Water-Supply and Irrigation Paper No. 153

Series {K, Pumping Water, 12
O, Underground Waters, 50}

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE UNDERFLOW IN ARKANSAS VALLEY IN WESTERN KANSAS

BY

CHARLES S. SLICHTER

WASHINGTON
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ILLUSTRATIONS.

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By Charles S. Slichter.

INTRODUCTION.

The investigation of the underflow of Arkansas River, described in this paper, was made during the summer of 1904. The field party was under the general supervision of the writer. Mr. Henry C. Wolff had charge of the measurements of the rate of movement of the ground waters. He also made careful determinations of the fluctuation of the position of the water plane, and the success of the field work was largely due to his skill and hard work. Mr. Ray Owen had charge of level and plane-table work, and made a contour map of the water plane.

A few of the principal conclusions may be summarized as follows:

1. The underflow of Arkansas River moves at an average rate of 8 feet per twenty-four hours, in the general direction of the valley.
2. The water plane slopes to the east at the rate of 7.5 feet per mile, and toward the river at the rate of 2 to 3 feet per mile.
3. The moving ground water extends several miles north from the river valley. No north or south limit was found.
4. The rate of movement is very uniform.
5. The underflow has its origin in the rainfall on the sand hills south of the river and on the bottom lands and plains north of the river.
6. The sand hills constitute an essential part of the catchment area.
7. The influence of the floods in the river upon the ground-water level does not extend one-half mile north or south of the channel.
8. A heavy rain contributes more water to the underflow than a flood.
9. On the sandy bottom lands 60 per cent of an ordinary rain reaches the water plane as a permanent contribution.
10. The amount of dissolved solids in the underflow grows less with the depth and with the distance from the river channel.

11. There is no appreciable run-off in the vicinity of Garden, Kans. Practically all of the drainage is underground through the thick deposits of gravels.

12. Carefully constructed wells in Arkansas Valley are capable of yielding very large amounts of water. Each square foot of percolating surface of the well strainers can be relied upon to yield more than 0.25 gallon of water per minute under 1 foot head.

13. There is no indication of a decrease in the underflow at Garden in the last five years. The city well showed the same specific capacity in 1904 that it had in 1899.

14. Private pumping plants in the bottom lands will be profitable for irrigation if proper kind of power be used. There should be a large field of usefulness for suction gas-producer power plants of from 20 to 100 horsepower, with Colorado hard coal or coke as fuel. Kansas crude oil in gas generators should prove profitable for use in the smaller plants. The present cost of pumping with gasoline for fuel is not encouraging.

CHAPTER I.

MEASUREMENTS OF THE UNDERFLOW OF ARKANSAS RIVER.

GENERAL STATEMENT.

Investigations of the underflow of Arkansas River were begun June 11, 1904. The work consisted of the mapping of the water plane or ground-water level within a distance of 6 to 12 miles from the river channel, and of observations by the electrical method of the rate of movement of the underflow. The ground-water levels were obtained by observing the water levels in private wells in the neighborhood of the river and in a few wells which were sunk especially for this purpose. The slope of the water plane was found to be between 7 and 8 feet to a mile in a general easterly direction, and from 2 to 3 feet to a mile toward the river channel from the country immediately to the north and south. The southern margin of the river valley is bordered for 5 to 10 miles to the south by sand hills, which are only partially covered with natural vegetation. These sand hills extend from east of Dodge, Kans., to beyond the Colorado line. The river valley proper varies in width from 1 to 5 miles. Near the river channel there is a strip known as "first bottoms," which is only a few feet above the river level. The principal cultivated portion of the valley lies from 3 to 8 feet higher than first bottoms, and is locally known as "second bottoms." North of the river valley the ground rises rather abruptly to the high plains with their well-known level topography and compact sod of native grasses. The slope of the water plane toward the channel of the river from the north is, as has been stated, about 2½ feet to a mile, but 10 to 14 miles to the north of the valley the slope of the water plane changes from southerly to northerly, and the land at the same time gently dips to the north toward the valley of White Woman Creek. The easterly slope of 7½ to 8 feet to the mile is maintained, however, quite constantly throughout all of this region. Fig. 1 shows the results of the determination of the water plane.

MEASUREMENTS 2 MILES WEST OF GARDEN, KANS. (CAMP 1).

The measurements showed a rate of movement much greater than had been anticipated. The first set of underflow stations were established at a point about 2 miles west of Garden (camp 1), as shown on the map (fig. 1). The stations were in a north-south line, which was about 1½ miles in length. At this point the river flows in an east by south direction, and borders closely on the north margin of the sand

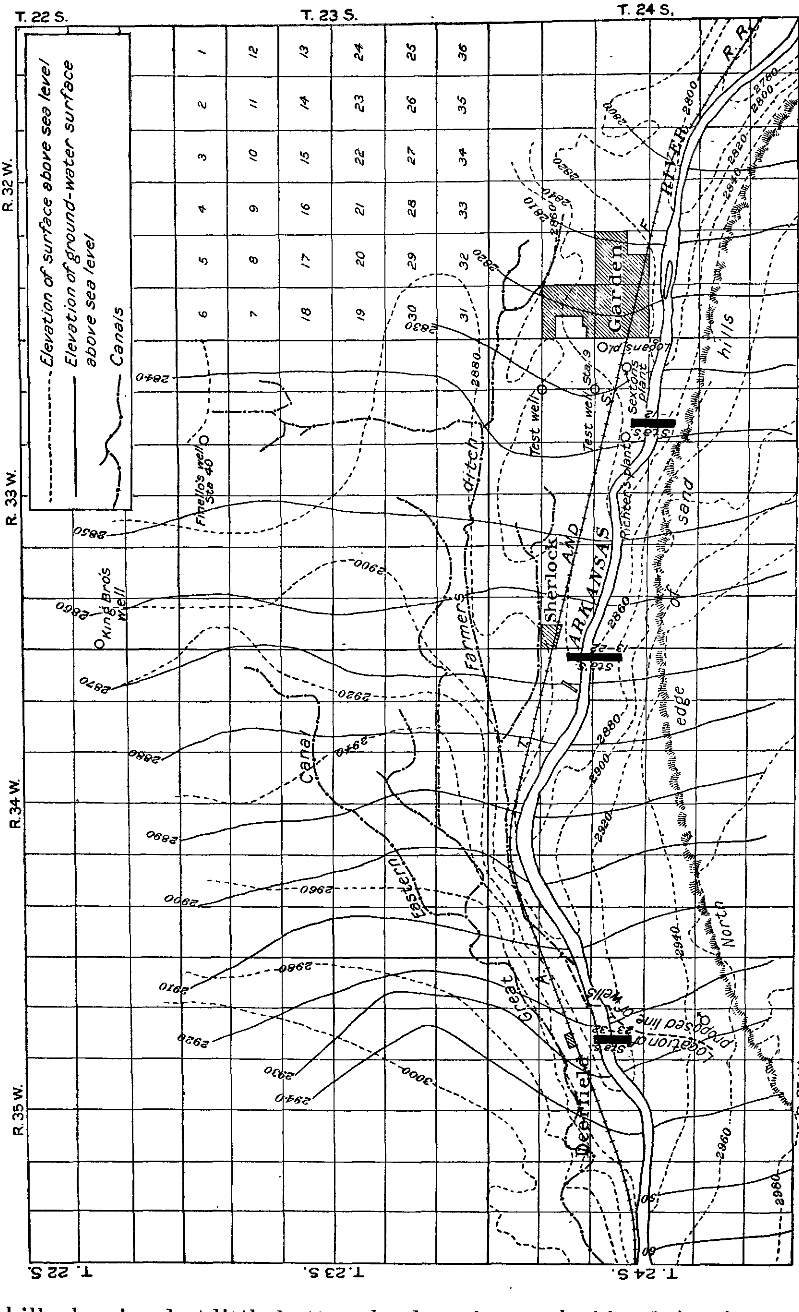


FIG. 1.—Map showing the water plane or ground-water surface between Garden and Deerfield, Kans., as determined during the summer of 1904. Underflow stations shown west of Garden, and near Sherlock and Deerfield, Kans.

hills, leaving but little bottom land on the south side of the river. The channel of the river where the observations were made is about 1,000 feet wide. On the north side is a strip of low land, or first bottoms, about 1,100 feet wide, which is only a few inches above the general bottom of the river bed. This low bottom has several sloughs running through it approximately parallel to the river. North of this low strip of bottom the land abruptly rises several feet and continues

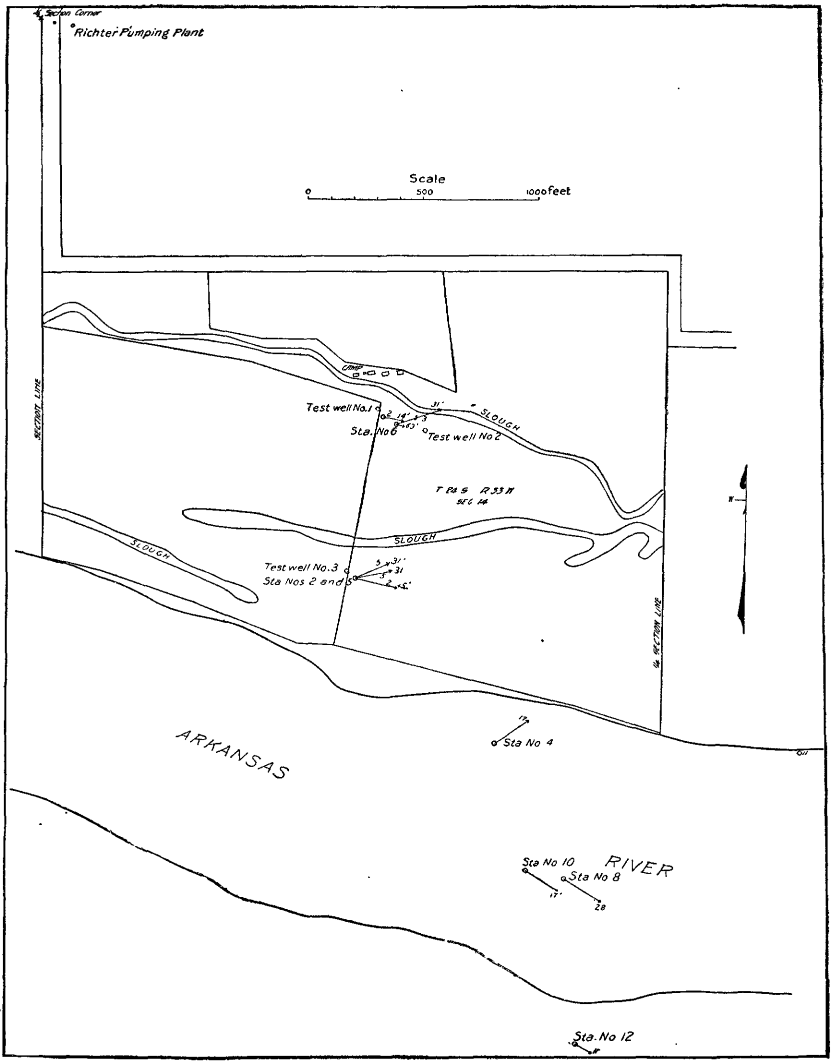


FIG. 2.—Map showing location of underflow stations and test wells at camp 1, 2 miles west of Garden, Kans. The velocity and direction of flow is shown by the length and direction of the arrows at the various stations. The depth is indicated in figures at each location.

to rise gradually for several miles farther north, this slope constituting the cultivated portion of the valley—the so-called second bottoms.

The measurements at this point were made at stations that lay, in general, in a straight line across the valley (fig. 2). Most of the measurements were made in the river channel itself, or on the low ground to the north. One test was made on the south side of the river at the foot of the sand hills and another 1 mile to the north. The velocities were determined at depths ranging from 11 to 65 feet. The results of the measurements at this location are given in Table 1.

TABLE 1.—*Underflow measurements at camp 1, 2 miles west of Garden, Kans.*

Date of test.	No. of station.	Depth of well.	Velocity of ground water.	Direction of flow, east of north.	Location and remarks.
1904.		*Feet.*	*Ft. per day.*	°	
June 30	9	16	5.3	90	1 mile north of river.
June 22	1	14	4.8	101	1,100 feet north of river.
Do	3	31	10.3	71	Do.
June 21	2	15	9.6	103	430 feet north of river.
June 24	5	31	8.0	65	Do.
June 26	5	29	8.0	77	Do.
June 25	4	17	9.0	55	In channel, 250 feet north of center.
July 6	8	28	9.6	121	In channel, 150 feet south of center.
July 4	10	17	8.2	121	Do.
July 9	12	11	4.0	120	250 feet south of river.
September 6	6	65	1.75	101	1,100 feet north of river.
September 8	40	25	1.3	104	NW. corner SW. ¼ sec. 2, T. 23 S., R. 33 W., 8½ miles north of river.
Average			6.6	94	

Mean direction of river channel, 100° east of north.

Of the stations for which data are given in this table, No. 9 was located on the second bottoms 1 mile north of the river, No. 40 was located on the uplands 8½ miles north of the river, and No. 12 was in the sand hills south of the river. The other stations were either in the first bottoms or in the channel. Station No. 6 reached so-called "second water," or the water beneath a layer of silt which seemed quite impervious to the flow of water. The mean of all of the observed velocities was 6.6 feet a day. The average direction of the motion was 94° east of north, which may be compared to the average direction of the river valley at this point, which we have estimated to be approximately 100° east of north. On the cross section through the river channel and the first bottoms (fig. 3) are shown the depth of a number of the test wells near the river channel and the velocity of the underflow.

Except for occasional layers of silt, the gravels were very uniform in size and character of grain; a large percentage of any one sample consisted of grains larger than grains of wheat. The gravel was also found to be very uniform in lateral extent, but showed a tendency to become coarser with the depth until 32 feet was reached. At about 32 feet fine sand and silt was encountered, which seemed, as nearly as could be determined from the wells sunk in a comparatively small radius, to be horizontal in extent. Fine material was encountered at a higher level at only one place, which was near the center of the river at a depth of about 18 feet, but 50 feet upstream it was entirely absent.

A well was put down at station No. 11 in order to secure a sample of this fine material. It was found at the same level as at stations No. 6 and No. 8, and consisted of about the same kind of material, except that it contained a considerable amount of gypsum mixed with sand. This fine sand must be more or less impervious, for no water could be drawn by means of a hand pump from a well driven in the sand, and a hole washed out 8 feet below the casing remained for a considerable time unfilled with sand.

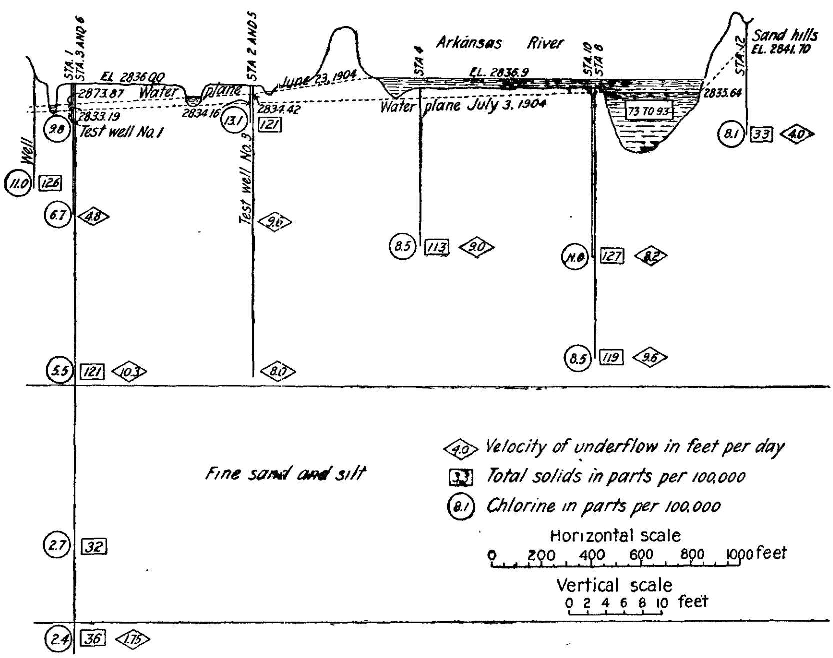


FIG. 3.—Cross section near camp 1, 2 miles west of Garden, Kans. The total solids dissolved in the ground water at various depths are shown, in parts per 100,000, by the numbers inclosed in rectangles. The numbers inclosed in circles express the amount, in parts per 100,000, of chlorine found at the position at which the circles are placed.

The velocities above this layer of silt are very uniform, ranging from 4.8 feet a day to 10.3 feet a day, with an average for ten tests of 7.68 feet a day, with the direction varying from 55° east of north to 121° east of north.

The direction of motion at these various stations, as has been stated, was in general toward the east, but several exceptions were noted from time to time. At the time field work was begun the channel of the Arkansas River was dry, as is very usual in the months from June to October. The summer of 1904, however, proved to be an exceptional one, and high floods were of constant occurrence throughout the season. One of these floods came down the river soon after the first underflow stations were established near the bank of the river. This offered an excellent opportunity of determining the influence of the river waters upon the underflow. At one underflow station, situated near the north bank of the channel of the river, 2 miles west of Garden, the direction of the flow of the ground waters was very greatly changed by the flood in the river. It was therefore possible to measure the rate at which the river contributed to the ground waters at this point. It was found that the water during the early stages of the flood flowed away from the river at the rate of 6 to 8 feet per twenty-four hours. This point can be established by consulting the record for stations No. 2 and No. 5, as given in Table 1. These stations are located at the same point. The velocity at station No. 2 on June 21, 1904, before a rain on the night of June 21, and before a flood which came down the river at 3 p. m. June 22, was 9.6 feet per twenty-four hours in a direction 103° east of north, which is substantially the direction of the river channel. After the flood the velocity at the same place (at a greater depth, however) was found to be 8 feet per twenty-four hours, in a direction 65° east of north, or at an angle of 35° away from the river channel, the flood having therefore changed the former direction of flow by about 38°. On June 26, when the flood had still further receded, a second determination of velocity showed the same rate as before, but the direction had shifted to 77° east of north, or at an angle of about 23° with the river channel.

It was not only possible to actually determine this rate of loss of water from the river by the use of the electric underflow meter, but the northerly progress of the water from the river into the gravels could be noted by observation of the changes in the temperature of the ground water as it flowed north. The river water was much warmer than the natural ground water, and the increased temperature could be followed away from the river bank. These facts are shown by the temperatures of the water recorded in Table 11. In that table will be found the following entries:

Temperature of water of river and test wells, June 20, 1904.

	°F.
River	71
Test well No. 3, 360 feet north of river	62.5
Test well No. 1, 1,100 feet north of river	59

The water taken from the other wells had a somewhat more uniform temperature, excepting in two cases—that taken from the wells at station No. 10 and station No. 8. At station No. 10, at a depth of 18 feet, the temperature was 51°; at station No. 8, 28 feet below the bottom of the river, the temperature was 48°, which was the coldest water found at any point. At these two stations the direction of the underflow was the most southerly of any found, being in each case 121° east of north.

It was also possible to partially trace inward moving ground water originating in the river by the change in the chemical composition of the water. Apparatus was at hand for determining the alkalinity, hardness, chlorine, and the total solids dissolved in the water; and this apparatus was used to secure the results just stated. A further verification of the inwardly moving ground water was found in the changed slope of the water plane during the flood periods in the river. The water plane sloped away from the river about 8 feet to the mile during the first stages of high water, and corresponded quite accurately with the observed velocities of the water. Fig. 3 shows the slope of the water plane on June 23 and July 3. Several gradients corresponding to other dates are given in Table 1.

MEASUREMENTS AT SHERLOCK, KANS. (CAMP 2).

Several underflow measurements were taken at camp 2, which was situated at Sherlock, Kans., 7 miles west of Garden. The results differed little from those found at the first set of stations at camp 1, except that more sorting of the gravels had taken place at the latter point, giving greater variety to the rate of movement. The location of the various test wells and underflow stations is marked in fig. 4. The same stations are shown in cross section in fig. 5. The details of the results are printed in Table 2. From this table it will be observed that the average velocity of the underflow for all of the stations was 8.9 feet per twenty-four hours. The mean direction of the motion was 93.5° east of north, which may be compared with the mean direction of the river valley at this point, which was computed to be 105° east of north. There was some water in the river throughout all of the time during which the tests were made, and on July 27 a heavy flood swept down the river.

TABLE 2.—*Underflow measurements at camp 2, Sherlock, Kans.*

Date of test.	No. of station.	Depth of wells.	Velocity of ground water.	Direction of flow, east of north.	Location and remarks.
1904.		*Feet.*	*Ft. per day.*	°	
July 16	13	18	5.7	64.0	700 feet north of river.
July 30	21	28	22.9	64.0	Do.
July 31	22	28	2.8	101.0	1,700 feet north of river.
July 17	14	22	9.1	75.0	In channel, 500 feet north of center.
July 23	18	21	16.0	101.0	In channel, 20 feet north of center.
July 22	17	36	3.0	103.0	In channel, 210 feet south of center.
July 18	15	22	16.7	132.0	Do.
July 29	20	26	2.2	122.0	200 feet south of river.
July 22	16	18	2.0	79.0	2,100 feet south of river.
Average			8.9	93.5	

Mean direction of river channel, 105° east of north.

