (three irrigations), the crop cut from the field averaged fully a ton to an acre, and at the selling price of $12 to $14 per ton, the irrigation with the pump could be carried on at a good profit. If the selling price had been as low as $7 per ton there would be no profit in the irrigation of alfalfa by pumping.

TESTS OF PUMPING PLANTS IN MESILLA VALLEY, NEW MEXICO.

PLANT OF F. C. BARKER.

This plant is located on the ranch of Mr. F. C. Barker, about 1 mile south of Las Cruces, N. Mex. The pumping plant is used to irrigate about 20 acres of garden truck. Water is obtained from a 6-inch well, 48 feet deep, containing 12 feet of slotted galvanized-iron strainer at the bottom. The water is raised by a No. 3 Byron Jackson horizontal-shaft centrifugal pump, driven by a 5-horsepower Otto gasoline engine. The engine is belted directly to the pump from a 20-inch driving pulley to a 6-inch driven pulley. The engine made 334 revolutions and from 92 to 97 explosions per minute. The speed of the pump was 1,110 revolutions per minute.

The vacuum-gage tap was 2.92 feet above the water plane in September, 1904, and 17.73 feet below the center of 3-inch horizontal discharge pipe. The lift of the pump above the vacuum-gage tap when discharging into the first of two irrigation reservoirs is 17.73 feet.

The lift above the vacuum-gage tap when discharging into the second irrigation reservoir was 20.18 feet. The vacuum gage read 24.50, which, when corrected for altitude, is equivalent to 22.50 inches of mercury, or 25.4 feet of water. This makes the total lift when filling the second reservoir 45.58 feet.

The discharge of the pump was ascertained by determining, by means of a stop watch, the time required to fill a tank holding 47.6 gallons. As the tank was filled in 21.8 seconds, the discharge of the pump is 0.291 second-foot, or 131 gallons per minute. As the water level in the well is lowered 22.48 feet during pumping, the specific capacity of the well must be 5.83 gallon per minute, or 0.337 gallons per minute for each square foot of strainer.

This pumping plant is unusually well constructed. The machinery is well housed, and there are two concrete-lined reservoirs for storing

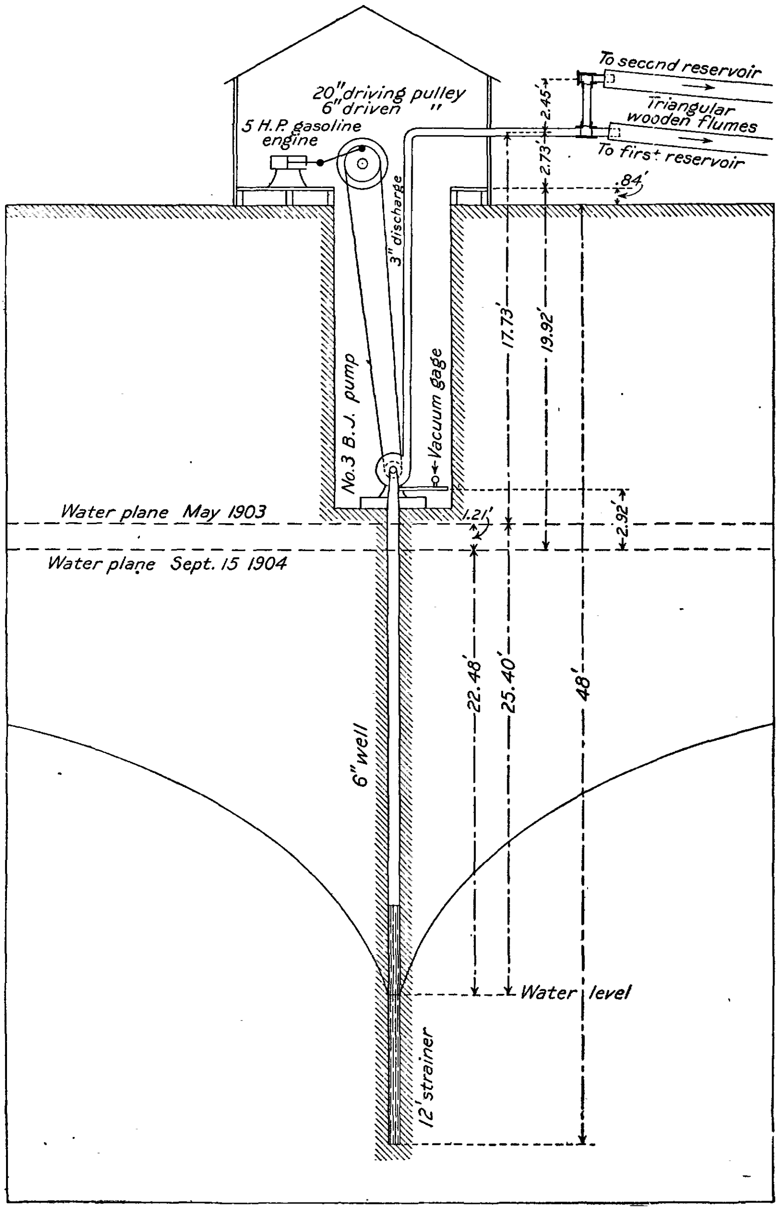


FIG. 18.—Diagram of pumping plant of F. C. Barker, near Las Cruces, N. Mex.

water for irrigation. It takes the pump eight hours to fill a reservoir, which is emptied in about an hour's irrigation. The cost of the plant complete was $1,200.

The amount of gasoline used was not accurately determined, but it hardly exceeded one-half gallon per hour when the engine was developing about its full horsepower. With gasoline at 17 cents a gallon, the fuel cost may safely be put at 9 cents an hour. On this basis the fuel cost of water was $0.0115 per 1,000 gallons, $3.73 per acre-foot, and $0.000252, or one-fortieth of a cent per 1,000 foot-gallons.

PLANT OF J. C. CARRERA.

This plant is located on the ranch of J. C. Carrera, about half way between Las Cruces and Mesilla Park, N. Mex., near the east or upper highway between the Agricultural College and Las Cruces. The well is 6 inches in diameter and 58 feet deep, and is equipped with a slotted galvanized-iron strainer 5½ inches in diameter by 15 feet long. The water is recovered by a No. 5 Byron Jackson horizontal-shaft centrifugal pump, driven by an 8-horsepower Fairbanks-Morse gasoline engine. The engine ran at a speed of 234 revolutions a minute, missing no explosions. The pump was driven at a speed of 560 revolutions a minute by direct belting to engine from 20-inch driving pulley to 8-inch driven pulley.

The vacuum-gage tap was 12.65 feet below the center of the 5⅝-inch horizontal discharge pipe and 5.72 feet above the water, which, when the well was first dug, three years before the test, was 2.7 feet higher than at present. The vacuum gage read 14.5 inches, which gives, after correction for altitude, 12.5 inches of mercury or 14.2 feet of water. The total lift was therefore 26.85 feet. The discharge of the pump was 1.44 second-feet or 648 gallons a minute. The water in the well was lowered only 8.48 feet, so that the specific capacity of the well is 76.4 gallons per minute, or 3.53 gallons per minute for each square foot of well strainer.

Twelve gallons of gasoline were used for eleven hours' run, including the amount consumed by igniting torch. With gasoline at 17 cents per gallon, the fuel cost of water is 17¾ cents an hour, 0.456 cents per 1,000 gallons, $1.48 per acre-foot, and $0.017 or one fifty-ninth of a cent per 1,000 foot-gallons.

PLANT OF FRANK BURKE NEAR MESILLA, N. MEX.

This plant is located on the ranch of Frank Burke, about one-half of a mile south of Mesilla Park, N. Mex. Water is obtained from a 12-inch well, 52 feet deep, containing 11½ feet of slotted galvanized-iron strainer at the bottom. The well passes through 8 feet of soil and sand, 14 feet of quicksand with small pebbles, and 38 feet of sand and gravel of maximum size 3 inches. The water is recovered by a No. 6 Byron Jackson horizontal-shaft centrifugal pump, driven by a 21-horsepower Otto gasoline engine. The engine is belted to a pump shaft from 40-inch driving pulley on engine, thence to a 20-inch driven pulley on countershaft, thence from 16-inch driving pulley on countershaft to 10-inch driven pulley on pump shaft. The speed of pump

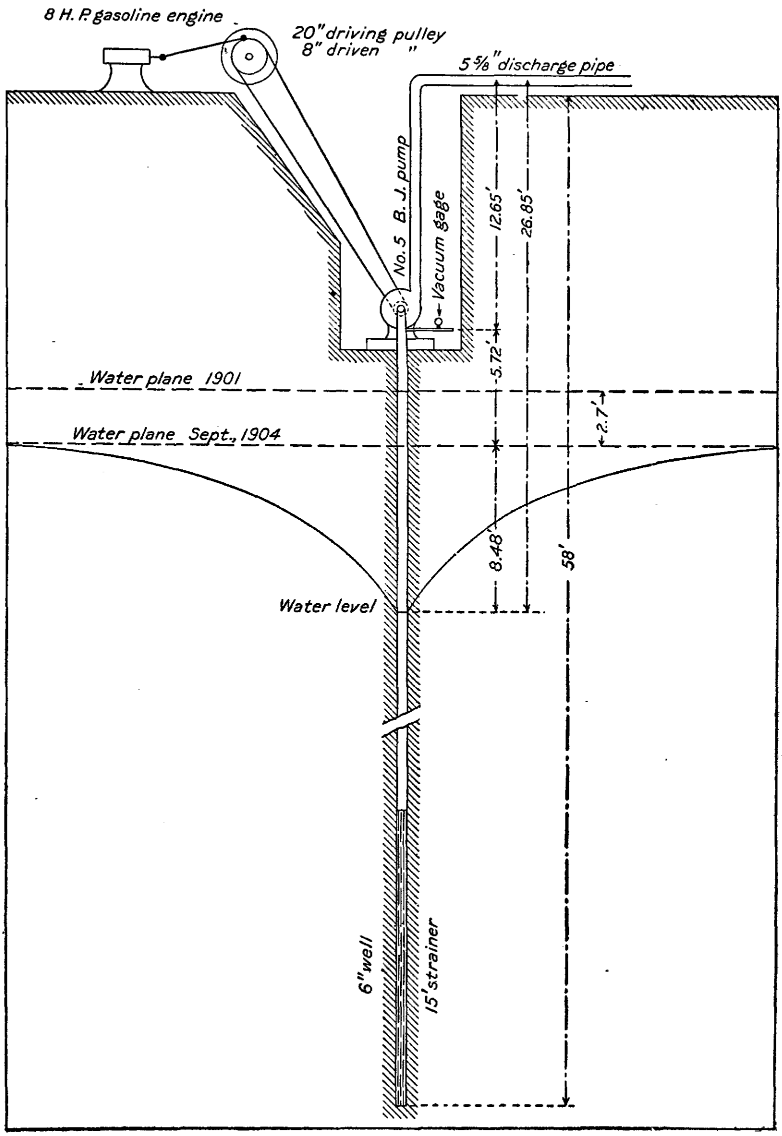


FIG. 19.—Diagram of pumping plant of J. C. Carrera, near Las Cruces, N. Mex.

during the test was 733 revolutions per minute, and of the engine 240 revolutions per minute.