By studying the results of the measurements it will be observed that station No. 22 was on the border of the second bottoms, 1,700 feet north of the north bank of the river. The velocity at this station was 2.8 feet per day, and the direction of flow was substantially the same as the direction of the river valley. This result is important, as the measurement was made on July 31, at a time when the

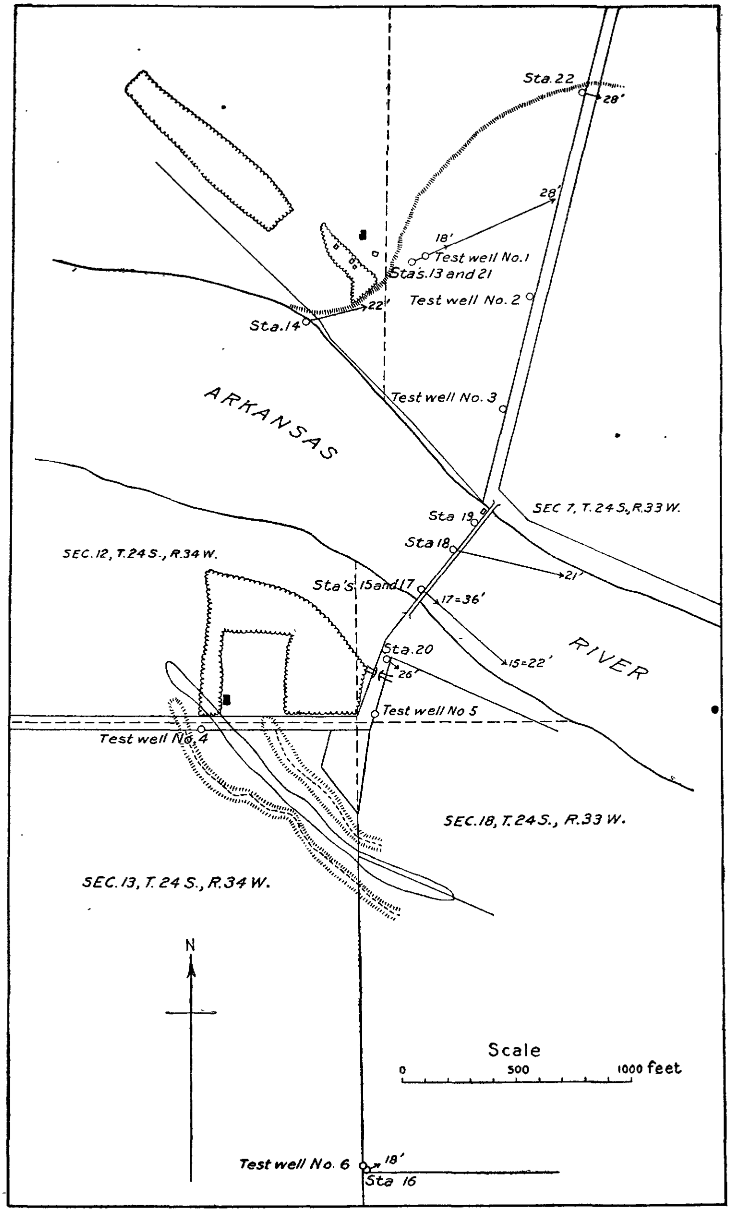


FIG. 4.—Map showing location of underflow stations and test wells at Sherlock, Kans., 7 miles west of Garden. The velocity and direction of flow of the ground water are shown by the length and direction of the arrows at the various stations. The depth is indicated in figures at each station.

flood of July 27 should have shown some influence upon the direction of flow, if it had any at all. The direction of motion at this station was in marked contrast to the direction of flow observed at stations

No. 13 and No. 21, located in the first bottoms, 700 feet north of the river. At both of the latter stations the direction of flow was 64° east of north, or in a direction making an angle of 41° northeast of the general direction of the river valley. These stations were within the immediate influence of the fluctuations of the height of the water in the river.[a]

Of the stations established in the channel of the river itself, it is interesting to note that a station located north of the center of the

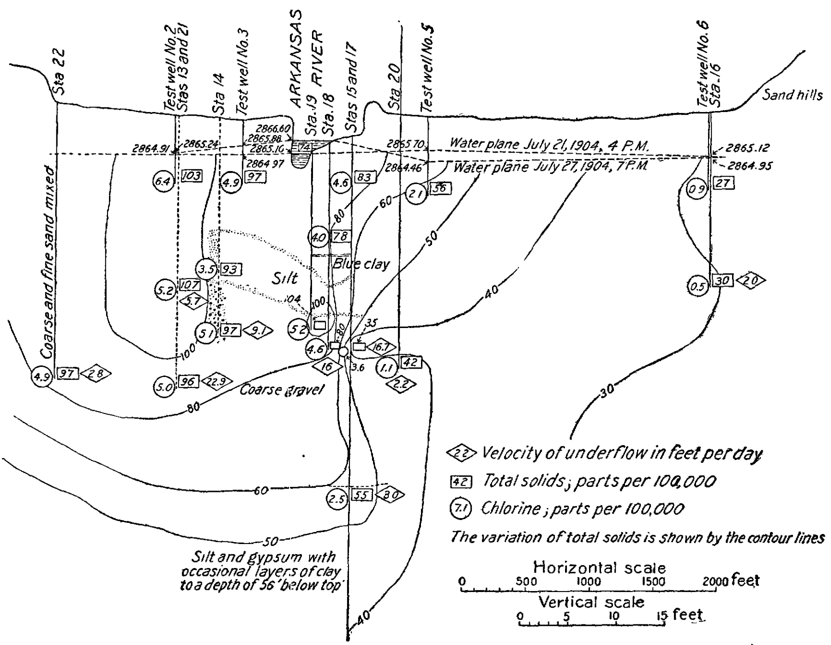


FIG. 5.—Cross section at camp 2, near Sherlock, Kans. The total solids dissolved in the ground water at various depths are shown in parts per 100,000 by the numbers inclosed in rectangles. The numbers inclosed in circles express the amount, in parts per 100,000, of chlorine found at the position where the circles are placed. The contour lines show the position of water of the same strength. The contribution of salt water from the sand hills is very apparent.

channel (station 18) showed a component of velocity northerly to the general trend of the valley, while a station south of the channel (station 15) showed a component of velocity southerly to the direction of the valley. At station No. 17, in the channel at the same point as station No. 15, but at a greater depth, the direction of the flow corresponded closely with the direction of the valley, indicating that the influence of flowing water in the river did not extend so deep. Station No. 20 was located on the first bottoms, 200 feet south of the south bank of the river. The motion at this point showed a southerly component, the direction of flow making an angle of 17° with the direction of the valley. The measurement was taken while the river was in

[a] This fact will be further illustrated at a later place in this report.

flood. Station No. 16 was located in the border of the sand hills, nearly a half mile south of the river. The direction of flow was toward the river and away from the sand hills, as should be expected on account of the excellent collecting area offered by the sand hills to the rainfall.

The fact that the influence of the river only extends to very shallow depths and that a considerable portion of the ground water originates in the sand hills is shown by the cross section (fig. 5). The contour lines in this figure correspond to equal amounts of total solids dissolved in the ground water. The soft water from the sand hills can be observed to be crowding the strong water of the underflow to the north of the valley.

MEASUREMENTS AT DEERFIELD, KANS. (CAMP 3).

Camp 3 was established near the Deerfield bridge, 14 miles west of Garden. The valley at this point lies mostly south of the channel. All of the south-side lands, to the edge of the sand hills, would probably be classed as "first bottoms." The surface of the ground on these lands is only a few feet above the river bed and the soil is unusually sandy. The topography of the sand hills south of the bottom lands is unusually well adapted for collecting the rainfall, there being several level stretches inclosed or hemmed in by the hills. A short distance south of station No. 23 there are found the remains of a former river bank, indicating that an ancient channel extended as far south as station No. 23 (see fig. 6).

On the north side of the channel the river sweeps a high bank from 6 to 10 feet above the river bed for a distance of about 3 miles. The uplands begin not more than 1 mile north of the river.

Since the channel here borders the extreme north margin of the valley the underflow measurements were made south of the river or in the channel. The results are printed in Table 3.

TABLE 3.—*Underflow measurements at camp 3, Deerfield, Kans.*

Date of test.	No. of station.	Depth of wells.	Velocity of ground water.	Direction of flow east of north.	Location and remarks.
1904.		*Feet.*	*Ft. per day.*	°	
August 6	25	16	6.3	66.0	In channel at center.
Do	24	21	12.5	67.0	In channel 400 feet south of center.
August 5	23	24	19.2	111.0	500 feet south of river.
August 8	26	36	9.2	111.0	Do.
August 9	27	24	14.8	129.0	1,050 feet south of river
August 12	28	21	1.25	74.0	1,800 feet south of river.
September 22	29	17	1.6	56.0	1.8 miles south of river.
August 17	32	31	2.2	63.0	1,800 feet south of river.
Average			8.4	84.6	

Mean direction of river channel, 70° east of north.

The average velocity of the ground water, 8.4 feet per twenty-four hours, compares accurately with the average velocities found for stations similarly located at previous camps. The mean direction does not correspond as accurately with the general trend of the river

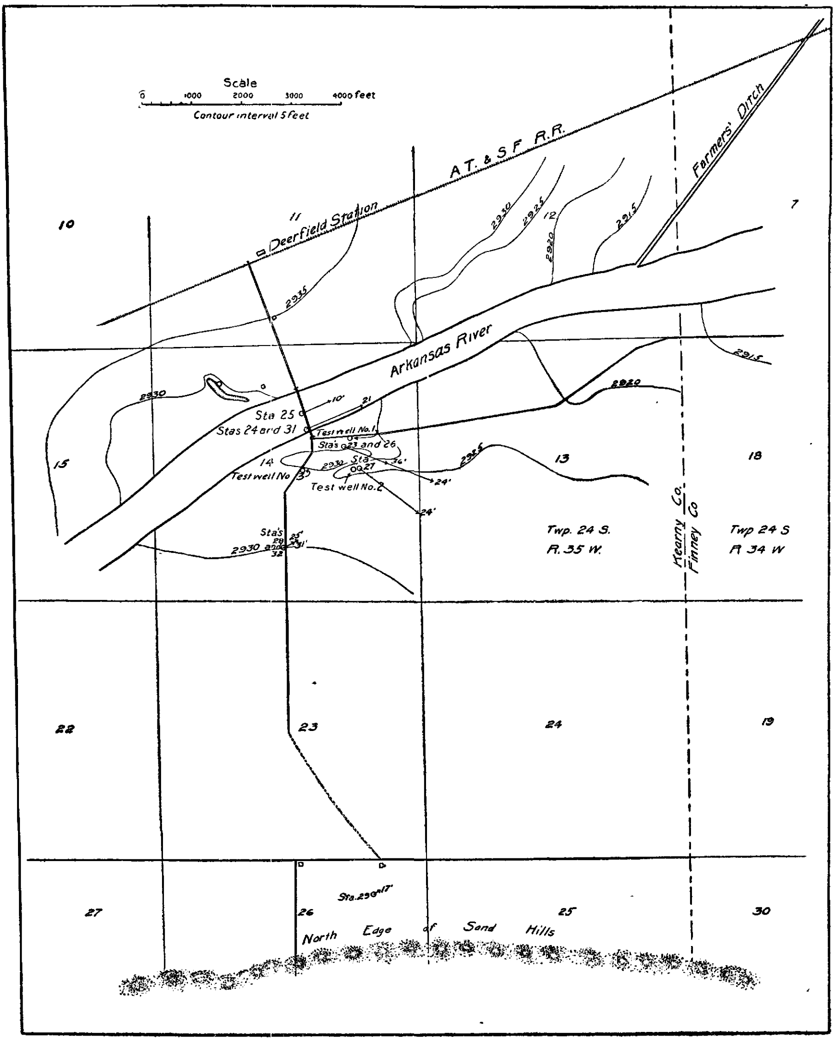


FIG. 6.—Map showing the location of underflow stations at camp 3, near Deerfield, Kans. The velocity and direction of flow of the ground water is shown by the length and direction of the arrows. The depth is indicated in figures at each station.

channel as at other stations, probably in part owing to the fact that the river has at this point a very northerly course.

It will be observed that the direction of flow at stations Nos. 23, 26, and 27, which are, respectively, 500, 500, and 1,050 feet south of the river, had a strong southerly component, the resultant direction of motion making angles in the three cases of 41°, 41°, and 59°, respectively, away from the river. These are to be contrasted with the direction of motion nearer the sand hills, at stations Nos. 29 and 32, where the direction of flow was away from the sand hills and toward the river, the direction of flow in the two cases making angles of 14° and 7°, respectively, toward the channel of the river.

MEASUREMENTS AT CLEAR LAKE, NEAR HARTLAND, KANS. (CAMP 4).

About 2½ miles southeast of Hartland, Kans., in section 13, T. 25 S., R. 37 W., there is situated a small body of water called Clear Lake. This pond is nearly circular, 320 feet in length and 280 feet across at the narrowest point. The pond is located within 500 feet of the south-side ditch, and the owners of the canal have had under serious consideration the erection of a pumping plant to take water from the pond to supply the ditch with water for irrigation. It was expected by the promoters of this scheme that the lake would act as an enormous well and would furnish a large amount of water when its level was lowered by means of large centrifugal pumps.

There have been the usual rumors current among the settlers to the effect that the pond was very deep, and that its elevation was independent of the amount of rainfall or the fluctuations in the river, which at this point is about 1 mile northwest of the pond. Investigations showed that the water in the lake was 11 feet below the water in south-side ditch. The location of the lake with reference to the ditch and the topography near it is shown on the map, fig. 7. This is a 5-foot contour map of the district surrounding the lake, made from the level of the water in the pond as datum. Mr. H. E. Hedge, engineer of the south-side ditch, furnished the field party much assistance, and especially aided them in the construction of a raft from which to take soundings, so as to make a hydrographic map of the bottom of the lake. The shores slope at an angle of about 35° to a depth of 16 feet, where there is practically a flat level floor of mud. At this depth the diameter of the lake is about 100 feet. From this it can be computed that the total volume of the lake is 483,000 cubic feet, or that the lake contains about 11 acre-feet of water. The bottom of the lake consists of an accumulation of black muck, which is very soft. A test well was sunk in the center of the lake from the raft for the purpose of determining the character of the material at the bottom, so as to settle, as far as practicable, the question of whether the lake could be used as a large well from which to secure a supply of water. In sinking a 2-inch pipe for this purpose it was found that it would sink of its own weight to a depth of 30 feet. The pipe was then forced down without driving to a depth of 40 feet, after which it was easily jetted and driven to a depth of 62 feet below the water, or 46 feet under the bottom of the lake. In clearing the material from the 2-inch pipe 75 feet of wash pipe was used, so that samples were washed up from a depth of about 12 feet below the bottom of the 2-inch well. The material washed out consisted of black mud and clay, with some quicksand.

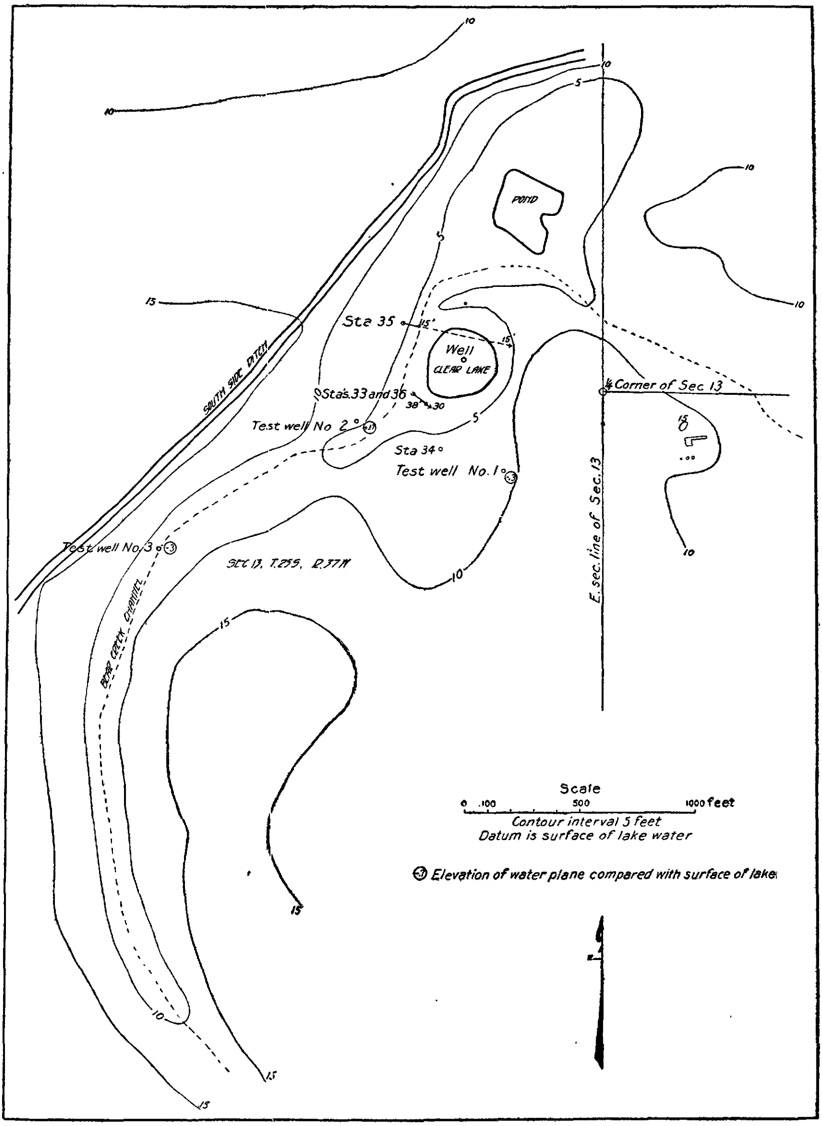


FIG. 7.—Map showing location of underflow stations and test wells near Clear Lake, Kansas.

A line of levels was run from Clear Lake to Arkansas River as nearly as practicable at right angles to the direction of the river channel. The result of this leveling showed that the river was at least 8 feet higher than the lake.[a]

[a] Field notes show that the river was quite high at the time of the observation on August 20, 1904.

This result was somewhat surprising, so that a second line of levels was run to the river along the east line of section 13 until this line intersected the river. This line of levels intersected the river at a point three-fourths of a mile below the former point. The river at this point was found to be 3 feet higher than the surface of Clear Lake. Since the river slopes about 7½ feet to the mile, this checks the former measurement that the river opposite the pond is 8 feet higher than the water in the latter.

The above observations seem to indicate that the small pond known as Clear Lake is one of the many circular depressions which are found throughout the western plains, and which have been fully described by Mr. Willard D. Johnson.[a]

This small pond is of especial interest because it is in line with the dry channel of a plains stream called Bear Creek. This stream rises in Colorado, and near the western border of Kansas has a well-marked valley, eroded to a depth of nearly 100 feet, but as it approaches Arkansas River, near the north edge of Grant County, it loses this, and its waters spread out on the plains and sink. The ordinary flow of this stream is very small, but during times of heavy rain in eastern Colorado and western Kansas it may carry a large quantity of water, which it pours out upon the high plains of northern Grant County and into the sand hills along the south side of Arkansas River. On some occasions the freshets in this stream have been so severe that the waters have nearly reached the Arkansas. There is a slight elongated depression extending through the sand hills in line with Clear Lake, which makes it possible to believe that the waters of Bear Creek have on some occasions in the past extended to the Arkansas, but so far as known there is no settler who can testify to having actually observed such an event.

It can easily be believed, from the rather remarkable character of Bear Creek, that settlers would naturally associate Clear Lake with the disappearing waters of Bear Creek, so that the story would become current that Clear Lake was merely an evidence or indication of the existence of an underground stream extending from the sand hills to Arkansas Valley itself. On this account belief in the adaptability of the lake for a supply of a large quantity of water for irrigation has been prevalent, so that an investigation of the conditions surrounding the lake has importance. There are several streams of the same type as Bear Creek in western Kansas.

Underflow stations Nos. 33, 35, and 36 were established, as shown on the map (fig. 7), for the purpose of determining the direction and magnitude of the velocity of the underground water. It was hoped to determine in this way whether or not there was any seepage at this point from the direction of Bear Creek toward Arkansas Valley. The

[a] The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1900, pp. 609, 693–715.

direction and velocity of movement are indicated by the arrows shown in fig. 7, and the details of the measurement are given in Table 4. Station No. 33, 25 feet south of Clear Lake, gave a velocity of 5 feet a day; the direction was almost exactly across the dry channel of Bear Creek and in the general direction of Arkansas Valley. Station No. 36, located at the same place, but at a depth of 38 feet, showed a velocity of 4.3 feet in the same direction. Station No. 35, 150 feet northwest of Clear Lake, showed a velocity of 5 feet a day at a depth of 30 feet. The velocities observed at this point may have been due in part to seepage from the south-side ditch, as the direction was almost directly away from this ditch and in the general direction of the slope of the ground. Even if this be the case, it nevertheless proves that there is no seepage nor movement of ground water extending down the so-called channel of Bear Creek, for if there had been such motion the resultant velocity found would at least have shown a component of motion in the direction of the flow in the channel of Bear Creek. It would be impossible for the seepage from south side ditch to disguise completely a ground-water movement in another direction.

TABLE 4.—*Underflow measurements at camp 4, Clear Lake, near Hartland, Kans.*

Date of test.	No. of station.	Depth of wells.	Velocity of ground water.	Direction of flow, east of north.	Location and remarks.
1904.		*Feet.*	*Ft. per day.*	°	
August 19	33	30	5.0	74	25 feet southwest of Clear Lake.
August 20	35	15	3.1	101	150 feet northwest of Clear Lake.
August 21	36	38	4.3	74	25 feet southwest of Clear Lake.