The vacuum gage was placed in the goose neck of the pump, and the tap was 14.85 feet below the center of the horizontal discharge pipe. The vacuum gage read 25.25 inches, which, when corrected for altitude, is equivalent to 23.25 inches of mercury, or 25.6 feet of water. The total lift of the pump was, therefore, 40.45 feet.

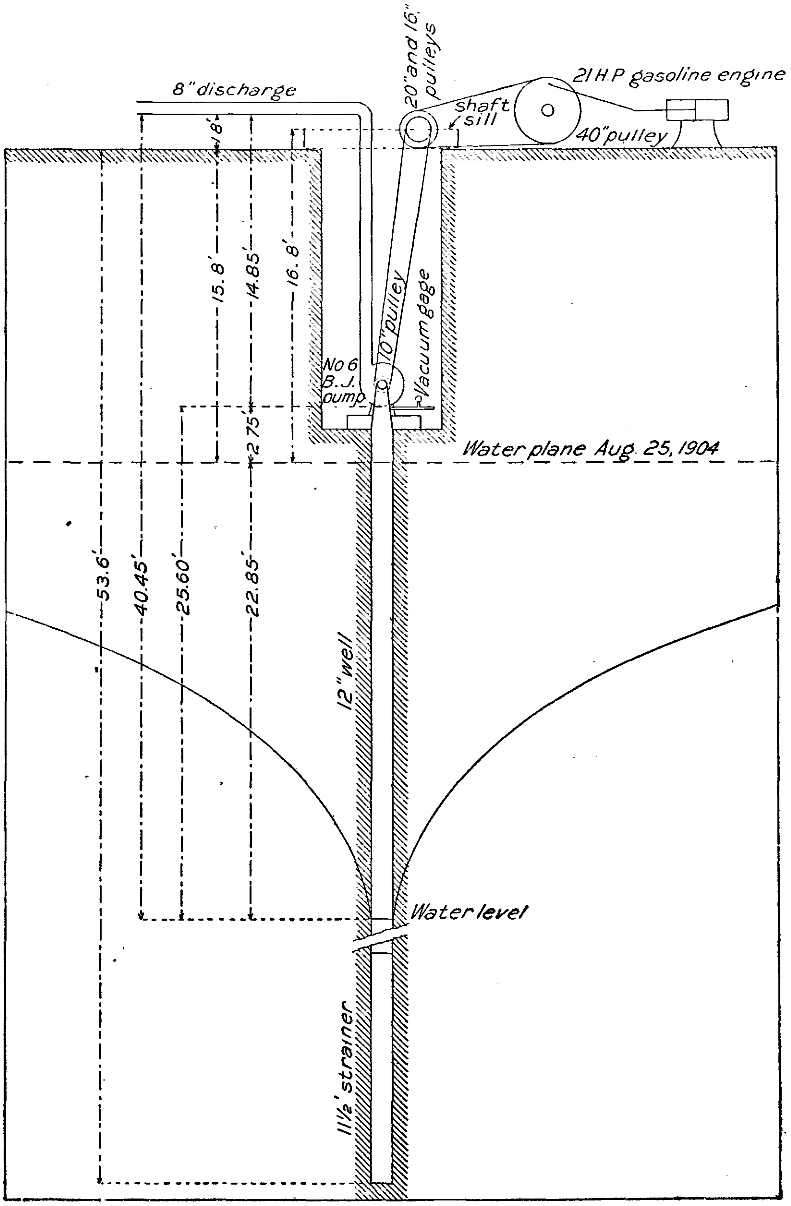


FIG. 20.—Diagram of pumping plant of Frank Burke, near Mesilla Park, N. Mex.

The discharge of the pump was determined by integrating with a Price acoustic-current meter in a rectangular flume through which the water was led after it had passed into the main ditch. The area of the water at the selected cross section was 0.383 square foot, and the mean velocity was 4.21 feet per second, making the discharge 1.61 second feet, or 725 gallons per minute. The level of the water in the well was lowered 22.85 feet by pumping, whence it is concluded that the specific capacity of the well is 25.4 gallons per minute, or 0.934 gallon per minute for each square foot of strainer.

This plant had been run for very short periods and no conclusive estimate of the amount of gasoline consumed can be made. During the test the engine was not run at its full capacity. The gasoline tank was so constructed that an accurate measurement could not be made. The amount of gasoline consumed, however, did not vary greatly from 2 gallons an hour. With gasoline at 17 cents per gallon, the fuel cost of water was 34 cents per hour, $0.0078 per 1,000 gallons, $2.52 per acre-foot, and $0.000193, or one fifty-second of a cent per 1,000 foot-gallons.

PLANT OF MRS. E. M. BOYER.

The plant of Mrs. E. M. Boyer is located about one-fourth of a mile north of the railroad station at Las Cruces, N. Mex. Water is obtained from a well 52 feet deep cased with 6-inch standard pipe. The well is equipped with a slotted galvanized iron Porcher strainer 5½ inches diameter and 12 feet in length. The slots are three-sixteenths by 1½ inches. The well driller reports the following log of the well: 18 inches of soil; dry sand to 20 feet; quicksand below this, changing to coarse gravel and bowlders containing sand, in which the strainer was left. The pumps threw a good heavy stream of water as soon as started, only a few bushels of sand being drawn through the strainer.

Water is recovered by means of a No. 5 Byron Jackson horizontal-shaft centrifugal pump, driven by a 12-horsepower Olds gasoline engine. The engine is directly belted to a pump from 30-inch driving pulley to 8-inch driven pulley. The engine made 208 revolutions and 93 explosions per minute. The speed of the pump was 728 revolutions per minute. The vacuum gage during pumping stood at 22 inches, which, corrected for altitude, is equivalent to 20 inches of mercury, or 22.7 feet of water. On September 19, 1904, the water plane stood 2.94 feet below the vacuum-gage tap, or 3,836.867 feet above mean sea level. The vacuum-gage tap was 14.3 feet below the surface and 17.6 feet below the center of the 6-inch horizontal discharge pipe. The discharge of the pump was 1.46 second-feet, or 658 gallons per minute. The total lift of the pump was 40.3 feet, and the water level in the well was lowered 19.76 feet during pumping. The specific capacity of the well is thus 33.3 gallons per minute, or 1.969 gallons per minute for each square foot of strainer.

A fifty-hour test of this pumping plant was run by F. H. Bascom, of

Las Cruces, who reports that 48 gallons of gasoline were consumed during that time. With gasoline at 17 cents a gallon the fuel cost of

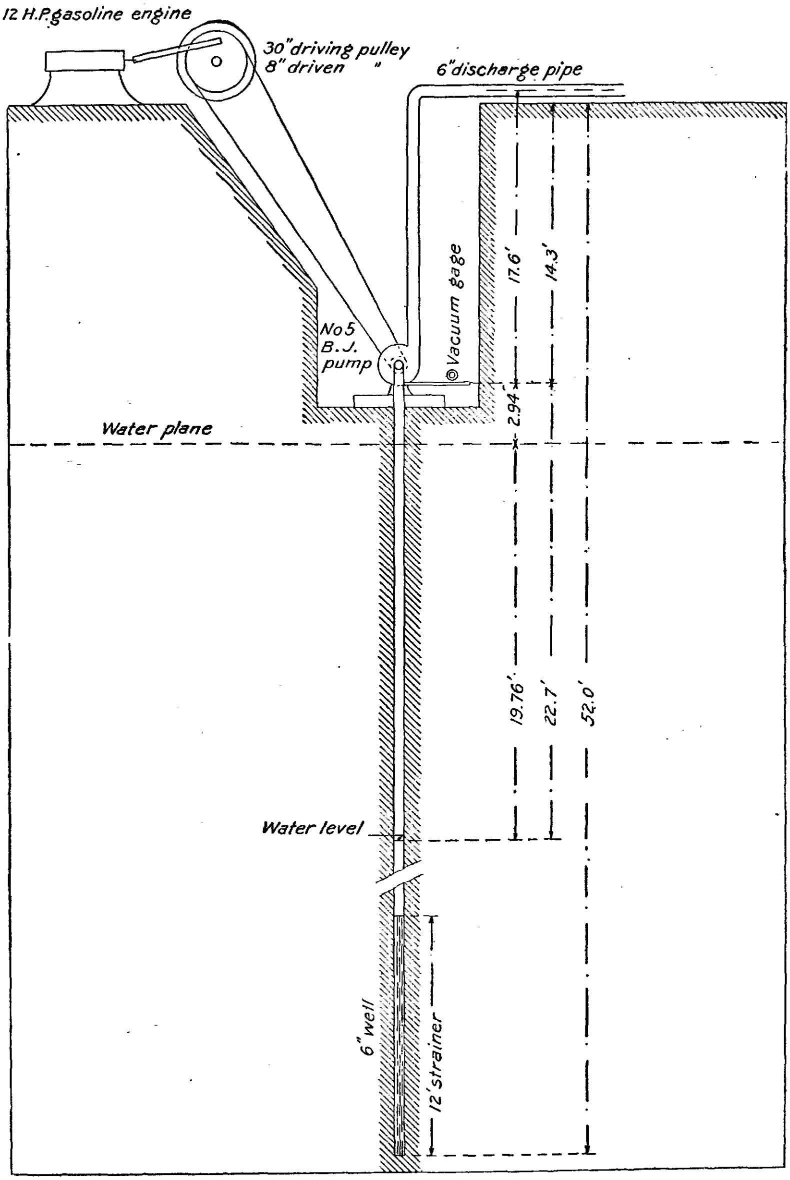


FIG. 21.—Diagram of pumping plant of Mrs. E. M. Boyér, near Las Cruces, N. Mex.

water would be 16.3 cents an hour, 0.412 cents per 1,000 gallons, $1.34 per acre-foot, and $0.000102, or one ninety-eighth of a cent per 1,000 foot-gallons.