An attempt was made to sink a set of wells at station No. 34, 230 feet south of Clear Lake. At this point wells were driven to a depth of 40 feet, but the material was so fine that no water could be pumped from the wells, except a very little at a depth of 16 feet. On this account no test was made.

It can easily be concluded from the tests made above that it is not feasible to use Clear Lake as a well from which a large quantity of water can be pumped for irrigation purposes. While Clear Lake undoubtedly has direct connection with the surrounding ground water and shows the level of the ground water in its neighborhood, the evidence from the character of the material encountered in stations Nos. 33, 35, and 36, and the evidence from direct observation of the flow of the water and the material encountered in the deep well sunk in the middle of the lake, show that the pond is not favorably situated for use as a source of a large supply of water for the south-side ditch.

These observations also show that no ground water reaches either Clear Lake or Arkansas River from the lost waters of Bear Creek. Any seepage water approaching Arkansas Valley from Bear Creek must take up a generally easterly movement almost immediately upon entering the sand hills.

MEASUREMENTS OF THE UNDERFLOW AT THE NARROWS OF ARKANSAS RIVER, NEAR HARTLAND, KANS. (CAMP 5).

Two miles west of Hartland, Kans., Arkansas River flows between rock bluffs, the distance between which at the narrowest portion is

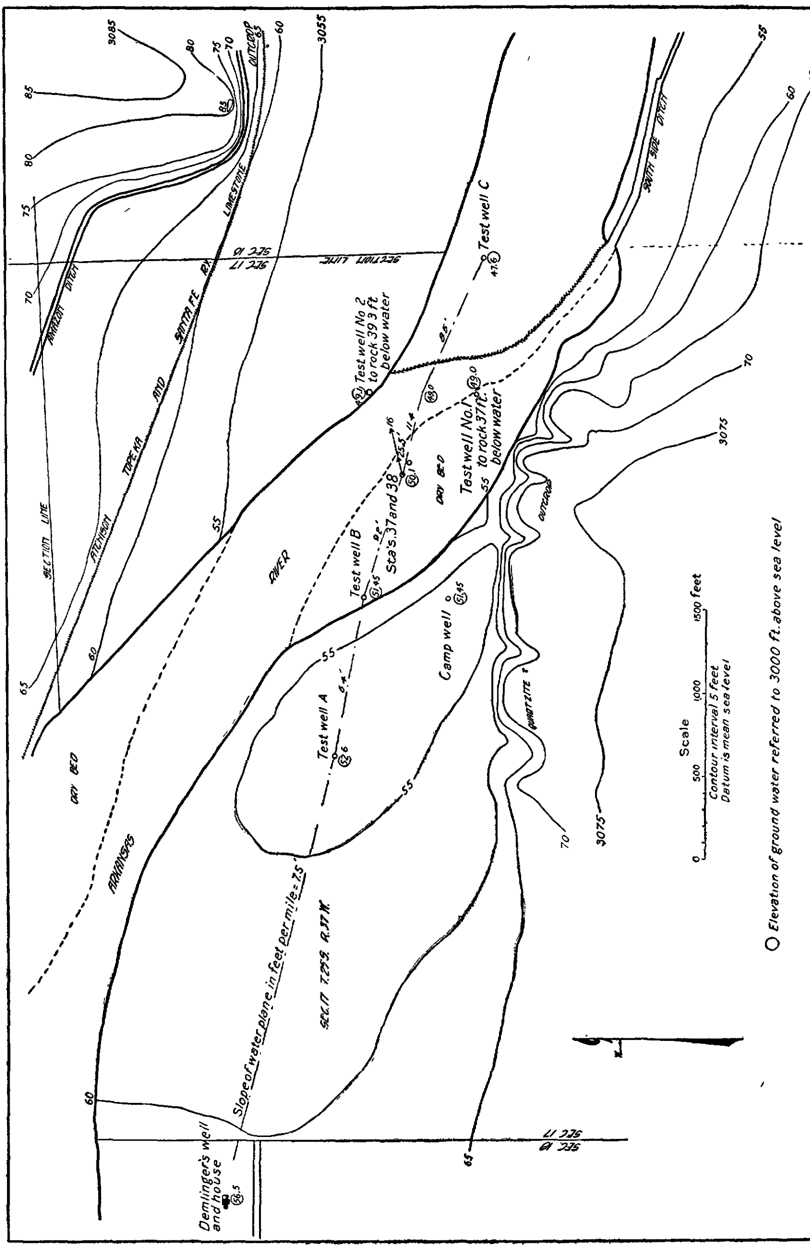


FIG. 8.—Map showing location of underflow stations and test wells near Hartland, Kans. Rock is exposed on both banks of the river at this point.

2,250 feet. The river channel occupies 900 feet of this distance, only a portion of which was utilized by flowing water on August 24, 1904.

Test wells A, B, and C were driven to shallow depths for the purpose of determining the slope of the water plane through the Narrows.

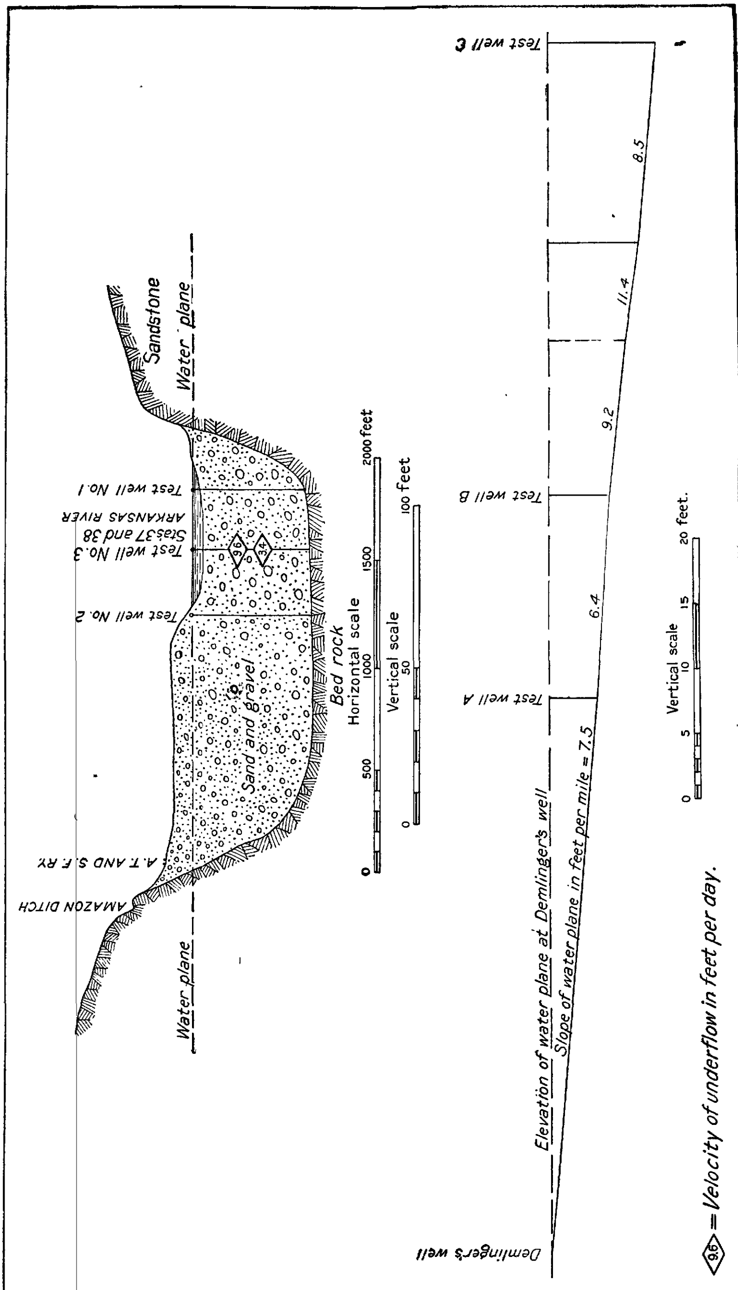


FIG. 9.—Cross section at the Narrows of Arkansas River, west of Hartland, Kans. The slope of the water plane through the Narrows is shown by the line at the bottom of the drawing.

In addition to these test wells, the elevation of the water was taken at Demlinger's well and in the wells of station No. 38, and in test wells driven for the purpose of testing for rock. These wells form a line about a mile long, as indicated on the map (fig. 8). The gradient of the water plane in the first portion of this line was 7.5 feet per mile; in the next portion it was 6.4 feet per mile, and in the next 9.2 feet per mile. Just above the Narrows the gradient was found to be 11.4 feet per mile, and in the last portion, in the Narrows itself, the slope of the water plane was 8.5 feet per mile. A profile showing these gradients is given at the bottom of fig. 9.

Test wells Nos. 1 and 2 (shown in fig. 8) were driven for the purpose of testing for bed rock. What is believed to be rock was struck at test well No. 1, at elevation 3,011.7, or 37 feet below the water plane, and at test well No. 2 rock was reached at elevation 3,009.8, or 39.3 feet below the water plane. Rock was also struck at station No. 38 at 38.75 feet below the water plane. As a diamond drill was not at hand, the evidence that bed rock was reached is, of course, not conclusive. The only test that could be applied was the evidence supplied by the drill on the wash pipe and by the way in which the 2-inch casing acted when an attempt was made to drive it.

Two measurements were made of the rate of movement of the underflow near the center of the Narrows at stations Nos. 37 and 38. The velocities determined were 9.6 feet per twenty-four hours at a depth of 16 feet and 3.4 feet per twenty-four hours at a depth of 25 feet.

TABLE 5.—*Underflow measurements at camp 5, Narrows of Arkansas River, near Hartland, Kans.*

Date of test.	No. of station.	Depth of wells.	Velocity of ground water.	Direction of flow, east of north.	Location and remarks.
1904.		*Feet.*	*Ft. per day.*	°	
August 23	37	16	9.6	77	Center of channel.
August 26	38	25	3.4	77	Do.

From the cross section of the Narrows (shown in fig. 9) an estimate can be made of the amount of water which flows through the Narrows. The total cross section of the sands, assuming the above test borings as indicating the true position of bed rock, is 75,000 square feet. Assuming one-third as the porosity of the sands and 10 feet per day as the average velocity of the ground water, the total flow through the Narrows would be 250,000 cubic feet per day, or 2.9 cubic feet per second. The actual average velocity of the underflow is undoubtedly much less than 10 feet per day, so that the above result represents the maximum that can be claimed in a high estimate.

CHAPTER II.

FLUCTUATIONS OF GROUND-WATER LEVEL.

INFLUENCE OF RAINFALL AND OF HEIGHT OF WATER IN ARKANSAS RIVER ON THE GROUND-WATER LEVEL.

During the field work of the summer several opportunities were found to observe the influence of a change of level of the water in the river upon the water plane in the adjacent bottom lands. The summer of 1904 was especially favorable for observations of this kind, as the season was an exceptional one, both in respect to the rainfall and as to the quantity of water flowing in the river. There was water in Arkansas River, in western Kansas, during nearly all of the time from the middle of June to the middle of September, and on several occasions floods of marked suddenness and great severity passed down the river. The rainfall during the same period was above the average. The record of rainfall from May 1 to October 1, as observed by the volunteer station of the United States Weather Bureau at Garden, Kans., is given in Table 6.

TABLE 6.—*Daily precipitation, Garden, Kans., May 1 to September 30, 1904.*

Date.	May.	June.	July.	August.	September.
1	0.58	0.0	0.0	0.03	0.0
2	Trace.	.25	.0	.0	.24
3	1.82	.04	.0	.0	.0
4	.75	.0	.95	.28	.0
5	.0	.0	Trace.	.0	.0
6	.0	.0	.12	.45	.0
7	.0	.0	.55	.0	.0
8	.20	.0	1.10	.0	.0
9	.0	.72	.0	Trace.	.0
10	.0	.0	.05	.0	.0
11	.0	.0	.0	.0	.0
12	Trace.	.0	1.32	.0	.0
13	.0	.30	.08	.0	.0
14	.0	.0	.0	.0	.0
15	Trace.	.0	.0	.0	.0
16	.0	Trace.	.0	.0	.0
17	.0	.19	.0	.0	.0
18	.0	.0	.0	.04	.0
19	.0	.0	.0	.32	.0
20	.0	.0	Trace.	.0	.0
21	.03	Trace.	Trace.	.0	.0
22	..85	.94	[a]1.42	.0	.0
23	.0	.0	.0	.0	.0
24	.0	.0	.0	.0	.0
25	.0	.0	.06	.11	.0
26	.0	.0	.0	.0	.0

[a] Much less at Sherlock, Kans.

TABLE 6.—*Daily precipitation, Garden, Kans., May 1 to September 30, 1904*—Continued.

Date.	May.	June.	July.	August.	September.
27	0.03	0.0	0.0	0.0	0.10
28	.04	.20	.0	.0	1.85
29	.0	.0	.0	.0	1.10
30	.0	.0	.0	.09	.10
31	.0	....	Trace.	Trace.	....
Total	4.30	2.64	5.65	1.32	3.39

Total for five months, 17.30.

Observations of the water plane were made very systematically during the various stages of the water in the river by Mr. Wolff, who was in charge of the party making the field observations. The results of these observations are given in the accompanying diagrams, which Mr. Wolff has constructed from the field notes. The first underflow determinations were made at the camp located about 2 miles west of Garden, Kans., on the ranch of Mrs. M. Richter, which is referred to in the text as camp 1. At this camp a number of shallow test wells were put in place for the special purpose of observing the position of the water plane. These test wells are shown on the map (fig. 2), from which it will be observed that test wells Nos. 1 and 2 were located north of the river bank at a distance of about 1,070 feet; test well No. 3 was closer to the river, at a distance of about 360 feet from the north bank. A large well located on the ranch of Mrs. Richter, and used for irrigation, was also used for the purpose of keeping track of the fluctuations of the water plane. The location of this well is shown on the map (fig. 2) near the quarter-section corner in the upper right-hand corner of the map. As will be observed, this well is situated a considerable distance upstream from test wells Nos. 1, 2, and 3; hence the water in it stood much higher than that in the test wells, since the water plane slopes eastward at the rate of about 7½ feet per mile. The land in which test wells Nos. 1, 2, and 3 are situated is what is commonly called in that locality "first bottoms." Immediately north of test wells Nos. 1 and 2 the "second bottoms" begin, the land here being some 3 to 5 feet higher than in the "first bottoms." Two sloughs shown on the map were grass covered, but contained more or less water either during high stages of the river or after heavy rains. In fig. 10 the elevations of water in Arkansas River from June 16 to July 11, 1904, and the elevations in test wells Nos. 1, 2, and 3 and in Mrs. Richter's well are represented graphically. The elevations are expressed in feet above mean sea level, as determined from the United States Geological Survey permanent bench marks in the valley. The detailed observations at these stations are printed in Table 7, in which the elevations are given in feet above mean sea level. The observation of the height of the river was made from a gage rod set up in the river and observed from the bank with a level. Observations were made morning and evening during the period covered by the table. There were occasional omissions of observation of river height, due to the absence of the level from camp.

TABLE 7.—*Elevation of ground water in the Arkansas River and in test wells near camp 1, 2 miles west of Garden, Kans.*

[Wells Nos. 1 and 2 are 1,070 feet north of river; well No. 3 is 360 feet north of river. Datum is 2,800 feet above mean sea level.]

Date.	Time.	Elevation of water in well No. 1.	Hydraulic gradient per mile from well No. 2 to well No. 1.	Elevation of water in well No. 2.	Hydraulic gradient per mile from well No. 1 to well No. 3.	Elevation of water in well No. 3.	Elevation of water in river.	Barometric pressure in inches of mercury.
1904.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Inches.*
June 16	12 m	33.97					36.7	28.60
Do	6 p. m	33.86						26.54
June 17	6 a. m	33.90						26.62
Do	12 m	33.87						26.55
Do	6 p. m							
June 18	6 a. m	33.98						26.63
Do	6 p. m	33.76	6.4	33.53	6.3	34.61	36.2	26.50
June 19	6 p. m	33.75	4.7	33.58	5.9	34.55		26.45
June 20	6 a. m	33.89	8.1	33.60	5.3	34.61	36.1	
Do	6 p. m					34.41	36.0	
June 21	6 a. m	33.82			4.8	34.47	36.0	26.47
Do	12 m	33.59	6.4	33.36	5.5	34.33		
Do	6 p. m	33.77	7.2	33.51	4.5	34.38		
June 22	6 a. m	34.45	8.9	34.13	4.2	35.02		
Do	12 m							
Do	6 p. m	33.94			8.8	35.12	37.7	
June 23	6 a. m	34.05	6.7	33.81	7.6	35.07	36.9	26.27
Do	6 p. m	33.87			8.0	34.95	36.9	
June 24	6 a. m	34.00	6.9	33.75	7.1	34.95	36.5	
Do	6 p. m	33.77	6.7	33.53	6.8	34.69	36.3	26.35
June 25	6 a. m	33.93	8.1	33.64	5.1	34.61	36.2	
June 26	6 a. m	33.93			3.6	34.42	35.9	
Do	12 m	33.77	6.1	33.55				
June 27	6 a. m	33.93	7.7	33.67	3.9	34.45	35.9	
Do	6 p. m						35.9	
June 28	6 p. m						35.9	
June 29	6 a. m						35.8	
Do	6 p. m						35.8	
July 1	6 a. m						35.7	
Do	6 p. m						35.7	
July 2	6 a. m						35.7	
Do	6 p. m						35.7	
July 3	6 a. m						35.7	
Do	6 p. m	33.19	6.7	32.95	7.2	34.16	35.6	
July 4	6 a. m						35.6	
July 5	6 a. m						35.6	
July 6	6 a. m						35.6	
July 7	6 a. m	33.99	7.2	33.73	2.72	34.35	35.6	
Do	6 p. m						35.6	
July 8	6 a. m	34.53	7.2	34.27	3.64	35.02	35.7	
July 9	6 a. m	33.88	8.1	33.59	1.71	34.11	35.7	
July 10	6 a. m						35.6	
July 11	6 a. m	33.68	8.1	33.39	3.15	34.10	35.8	

From the morning of June 21 until noon of June 22, which are left blank in the table, there was no material change in the height of the river. The water in the river slowly sank during the period covered from noon of June 16 to noon of June 22. The record shown in fig. 10 begins on June 16. The levels in the various wells remained substantially stationary from that date until June 22. During the night of June 21 a heavy rain fell, which is given on the official record at Garden as 0.94 of an inch. The test wells on the morning of June 22 showed marked changes in the elevation of the ground water, due to the rain of the previous night. Well No. 1 rose 0.68 of a foot; well No. 2 rose 0.62 of a foot; well No. 3 rose 0.64 of a foot, while the Richter well rose 0.05 of a foot before noon of June 22, and by the morning of June 24 had risen 0.10 of a foot. The river remained stationary until 3 p. m. of June 22, when a flood consisting of an abrupt wave swept down the river, causing a rise of 1.7 feet. Notwithstanding this rise in the river, the water in test wells Nos. 1 and 2, 1,070 feet from the river, fell during the interval between the morning and evening of June 22, while test well No. 3, which was situated within 360 feet of the river bank, was only 0.1 higher at 6 p. m. of June 22 than it was at 6 a. m. on the same day. These results show that the heavy rain of the night of June 21 raised the water in all of the test wells, but that the flood of the afternoon of June 22 raised the water only in the well nearest the river. The river gradually receded from the high-water mark reached on the afternoon of June 22, and all of the test wells gradually fell. There was no rain until July 4, except a slight shower on June 28. Test wells Nos. 1, 2, and 3 showed a tendency to fall, although the water in the river was from 2 to 3 feet higher than the water in the wells during all of this period.

The rise in the water plane from 6 p. m. of June 21 to 6 a. m. of June 22, amounting to a rise of 0.68 foot in test well No. 1 and 0.62 foot in test well No. 2, was due, as stated above, to a heavy rain which fell during the night. From the data at hand it is possible to express the magnitude of the contribution to the underflow as so many cubic feet of water for each mile of the river valley. If this contribution be supposed to extend uniformly over a given period of time, then the addition to the ground water may be expressed as a continuous flow of so many cubic feet of water per second for each linear mile of the river valley. Thus, in the present case, if we suppose that the rainfall of the night of June 21 fell uniformly during the twelve hours from 6 p. m. to 6 a. m., we can readily compute that the observed increased amount of ground water was equivalent for each mile of valley along the river to a continuous flow of water amounting to 23.8 cubic feet per second. To put this in other words, we can say that if the sands of the valley had contributed to the river by seepage all of the water which the rain added to these same sands, the seepage would amount to a continuous flow into each mile of the river of 23.8 cubic feet per second, maintained for twelve hours.

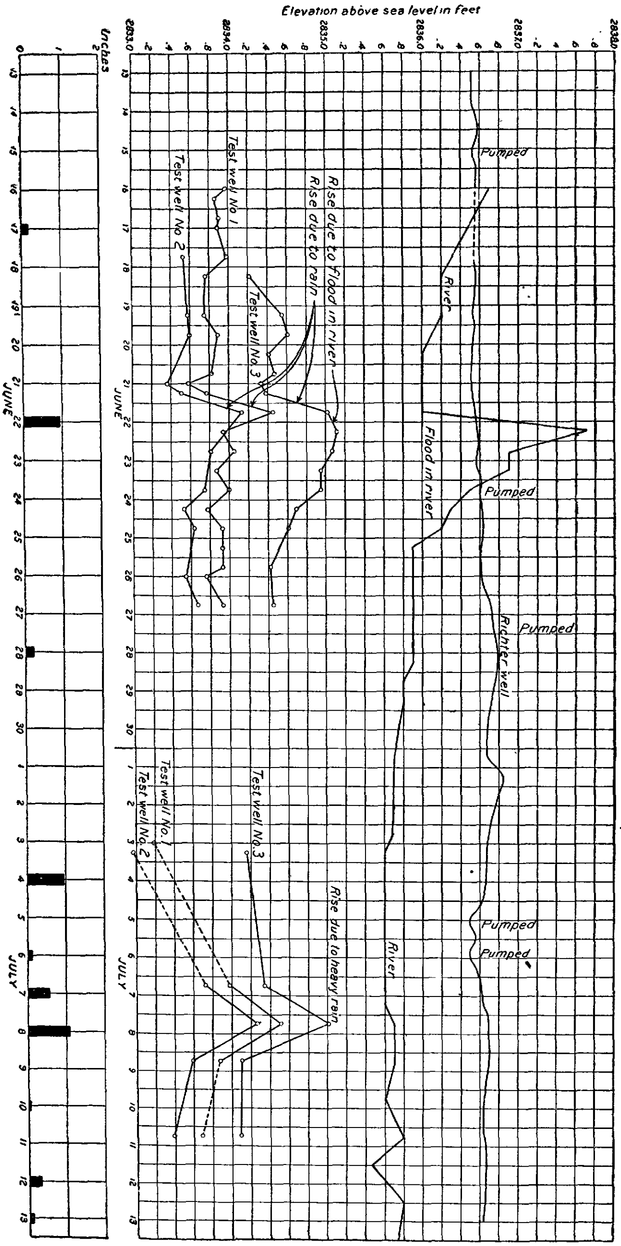


FIG. 10.—Elevation of water in Arkansas River and test wells, Garden, Kans., from June 16 to July 11, 1904. Test well No. 1 is 1,070 feet north of river; test well No. 2 is 190 feet east of test well No. 1; test well No. 3 is 360 feet north of river; Richter well is 2,500 feet north of river.

In a similar way, if the water contributed to the ground by the flood in the river from 3 p. m. to 6 p. m. of June 22 be considered as spread uniformly over twelve hours, it can readily be computed that the gain by the ground due to this cause represents a seepage loss for each mile of the river of 6.4 cubic feet of water per second. It can readily be seen, therefore, that the rainfall contributed a much greater volume of water to the underflow than was contributed by the flood in the river.

The average rise of the ground water during the night of June 21 was such that it would require a rainfall, without run-off, of 2.2 inches to fully account for it. The rainfall recorded at Garden for the night of June 21 was 0.94 inch. The difference between the measured rise of the ground water and the rainfall is explained by the fact that there is almost no run-off from the level lands of the river valley, so that nearly all of the drainage is underground by means of the deposits of sands and gravels. The seepage of this drainage is in part toward the low-water plane along and near the river channel. At such a place the amount of rise in the ground water would naturally be higher than could be accounted for by the localized rainfall.

After the high water of June 22 the river gradually fell until, on the morning of June 27, it had reached an elevation of 2,835.9 feet, which was 0.1 foot lower than its elevation on the morning of June 22. The water in the test wells gradually fell during the same period, the corresponding loss of ground water being given in Table 8 as a continuous flow of water expressed in cubic feet per second for 1 mile of river valley. By the morning of June 27 nearly all of the water contributed to the sands of the valley by the rain of June 21 and the flood of June 22 had disappeared. The gain and loss can be expressed as follows, in the form of a balance sheet:

TABLE 8.—*Loss and gain of ground water per mile of river valley, 1904.*

I.—FROM RIVER TO WELL NO. 1, 1,070 FEET NORTH OF RIVER, GARDEN, KANS.

Time..	Gain in ground water per mile of river valley.	Remarks.
	Sec. feet.	
June 18, 6 p. m., to June 21, 6 p. m.	− 0.93	No change in elevation of river water, and only slight change in elevation of water in well No. 1 until June 22.
June 21, 6 p. m., to June 22, 6 a. m.	23.8	Due to rainfall of 0.94 inch.
June 22, 6 a. m., to June 22, 6 p. m.	7.3	Due to rise in river.
June 22, 6 p. m., to June 23, 6 a. m.	− 5.4	
June 23, 6 a. m., to June 24, 6 a. m.	− 3.1	
June 24, 6 a. m., to June 27, 6 a. m.	− 2.7	
July 3, 6 p. m., to July 7, 6 a. m.	2.3	Due to rain. No change in elevation of river water.
July 7, 6 a. m., to July 8, 6 a. m.	22.4	Due to rain night of July 7. No change in elevation of river water.
July 8, 6 a. m., to July 9, 6 a. m.	−14.6	Rate of loss during 24 hours after precipitation of 1.2 inches of night of July 7.
July 9, 6 a. m., to July 11, 6 a. m.	− 1.0	

TABLE 8.—*Loss and gain of ground water per mile of river valley, 1904*—Continued.

II.—FROM RIVER TO WELL NO. 2, 900 FEET NORTH OF RIVER, SHERLOCK, KANS.

Time.	Gain in ground water per mile of river valley.	Remarks.
	Sec. feet.	
July 15, 9 a. m., to July 20, 7.30 a. m	− 2.0	
July 20, 7.30 a. m., to July 25, 6 a. m	− 1.0	
July 27, 11 a. m., to July 27, 1 p. m	54.0	
July 27, 1 p. m., to July 27, 3 p. m	72.0	
July 27, 3 p. m., to July 27, 5 p. m	65.0	
July 27, 5 p. m., to July 27, 7 p. m	37.0	
July 27, 7 p. m., to July 28, 6 a. m	1.5	
July 28, 6 a. m., to August 1, 6 a. m	− 1.8	

III.—FROM RIVER TO WELL NO. 5, 550 FEET SOUTH OF RIVER, SHERLOCK, KANS.

Time.	Gain in ground water per mile of river valley.	Remarks.
July 18, 7 a. m., to July 20, 7 a. m	− 1.35	
July 20, 7 a. m., to July 25, 7 p. m	− .54	
July 25, 7 p. m., to July 27, 11 a. m	− .20	
July 27, 11 a. m., to July 27, 1 p. m	63.8	
July 27, 1 p. m., to July 27, 3 p. m	28.9	
July 27, 3 p. m., to July 27, 5 p. m	13.4	
July 27, 5 p. m., to July 27, 7 p. m	1.34	
July 27, 7 p. m., to July 29, 8 a. m	− .22	
July 29, 8 a. m., to August 1, 8 a. m	− .92	

IV.—FROM WELL NO. 5 TO WELL NO. 6, 2,500 FEET SOUTH OF RIVER, SHERLOCK, KANS.

Time.	Gain in ground water per mile of river valley.	Remarks.
July 18, 7 a. m., to July 20, 12 m	− 2.6	
July 20, 12 m., to July 25, 8 a. m	− 1.5	
July 25, 8 a. m., to August 1, 8 a. m	− .5	

V.—FROM RIVER TO WELL NO. 2, 1,730 FEET SOUTH OF RIVER, DEERFIELD, KANS.

Time.	Gain in ground water per mile of river valley.	Remarks.
August 4, 9 a. m., to August 9. a. m	− 0.51	
August 6, 9 a. m., to August 8, 7.30 a. m	5.26	
August 8, 7.30 a. m., to August 9, 9 a. m	1.82	
August 9, 9 a. m., to August 10. 7.30 a. m	− .61	

Summary of loss and gain of ground water per mile of river valley.

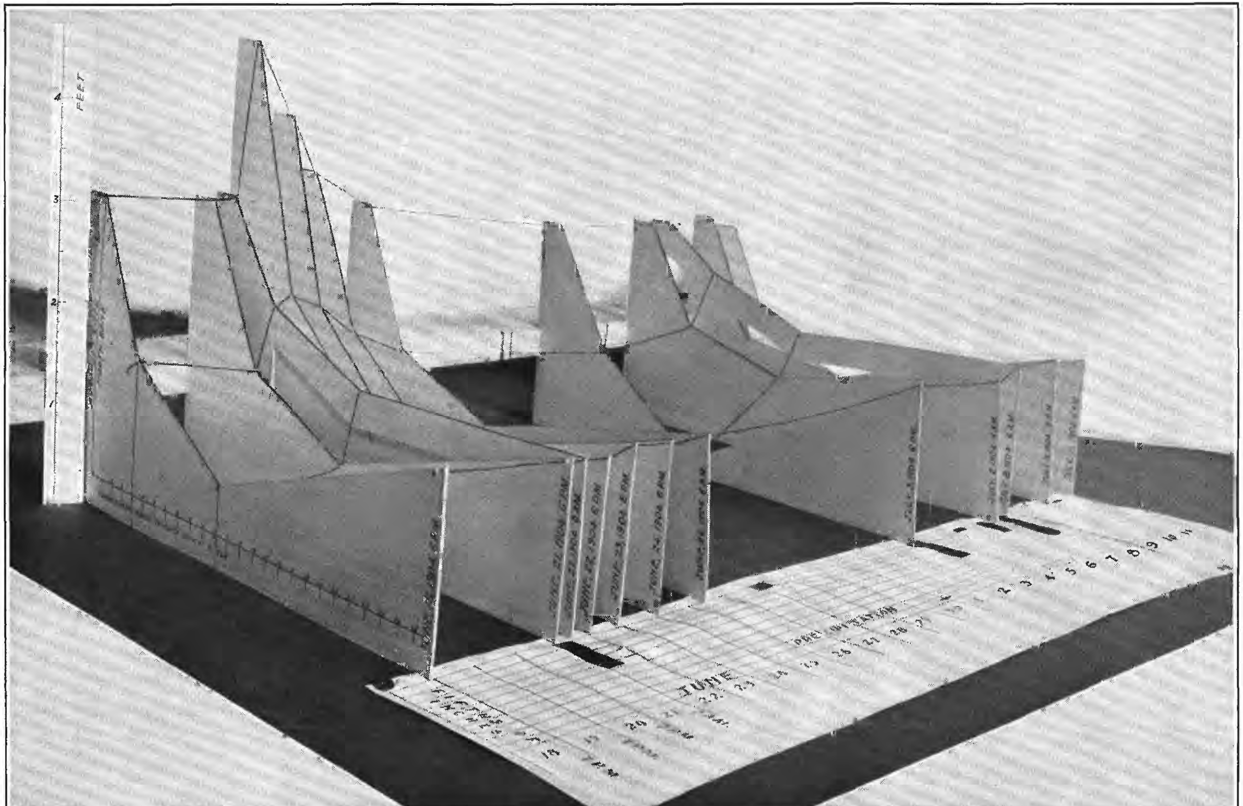
	Cubic feet.	Acre-feet.
GAIN.		
Rain of night of June 21. From 6 p. m., June 21, to 6 a. m., June 22, 12 hours, at 23.8 cubic feet per second	1,030,000	23.6
Flood of afternoon of June 22. From 6 a. m., June 22, to 6 p. m., June 22, 12 hours, at 7.3 cubic feet per second	315,000	7.2
Total gain	1,345,000	30.8
LOSS.		
6 p. m., June 22, to 6 a. m., June 23, 12 hours, at 5.4 cubic feet per second	233,000	5.4
6 a. m., June 23, to 6 a. m., June 24, 24 hours, at 3.1 cubic feet per second	268,000	6.1
6 a. m., June 24, to 6 a. m., June 27, 72 hours, at 2.7 cubic feet per second	700,000	16.1
Total loss	1,201,000	27.6
Net gain	144,000	3.2

In Pl. I there is shown a view of a model designed to illustrate the changes in ground-water levels which have just been discussed. This model shows, by cardboard cross sections, the level of the water in Arkansas River and in three wells north of the river on various dates in June and July, 1904. These are the same wells and the same data given in Table 8 and represented graphically in fig. 10. The height of the river is represented at the left end of each cardboard section and the position of the surface of the ground water in the three wells appears at the appropriate distances to the right, the wells being indicated by vertical lines and by the right end of the card. The well represented by the right end of each cardboard section is located about 2,500 feet north of the north bank of the river.

The surface of the ground water is represented in the model by the straight lines forming the top of each piece of cardboard. Of course the actual surface did not consist of a broken line, as shown, but of a curved line passing smoothly through the angles of the broken line. The representation of the ground-water surface as straight lines between the various wells introduces no substantial error in the results, and it illustrates the characteristic changes with greater fidelity than curved lines, whose forms, in any case, could be known only approximately.

It can readily be observed from this diagram that the river and water plane remained substantially stationary from June 18 to June 21. The influence of the heavy rain of the night of June 21 is shown on the third cardboard section by the more elevated water plane of the next morning, the river remaining stationary during this interval. The fourth cardboard cross section (6 p. m., June 22) shows the river flood, which began at 3 p. m. June 22. This cross section shows that the water plane sank, notwithstanding this heavy flood, except at the well nearest the river. The river gradually fell, the water plane also falling at the same time. The model shows the water plane at its lowest observed position on July 3. The section shown in the model for July 7 illustrates the influence of the rains falling from July 3 to July 7 in raising the water plane. The greatest rise in the water plane observed at any time is shown in the model by the third section from the end, that corresponding to the morning of July 8. This rise was due to a rain of more than 1 inch on the night before. As in the previous instances, the water plane rapidly fell away after the rise. It is important to bear in mind that the height of the river remained almost constant from July 3 to 9.

These same changes are also shown in fig. 10, where a curve is given for the changing height of water in each well and the river. In using this diagram or the table it is important to know that it is usually necessary to compare evening observations with evening observations, and not with morning observations. Owing to changes in tempera-



CARDBOARD MODEL OF CHANGES IN WATER PLANE NEAR CAMP 1.

ture and barometer there are diurnal periodic changes in the position of the water plane, and these fluctuations are such that it is always more satisfactory to compare observations taken at corresponding times of the day, unless the intermediate changes are very violent. The morning level of the ground water is normally higher than the

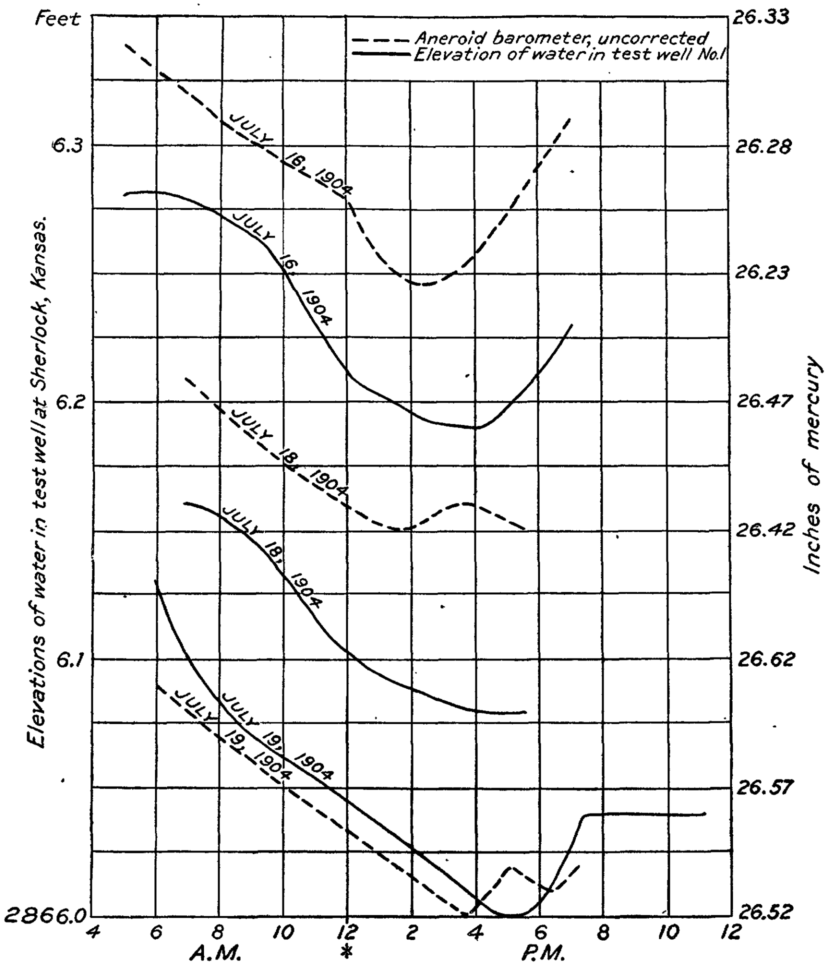


FIG. 11.—Curves of barometric pressure and height of water plane, showing correspondence between the fluctuations of the barometer and the water plane as observed on several dates at Sherlock, Kans. The dotted lines give the diurnal variations in the barometric pressure; the full lines show the elevations of the water in test well No. 1.

evening level, the fluctuations in the wells discussed above being indicated very clearly by some of the lines in fig. 10, especially those showing the June fluctuations in test wells Nos. 1, 2, and 3.

Some results showing the correspondence between the barometric pressure and the ground-water elevation were sought for at camp 1, near Sherlock, Kans. The data obtained are depicted graphically in fig. 11. The results were not what were expected, as the influence of the barometric pressure should be to raise the ground water as the barometer falls.[a] This indicates that the low position of the ground water in the afternoon of each day is probably a temperature effect, due to the decrease in the capillarity of the water with the temperature. The ground water at test well No. 1, Sherlock, and in test wells Nos. 1, 2, and 3, Garden, was within 3 feet of the surface of the ground and the difference in temperature of day and night was very great.

In fig. 10 the level of water in the Richter well, 2,500 feet north of the river, is compared for a period of about thirty days with the elevation of the water in Arkansas River. The total variation of the water plane, as shown by the levels observed in the well twice daily during the thirty-day interval, did not exceed 2 inches. This shows that the influence of the river upon the ground water dies out to practically nothing in a distance of one-half mile. The influence of the rainfall upon the water in the well is traceable by a comparison of the rainfall record and the well curve, but it is uncertain whether any connection can be detected between the elevation of the river and the well curve. The influence of occasional pumping upon the ground-water level is quite pronounced.

The observations given above indicate the following conclusions:

1. The level of the ground water shows a marked tendency to remain at a level lower than the channel of the river at a point about one-fourth mile north of the river channel.

2. The elevation of the water plane is very sensitive to the amount of rainfall, the rise in the water plane (due to a rain) in the first bottoms being greater than can be accounted for by the localized precipitation.

3. High water in the river has much less effect upon the level of the ground water than the rainfall, its influence being confined to a distance of a few hundred feet from the river channel.

4. The water plane falls at a very rapid rate after its elevation has been increased by rainfall or by a flood in the river.

5. The fact that the water plane lies for a considerable distance at a level lower than the river channel, even when there is water in the river for an extended length of time, and the rapid way in which the ground water sinks after its rise due to heavy rain, establishes the fact that the underground drainage through the sands and gravels beneath the river valley is more than sufficient to carry off all of the rainfall without run-off into the river channel.

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[a] Slichter, C. S., Motions of underground waters: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, p. 73.

FLUCTUATION OF GROUND-WATER LEVEL AT SHERLOCK, KANS.

Observations of changes of level of ground water near Sherlock, Kans., were made during the period extending from July 15 to August 3, 1904. For this purpose a number of test wells were driven, the location of which is shown in fig. 4. Of these test wells, No. 2 was 900 feet and No. 3 was 400 feet north of the river; No. 5 was 550 feet and No. 6 was 2,500 feet south of the river. The complete record of observations taken in the field is given in Table 9. The principal results presented by this table are shown graphically in fig. 12. As shown by this diagram, Arkansas River gradually fell from July 15 until July 27. At this time the water in the river had reached a very low stage, the flowing water occupying a width in the channel of about a rod and a depth of about 6 inches.

TABLE 9.—*Elevation of water in river and in test wells, Sherlock, Kans.*

[Datum: 2,800 feet above mean sea level.]