PLANT OF W. N. HAGER.

This pumping plant is located on the ranch of W. N. Hager, about one-half mile west of the railroad station at Mesilla Park, N. Mex.

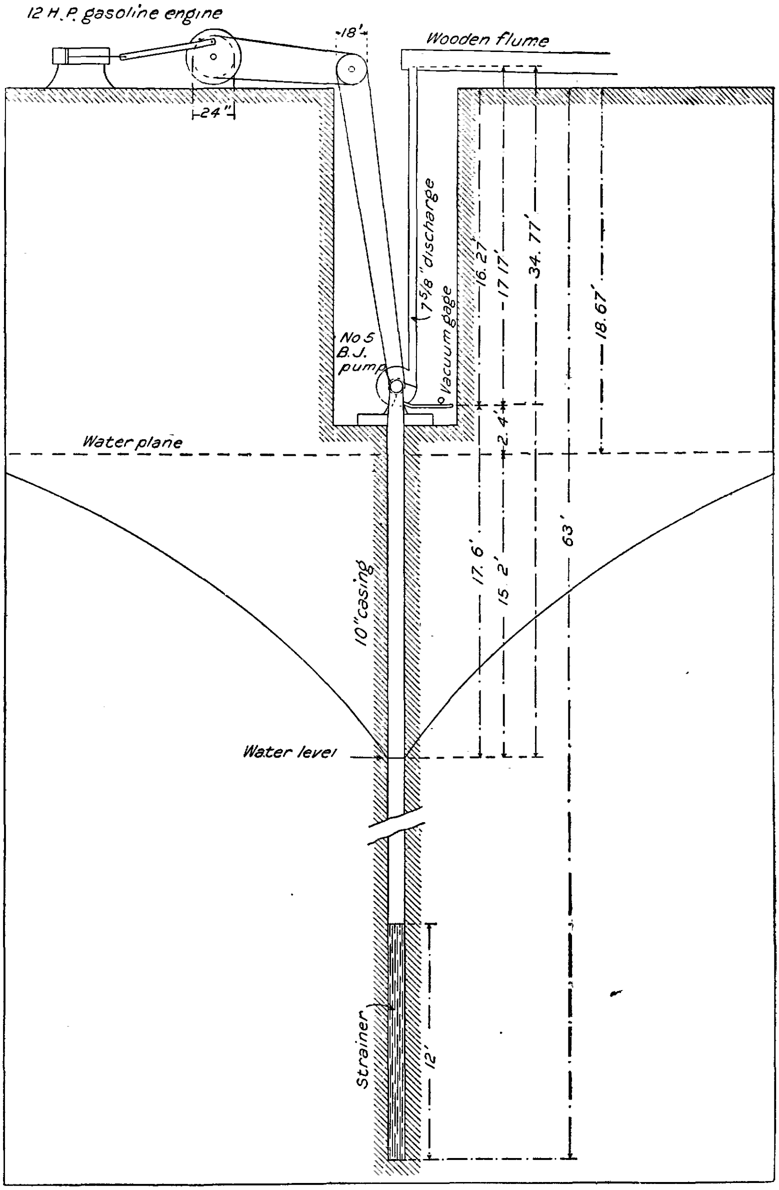


FIG. 22.- Diagram of pumping plant of W. N. Hager, near Mesilla Park, N. Mex.

Water is obtained from a 10-inch well, 63 feet deep, containing a 12-foot, slotted, galvanized-iron Porcher strainer, 9¾ inches in diameter. The pumping is done by a No. 5 Byron Jackson horizontal-shaft, centrifugal pump, directly connected to the 10-inch well casing. The pump is driven by a 12-horsepower Weber gasoline engine, power being transmitted by a belt from 24-inch driving pulley to 18-inch pulleys on countershaft, thence to 8-inch driven pulley on pump shaft.

At the time of the test the engine made 243 revolutions and 76 explosions per minute. The speed of the pump was 668 revolutions a minute. The pump discharges through a 7⅝-inch vertical discharge pipe into a rectangular wooden flume. The discharge was measured by integrating in this flume with a Price acoustic current meter. The width of flume was 1.63 feet. At the selected cross section the water had an average depth of 0.308 feet and an average velocity of 1.171 feet per second. The total discharge was therefore 0.590 second-feet, or 325 gallons a minute. An attempt was made to catch the water in a tub holding 15.9 gallons. The time required to fill the tub was determined by a stop watch, but as the water had to be diverted into the tub by closing a gate at the end of the rectangular flume, the results are not satisfactory. The average time required to fill the tub in seven trials was 4.3 seconds, indicating a discharge of only 209 gallons a minute. This result is known to be valueless, but it illustrates the impracticability of measuring such a discharge by means of a small tub, unless the tub can be placed directly under the discharging stream of water without the necessity of diverting the water to one side.

The vacuum-gage tap was 16.27 feet below the surface, and 16.84 feet below the top of the 7⅝-inch discharge pipe. The water jet is 0.33 feet above the mouth of the discharge pipe. The vacuum gage read 17.5 inches, or 15.5 inches of mercury, when corrected for altitude. This is equivalent to 17.6 feet of water, making total lift of pump 34.77 feet. The vacuum-gage tap was 2.405 feet above the water plane, so that the water in well was lowered 15.2 feet during pumping. The specific capacity of the well is therefore 22.5 gallons per minute, or 0.76 gallons per minute for each square foot of well strainer.

The amount of gasoline used was determined by measurement in a round tank 1.87 feet in diameter. In one hour a depth of 0.09 feet of gasoline was consumed, or 1.84 gallons. With gasoline at 17 cents per gallon, the fuel cost of water was 31 cents per hour, 1.6 cents per 1,000 gallons, and $5.14 per acre-foot. The lift being 34.77 feet, the cost of fuel for 1,000 foot-gallons was $0.00046, or one twenty-second of a cent.

PLANT OF A. L. HINES.

This plant is located on the ranch of Dr. A. L. Hines, about 1 mile north of east from the old village of Mesilla. Water is obtained from a well 5⅝ inches in diameter and 59 feet deep. The log of this well showed 8 feet of soil, 11 feet of dry sand, 28 feet of quicksand, and 12 feet of gravel on top of quicksand of unknown thickness. The water is recovered by a No. 4 Rumsey horizontal-shaft centrifugal pump, which is driven by an 8-horsepower vertical gasoline engine placed on

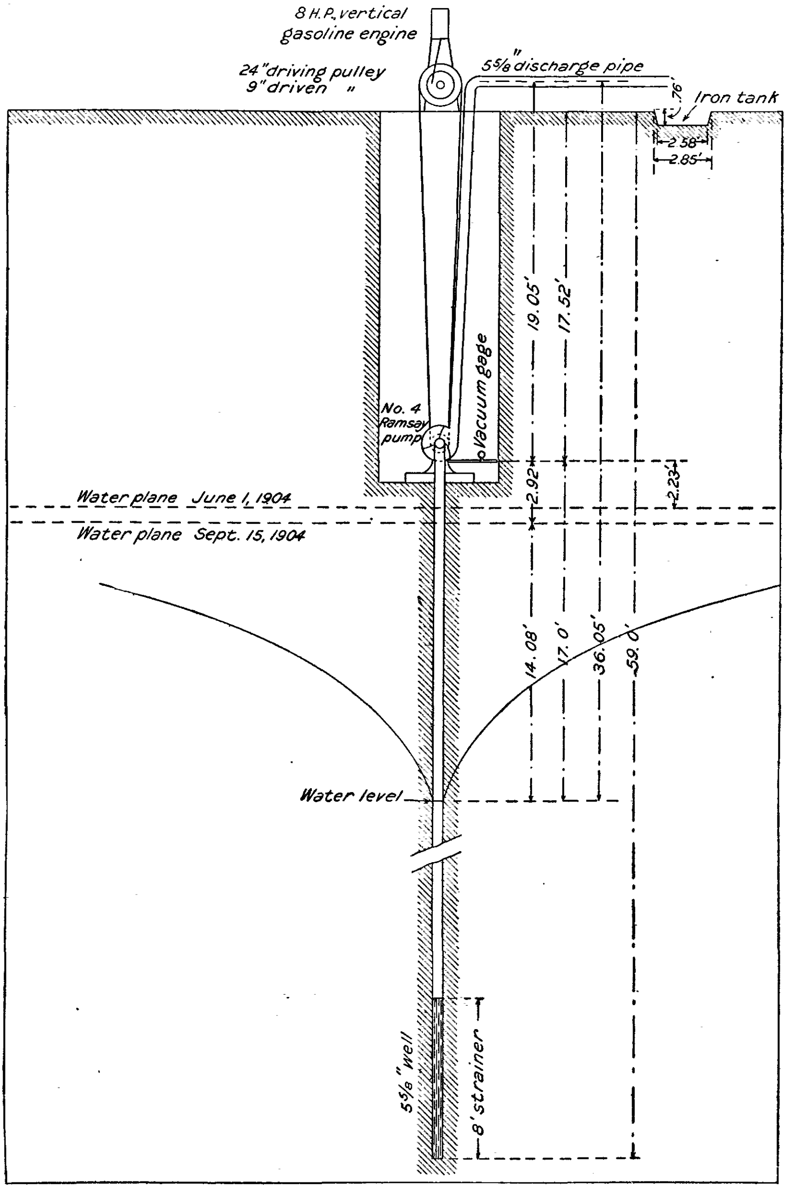


FIG. 23.—Diagram of pumping plant of A. L. Hines, near Mesilla, N. Mex.

sills extending across the top of the well pit. The engine was manufactured by the Chicago Gas Engine Company. It is directly belted to pump shaft from a 24-inch driving pulley and 9-inch driven pulley.

The engine made 238 revolutions and 119 explosions per minute. The speed of the pump was 594 revolutions per minute.

The water plane was 2.92 feet below the vacuum-gage tap in gooseneck of pump on September 15, 1904, and 2.23 feet below on June 1, 1904; the water plane had fallen, therefore, in this interval about 8½ inches. The pumping plant had been in use only twenty days during the summer. The vacuum-gage tap was 19.05 feet below the center of the horizontal 5⅝-inch discharge pipe. The vacuum gage read 17 inches, which, corrected for altitude, is equivalent to 15 inches of mercury, or 17 feet of water. The total lift of the pump was, therefore, 36.05 feet.

The discharge was measured with great precision by determining with a stop watch the time required to fill a wrought-iron rectangular tank. The water was conducted across the tank by means of an extra piece of iron pipe until the pumping plant had been in operation for some time, when the extra pipe was suddenly pulled off. The tank held 15.08 cubic feet and was filled in 30.6 seconds. The discharge was, therefore, 0.492 second-foot, or 271 gallons per minute.

An excellent opportunity was offered for testing the accuracy of estimating the discharge from partly filled pipes by determining the mean velocity of the stream by a small current meter. Only 44.3 per cent of the cross section of the 5⅝-inch discharge pipe was filled by the water raised by the pump. The area of the cross section was 0.076 square foot, and the velocity of the water, as given by the current meter, was 8.47 feet per second. The discharge was, therefore, 0.642 second-foot, or 290 gallons per minute. The true discharge was 271 gallons per minute, showing an error of 5.3 per cent in the meter determination.

The water in the well was lowered 14.08 feet during pumping; therefore, the specific capacity of the well was 19.2 gallons per minute. As the area of the well strainer was 11.3 square feet, the specific capacity per square foot of well strainer was 1.79 gallons per minute.

At this plant 1.5 gallons of gasoline were used per hour. This is at least 50 per cent more than should have been used. With gasoline at 17 cents a gallon, the hourly cost of fuel was 25½ cents. As the yield was 16,250 gallons of water an hour, the fuel cost was $0.0157 per 1,000 gallons, $5.10 per acre-foot, and $0.000435, or one twenty-third of a cent per 1,000 foot-gallons.

PLANT OF THEODORE ROUALT.

This plant is on the ranch of Theodore Roualt, about 3 miles northwest of Las Cruces, N. Mex. Water is obtained from a 10-inch well 48 feet deep that contains 10 feet of 9¾-inch slotted galvanized-iron strainer. It is raised by a No. 3 Van Wie vertical-shaft centrifugal pump, driven by a 10-horsepower Nagle steam engine, on 18-horsepower horizontal wood-burning boiler. The engine is directly belted to the pump shaft from a 30-inch driving pulley to a 12-inch driven pulley.

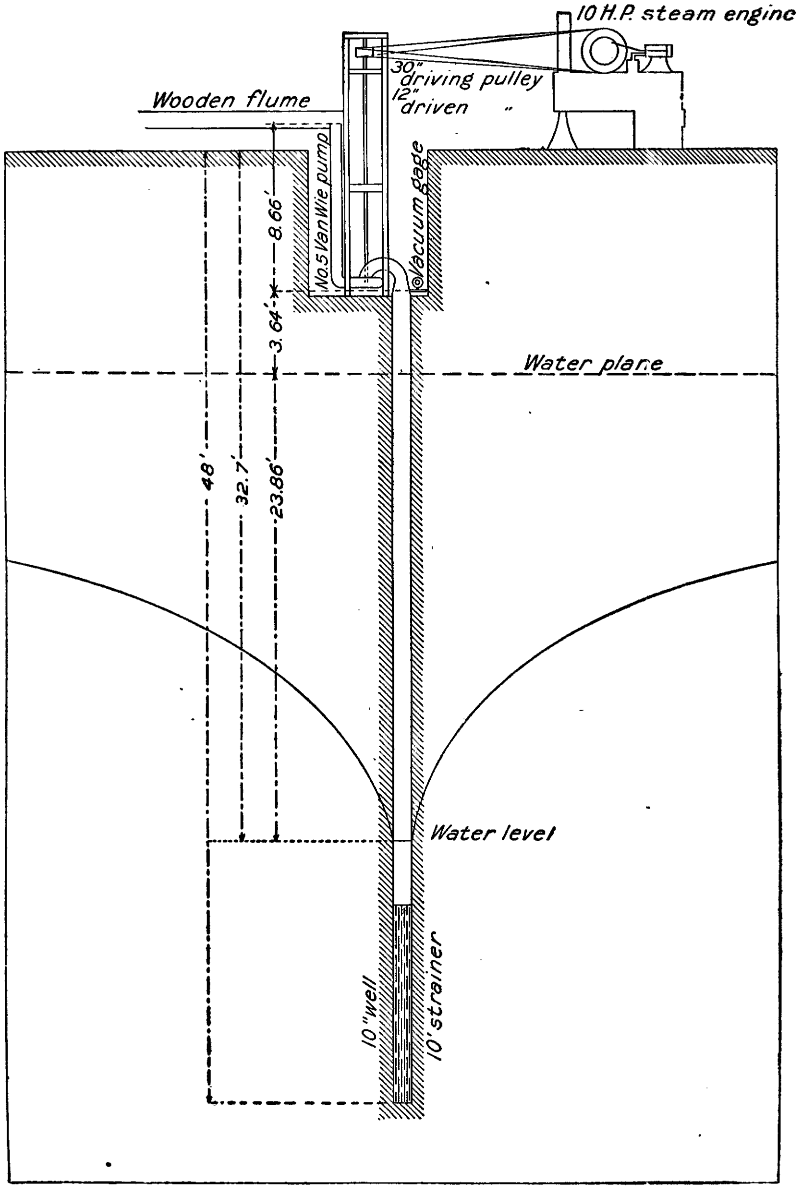
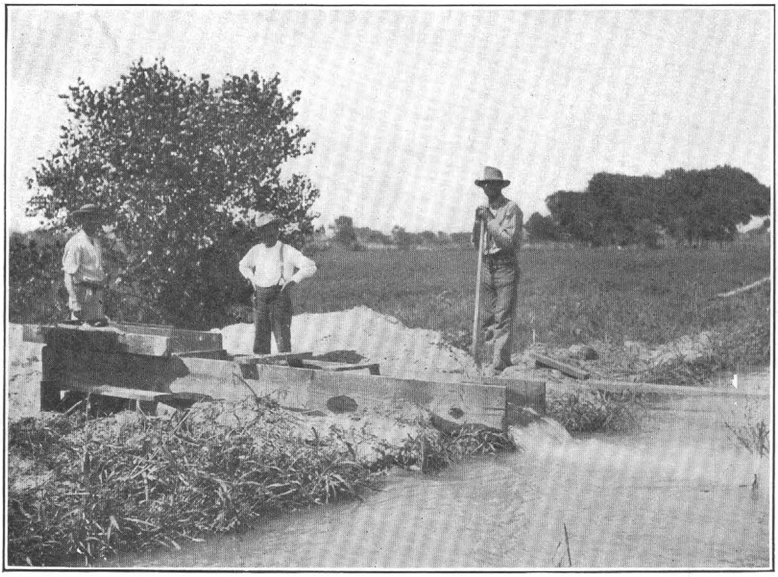


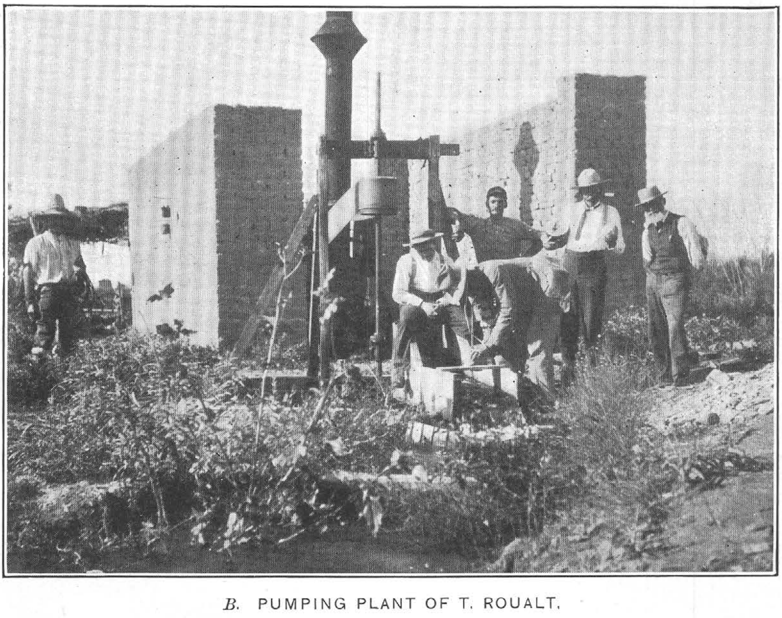
FIG. 24.—Diagram of pumping plant of Theodore Roualt, near Las Cruces, N. Mex.

The water is discharged through an 8-inch vertical pipe into a rectangular flume.

The engine made 205 and the pump 525 revolutions per minute.



A. DISCHARGE FROM WELL NO. 1, HORACO RANCH COMPANY.



B. PUMPING PLANT OF T. ROUALT.

The steam pressure varied between 81 and 83 pounds. The vacuum-gage tap was 3.64 feet above the water plane, 7.96 feet below the top of bottom plank of flume, and 8.66 feet below the top of water jet.

The vacuum gage read 24.25 inches, which is equivalent, when corrected for altitude, to 22.25 inches of mercury, or 25.5 feet of water, making the total lift 34.16 feet. The discharge was measured by integrating with a Price acoustic current meter in the rectangular flume. The selected cross section had a width of 1.19 feet, an average depth of 0.35 foot, and an area of 0.417 square foot. As the average velocity was 1.867 feet per second, the discharge was 0.78 second-foot or 351 gallons per minute. From this it is estimated that the specific capacity of the well is 16 gallons per minute, or 0.627 gallon per minute for each square foot of strainer.

The cost of fuel used for pumping can be readily estimated from careful tests by Mr. Roualt. For one irrigation of a 70-acre field of tomatoes the pump was run twenty-eight days of twenty-four hours, and 75 cords of cottonwood, costing $2 per cord, were consumed. During the twenty-eight days of twenty-four working hours each 14,150,000 gallons, or 43.5 acre-feet, of water were pumped. The total cost of wood being $120, the fuel cost of water was 1.06 cents per 1,000 gallons, $3.45 per acre-foot, and $0.00031, or about one thirty-second of a cent, per 1,000 foot-gallons.

PLANT OF G. H. TOTTEN.