Date.	Time.	Elevation of water in well No. 1.	Hydraulic gradient per mile from well No. 2 to well No. 1.	Elevation of water in well No. 2; 900 feet north of river.	Hydraulic gradient per mile from well No. 2 to well No. 3.	Elevation of water in well No. 3; 400 feet north of river.	Hydraulic gradient per mile from well No. 3 to river.	Elevation of water in river.	Hydraulic gradient per mile from well No. 5; 550 feet south of river.	Elevation of water in well No. 5; 550 feet south of river.	Elevation of water in well No. 6; 2,500 feet south of river.	Hydraulic gradient per mile from well No. 6 to well No. 5.	Elevation of water in well No. 4; 1,000 feet south of river.	Hydraulic gradient per mile from well No. 5 to well No. 4.	Barometer pressure of mercury, uncorrected.
1904.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Inches.*
July 15	9 a. m.	66.36	9.1	65.50	2.4	65.73	2.9	65.95							26.34
July 16	5 a. m.	66.28	8.8	65.45	4.5	65.68									26.32
Do	9.30 a. m.	66.26						65.85							
Do	10.30 a. m.	66.24													26.27
Do	12 m.	66.21	9.8	65.28	3.1	65.57									26.26
Do	1.30 p. m.	66.20													26.23
Do	3.30 p. m.	66.19													26.23
Do	7 p. m.	66.23													26.29
July 17	8 a. m.	66.23						65.75							26.45
Do	11.30 a. m.	66.21	9.5	65.31	2.2	65.52									26.35
July 18	7 a. m.	66.16	9.3	65.23	2.1	65.48	2.4	65.60	3.3	65.94	65.32	1.7	67.07	7.9	26.48
Do	10.45 a. m.	66.12	9.8	65.19	2.5	65.43				65.93	65.28	1.8	67.00	7.5	26.44
Do	12 m.	66.10	9.7	65.18	2.6	65.43									26.43
Do	1.30 p. m.	66.09	9.8	65.16	2.7	65.42				65.90	65.26	1.7	66.97	7.4	26.42
Do	3.30 p. m.	66.08	9.9	65.14	2.8	65.41				65.89	65.25	1.7	66.95	7.4	26.44
Do	5.30 p. m.	66.08	9.6	65.16	2.6	65.41	3.2	65.65	2.2	65.88	65.24	1.7	66.95	7.4	26.42
July 19	6 a. m.	66.13						65.55							26.61
Do	8 a. m.	66.08													26.59
Do	10 a. m.	66.06													26.57
Do	3.40 p. m.	66.01													26.52
Do	5 p. m.	66.00	9.9	65.06	2.1	65.26					65.17				26.54
Do	6.15 p. m.	66.01													26.53
Do	7.15 p. m.	66.04						65.45							26.54
Do	9.15 p. m.	66.04													
Do	11.15 p. m.	66.04													

July 20	7.30 a. m.	65.99	9.5	65.09	.9	65.18	.9	65.25	5.4	65.81			66.96	8.1	26.62
Do	12 m	65.93								65.79	65.17	1.7			26.54
July 21	4 p. m	65.86	10.0	64.91	.6	64.97	.4	65.10		65.70	65.12	1.6	66.82		26.46
Do	7 p. m	65.87						65.00							26.50
July 22	2 p. m									65.76	65.19	1.5	66.97		
Do	5 p. m							65.15			65.16				
July 23	3 p. m							65.05	5.9	65.66	65.11	1.5	66.81	8.1	
July 24	6 p. m	65.79	9.9	64.85	.3	64.88	1.6	65.00							
July 25	7 a. m	65.82	9.4	64.93	.2	64.95	.7	65.10							
Do	10 a. m			64.83	.5	64.88									
Do	6 p. m	65.74	10.0	64.79	.5	64.84	2.1	65.00	5.1	65.53	65.03	1.4	66.67	7.9	
July 26	9.30 a. m							65.05		65.52	65.02	1.4	66.69	8.1	
Do	5 p. m							65.00		65.49	64.99	1.4	66.64	8.0	
July 27	11 a. m	65.70	10.0	64.75	.8	64.83	1.7	65.00		65.46	64.97	1.3	66.62	8.1	26.51
Do	1 p. m			64.73	1.7	64.89	14.6	66.00	4.0	65.42					
Do	3 p. m	65.80	9.8	64.87	4.4	65.29	14.6	66.40	9.2	65.44	64.95	1.3	66.57	7.9	
Do	5 p. m	65.91	8.9	65.07	6.4	65.68	12.3	66.60	11.2	65.44					
Do	7 p. m	66.04	8.5	65.24	6.8	65.88	10.8	66.60	10.9	65.46					
July 28	6 a. m	66.21	8.0	65.45	5.3	65.95	5.3	66.35							
July 29	8 a. m	66.25	9.0	65.40	5.1	65.88	5.5	66.30	5.8	65.70	64.89	2.2	66.78	7.5	
July 30	8 a. m	66.12	9.0	65.27	3.1	65.56	4.5	65.90							
July 31	8 a. m									65.71					
August 1	8 a. m	66.10	9.2	65.23	2.9	65.50	2.6	65.70	.2	65.72	64.79	2.5	66.79	7.5	
August 2	6 p. m							65.45							
August 3	7 a. m							67.10							

During this same period of fall in the river there was no rainfall except on July 22 and a very light rain on July 25. The rain of July

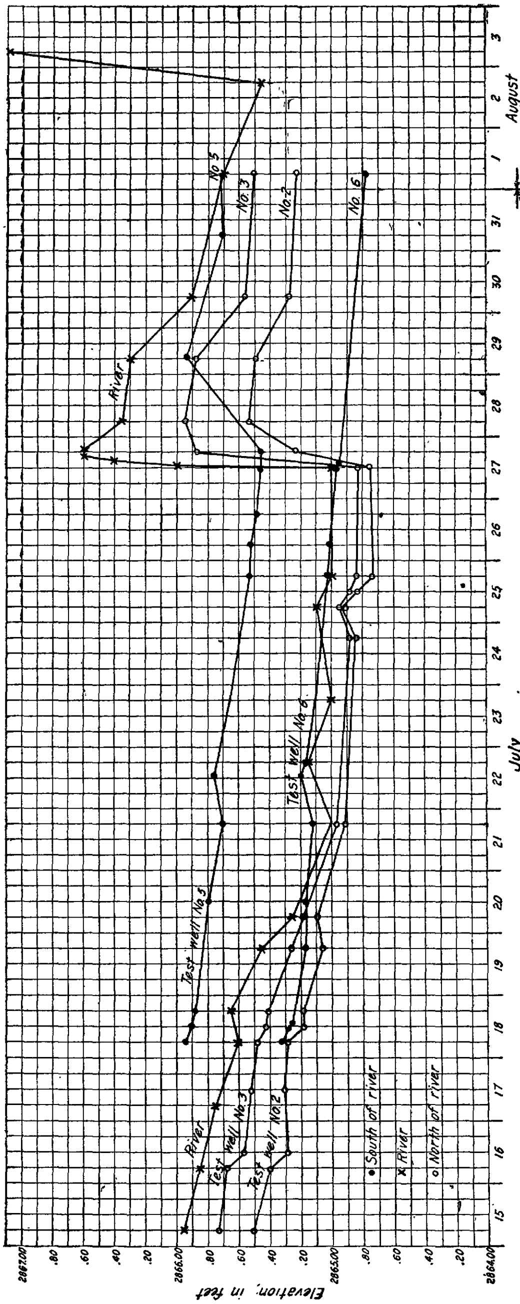
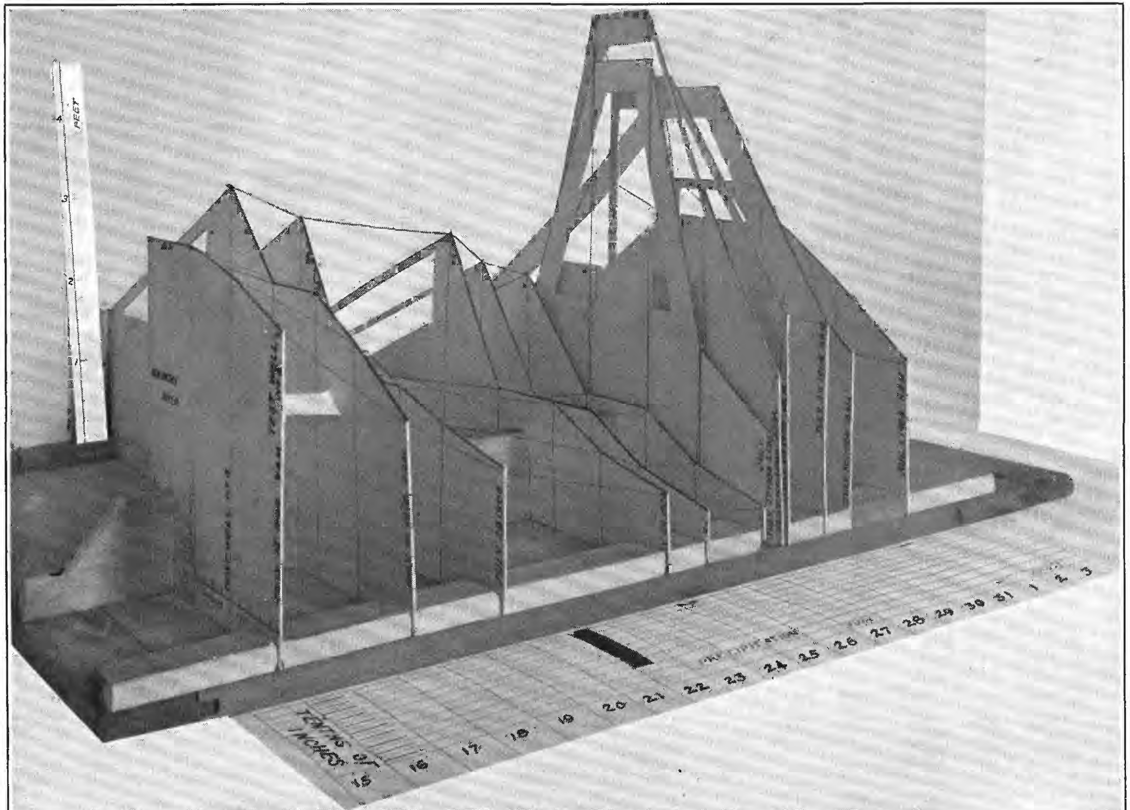


FIG. 12.—Elevation of water in test wells and in Arkansas River for the various dates from July 15 to August 3, 1904, at Shelrock. Preceding the entries in this diagram considerable rain had fallen. There were several heavy rains between July 3 and 13. These rains undoubtedly account for the high position of the water plane in all of the wells at the beginning of the period for which the diagram is constructed. Test well No. 2 is 900 feet north of river; test well No. 3 is 400 feet north of river; test well No. 5 is 550 feet south of river; test well No. 6 is 2,500 feet south of river.

22 was measured at Garden by the volunteer observer of the United States Weather Bureau as 1.42 inches, but the rainfall at Sherlock was very much less. During this period of fall of level of the water



CARDBOARD MODEL OF CHANGES IN WATER PLANE NEAR SHERLOCK, KANS.

in the river the test wells north of the river fell at corresponding rates. The total fall in the river amounted to 0.95 of a foot; the fall in test well No. 3, 400 feet north of the river, during the same period was 0.9 of a foot; in test well No. 2, 900 feet north of the river, 0.77 of a foot; in test well No. 5, 550 feet south of the river, 0.5 of a foot; and in test well No. 6, 2,500 feet south of the river, 0.3 of a foot. On July 27, between 11 a. m. and 5 p. m., the river rose 1.6 of a foot, restoring the level of water in the river to the height of July 15 plus 0.6 of a foot. This sudden rise in the river was not accompanied by rainfall in the neighborhood of Sherlock. Its influence upon the various test wells is shown by fig. 12. The immediate effect upon test wells Nos. 2 and 3, north of the river, was very apparent. Between 11 a. m. and 7 p. m. test well No. 3, 400 feet north of the river, rose 1.05 feet, and test well No. 2, 900 feet north of the river, rose 0.49 of a foot. By the next morning at 6 a. m. the river had fallen 0.25 of a foot; test well No. 3, 400 feet north of the river, had risen about 0.1 of a foot, and test well No. 2, 900 feet north of the river, had risen 0.23 of a foot. The river continued to fall very slowly, on the morning of July 29 having fallen only about one-half of 0.1 of a foot from its elevation on July 28; the water in test wells Nos. 2 and 3 had dropped about the same amount, and on August 1, at 8 a. m., when the river had fallen 0.6 of a foot below its elevation of July 29, test wells Nos. 3 and 2 had dropped 3.6 and 1.8 feet, respectively. During this same period of time the water plane south of the river acted very differently from that observed on the north side of the river. The water in test well No. 6, 2,500 feet south of the river, fell continuously from July 18 to August 1, notwithstanding the flood of July 27; and that in test well No. 5, 550 feet south of the river, fell from July 18 until July 27, the total fall amounting to 0.47 of a foot. No observation was made at this test well on July 28, but by the morning of July 29 the water had risen 0.45 of a foot. On August 1 it had fallen 0.2 of a foot below its level on the morning of July 29, in sympathy with the general fall of the water in the river. It can be seen from this that the elevation of the water in the various test wells showed all varieties of change during the flood in the river. The wells within 900 feet of the river fluctuated quite accurately with the changing level in the river itself, while the water in the test well one-half mile from the river seemed to show no effect of the flood in the river during the period of observation.

In explanation of the gradual fall in the test wells from July 18 to July 27, it must be remembered that the position of the water, as found on July 18, was high on account of the heavy rains which fell during the first twelve days of July. From July 4 to July 13, inclusive, 3.27 inches of rain were caught at the rain gage at Garden, Kans.; the rainfall at Sherlock, Kans., was probably as great, so it is very likely that the level of the water found in the test wells on July 15 and 18 was high owing to the previous rains. In fig. 13 the results of the flood of July 27 are shown in greater detail than in the previous diagram.

A photograph of a cardboard model showing the changing positions of the water plane at Sherlock is reproduced in Pls. II and III. The top of each cardboard corresponds to a cross section of the water plane taken across the valley on a certain date, the right side of each card corresponding with the north side of the valley, the left side corre-

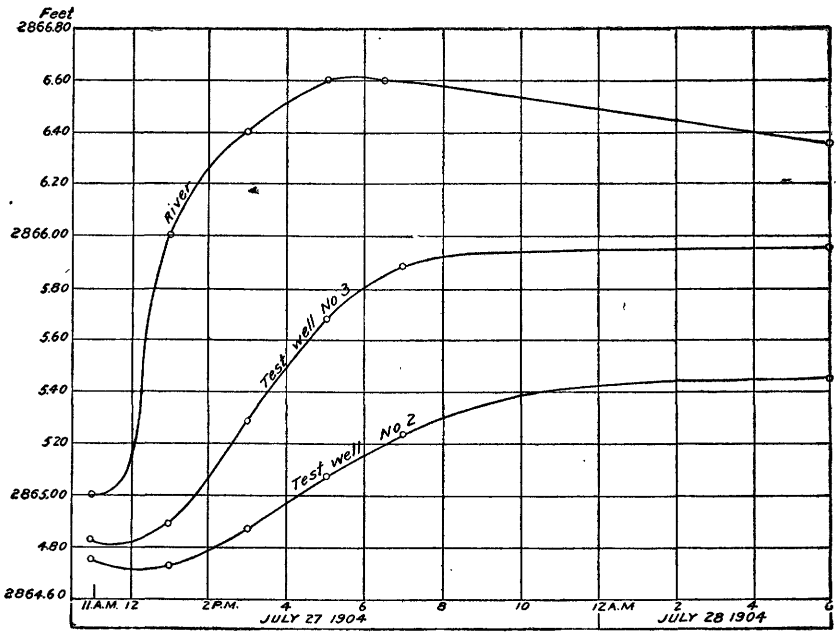
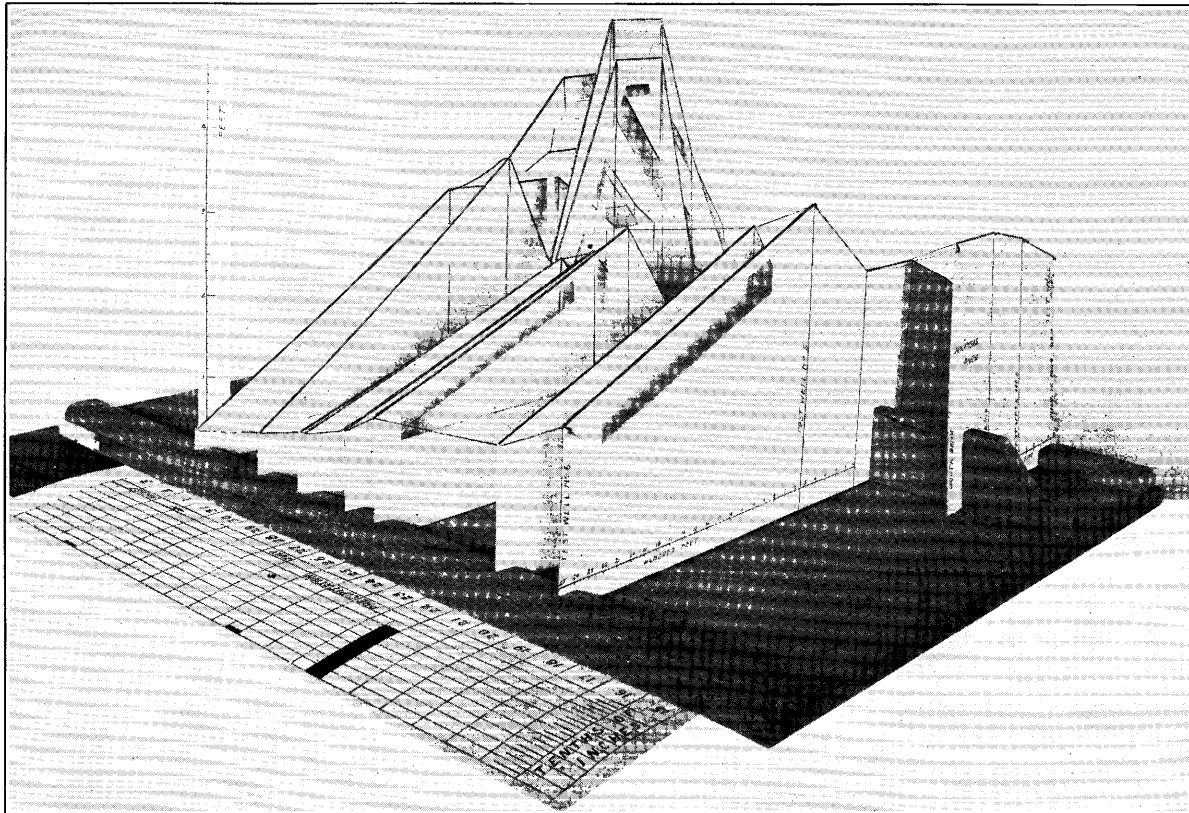


FIG. 13.—Elevation of water in Arkansas River and in two test wells near Sherlock, Kans., for various hours during the flood of July 27, 1904. The vanishing influence of the flood with increasing distance from the river is clearly brought out by the diagram. Test well No. 2 is 900 feet north of north bank of river; test well No. 3 is 400 feet north of north bank of river.

sponding with the south side of the valley. The location of each test well is shown by a vertical line, and the position of the channel of the Arkansas is indicated by the level segment of each card near the middle of each section. The model shows to the eye the way in which the river and the water in all of the test wells gradually fell from July 13 to July 27, and it also illustrates the influence of the flood of July 27 upon the wells near the river. It also shows that the level of water in well No. 6, one-half mile south of the river, was not influenced by the flood in the river, but continued to fall during the entire period. The decreasing influence of the river on the water plane with the distance from the river is brought out clearly by the diagram (fig. 13).

It is apparent from this model, as well as from the one shown for camp 1, that there is a marked tendency for the ground water near the river, especially on the north side, to remain at a lower level than



CARDBOARD MODEL OF CHANGES IN WATER PLANE NEAR SHERLOCK, KANS.

the water in the river itself. At the time the data presented by the model were obtained, there had been water in the river for six or seven weeks and the amount of rainfall had been above the average. These facts indicate that the underground drainage through the sands and gravels is more than sufficient to drain off the precipitation, without return seepage into surface streams and without run-off from the surface of the ground.

The various amounts of ground water gained or lost by each mile of the valley along the river at Sherlock from July 15 to August 1, 1904, is expressed in Sections II, III, and IV of Table 8 (p. 31). For the purpose of making the results as definite as possible the gain or loss for each mile of valley is given as a continuous flow of water expressed in cubic feet per second. Thus, according to the table, the strip of ground between the river bank and test well No. 2, 900 feet north of the river, extending along the stream for a distance of a mile, lost water from July 15 to to July 20 at a rate equivalent to a steady flow of water equal to 2 cubic feet per second. During the flood on July 27 this same strip of country absorbed water from the river during the first two hours of flood at the rate of 54 cubic feet per second. The rate of gain during the three following periods of two hours each was 72, 65, and 32.4 second-feet, respectively. During the eleven hours from 7 p. m., July 27, to 6 a. m., July 28, the rate of gain fell to 1.5 second-feet, after which the ground lost water. These results, and similar results for the south side of the river, are given in the table. Putting all of these results together we can compute the amount of water furnished to the sands by the flood in the river as follows, the computation applying to 1 mile of the river valley only:

Water furnished to sands near Sherlock, Kans., by flood of Arkansas River.

	Cubic feet.
North of river:	
July 27, 11 a. m. to 1 p. m., 2 hours, at 54 cubic feet per second	389,000
July 27, 1 p. m. to 3 p. m., 2 hours, at 72 cubic feet per second	525,000
July 27, 3 p. m. to 5 p. m., 2 hours, at 65 cubic feet per second	467,000
July 27, 5 p. m. to 7 p. m., 2 hours, at 32.4 cubic feet per second	234,000
July 27, 7 p. m. to 6 a. m. July 28, 11 hours, at 1.5 cubic feet per second	59,500
Total gain	[a] 1,674,500
South of river:	
July 27, 11 a. m. to 1 p. m., 2 hours, at 63.8 c bic feet per second	459,000
July 27, 1 p. m. to 3 p. m., 2 hours, at 28.9 cubic feet per second	208,000
July 27, 3 p. m. to 5 p. m., 2 hours, at 13.4 cubic feet per second	96,500
July 27, 5 p. m. to 7 p. m., 2 hours, at 1.34 cubic feet per second	9,650
Total gain	773,150
July 27, 7 p. m. to 8 a. m. July 28, loss at 0.22 cubic foot per second	10,296
Net gain	[b] 762,854
Total gain both sides of river	[c] 2,437,354

[a] Equals 38.4 acre-feet. [b] Equals 17.6 acre-feet. [c] Equals 56 acre-feet.