This plant is located on the ranch of G. H. Totten, about one-half of a mile west of the old village of Mesilla, N. Mex. Water is obtained from a 10-inch well, 62 feet deep, that contains 11½ feet of 9-inch slotted galvanized-iron strainer. It is raised by a No. 6 Byron Jackson horizontal-shaft centrifugal pump, driven by a 28-horsepower Ohio gasoline engine. The engine is belted from a 36-inch driving pulley to a 16-inch pulley on countershaft; thence from a 15-inch pulley on countershaft to a 10-inch pulley on pump. The engine made 205 revolutions and an average of 78 explosions per minute. The speed of the pump was 692 revolutions a minute.

The water is delivered through an 8-inch vertical discharge pipe into a horizontal rectangular wooden flume. The vacuum-gage tap on pump was 3.9 feet above the water plane, 16.83 feet below top of discharge pipe, and 16.95 feet below top of water jet. The vacuum gage read 25.25 inches, which is equivalent, after correction for altitude, to 23.25 inches of murcury, or 26.4 feet of water. The total lift is, therefore, 43.35 feet.

The discharge was measured by integrating with a Price acoustic current meter in rectangular flume. The selected cross section had a width of 1.83 feet, an average depth of 0.38 foot, and an effective area of 0.695 square foot. The mean velocity of the water was 1.482 feet per second, giving a total discharge of 1.03 second-feet, or 464 gallons per minute.

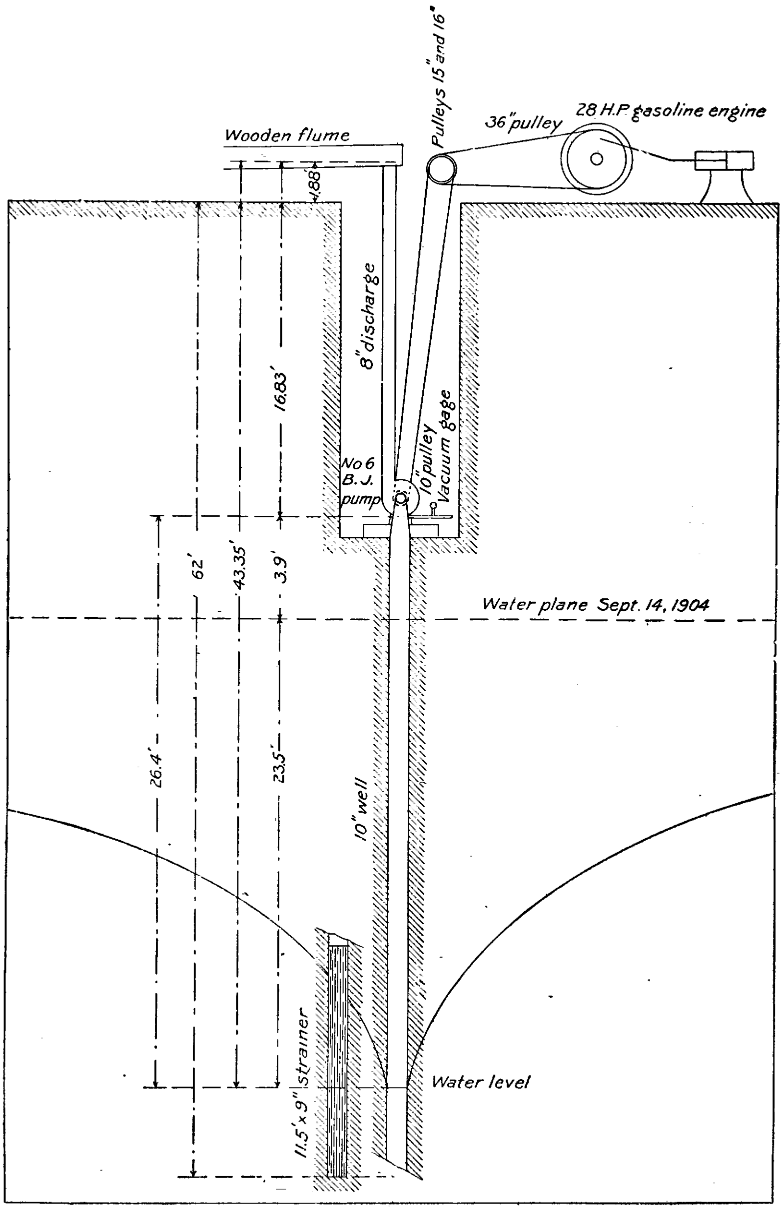


FIG. 25.—Diagram of pumping plant of G. H. Totten, near Mesilla, N. Mex.

The water in the well was lowered 22.5 feet during pumping, from which the specific capacity of the well is estimated to be 20.6 gallons a minute, or 0.76 gallon per minute for each square foot of strainer.

The discharge was also determined from the dimensions of the parabola of flow as the water left the flume. The end of the flume was almost exactly level and the water fell freely for a sufficient distance to permit the determination of the dimensions of the parabola of the fall. This is shown in fig. 26. The water had an average depth of 0.171 foot at the end of flume, and in a total fall of 2.05 feet moved forward 1.285 feet. According to the laws of falling bodies, a body falls 2.05 feet in 0.356 second. If the water advances 1.285 feet in 0.356 second, its mean velocity per second would be 1.285 divided by 0.356, or 3.6 feet. The area of the stream is 0.171 by 1.83, or 0.313 square foot. This gives a total discharge of 1.13 second-feet, or 507 gallons per minute. These results are undoubtedly slightly too large.

The pumping plant had been used but a short time, and no experimental run had been made to determine the quantity of gasoline required. As the gasoline tank was situated so that without a considerable expenditure of time it was impracticable to ascertain the amount of gasoline used, no determination was made during the test. However, it was estimated that the 28-horsepower engine gave 22 effective horsepower. It may therefore be safely assumed that about 2.2 gallons of gasoline were used per hour. If this amount were used, and gasoline costs 17 cents per gallon, the fuel cost of water would be 37 cents an hour, $0.0133 per 1,000 gallons, $4.34 per acre-foot, and $0.000307, or about one thirty-third of a cent per 1,000 foot-gallons.

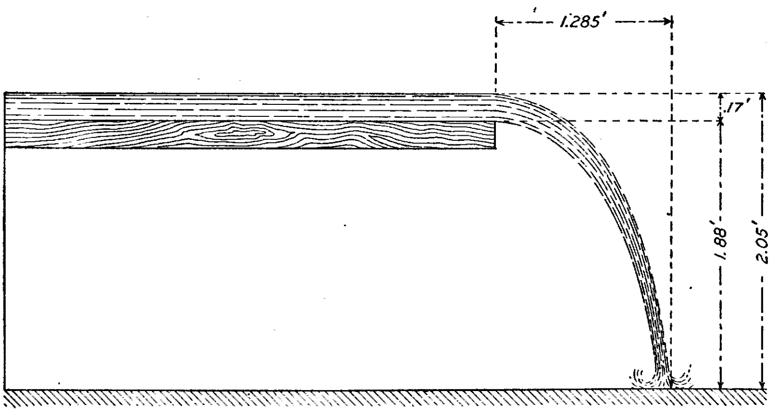


FIG. 26.—Parabola of discharge from flume at Totten's well.

PLANT AT AGRICULTURAL COLLEGE.

This plant consists of a 12-inch and a 6-inch well located on the experimental farm of the New Mexico Agricultural College. A complete test of this plant was not made, as the work with these wells is frequently reported upon by members of the faculty of the Agricultural College. Only sufficient tests were made to determine the specific capacity of the large well in order to make comparisons possible with the other pumping plants in the valley. At the time of the test a

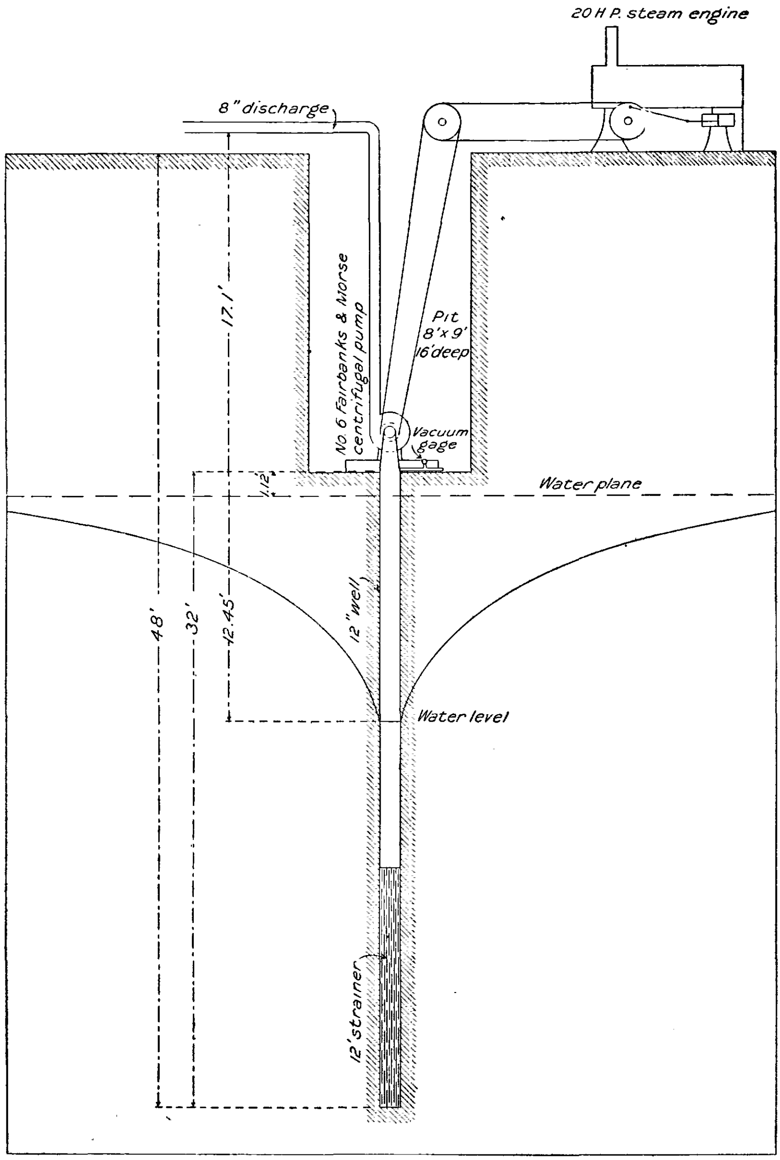


FIG. 27.—Diagram of Agricultural College 12-inch well, Mesilla Park, N. Mex.

No. 6 Fairbanks-Morse centrifugal pump was in use, but the pumps are frequently changed for experimental purposes. The pump is speeded so as to discharge 1,000 gallons a minute at the measuring weir, in order that a known amount of water may be provided for the experimental plats of ground.

At the time of the test there was in use a 30-horsepower steam engine, which has ample power to drive pumps placed on both wells. When both wells are used, about 1,800 gallons per minute can be obtained.

On August 25, 1904, the vacuum gage read 13 inches, which, corrected for altitude, is equivalent to 11 inches of mercury, or 12.45 feet of water. The lift above the vacuum-gage tap was 17.10 feet, making the total lift 29.55 feet. The water level in the well was lowered 11.37 feet by pumping, from which the specific capacity of the well is computed to be 88 gallons per minute. As the well strainer is 12 inches in diameter, 12 feet long, and 27.6 square feet in area, the specific capacity per square foot of strainer is 2.32 gallons per minute.

The cost of fuel per acre-foot, as given in the table on p. 35, is taken from the bulletin issued by Professors Vernon and Lester in 1903. These results were obtained with a 20-horsepower steam engine formerly used. These results are included in the table for the purpose of comparison with the results at other plants.

TESTS OF PUMPING PLANTS NEAR BERINO, N. MEX.

PLANTS OF HORACO RANCH COMPANY.

The Horaco Ranch Company has three plants in an east-west line on a ranch just west of Berino, N. Mex. The east well is No. 3, the middle well is No. 1, and the west well is No. 2.

Well No. 3 is 62 feet deep. It is cased with 9⅝-inch pipe and contains 18 feet of strainer made of 9⅝-inch casing drilled with forty 1½-

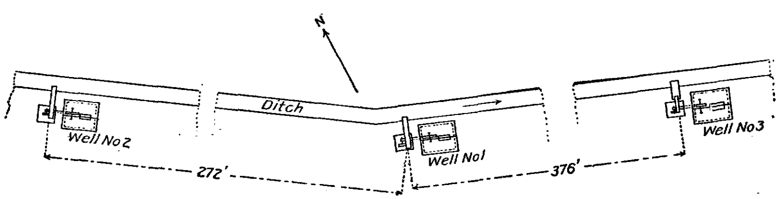


FIG. 28.—Plan of pumping plants of the Horaco Ranch Company, Berino, N. Mex.

inch holes to every linear foot of strainer and wound with No. 9 galvanized-iron wire wrapped so as to leave horizontal slots one-eighth of an inch in width. This strainer is locally known as the "Mott" strainer.

Water is obtained by means of a No. 5 Byron Jackson horizontal-shaft centrifugal pump, driven by a 12-horsepower Weber gasoline engine. The water is discharged through a 7-inch pipe, which rises at an angle of 45° from the pump in the well pit. The engine made 244 revolutions and 97 explosions per minute. The pump made 692 revolutions a minute, and was belted directly to the engine from a

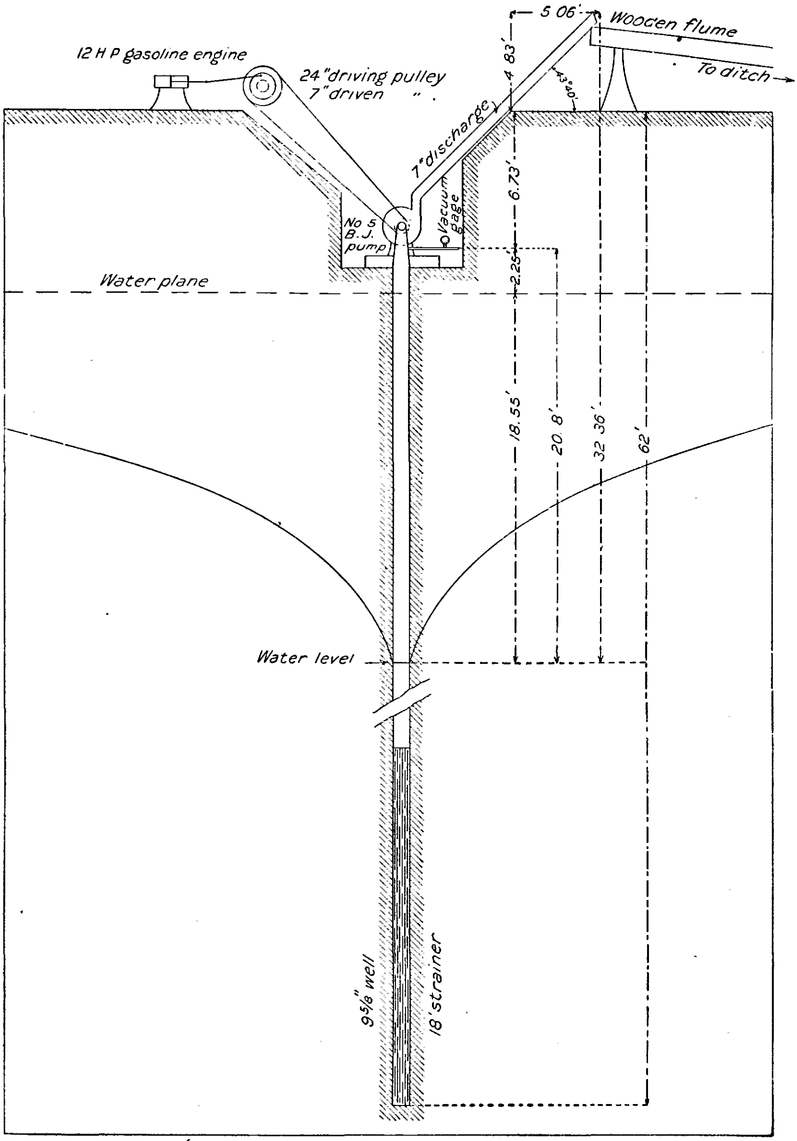


FIG. 29.—Diagram of pumping plant No. 3, Horaco Ranch Company.

24-inch driving pulley to a 7-inch driven pulley. On September 11, 1904, the water plane was 2.25 feet below the vacuum-gage tap, which was 11.56 feet below the end of the discharge pipe. The vacuum gage read, after one hour's pumping, 19.8, which, when corrected for altitude, is equivalent to 17.8 inches of mercury, or 20.8 feet of water. The total lift of the pump was, therefore, 32.36 feet.

The discharge was measured by holding a small Price acoustic current meter in the mouth of the 7-inch discharge pipe. It was 1.71 second-feet, or 750 gallons a minute.

As determined by Mr. E. L. Houck, principal owner of the Horaco ranch, a barrel of 50 gallons of gasoline was consumed by the engine at well No. 3 in fifty-three hours. With gasoline at 17 cents per gallon the fuel cost of water was 16 cents an hour, or $0.00356 per 1,000 gallons, or $1.16 per acre-foot. Since the total lift of the pump is 31.76 feet, the cost of fuel for 1,000 foot-gallons is $0.000112, or one eighty-ninth of a cent. The consumption of gasoline at the time of the test was measured by noting the changing level of the gasoline in a cylindrical tank 1.85 feet in diameter. The change of level in one hour was 0.0867 foot. This is equivalent to 1.76 gallons an hour. On this basis the fuel cost of water was $2.23 per acre-foot, and $0.000314, or one forty-seventh of a cent per 1,000 foot-gallons.

Well No. 1 of the Horaco Ranch Company is 376 feet west from well No. 3. It is 75 feet deep, is cased with 7⅝-inch pipe, and equipped with 18 feet of Mott strainer. Water is delivered through a 7⅝-inch vertical pipe opening into a horizontal wooden flume. It is raised by a No. 5 Byron Jackson horizontal-shaft centrifugal pump, driven by a 12-horsepower Weber gasoline engine. The engine made 238 revolutions and 106 explosions a minute. The pump made 815 revolutions a minute and was belted directly to the engine from a 24-inch driving pulley to a 7-inch driven pulley.

The vacuum-gage tap was 0.43 foot above the water plane on September 11, 1904. It was 7.1 feet below the surface and 8.95 feet below the end of vertical discharge pipe. As the water jet rose 0.762 foot above the end of the discharge, the total lift above the vacuum-gage tap was 9.71 feet. The vacuum gage read 14.5, which, corrected for altitude, is equivalent to 12.5 inches of mercury, or 14.18 feet of water. The total lift of the pump was, therefore, 23.89 feet.

The discharge was measured by integrating with a Price acoustic current meter in the rectangular flume. The selected cross section had an average depth of 0.278 foot, an average width of 1.42 feet, and an area of 0.395 square foot. The average velocity of the water was 4.707 feet per second, giving a discharge of 1.86 second-feet, or 837 gallons per minute.

The area of the well strainer is 36 square feet. The water level in the well was lowered 13.75 feet during pumping, and therefore the specific capacity of the well is 60.8 gallons per minute, or 1.69 gallons per minute for each square foot of strainer.