The gain of 56 acre-feet took place on land having an area of 175 acres.

The above results show the gain between test well No. 2, 900 feet north of the river, and test well No. 5, 550 feet south of the river. There was some gain in ground water in the lands north and south of these boundaries, but the data are not at hand for the computation. The susceptibility of the adjoining lands in receiving seepage water from the river was greater on the north side than on the south side of the river.

FLUCTUATION OF GROUND-WATER LEVEL AT DEERFIELD, KANS.

Observation of the ground-water level was made at camp 3, near Deerfield, in three test wells. The location of these test wells appears on the map, fig. 6. The water in the river occupied but a small part of the river channel during most of the time during which these observations were made, and therefore the distances of the test wells from the edge of the flowing water are given in fig. 19, in preference to the distances from the river bank. Test well No. 1 was 1,100 feet, and well No. 2, 1,730 feet south of water in the river. Test well No. 3 was 1,100 feet south of the river, but 1,000 feet upstream from test well No. 2.

TABLE 10.—*Elevation of water in river and test wells at Deerfield, Kans.*

Date.	Time.	Elevation of water in well No. 1, 1,100 feet from river.	Hydraulic gradient, per mile, from well No. 1 to well No. 2.	Elevation of water in well No. 2, 1,730 feet from river.	Hydraulic gradient, per mile, from well No. 2 to well No. 3.	Elevation of water in well No. 3, 1,100 feet from river.	Hydraulic gradient, per mile, from river to well No. 3.	Elevation of water in river.
1904.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
August 4	9 a. m	2,923.02	0.25	2,922.99	8.7	2,924.57	−1.10	2,924 80
August 5	do	2,923.14	.17	2,923.12	9.0	2,924.75	1.44	2,924.45
August 6	do	2,923.21	.50	2,923.27	8.8	2,924.87	2.98	2,924.25
August 8	7.30 a. m	2,923.23	.50	2,923.29	8.4	2,924.82	−1.58	2,925.10
Do	10 a. m	2,923.23	.34	2,923.27	8.5	2,924.83		
Do	12 m	2,923.23	.42	2,923.28	8.5	2,924.83		
Do	4.30 p. m	2,923.23	.25	2,923.26	8.7	2,924.84		
August 9	9 a. m	2,923.27	.17	2,923.29	8.8	2,924.89	−1.49	2,925.20
Do	2.30 p. m	2,923.29	.08	2,923.28				
August 10	7.30 a. m	2,923.32	.00	2,923.32	8.7	2,924.91	1.73	2,924.55

The chart given in fig. 14 shows that a flood on August 7 in the river had no influence upon the water level in any of the wells, although frequent observations were made to detect such influence. The diagram likewise shows the effect of the rain in raising the ground water as shown by all of the wells from August 4 to August 7. During this same interval the river was falling, while the ground water was rising. The rainfall was measured at camp by catching rain in a tin bucket and correcting for difference in area between top and bottom of bucket. The observed rainfall on August 4 and August 5 amounted to about 1.75 inches. The water in the various test wells rose by the following amounts between August 4 and August 6: Test well No. 1, 0.17 foot, or 2.02 inches; test well No. 2, 0.29 foot, or 3.48 inches; and test well No. 3, 0.30 foot, or 3.60 inches. If we assume that the soil had a porosity of 33⅓ per cent, these observed changes in the level of the water plane are equivalent to actual increments of 0.7, 1.16, and 1.2 inches, respectively. These amounts will average

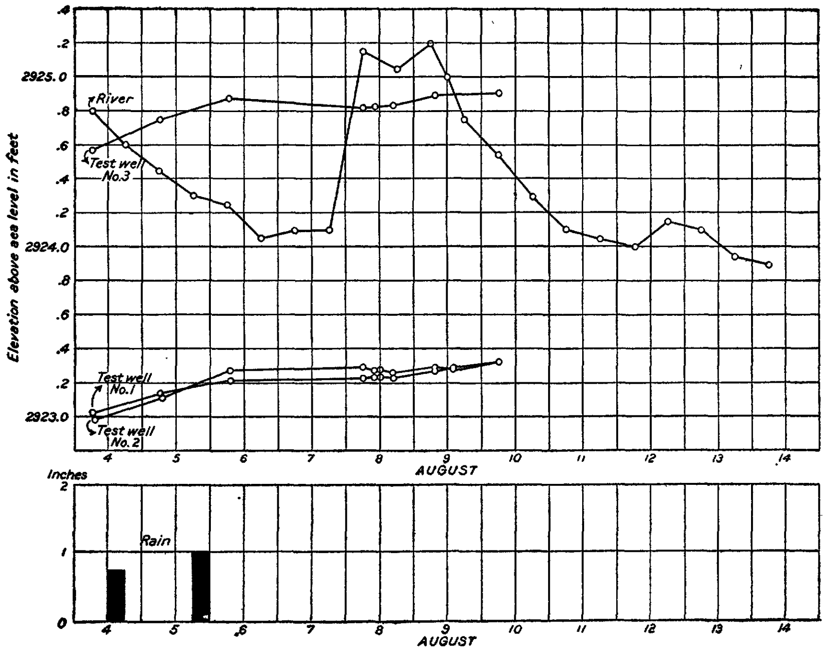


FIG. 14.—Elevation of water in Arkansas River and test wells at Deerfield, Kans., August 4 to 14, 1904. Test well No. 1 is 1,100 feet south of stream. Test well No. 2 is 1,730 feet south of stream. Test well No. 3 is 1,100 feet from stream and 1,000 feet from test well No. 2.

almost exactly 60 per cent of the rainfall for the two days, August 4 and August 5, 1904. This result gives very direct proof of the excellent quality of the catchment area furnished by the sandy bottom lands on the south side of the river at Deerfield.

EVAPORATION EXPERIMENTS NEAR DEERFIELD.

The table of meteorological data below has value in showing that a considerable amount of stored ground water is lost in the first bottoms of Arkansas River by evaporation. Although these measurements extend over only a very brief period, they are sufficient to establish the fact that the loss of ground water by evaporation is about ten times as great where the water is within 1 foot of the surface of the ground as it is where the water lies at a depth of 3 feet. The pumping plants that materially lower the ground water in the bottom lands will thus save a considerable amount of water that now goes to waste in evaporation and in supplying the rank growth of wild grasses that flourish in the first bottom lands. It is safe to say that this savable loss amounts on the average to a foot of water for each acre of first bottoms for the months of July and August alone.

The following is a record of observations of evaporation from three tanks filled with natural soil in which the water plane was kept at a constant depth, compared with the evaporation from a tank of open water. The tanks were located in the bottom lands of Arkansas Valley, near the head gates of the Farmers' ditch. The soil is a sandy loam changing to coarse sand at a depth of about 3 feet.

Meteorological records at Deerfield, Kans., from July 3 to September 8, 1905.

Week of—	Rainfall in inches.	Vapor pressure.	Per cent of relative humidity.	Velocity of wind in miles.	Evaporation in inches.				
					Open water.	1 foot to water, soil cultivated.	1 foot to water; soil uncultivated.	2 feet to water.	3 feet to water.
July 3-9[a]	0.11	....	....	16.50	....	....	....	....	0.13
July 9-16	0.0	.440	47.3	15.89	....	....	....	....	0.13
July 16-23	0.08	.482	50.2	16.13	2.53	....	....	....	0.23
July 23-30	1.24	.560	61.2	19.78	2.39	....	....	....	1.40
July 30-Aug. 6	1.50	.568	63.9	12.05	1.80	....	....	....	0.05
Aug. 6-13	0.38	.478	54.8	13.62	2.45	1.48	1.73	0.65	0.43
Aug. 13-20	0.05	.530	57.3	13.26	2.22	1.34	1.21	0.60	0.17
Aug. 20-27	0.0	.520	49.3	19.58	3.04	1.14	1.38	0.49	0.08
Aug. 27-Sept. 3	0.03	.395	41.4	17.19	3.19	0.92	1.51	0.49	0.12
Sept. 3-8[a]	0.71	.489	60.4	14.54	1.21	0.70	0.87	0.60	0.04

[a] Week incomplete.

CHAPTER III.

CHEMICAL COMPOSITION OF THE WATERS OF THE UNDERFLOW.

Chemical tests of the ground waters were made wherever possible during the process of the work. Portable field apparatus was at hand which could be used in making a few simple tests. The determinations made included titrations for chlorine, alkalinity, and hardness. Total solids were determined by means of the Whitney electrolytic bridge. The curve of total solids used in this case was obtained by evaporating a sample of water containing 95.9 parts per 100,000 total solids. The results of the test are brought together in Table 11, and the curve used for the determination of the total solids is printed as fig. 15 (p. 47).

TABLE 11.—*Analyses of ground water in the Arkansas Valley, western Kansas.*

WEST OF GARDEN, KANS.

Date.	Chlorine (parts per 100,000).	Alkalinity as $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.	Depth of well.	Location.
1904.					°*F.*	*Feet.*	
June 16	4.61	14.0	21.35	....	....	....	River water.
June 20	....	....	....	....	71.0	....	Do.
June 28	5.31	31.0	30.9	93	67.0	....	Do.
July 11	5.85	13.75	49.1	105	88.0	....	Do.
July 6	21.79	22.9	25.3	49	55.0	10	Windmill south of river.
July 5	8.10	16.5	....	33	58.0	9	Station 12.
June 28	8.51	19.0	34.7	119	48.0	28	Station 8.
Do	11.00	22.0	37.6	127	51.0	17	Station 10.
June 21	8.51	17.0	33.9	113	58.5	17	Station 4.
June 20	....	24.5	38.65	....	....	15	Station 2.
Do	6.72	15.0	43.20	....	52.0	15	Station 1.
June 18	4.96	20.0	40.51	....	....	32	Station 3.
July 8	6.00	16.1	39.5	121	52.0	32	Station 6, well A.
Do	3.05	11.4	13.9	37	52.0	58	Do.
July 9	2.70	12.9	21.6	32	55.0	48	Station 6, well B.
Do	1.67	11.9	14.6	36	53.0	56	Do.
July 6	4.59	14.7	33.5	105	55.0	30	Station 11.
Do	5.42	20.4	38.8	114	52.0	16	Mrs. Richter's well at camp.
June 15	13.50	23.0	53.5	....	....	5	Do.
June 16	12.80	19.5	47.9	....	....	5	Do.
Do	9.60	22.0	48.0	....	....	3–4	Test well No. 1.
June 20	21.30	20.5	48.0	....	59.0	3–4	Do.
Do	6.72	17.5	36.0	....	62.5	3–4	Test well No. 3.
June 23	13.12	24.0	39.1	121	60.0	3–4	Do.
June 28	11.00	20.0	39.5	126	52.0	12	New well (camp).

TABLE 11.—*Analyses of ground water in the Arkansas Valley, western Kansas*—Cont'd.

WEST OF GARDEN, KANS.—Continued.

Date.	Chlorine (parts per 100,000).	Alkalinity as $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.	Depth of well.	Location.
1904.					°F.	Feet.	
June 16	8.88	19.5	39.9	....	....	12	New well (camp).
Do	10.62	22.5	43.7	....	....	14	Station 1.
July 7	.78	13.1	10.7	6	65.0	....	Sand hills, sec. 36, T. 24 S., R. 34 W.
Do	.67	13.6	11.2	6	57.0	....	Do.
September 22	2.06	19.9	25.6	35	....	16	Sec. 2, T. 23 S., R. 33 W.
1905.							
January 24	4.2	19.2	53.3	86	....	25	Poor farm.
Do	2.1	11.4	31.1	57	....	20	Shultz.
Do	5.1	18.0	82.0	119	....	40	L. C. Working.
Do	4.1	20.5	31.2	102	....	36	A. Robinson.
Do	3.4	18.1	27.9	68	....	*a* 13	Foreman.
Do	11.4	19.2	39.3	76	....	115	Faye.
Do	17.6	22.7	45.9	150	....	35	M. McClurken.
Do	1.2	18.5	21.3	26	....	*a* 30	Frank Kolbus.

GARDEN, KANS.

Date.	Chlorine (parts per 100,000).	Alkalinity as $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.	Depth of well.	Location.
1904.							
September 22	0.92	14.1	25.6	16	....	130	Atchison, Topeka and Santa Fe R. R. well.
Do	.85	15.9	30.0	16	....	110	Carter's well.
Do	3.96	20.3	69.2	80	....	16+40	City waterworks well.
1905.							
January 24	1.6	18.8	29.5	42	....	78	S. L. Leonard.

SHERLOCK, KANS.

Date.	Chlorine (parts per 100,000).	Alkalinity as $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.	Depth of well.	Location.
1904.							
July 16	4.04	13.20	27.70	73.0	71.0	....	River water.
July 22	3.85	13.90	37.90	74.0	73.0	....	Do.
July 16	.89	21.20	13.09	27.0	63.0	8	Test well No. 6.
July 19	.50	17.50	4.64	30.0	58.5	18	Station 16.
July 16	.58	21.50	2.38	56.0	60.0	8	Test well No. 4.
July 26	1.10	17.85	26.20	42.0	56.0	26	Station 20.
July 18	3.62	16.75	27.30	35.0	57.0	22	Station 15.
July 21	2.46	21.30	28.10	55.0	56.2	36	Station 17.
July 30	4.61	19.45	44.70	83.0	65.0	10	Near station 17.
July 22	4.58	15.90	40.60	80.0	56.0	22	Station 18.
Do	4.05	15.90	42.90	78.0	57.0	14	Do.
July 23	5.20	17.45	46.30	104.0	53.0	20	Station 19.
July 16	3.47	14.65	30.00	93.0	57.7	18	Station 14.
Do	5.10	15.75	31.10	97.0	55.0	22	Do.
July 15	5.18	15.50	....	107.0	54.0	18	Station 13.
July 27	4.97	15.25	48.5	96.0	55.5	28	Station 21.
Do	4.90	16.25	50.6	97.0	57.5	28	Station 22.
July 19	.96	16.85	20.0	21.0	....	....	Sec. 30, T. 24 S., R. 34 W.
Do	.17	19.00	25.9	37.0	....	....	Sec. 20, T. 24 S., R. 34 W.
September 22	2.24	21.30	29.9	44.0	....	40	Sec. 30, T. 22 S., R. 33 W.

a To water.

TABLE 11.—*Analyses of ground water in the Arkansas Valley, western Kansas*—Cont'd.

DEERFIELD, KANS.

Date.	Chlorine (parts per 100,000).	Alkalinity as $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.	Depth of well.	Location.
1904.					°F.	*Feet.*	
September 22..	1.49	15.1	31.2	22.0	66.0	10	NE. quarter sec. 26, T. 24 S., R. 35 W.
August 6.......	2.60	14.7	28.9	49.0	....	24	SW. quarter sec. 24, T. 24 S., R. 35 W.
August 10......	2.45	17.7	32.7	74.0	60.0	12	Near station 28.
August 9.......	5.00	15.7	51.2	95.0	56.0	24	Station 27.
August 4.......	7.60	16.2	55.2	117.0	59.5	12	Well at camp.
Do........	6.64	15.3	57.0	114.0	58.0	25	Station 23.
August 8.......	5.11	16.0	48.4	90.0	57.0	37	Station 26.
August 4.......	8.61	17.7	65.9	117.0	59.5	6	Test well No. 1.
August 5.......	5,32	15.5	44.4	108.0	59.0	21	Station 24.
August 6.......	5.39	16.7	48.3	106.0	57.0	16	Station 16.

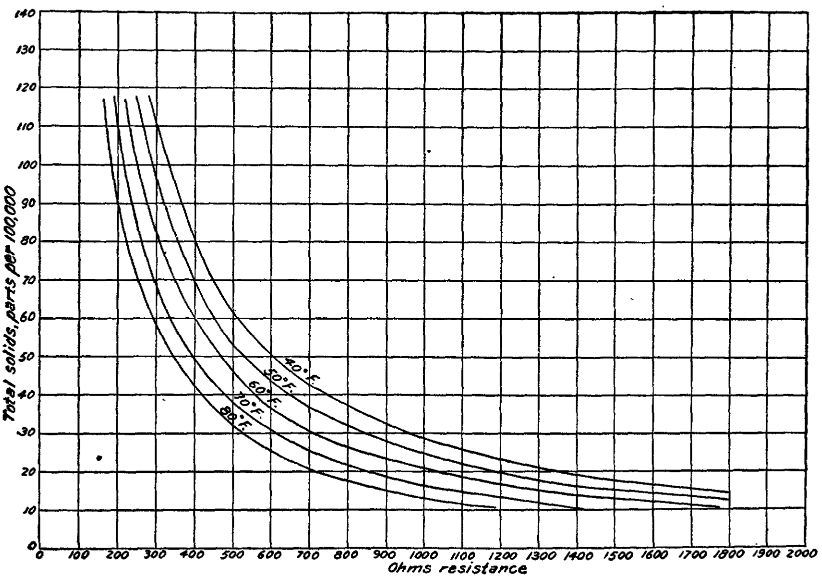


FIG. 15.—Curve for Whitney electrolytic bridge used in converting resistance in ohms into total solids for ground waters of Arkansas Valley.

A comparison of the results of the tests at various stations shows a marked decrease in the quantity of dissolved solids in the water with the depth at which the sample was taken. In forcing down test wells at almost any point in the bottom lands of Arkansas River the increasing softness of the water can be noted almost from foot to foot. At a considerable depth, say from 60 to 100 feet or more, there are found waters which are popularly called in this region "second" or "third" waters, which are very much softer than the water obtained from shallow wells. At points located in the sand hills south of the river there are places where shallow wells furnish water much softer than the so-called second or third waters found in the vicinity of Garden.

The total solids in the ground water determined at wells in the first camp, 2 miles west of Garden, varied from 121 parts per 100,000 for water taken 4 feet below the water plane to 103 parts per 100,000 for water taken at 6 feet, and 80 parts per 100,000 for water taken at 14 feet. Water taken from the railroad well, 130 feet deep, at Garden, showed total solids of 16 parts per 100,000. Water in the sand hills south of the river at a depth of 9 feet showed 33 parts per 100,000 total solids, and another well, deeper, but of unknown depth, showed 6 parts per 100,000 total solids. The tendency of the ground water near the surface in the bottom lands of the river to run high in solids seems to indicate that this increased hardness is due to the loss of the ground water by evaporation. The water plane in these bottom lands lies close to the surface of the ground and is subject to frequent fluctuations due to rain and changes of conditions in the river itself. These changes are sufficient to account for a large excess of dissolved solids in the surface waters, and it is believed that no other explanation is necessary. As the ground water moves downstream, the various filaments of moving water must thread themselves around the grains of sand and gravel, continually dividing and subdividing the water as it moves through the capillary pores. The effect of this action is to slowly work the concentrated water near the surface down to greater depths, forming a ground water of graduated strength. Every layer of silt, clay, or other impervious material which possesses a considerable area acts as a partition, separating the moving ground water into layers which do not mix, except where the impervious strata give out. This results in layers of water of distinct difference in total solids, which are locally known as "first," "second," and "third" water, etc.

In the following table (Table 12) the various samples of ground water are classified by depth of the wells, and the averages of the different determinations are tabulated. From this arrangement a comparison is possible between the waters of different depths, in which the errors due to special peculiarities of particular wells are partly eliminated. Some of the well water taken from stock or domestic wells showed marked pollution, but all such samples have been included in the table.

TABLE 12.—*Quality of ground water in Arkansas River Valley, as determined from the averages of classified samples.*

Classification.	Chlorine (parts per 100,000).	Alkalinity $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.
Wells under 10 feet deep:					° *F.*
Average of 11 samples	10.32	20.84	38.53	75.80	60.50
Probable error	1.45	.434	3.76	10.47	.735
Error ... per cent	14.05	2.08	9.77	13.83	1.21
Wells 10 to 20 feet deep:					
Average of 18 samples	7.77	18.55	40.13	96.73	56.15
Probable error	.829	.520	1.321	4.87	.795
Error ... per cent	10.66	2.80	3.30	5.04	1.42
Wells 20 to 30 feet deep:					
Average of 14 samples	4.96	16.28	40.95	91.00	55.50
Probable error	.335	.251	1.989	5.162	.552
Error ... per cent	6.76	1.54	4.85	5.68	.995
Wells 30 to 40 feet deep:					
Average of 10 samples	4.62	17.62	38.00	92.75	55.05
Probable error	.397	.862	2.312	9.5	.74
Error ... per cent	8.60	4.89	6.08	10.23	1.34
Wells 40 to 70 feet deep:					
Average of 6 samples	2.47	12.07	16.70	35.00	53.33
Probable error	.28	.298	1.659	1.031	.596
Error ... per cent	11.33	2.47	9.93	2.95	1.12
Wells over 70 feet deep:					
Average of 4 samples	1.12	16.27	28.37	24.67	....
Probable error	.160	.924	.939	5.854	....
Error ... per cent	14.29	5.67	3.31	23.7	....
Sand hills wells:					
Average of 9 samples	1.24	16.41	18.21	26.86	61.25
Probable error	.222	.587	2.32	4.05	1.07
Error ... per cent	17.9	3.57	12.73	15.06	1.75

The above table is not free from objection, since the waters of the first bottoms, second bottoms, etc., have all been grouped together. The water in the first bottoms is softer than that in the second bottoms, owing to the ease with which both the rainfall and the softer water from the river contribute to its supply. In Table 13 all wells north of the river, less than 40 feet in depth, have been classified as first-bottom, second-bottom, and upland wells, and the averages of the various groups have been taken.

TABLE 13.—*Quality of ground water in wells north of Arkansas River Valley and less than 40 feet in depth, as determined from the averages of classified samples.*

Classification.	Chlorine (parts per 100,000).	Alkalinity $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.
First-bottom wells:					° *F.*
Average of 38 samples	6.86	18.18	42.81	93.75	56.67
Probable error	.447	.309	1.672	3.318	.387
Error ... per cent.	6.52	1.7	3.91	3.54	.683
Second-bottom wells:					
Average of 7 samples	4.04	18.27	47.64	89.43	52.0
Probable error	.280	.819	5.40	5.938	(*a*)
Error ... per cent.	6.93	4.48	11.3	6.65	....
Upland wells:					
Average of 3 samples	1.83	19.90	76.80	35.0	....
Probable error	.216	.545	1.673	3.5	....
Error ... per cent.	11.8	2.74	2.18	10.0	....

a One observation.

CHAPTER IV.

ORIGIN AND EXTENT OF THE UNDERFLOW.

ORIGIN.

The investigations which have been explained in the preceding pages of this report indicate that the water of the Arkansas underflow has its main source in the rainfall upon the sand hills south of the river and upon the bottom lands and uplands north of the river.

The average annual rainfall in the vicinity of Garden is about 20 inches. A very large portion of this passes into the level and porous soil, so that the actual contribution to the underflow must be considerable. As previously stated in this paper there is a ground water district along the river that remains lower than the river, whether the same be flowing or not, in which region the rise in the ground water after a rain is more than can be accounted for by the localized precipitation. This fact indicates not only that the underground drainage at this point is contributed to by rainfall on distant catchment areas, but that the underflow constitutes a separate drainage system which is more than sufficient to take care of the rainfall. Determinations made in the sandy flats south of the river at Deerfield (see Chap. II) show that the rise in the water plane, observed after a rain storm, amounts to as much as 60 per cent of the water that fell. This fact verifies what is quite obvious to a careful observer, that there is no run-off from the lands adjacent to Arkansas River in the region under discussion.

The total depths of the deposits of sand and gravels at Garden is not known very exactly. A deep well was sunk at Garden in 1888, which, according to a partial log printed in the local newspaper, showed that rock was reached at a depth of 311 feet. Every indication drawn from the behavior of the ground water shows that the gravels must extend to a considerable depth, so that it is safe to assume that the well log just referred to gives a correct notion of the depth to rock. However, as one approaches the western boundary of Kansas, bed rock comes near the surface, which fact, even if no other evidence were at hand, would show that no portion of the ground water could originate in Colorado. The former popular belief in a Colorado source of the ground water has practically disappeared, although a few settlers still adhere to it. During the summer of 1904 one resident of Finney County informed the writer that the water in his well was invariably roily after a rain storm during the preceding night in Colorado. This corresponds to nearly passenger-train speed for the flow of ground water. The story may be regarded as about the sole surviving ghost of the numerous extravagant beliefs which were formerly current among the settlers.

The region near Garden, Kans., is peculiarly the area properly called the High Plains. The land is level and completely covered in its natural condition with a short compact sod of buffalo grass. Johnson and other writers on this region have remarked the complete lack of run-off from this portion of the plains area. The precipitation falls mostly during the summer months and is sufficient in amount to maintain a luxuriant sod, which not only protects the soil against erosion, but prevents, by the obstruction offered by the grass, the escape

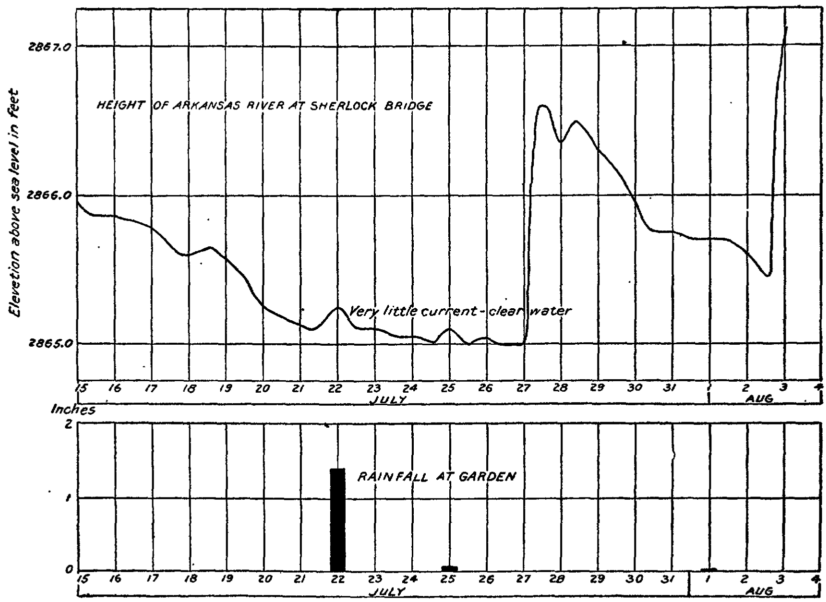


FIG. 16.—Elevation of water surface of Arkansas River at Sherlock Bridge, compared with rainfall record at Garden, Kans.

of the water in flowing torrents. In consequence the rainfall is completely taken care of by absorption into the ground and by evaporation and use by the vegetation. Eastward from the High Plains region rainfall is greater, and the sod is not able to prevent the formation of rills and eroded channels, so that much of the water runs off into surface streams. Westward from the High Plains district, as Colorado is approached, the rainfall decreases and in consequence vegetation becomes so scant that it is not able to protect the surface of the ground from erosion even from a diminished rainfall. Hence it is that both to the east and west of the High Plains there is a marked run-off, but in the plains district proper the rains are disposed of by absorption.

The above facts are well shown by the results previously discussed in this paper. The summer of 1904 was one of unusually ample rainfall in the plains, and many floods came down the river. The river was carefully watched by the field party and its elevation noted. Figs. 16 and 17 show the elevation of the river at Sherlock and Deerfield bridges, respectively, compared with the rainfall at Garden. A similar diagram for camp 1, near Garden, is given in fig. 10. A study of these diagrams shows practically no influence of the rainfall upon

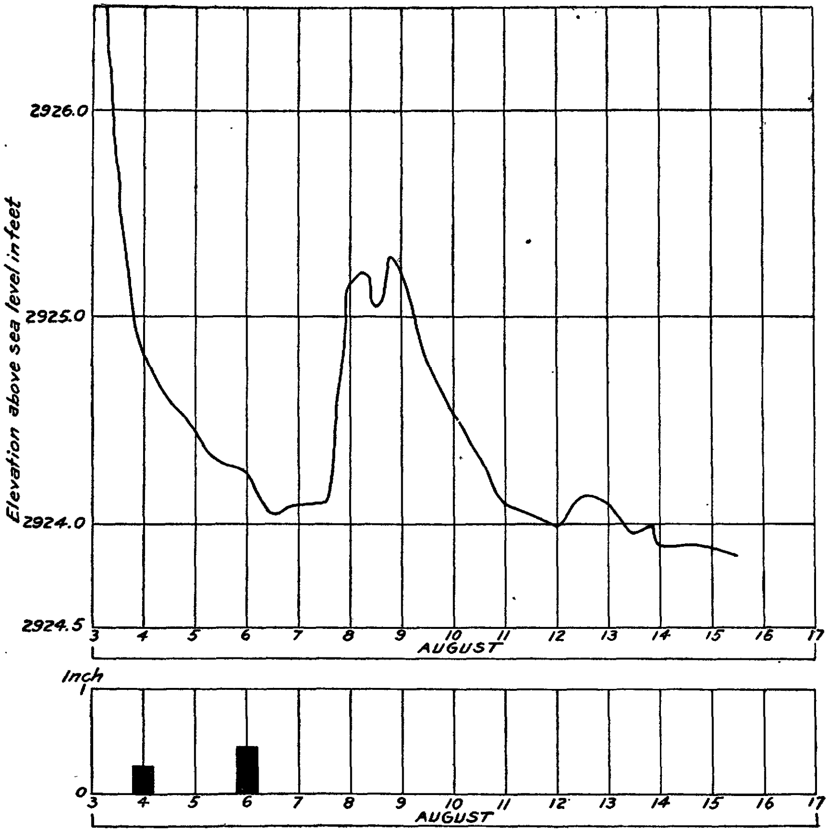


FIG. 17.—Elevation of water surface of Arkansas River at Deerfield Bridge, compared with rainfall record at Garden, Kans.

the stream. Many of these rains extended into Colorado, where they were the cause of floods that showed themselves at the camps in Kansas many hours after the rain. Thus we have ample evidence of no run-off from the country between Garden and Deerfield, and at the same time have proof of a considerable run-off from the watershed toward the western limit of Kansas and in Colorado.

The few instances in which small surface streams are formed near the Colorado line—like the plains streams known as Bear Creek and White Woman Creek—are no exception to the statement above that there is no run-off into the Arkansas in the High Plains district, for these streams entirely disappear as surface streams before the Arkansas is reached. Their waters, less the evaporation, are ultimately joined to the underflow. The situation may be summarized in the following words: The underground drainage in this region is so enormous, and the water passes through the gravel so freely, that there is no surplus water left to form surface streams, or to form a perennial supply for Arkansas River. If the gravels of the plains near Garden were less deep, it is entirely conceivable that the Arkansas River would be a perennial spring-fed stream at this point.

The large contribution to the underflow, which is made by the rainfall upon the sand hills south of the river, is clearly demonstrated by the course of the contours in fig. 5. In this diagram the soft water from the south side of the river can be observed to be pressing the hard water of the first bottoms northward toward the left side of the river valley.

Annual precipitation at Dodge and Garden, Kans.

Year.	Dodge.	Garden.	Year.	Dodge.	Garden.
1875	10.78	....	1890	11.72	....
1876	15.40	....	1891	32.34	27.21
1877	27.89	....	1892	19.66	....
1878	17.96	....	1893	10.12	....
1879	15.43	....	1894	12.60	11.45
1880	18.12	....	1895	20.31	....
1881	33.55	....	1896	19.87	....
1882	13.14	....	1897	21.58	....
1883	28.50	....	1898	31.46	28.75
1884	30.36	....	1899	28.45	20.58
1885	23.71	....	1900	20.76	19.29
1886	19.35	....	1901	16.06	18.34
1887	15.71	....	1902	17.70	19.65
1888	22.94	....	1903	15.27	20.64
1889	19.17	....	1904	17.19	21.05

NORTH AND SOUTH LIMITATIONS.

A noteworthy feature of the underflow is the lack of any natural north or south limitation to the easterly moving stream. There are important changes from place to place in the north and south slope of the water plane, but none are of sufficient consequence to materially modify the dominant influence of the easterly gradient of 7 to 8 feet to the mile. The velocities found at the edge of the sand hills to the south of the river, and at a distance as high as 9 miles from the channel of the river, are about the same as those found near the bed of the river in similar material. There is nothing surprising in this except that the stratification of the sand and gravel on the High Plains is such that there is no natural north or south limitation to the eastward-moving ground waters.

CHAPTER V.

SUMMARY OF TESTS OF SMALL PUMPING PLANTS IN THE ARKANSAS VALLEY.

GENERAL RESULTS.

Table 14 shows the results of tests of a number of pumping plants used for irrigation in Arkansas Valley between Garden and Lakin, Kans. Most of the entries in the table explain themselves.

The fuel used in most of the plants is gasoline, the current price of which during the summer of 1904 was 22 cents a gallon, a cost that is almost prohibitive, even when pumping water from the most excellent wells found in the valley.

TABLE 14.—*Tests of small pumping plants, Arkansas Valley, Kansas.*

1	2	3	4	5	6	7
Owner of plant.	Location.	Kind of pump.	Horse-power of engine.	Fuel used.	Price of fuel per gallon.	Total lift.
						Feet.
D. H. Logan	Garden, Kans.	No. 3 centrifugal	6	Gasoline	$0.22	22.1
Mrs. M. Richter	do	Menge	10	do	.20	15.5
C. E. Sexton	do	2 vertical 6 by 16 cylinder.	1½	do	.22	15.06
Nathan Fulmer	Lakin, Kans	Chain and bucket	7	do	.21	17.0
J. M. Root	do	do	2½	do	.22	15.8
King Bros	Garden, Kans.	No. 4 centrifugal	14			63.0
Waterworks	do	2 duplex steam				
I. L. Diesem	do	No. 4 centrifugal	10	Gasoline	.12¼	22.13
L. E. Smith	do	No. 3 centrifugal	6	do	.12½	17.60
H. B. Holcomb	Sherlock, Kans	No. 14 centrifugal	80	Coal	a 4.00	23.0
H. S. Kipp	Garden, Kans.	2 horizontal 5 by 5 cylinders.	3½	Gasoline	.12½	21.7
J. R. McKinney	do	No. 4 centrifugal	5	do	.12½	21.47

a Price per ton.

TABLE 14.—*Tests of small pumping plants, Arkansas Valley, Kansas*—Continued.

1	8	9	10	11	12	13	14
Owner of plant.	Distance water is lowered	Yield of well per minute.	Specific capacity of well per minute.	Area of percolating or strainer surface.	Specific capacity per square foot of strainer per minute.	Cost of fuel per acre-foot of water.	Cost of fuel per 1,000 foot-gallons.
	Feet.	*Gallons.*	*Gallons.*	*Sq. feet.*	*Gallons.*		*Cents.*
D. H. Logan	6.85	272	42.2	107.0	0.394	$2.93	$\frac{1}{25}$
Mrs. M. Richter	5.3	394	73.0	266.5	.27	2.90	$\frac{1}{17}$
C. E. Sexton	3.0	91	30.3	57.2	.53	3.75	$\frac{1}{13}$
Nathan Fulmer	6.35	540	85.0	334.0	.254	1.37	$\frac{1}{40}$
J. M. Root	4.16	215	51.7	210.0	.246	2.78	$\frac{1}{19}$
King Bros	20.3	183	9.0	85.0	.106	....	....
Waterworks	5.48	290	77.0	247.0	.31	....	....
I. L. Diesem	6.72	363	54.0	151.0	.356	2.10	$\frac{1}{34}$
L. E. Smith	2.16	198	91.6	70.7	1.290	1.67	$\frac{1}{34}$
H. B. Holcomb	9.60	2,300	240.0	1,876.0	.128	*a* .85	$\frac{1}{90}$
H. S. Kipp	2.83	96	34.0	45.3	.75	1.09	$\frac{1}{65}$
J. R. McKinney	8.39	420	50.0	116.0	.42	1.20	$\frac{1}{58}$

a Including cost of labor and lubricating oil.

SPECIFIC CAPACITY.

The numbers in column 10 express the readiness with which the well furnishes water to the pump. The numbers in each case were found by dividing the numbers in column 9 by the corresponding numbers in column 8; these numbers, therefore, express the amount of water the well would furnish if the water level was lowered but 1 foot. These numbers constitute what the writer has called the "specific capacity" of the well, and are large in the case of a good well and small in the case of a poor well.

The water-bearing gravels are usually from 9 to 15 feet below the surface of the ground, and good wells can be very cheaply constructed. There is no quicksand or hardpan or other troublesome material above the water-bearing gravels. The well tubes or strainers are usually 12 to 20 inches in diameter, and are made of slotted galvanized iron. For the most part the wells are of the very best design and possess a remarkably high specific capacity; the writer knows of few places where better ones can be constructed.

The usual construction consists of a dug well, 6 to 10 feet in diameter, excavated several feet below the level of ground water, with a number of "feeders" or tubular wells penetrating the bottom of the well. No better construction can be suggested for small plants. The only modification in detail that seems likely to better the present excellent results would be the use of galvanized-iron strainers with larger slots than are at present in use. This would be practicable at some of the wells. Heavy pumping would remove much of the fine material that now remains in contact with the present well strainers.

In column 12 there are given the same magnitudes as are expressed in column 10, reduced in each case to 1 square foot of well strainer. The numbers in this column express, therefore, 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.

These numbers are almost the same for all of the well plants, when proper allowance is made for difference in construction. At the Richter, Fulmer, and Root plants, there are large dug wells with several feeders in the bottom. The numerous feeders interfere with each other somewhat, keeping the specific capacity lower than it would otherwise be. At the Logan and Sexton plants the construction is different. The Logan well is constructed of 20-inch casing, through the bottom of which are two 4-inch feeders extending 26 feet below the bottom of the 20-inch casing. The 20-inch casing is perforated for 10 feet at the bottom. At the Sexton plant there is a 12-inch well 22 feet deep, and a 10-inch well 31 feet deep, both perforated 10 feet from the bottom.

COST OF PUMPING.

While the cost of water at these various pumping plants may at first glance seem high, and the results not especially encouraging, yet a more careful inspection shows that the facts are really highly favorable. It must be remembered that the cost of pumping is based upon a 22-cent price of gasoline. This price is almost prohibitive, but fortunately there exist several possible ways of cutting down very materially the cost of power, and on this point the following suggestions are offered:

In the first place, the cost of pumping can be reduced by the use of crude oil in place of the gasoline. Crude oil from Kansas fields should be laid down at Garden at from 3 to 4 cents a gallon. The crude oil requires a special device, which must be used in connection with the gasoline engine, called a generator, in which the crude oil, or part of it, is converted into a gas before it is led into the engine cylinder. By the use of such a generator the cost of fuel can be lowered to a point about equivalent to a 5 cents a gallon price for gasoline. The crude-oil generators will work best on engines of 12 to 30 horsepower.

If plants of from 20 to 50 horsepower are constructed, as I believe will inevitably be the case in the near future, the cheapest power will probably be found in the use of coal in small gas-producer plants in connection with gas engines.[a] These small gas-producer plants are largely automatic in action and can be operated by anyone. With hard coal or coke or charcoal at $8 per ton, the cost of power would be less

[a] See test of producer-gas plant, Chapter VI.

than one-half cent per horsepower for one hour, or only one-fifth of the cost of power from gasoline at 22 cents a gallon. The writer anticipates no difficulty, therefore, in keeping the cost of water below 60 to 75 cents an acre-foot for fuel, or below $1.25 to $1.50 per acre-foot for total expense. Hundreds of such plants have been put in use in England during the past ten or more years, and they are in charge of unskilled labor. These gas-producer plants are used in England for a great variety of purposes, such as power for agricultural machinery, and for small electric-light plants for country estates, etc. They are used in as small units as 5 horsepower.

In this country the producer-gas plants have been in use for several years, and at the present moment they are fast taking the place of steam power in new plants. The cost of a producer plant and gas engine is about the same as the cost of a steam engine and boiler of same size when everything is included, but the cost of power from the producer-gas plant is very much less than that obtained from small steam engines.

In producer plants, ranging upward from 100 horsepower, a style of plant may be installed in which soft coal or lignite may be successfully used. This still further cuts down the cost of power. In fact, large plants of this type furnish the cheapest artificial power that has yet been devised. The saving is not only in fuel, but also in labor, as one man is capable of running a 300-horsepower plant.

That part of the operating expense which is properly chargeable to fuel cost can be accurately determined. Column 13, Table 14, expresses the cost per acre-foot of water recovered. In column 14 is given the cost of fuel for lifting 1,000 gallons of water 1 foot. For the purpose of comparison, these results are expressed in fractional parts of a cent. It should be noted that the cost given in the table is based upon a 22-cent price for gasoline. There is no doubt but that producer-gas plants in moderate-sized units would enable irrigation by pumping in the bottom lands of Arkansas River to be highly profitable.

No allowance has been made for interest, depreciation, and labor. These expenses, if included, would about double the cost per acre-foot.

CHAPTER VI.

DETAILS OF TESTS OF PUMPING PLANTS.

TEST OF PUMPING PLANT OF D. H. LOGAN, GARDEN, KANS.

This plant is located in the northeast corner of sec. 13, R. 33 W., T. 24 S., and is in the northwest corner of the city of Garden. The outfit consists of a 6-horsepower Fairbanks, Morse & Co. horizontal gasoline engine connected by a belt to a No. 3 centrifugal pump. The well is constructed of 20-inch galvanized-iron casing 32 feet long, perforated 10 feet up from the bottom, inside of which are two 4-inch feeders 28 feet long, perforated their entire length, and extending 26 feet below the bottom of the 20-inch casing, making a total depth of 58 feet. The pump has been in operation since April, 1902, and the engine since April, 1903. The water was measured by the use of a fully contracted weir with a length of crest of 0.66 foot.

The engine was started at 9 o'clock and the weir was ready for water at about 10.30. The water was turned on weir and the head read until it became constant at 1 p. m. In order to determine the expense of pumping, all of the gasoline was used out of the reservoir, then 1 gallon was poured in and the length of the run noted to be one hour and thirty-two minutes, or two-thirds gallon per hour. As the engine is a 6-horsepower one, this equals 0.111 gallon, or 0.445 quart of gasoline per horsepower hour.

The average corrected head on the weir was found to be 0.440 foot. Using weir formula

$$q=c\ \tfrac{2}{3}\ \sqrt{2\ g}\ b\ H^{\frac{3}{2}},$$

where $b=0.66$, whence $c=0.592$, the discharge is found to be

$$q=0.6045 \text{ second-foot}=272 \text{ gallons per minute.}$$

Data of Logan pumping plant, Garden, Kans.

	Feet.
Average depth to water while pumping	18.6
Normal depth to water	11.75
Amount lowered by pumping	6.85
Elevation of well platform	2,835.26
Distance water was raised above platform	3.5
Lift, or total distance water was raised	22.1

Total area of well strainer, 107 square feet.