Although the amount of water obtained at well No. 1 is very much greater than at well No. 3, the cost for fuel is substantially the same. The consumption of gasoline is slightly less than 1.2 gallons an hour. With gasoline at 17 cents a gallon, the hourly cost is 20 cents. The

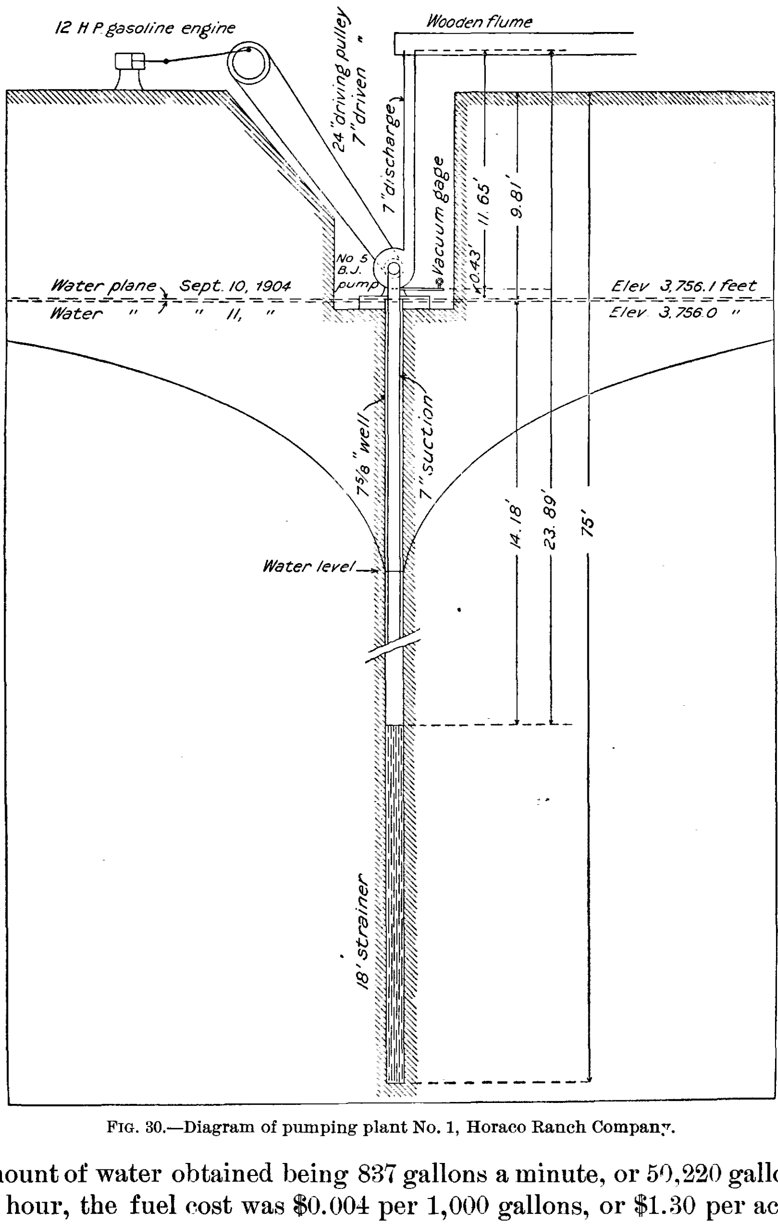


FIG. 30.—Diagram of pumping plant No. 1, Horaco Ranch Company.

amount of water obtained being 837 gallons a minute, or 50,220 gallons an hour, the fuel cost was $0.004 per 1,000 gallons, or $1.30 per acre-foot. The lift at well No. 1 being 23.89 feet, the cost of fuel for each 1,000 foot-gallons was $0.000167, or one-sixtieth of a cent.

Well No. 2 of the Horaco Ranch Company is 376 feet west of well No. 1. It is 53 feet deep, is cased with 9⅝-inch pipe, and is equipped with 18 feet of Mott strainer at the bottom. Water is raised by a No. 5 Byron Jackson horizontal-shaft centrifugal pump, driven by a

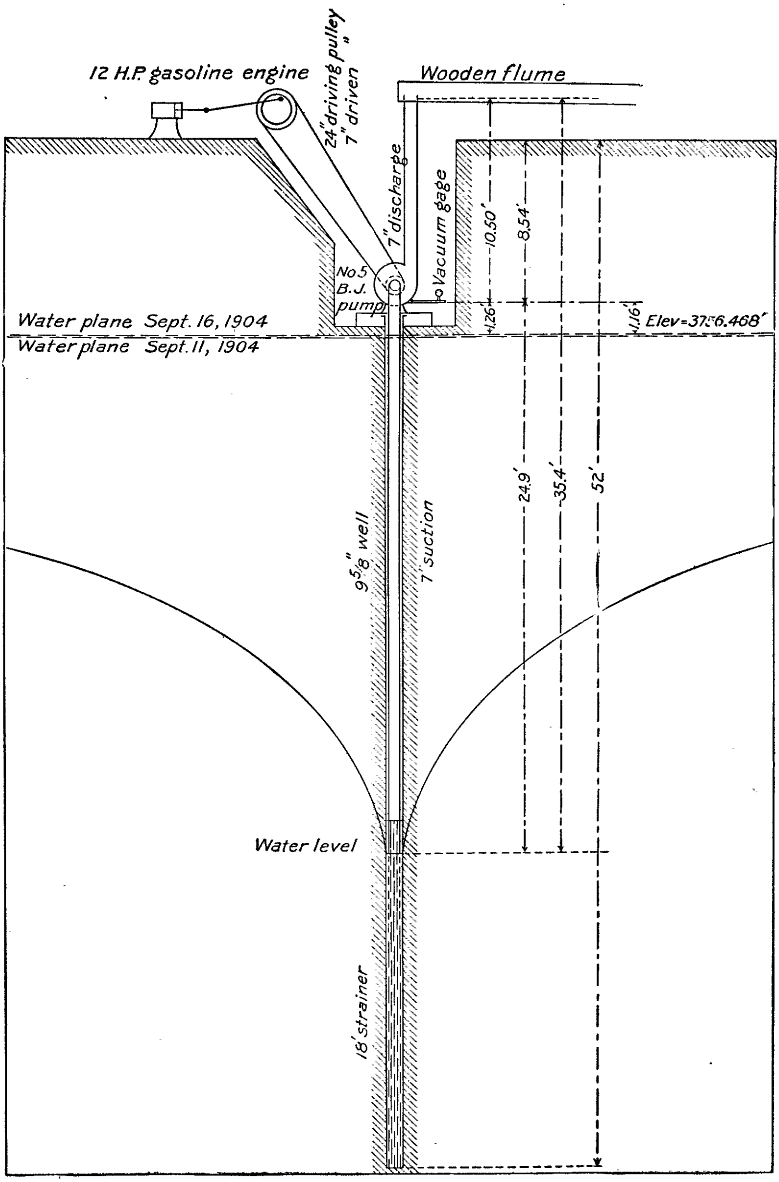


FIG. 31.—Diagram of pumping plant No. 2, Horaco Ranch Company.

12-horsepower Weber gasoline engine. It is taken from the well through a 7-inch suction and discharged through a 7-inch vertical pipe into a horizontal flume. The engine made 239 revolutions and

103 explosions a minute. It was belted directly to the pump shaft from a 24-inch driving pulley to a 7-inch driven pulley. The speed of the pump was 700 revolutions a minute.

The vacuum-gage tap placed in the goose neck of the pump was 1.26 feet above the water plane and 10.02 feet below the top of the vertical discharge pipe. As the water jet rose 0.34 foot above the discharge pipe, the total lift of the pump above the vacuum-gage tap was 10.36 feet. The vacuum gage read 24 inches, which, corrected for altitude, is equivalent to 22 inches of mercury, or 24.9 feet of water. The total lift of the pump was therefore 35.26 feet.

The discharge was measured by integrating with a Price acoustic current meter in the rectangular flume. The selected cross section had an average depth of 0.251 foot, a width of 1.44 feet, and an area of 0.362 square foot. The mean velocity was 1.172 feet per second, which gives a total discharge of 0.425 second-foot, or 191 gallons per minute.

The water in the well was lowered 23.64 feet by pumping. This makes the specific capacity of the well 8.1 gallons per minute, or 0.178 gallon per minute for each square foot of strainer.

The consumption of gasoline by the engine at well No. 2 is known by comparison with that at well No. 3. Although the amount of water pumped is very much less than at well No. 3, the consumption of gasoline is as great, and even slightly greater, say 1.2 gallons an hour. With gasoline at 17 cents per gallon the hourly cost of fuel is 20.4 cents. The fuel cost of water is then 1.78 cents per 1,000 gallons, $0.000505, or one-twentieth of a cent per 1,000 foot-gallons, and $5.80 per acre-foot.

Mr. Houck gives the combined cost of the three pumping plants on the Horaco ranch as follows:

Cost of pumping plants on Horaco ranch.

Three 12-horsepower Weber gasoline engines, three No. 5 Byron Jackson pumps with piping, belting, etc., all in place	$2,100.00
Wells at $2.50 per foot	475.00
Well pits, buildings, flumes, etc., extra	400.00
	2,975.00

Depreciation at 10 per cent and interest at 8 per cent amounts to $536 per annum. For an irrigation season of one hundred days this averages $5.36 per day, or $1.80 a day for each plant.

The hourly cost of plant No. 1 may be figured as follows:

Hourly cost of pumping plant No. 1 at Horaco ranch.

Fuel (gasoline)	$0.16
Interest and depreciation	.18
Labor, lubricating oil, etc	.10
Total	.44

The last item is based on the supposition that one man can run the three plants.

At well No. 1 the yield of water is 837 gallons a minute, or 50,220 gallons an hour. The cost is therefore $0.00876 per 1,000 gallons, or $2.85 per acre-foot.

The cost at the other plants is much greater on account of poorer wells. The wells would probably show little difference in capacity or cost of the water if they were all as deep as well No. 1. The coarse gravels were not reached at all in well No. 2, and were not penetrated in well No. 3.

Mr. Houck made a careful test of the amount of gasoline used at pumping plants Nos. 1 and 3 in November, 1904. Each of the engines at these plants ran sixteen hours on 16 gallons of gasoline. These tests are in substantial accord with the former tests quoted above, but show a slightly smaller quantity of gasoline consumed.

Plants Nos. 1 and 3 were used on two occasions to irrigate 25 acres of land, consisting of 21 acres of alfalfa and 4 acres of orchard and garden, and sixteen hours of continuous run were required at each trial. This is equivalent to about 2¼ inches of water per irrigation.

An interesting observation was made of the effect of stopping the pumps during the night instead of making a continuous run as above. When this was done the pumps had to be run two and one-half hours longer to irrigate land that had previously been irrigated in sixteen hours.

APPENDIX.

ANALYSES OF WELL WATER AND DATA CONCERNING WELLS AT AND NEAR EL PASO, TEX.

This information was furnished by Mr. A. Courchesne, of El Paso, Tex.

Water in corral at stone quarry above El Paso, Tex.

Analysis.	Parts per 100,000.	Probable combinations.	Parts per 100,000.
Silica	3.00	Silica	3.00
Alumina	2.00	Alumina	2.00
Lime	26.20	Carbonate of lime	34.00
Magnesia	6.11	Sulphate of lime	17.65
Soda	18.84	Sulphate of magnesia	18.30
Carbonic acid	15.00	Sulphate of soda	1.90
Sulphuric acid	23.70	Chloride of sodium	33.95
Chlorine (Cl)	20.60	Water of crystallization, etc	1.20
Water of crystallization, or loss	1.20	Total solids	112.00
	116.65	Total hardness	62.20
Oxygen equivalent to Cl	4.65	Permanent hardness	28.20
Total solids	112.00		

This is not a good boiler water, though most of the solids will come down as sludge instead of sticking to tubes. Still there is enough in combination to make a hard seal of sulphate of lime and carbonate of magnesia. The water will corrode, but not badly.

Analysis of water from mile 211, El Paso and Southwestern Railroad.

Constituent.	Parts per 100,000.	Probable combination.	Parts per 100,000.
Silica	7.00	Silica	9.00
Alumina	1.00	Alumina	1.00
Lime	6.70	Carbonate of lime	12.00
Magnesia	2.80	Carbonate of magnesia	3.62
Soda	16.40	Sulphate of magnesia	3.45
Sulphuric acid	13.65	Sulphate of soda	20.33
Carbonic acid	7.48	Chloride of sodium	14.35
Chlorine (Cl)	8.70	Water of crystallization	.25
Water of crystallization	25	Total solids	62.00
	63.98		
Oxygen equivalent to Cl	1.98		
Total solids	62.00		

This is a good locomotive water, and is a fairly good drinking water, very slightly medical from Glaubers salts.

Water from 70-foot well at ranch of A. Courchesne, near Ysleta, Tex.

Constituent.	Parts per 100,000.
Silica	3.00
Alumina and phosphate	10.00
Carbonate of lime	15.00
Carbonate of magnesia	3.01
Carbonate of soda	12.13
Sulphate of soda	7.80
Chloride of sodium	23.30
Organic and water of crystallization	1.76
	106.00

This water is comparatively soft and good for boiler use. It has too much organic matter in it for a safe drinking water. The dried solids blacken on ignition and smell badly. It is probably polluted with sewage.

Water from lime quarry, El Paso, 30 feet deep.

Constituent.	Parts per 100,000.	Probable combinations.	Parts per 100,000.
Silica	2.60	Silica	2.60
Alumina	2.00	Alumina	2.00
Lime	44.72	Carbonate of lime	32.00
Magnesia	10.80	Sulphate of lime	65.30
Soda	65.80	Sulphate of magnesia	32.40
Sulphuric acid	60.00	Chloride of sodium	124.20
Carbonic acid	14.00	Water of crystallizatior	27.50
Carbonic	75.60	Total solids, 100 c	286.00
Water of crystallization	27.50	Total solids, grains per gallon (US)	167.00
	303.02		
Oxygen equivalent to Cl	17.02		
Total solids, 100 c	286.00		

This water is not good for drinking or boiler purposes. It will scale and corrode badly. It could be made usable for boilers by treatment with caustic and carbonate of soda, but it would not then be a good water on account of high proportions of common salt.

Analyses of waters from wells of El Paso ice plant.

Constituent.	Surface water.	300-foot well (grains per U. S. gallon).	80-foot well (grains per U. S. gallon.)
Organic	5.4	3.033	5.249
Silica	2.8	....	1.166
Sulphate of lime	....	....	35.003
Carbonate of lime	26.3	9.580	10.940
Carbonate of magnesia	5.3	1.102	.883
Chloride of sodium	36.9	6.102	52.464
Chloride of lime	....	....	4.391
Chloride of magnesia	....	....	9.802
Sulphate of magnesia	....	....	5.148
Sulphate of sodium	32.5	7.407	....
Carbonate of sodium	5.2	....	....
Iron and alumina	.6	....	....
Total solids	115.0	27.224	125.046
Incrustants	34.9	10.682	47.992
Corroding salts	....	....	19.341
Rating for boiler purposes	Bad.	Good.	Very bad.

Analysis from water from new 400-foot well of El Paso Ice and Refrigerator Company, El Paso, Tex.

Constituent.	Parts per 100,000.	Probable combinations.	Parts per 100,000.
Silica	0.50	Silica	0.50
Alumina	Tr.	Alumina	Tr.
Lime	2.23	Carbonate of lime	4.00
Magnesia	3.00	Carbonate of magnesia	6.30
Soda	8.98	Carbonate of soda	1.59
Chlorine	5.31	Sulphate of soda	7.90
Carbonic acid	5.72	Chloride of sodium	8.71
Sulphuric acid	4.45	Total solids	29.00
	30.19	Total hardness	11.5
Oxygen equivalent to Cl	1.19		
Total solids	29.00		

This is a good water. The hardness is rather high, but it is temporary, and only a small part (about 20 per cent) will incrust, the rest falling as slugs in the boiler, which can be blown out.

Analysis of El Paso well water.

Constituent.	Grains per U. S. gallon.
Incrusting solids:	
Calcium carbonate	3.20
Calcium sulphate	None.
Calcium chloride	None.
Magnesium carbonate	1.39
Magnesium sulphate	None.
Magnesium chloride	None.
Iron and alumina	.07
Silica	1.61
Suspended matter	Trace.
Total	6.27
Nonincrusting solids:	
Sodium sulphate	5.82
Sodium chloride	7.02
Sodium carbonate	4.19
Total	17.03
Alkalinity	9.33
Hardness	5.26
Carbonic acid	2.42
Pounds of incrusting solids per thousand gallons	.90

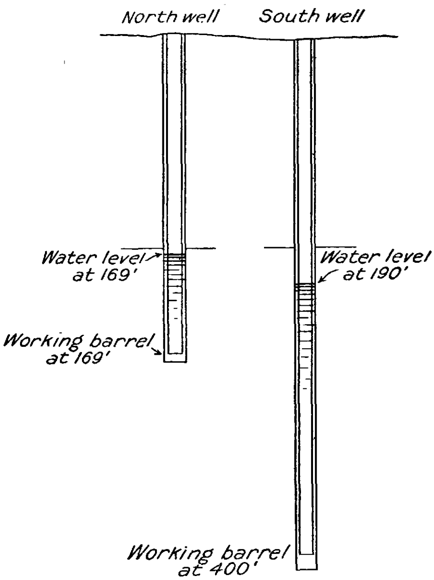


FIG. 32.—Wells at Fort Bliss station, El Paso and Northeastern Railroad.

Data concerning wells at Fort Bliss

NORTH WELL.

Completed: July 22, 1901.
Total depth: 249 feet.
Casing: 249 feet of 6-inch.
Depth of working barrel: 245 feet.
Water level: 169 feet below earth's surface.
Pump: 12 by 36 inches, Cook.
Tested capacity of well: 80,000 gallons per twenty-four hours.

SOUTH WELL.

Completed: 1901.
Total depth: 410 feet.
Casing: 410 feet of 6-inch.
Depth of working barrel: 400 feet.
Water level: 190 feet below earth's surface.
Pump: 10 by 36 inches, Cook.
Tested capacity of well: 30,000 gallons per twenty-four hours.

FEATURES COMMON TO NORTH AND SOUTH WELLS.

Contractor: William McLease.
Size of hole: 8 inches.
Pump column: 6-inch standard.
Working barrel: 5½-inch, Cook.
Well rods: No. 3; 3-inch hickory, 1½-inch straight pins.
Storage: 50,000 gallons, wooden tank.
Boiler: 30 horsepower, Economic.

Analysis of Fort Bliss well water.

Constituent.	Grains per U.S. gallon.
Calcium carbonate (incrusting)	4.90
Magnesium carbonate (incrusting)	3.09
Silica (incrusting)	1.34
Oxides, alumina and iron (incrusting)	.06
Alkali carbonates (nonincrusting)	2.74
Alkali sulphates (nonincrusting)	2.62
Alkali chlorides (nonincrusting)	1.63
Alkali nitrates (nonincrusting)	.70
Sulphates, lime, and magnesium	Traces.
Total incrusting solids	9.39
Total nonincrusting solids	7.69
Pounds incrusting matter per 1,000 gallons	1.34
Pounds nonincrusting matter per 1,000 gallons	1.09

This water should be classed as good.

INDEX.

O

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 141.]

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.

Most of the above publications may be obtained or consulted in the following ways:

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.

2. A certain number are allotted every member of Congress, from whom they may be obtained, free of charge, on application.

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4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they may be consulted by those interested.

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 eleventh in Series K and the forty-fourth in Series O, the complete lists of which follow (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

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WS 1. Pumping water for irrigation, by H. M. Wilson. 1896. 57 pp., 9 pls.
WS 8. Windmills for irrigation, by E. C. Murphy. 1897. 49 pp., 8 pls.
WS 14. New tests of certain pumps and water lifts used in irrigation, by O. P. Hood. 1898. 91 pp., 1 pl.
WS 20. Experiments with windmills, by T. O. Perry. 1899. 97 pp., 12 pls.
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WS 42. The windmill, Pt. II (continuation of No. No. 41). 1901. 73–147 pp., 15–16 pls.
WS 91. Natural features and economic development of Sandusky, Maumee, Muskingum, and Miami drainage areas in Ohio, by B. H. Flynn and M. S. Flynn. 1904. 130 pp.
WS 136. Underground waters of Salt River Valley, Arizona, by W. T. Lee. 1905. 194 pp., 24 pls.
WS 141. Observations on the ground waters of the Rio Grande Valley, 1904, by C. S. Slichter. 1905. 83 pp., 5 pls.

SERIES O, UNDERGROUND WATERS.

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WS 6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls.
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WS 54. Geology and water resources of Nez Perces County, Idaho, Pt. II, by I. C. Russell. 1901. 87–141 pp.

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WS 57. Preliminary list of deep borings in the United States, Pt. I, by N. H. Darton. 1902. 60 pp.
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B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.
WS 120. Bibliographic review and index of papers relating to underground waters published by the United States Geological Survey, 1879–1904, by M. L. Fuller. 1905. 128 pp.
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WS 141. Observations on the ground waters of the Rio Grande Valley, 1904, by C. S. Slichter. 1905. 83 pp., 5 pls.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

SEPTEMBER, 1905.

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Slichter, Charles S[umner] 1864–

... Observations on the ground waters of Rio Grande Valley, by Charles S. Slichter. Washington, Gov't print. off., 1905.

83, iii p. illus., V pl., diagrs. 23cm. (U. S. Geological survey. Water-supply and irrigation paper no. 141)

Subject series: K, Pumping water, 11; O, Underground waters, 44.

Appendix: Analysis of well water and data concerning wells at and near El Paso, Texas.

1. Water, Underground—Texas. 2. Water, Underground—New Mexico.

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no. 141. Slichter, C. S. Observations on the ground waters of Rio Grande Valley. 1905.

Reference.

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