The fuel cost of pumping was, therefore, 0.9 cent per 1,000 gallons of water recovered, or $2.93 per acre-foot. The cost of 1,000 foot-gallons (1,000 gallons raised 1 foot) was, therefore, 0.0406 cent, or one twenty-fifth cent.

The specific capacity of the well is 42.2 gallons a minute, or 0.394 gallon for each square foot of well strainer.

The engine ran at a speed of 350 revolutions a minute, exploding 143 times a minute. The diameter of engine pulley is 16 inches and of pump pulley 10 inches. This gives a speed of 560 revolutions a minute to the pump.

The size of the pond was 40 feet by 60 feet, mostly covered with a green scum, which would prevent evaporation. As to seepage, the pond falls 8 inches in twelve hours at night. The pond being 2,400 square feet in area, the observed seepage represents a loss of 16.68 gallons per minute, which should be added to the capacity of pump and well, but not to the effective capacity for Mr. Logan.

There is a windmill at a well 20 feet north of the one pumped by the gasoline engine—a 12-foot airometer connected to a 10-inch pump of 12-inch stroke. After the weir measurements were completed the windmill was thrown into gear. There was a brisk wind from the south and the pump threw a good quantity of water, but no appreciable lowering of the water in the gasoline-engine well 20 feet away was detected. The rise of the water in the well was obtained twice.

Below are the two sets of observations:

Rise of water after cessation of pumping in Logan well, Garden, Kans.

FIRST TRIAL—WINDMILL NOT RUNNING.

Time.	Depth to water.	Time.	Depth to water.
	Feet.		*Feet.*
55 seconds	[a] 18.60	2 minutes and 8 seconds	12.35
1 minute and 5 seconds	16.05	2 minutes and 22 seconds	12.35
1 minute and 20 seconds	14.55	2 minutes and 33 seconds	12.25
1 minute and 37 seconds	12.95	2 minutes and 48 seconds	12.15
1 minute and 55 seconds	12.50		

SECOND TRIAL—WINDMILL RUNNING.

24 minutes and 30 seconds	([a])	25 minutes and 48 seconds	12.55
24 minutes and 35 seconds	18.0	26 minutes	12.45
24 minutes and 45 seconds	16.5	26 minutes and 23 seconds	12.25
24 minutes and 48 seconds	14.35	26 minutes and 58 seconds	12.25
25 minutes and 10 seconds	13.10	27 minutes and 15 seconds	12.25
25 minutes and 26 seconds	12.90	27 minutes and 30 seconds	12.25
25 minutes and 38 seconds	12.55		

[a] Stopped pumping.

The curves showing the rate of rise of water in the Logan well after pumping ceased are given as curves 1 and 2 in fig. 18. Curve 2 is the one which was produced when the windmill was pumping from a well 20 feet away. The comparison of this curve with curve 1, which was produced when the neighboring well was not used, is very interesting, showing, as it does, a less rapid rise when the neighboring well was in use. To find the specific capacity for the Logan well from these curves we must substitute the values of the various constants in the formula

$$c=17.25 \frac{A}{t} \log \frac{H}{h} \text{ ga..ons per minute.}$$

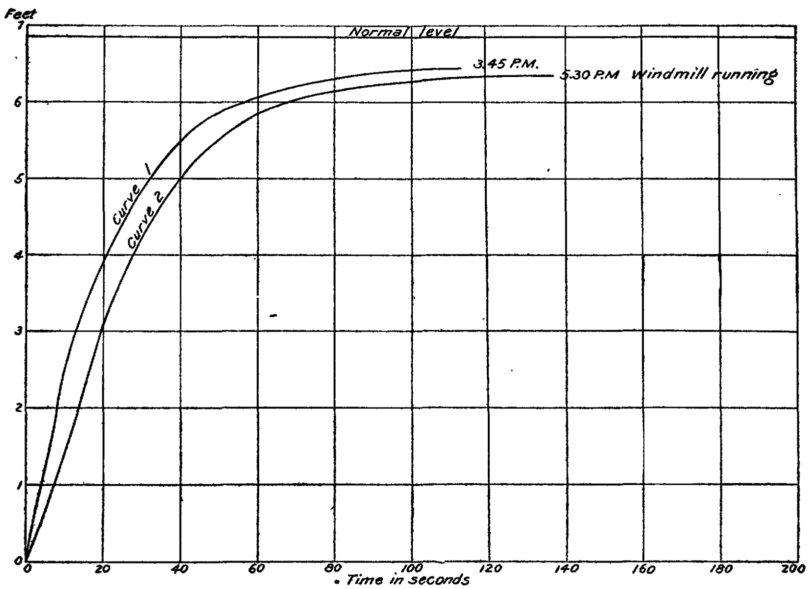


FIG. 18.—Rising curves for Logan well. Curve 2 taken when neighboring well was being pumped by windmill. Curve 1 taken when windmill was shut off.

The value of the area, A, of cross section of the well casing is 2.17 square feet, and H, the amount the water is lowered by the pump, is 6.85 feet. The amount of depression, h, of the water level below the natural level at any time can then be selected from the curve, and the specific capacity readily computed. If t be taken to be 40 seconds, or $\frac{2}{3}$ of a minute, h will be found from the curve to be equal to $6.85-5.5=1.35$ feet, hence

$$c = 17.25 \times \tfrac{3}{2} \times 2.17 \times \log \left(\frac{6.85}{1.35}\right) \text{ gallons per minute} = 39.5 \text{ gallons per minute.}$$

The yield of the well for the maximum depression, 6.85 feet, must then be

$$6.85 \times 39.5 = 270 \text{ gallons per minute.}$$

The curve of rise of water forms one of the best methods of determining the yield of a well. Such curves can readily be obtained. Well data should always include measurements of the amount of lowering of the water surface by the pumps, and it is only necessary to continue these measurements after the pumps have stopped to secure sufficient data to estimate the specific capacity and total yield of the well. This avoids the necessity of constructing a weir or other method of measuring the water discharge. The accuracy is sufficiently great for the purpose for which such data are used. The method can be used only in cases where an internal suction pipe extends into the well casing with sufficient room around it to permit a sounder to be lowered to the water surface. If there is no foot valve or other means for preventing the water from returning to the well after pumping ceases, the rising curve may still be used for the determination of the specific capacity, provided that only the portion of the curve be used which was formed after the water had completely returned to the well from the pump.

TEST OF THE RICHTER PUMPING PLANT, NEAR GARDEN, KANS.

This plant is located in the northwest corner of SW. ¼ sec. 14, R. 33 W., T. 24 S. The upper part of this well is cased with part of the old standpipe from Garden. The casing is 10 feet in diameter and extends down 20 feet. In the bottom of this part of the well are placed four 8-inch galvanized-iron feeders, arranged symmetrically about the center; each feeder is 25 feet long, perforated its entire length, and extends about 2½ feet above the bottom of the large part of the well.

The pump used is a Menge pump, which operates on the principle of a screw propeller of a steamship. It bores the water out and up a square wooden penstock or pump shaft. There are two of these propellers mounted one above the other on vertical iron shaft inside the penstock. The top of the iron shaft carries the belt pulley and has a shoulder bearing which takes the thrust of the pump as a pull above. This pump is made in New Orleans.

The pump is run by a 10-horsepower Otto gasoline engine, which runs at a speed of 300 revolutions per minute. The circumference of the drive pulley is 5.25 feet, and of the driven pulley 2.65 feet, making the pump run at 595 revolutions per minute. The screws are boxed up and under water when the pump is not in operation. A small pond was constructed at the end of the discharge trough and a fully contracted rectangular weir of length of crest of 1.2 feet was used to measure the discharge. The measurements for head were taken 6 feet away from the weir, and boards were interposed between the discharge trough and weir to cut down the velocity, which might tend to give erroneous results. The average corrected head on the weir was 0.371 foot. Using the weir formula

$$q=c\tfrac{2}{3}\sqrt{2\,g}\;b\;H^{\frac{3}{2}}$$

and taking c from Merriman's tables as 0.603,

$$q=0.876 \text{ second-foot}=394 \text{ gallons per minute.}$$

Using a small Price acoustic water meter in the discharge trough, by measuring the velocity at different places and also by integrating, the discharge was found to be 0.76 second-foot, or 342 gallons per minute. The water in the flume was so shallow that this determination is of little value. By putting chips in the discharge trough and catching the time with a stop watch, the surface velocity was found to be 1.565 feet per second. This number multiplied by 0.8 gives an average velocity of 1.25 feet per second and a discharge of 0.884 second-foot, or 397 gallons per minute.

An attempt was made to determine the amount of gasoline used. The reservoir was filled full and the engine run for 1 hour and 36 minutes, or 1.6 hours. All the gasoline we had, 9¼ quarts, did not then fill the tank. This was at noon, July 6. On the morning of July 7, 9½ quarts were required to completely fill the reservoir, a total of 18¾ quarts or 37½ pints for the run of 1.6 hours for a 10-horsepower engine. The makers claim their engines use one pint per horsepower hour. This would require in this case 16 pints, or less than half of what was actually measured, if the engine developed its full horsepower. A leak in the tank or feed pipe is clearly indicated, so this amount, while being of value to the owner of the plant, is valueless so far as comparative cost of pumping is concerned.

Two observations of the rising curve were obtained which plot well together. The lower part of the curve is not accurate, because of the water in the penstock dropping back into the well when pumping ceases.

Data of Richter pumping plant, near Garden, Kans.

	Feet.
Elevation of the ground at well	2,846.0
Average elevation of water in well	2,836.8
Average elevation of water in well when pumping	2,831.5
Elevation of discharge from penstock	2,847.0
Lift	15.5
Average amount water is lowered by the pump	5.3

Number of explosions of engine, 126.5 per minute.

Total area of surface of well strainers and all percolating surfaces, 226.5 square feet.

The curves of rise for this well were obtained on two different occasions and are shown as curves 1 and 2 in fig. 19. They plot together very well. To find the specific capacity of the well from the curve, we note the following values of the constants in the formula for specific capacity:

$$c=17.25 \frac{A}{t} \log \frac{H}{h} \text{ gallons per minute.}$$

The area, A, of cross section of the well casing, less the amount occupied by obstructions, is 76.79 square feet. The amount, H, that the water is lowered by the pump is 5.3 feet. The amount of depression, h, of the water surface below the natural level at any time can be selected from the curve. From the curve, at the close of ten minutes, h equals 5.3 less 4, or 1.3 feet.

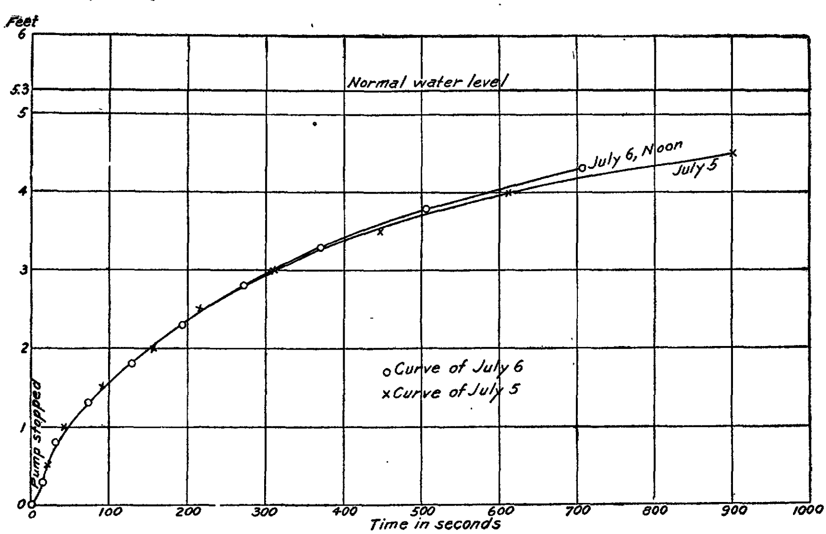


FIG. 19.—Rising curves for Richter well, near Garden, Kans.

Hence the specific capacity

$$c=17.25\times\frac{76.79}{10} \log \frac{5.3}{1.3}=81 \text{ gallons per minute.}$$

Multiplying by 5.3, the head under which pumping took place, the total yield of the well is 81×5.3=430 gallons per minute.

The above determination of the specific capacity is inaccurate, since the first portion of the rising curve does not show the true rate of rise of water in the well. The penstock of the propeller pump holds 37.7 cubic feet of water, which immediately returns to the well when the pump is stopped. This amount of water is sufficient of itself to raise the level in the well by 0.465 foot. For this reason, only that portion of the rising curve should be used which is not influenced by the returning water from the penstock. Thus, if we use that part of the curve from $t=100$ seconds to $t=600$ seconds, we will eliminate the inaccurate portion. Making this modification, the data are changed to

$$H=3.75 \text{ feet};\ h=1.30 \text{ feet};\ t=8\tfrac{1}{3} \text{ minutes}.$$

Computing the specific capacity on this basis, we obtain

$$c=73 \text{ gallons a minute}.$$

Multiplying this by 5.3, the total estimated yield is 388 gallons a minute, which checks remarkably with 394 gallons a minute obtained.

The area of the strainer and bottom of the well is 266.5 square feet. The above specific capacity divided by 266.5 gives 0.341 gallon per minute as the specific capacity per square foot of percolating surface.

The engine ran at a speed of 300 revolutions and exploded 125 times per minute. This would indicate that it was working at about 83 per cent of its rated capacity. Assuming that such was the case, and that it would then use 83 per cent of the fuel necessary to run it at its full rated power (10 horsepower), we have 8.3 pints as the probable amount of gasoline used per hour by the engine during the test. This, at 20 cents per gallon, would make a cost of 21 cents per hour. This assumption makes the cost of water 0.89 cent per 1,000 gallons, $2.90 per acre-foot, and one-seventeenth cent per 1,000 foot-gallons.

TEST OF PUMPING PLANT OF C. E. SEXTON, NEAR GARDEN, KANS.

This plant is located at about the center of sec. 13, R. 33 W., T. 24 S., and is 1 mile west of Garden. It consists of two pumps of 16-inch stroke, with 6-inch pistons, connected to a walking beam and driven by 1½-horsepower Fairbanks, Morse & Co. vertical gasoline engine. The east well has a 12-inch casing 22 feet deep, and the west well a 10-inch casing 31 feet deep, both casings being perforated for a distance of 10 feet up from the bottom. The pump rods are 2 by 4 timbers.

The two pumps discharge into an artificial pond or reservoir, and the flow was measured with a weir at the outlet of the reservoir. The weir was fully contracted with a length of crest of 0.66 foot.

The height of water on the weir was measured by placing a stick on the head of the nail and marking the water line on the stick with a pencil, then measuring with a pocket tape; in the absence of a hook gage this was the best method that suggested itself.

The weir heights taken as a measure of the discharge of the pump are those obtained after the water level in the reservoir had become stationary, as indicated by an absence of systematic variation of the weir heights. As evaporation would make the results too small, the following data are important:

The size of reservoir is 50 feet by 90 feet, or 4,500 square feet; trees border the north and south sides, with high grass along the banks; brisk wind was blowing from southwest; temperature of air was 80°, temperature of water, 52°; there was sunshine until about 3 p. m., when it became cloudy and the wind moderated.

The east well threw a much smaller stream than the west well, probably due to a leak in the suction pipe, and consequent pumping of air. No air was pumped by the west pump.

Measurements to the water surface in the east well were made at five-minute intervals, but no soundings were obtained in the west well. The number of strokes of each pump averaged 24.5 per minute during the test; the number of explosions of the gasoline engine averaged 106.2 per minute. The battery used with the engine not working satisfactorily, a gasoline torch was used for ignition. Gage readings of distance to water in well were made downward from a point on the well platform whose elevation above sea level was 2,836.69.

Data of Sexton pumping plant, near Garden, Kans.

	Feet.
Distance to water when level is normal	8.8
Distance to water when pumping	11.86
Amount water level was lowered	3.06
Elevation	2,827.9
Distance water was raised above point on platform	3.2
Total distance water was raised (11.86+3.2)	15.06

Total area of well strainers, 57.2 square feet.

The reservoir has been in use for some time and the seepage was probably quite small, a small enough per cent to be negligible. There was no leakage around the weir, or elsewhere.

The gasoline tank was filled at the start, and when the run was completed the amount needed to refill was measured, thus getting the amount used by the engine, which was 11 quarts for a run of 9 hours and 37 minutes, or 1.14 quarts per hour, making a trifle over three-fourths quart per horsepower hour. The average corrected weir height was 0.206 foot.

Using the formula for a contracted weir

$$q=c\tfrac{2}{3}\sqrt{2g}\,b\,H^{\frac{3}{2}},$$

and taking from Merriman's Hydraulics the value of the constant c for $b=0.66$ and $H=0.206$ as 0.611, we have for the discharge

$$q=0.202 \text{ second-foot,}=91 \text{ gallons per minute.}$$

With gasoline at 22 cents per gallon, or 5½ cents per quart, the expense of an hour's run, not counting gasoline used for ignition tube, is

$0.0625 per hour, or $0.0115 per thousand gallons of water pumped, or $3.75 per acre-foot. The lift being 15.06 feet, the cost per 1,000 foot-gallons is 0.076 cent, or about one-thirteenth cent per 1,000 gallons raised one foot.

On July 8 the rise of water in the east well was taken by means of a thin pine board stuck down between the casing and pump. The intervals of time were measured with a stop watch. The pine strip was lowered into the well until the water was reached, after which the board was drawn up, the wet line marked, the time recorded, and the board replaced, the observations being repeated as fast as possible. The distances marked on the strip were measured later.

Rise of water after cessation of pumping in Sexton well, near Garden, Kans.

Time.	Rise.
	Feet.
8 seconds	0.46
20.5 seconds	2.44
56.6 seconds	2.92
82 seconds	3.01
104.6 seconds	3.02
134.5 seconds	3.03

The rising curve plotted from these data was of little use in determining the specific capacity of the wells, both on account of an unknown amount of water returned to the well by leakage of the pump, and because of the unknown amount of lowering of the water in the west well.

TEST OF PUMPING PLANT OF NATHAN FULMER, LAKIN, KANS.

This plant is in the center of NE. ¼ sec. 10, R. 36 W., T. 25 S., Kearney County, 3 miles south of Lakin, Kans. The well consists of a wooden casing, 6 feet in diameter and 10 feet deep, sunk with the top flush with the surface of the ground. Inside of this cylindrical casing and extending 9½ feet below the bottom of it is a tapered wooden curbing 10 feet long, 4 feet in diameter at the top, and 5 feet in diameter at the bottom. This curb was given the tapering form in order to lessen the friction on the sides in sinking the well. The total depth of the two large curbs is 19½ feet. Arranged in a circle in the bottom of the main well, about 5 inches from the edge, are 7 feeders. Four of these feeders are 7 inches and 3 are 8 inches in diameter. The length of each feeder is 23 feet 4 inches. The feeders extend down to within 3 or 4 inches of an underlying clay or silt and 8 inches above the bottom of the large well. The total depth of the well is 42 feet. The feeders are made of No. 20 galvanized sheet iron with three-eighths-inch perforations arranged in circles from three-fourths of an inch to 2 inches apart.

The material encountered in sinking the well, according to Mr. Fulmer, was, first, 4 feet of clay, then sand, which became coarser with the depth. The bottom stratum consists of a mixture of fine sand and gravel, some of the latter being the size of a hen's egg. Water was found at a depth of 8 feet.

A local make of chain and bucket pump, known as the Pittman pump, is used in this well. It consists of an upper shaft and submerged lower shaft around which run the two sprocket chains to which are attached the galvanized iron buckets, each with a capacity of 12.5 gallons. The buckets, 33 in number, are hung between the chains and are of such shape that when they come over at the top of the circuit they discharge the water readily into the discharge trough, allowing very little to run back into the well. To aid in starting the water down the trough a number of horizontal guide vanes are placed therein with a slope away from the descending buckets in such a way that the water is started down the trough with very little splashing back into the well. These pumps are of a recent design, and are made in Kearney County. There are three such pumps in operation, one run by a windmill near Garden, and one owned by Mr. Root, a test of which is described in this report (pp. 70–73).

The power is supplied through the proper gearing by a Howe gasoline engine, built by the Middletown Machine Company, which develops about 7 horsepower at 285 revolutions per minute. The engine is cooled by water taken from the discharge trough. The supply of gasoline is put in a rectangular sheet-iron tank, 2.4 feet by 2.6 feet by 1 foot high, which is placed in the ground outside the engine house. The ratio of the gearing between the engine and bucket chain is such that $175\frac{1}{2}$ revolutions of the engine produce 1 revolution of the bucket chain, or $5\frac{1}{3}$ revolutions of the engine to each bucket discharge.

The discharge trough empties into a reservoir from which the seepage is quite rapid. As there was no chance to put a weir between the pump and the reservoir, and since one placed at the outfall of the reservoir would measure only a portion of the water entering the reservoir, the amount of water pumped was measured by counting the number of revolutions of the bucket chain and computing the capacity of several buckets to secure an average value. The average capacity was found to be 12.52 gallons. The computed discharge, obtained by counting the revolutions of the bucket chain and noting the time, was 561 gallons per minute. It was estimated that the buckets lacked about 0.05 foot of being full, this being about 4 per cent of the measured capacity of the buckets. Also, during the run, 22 buckets came up empty, caused by the failure of the valve in the bottom to work, which amounts to a loss of one-fourth of 1 per cent of the total discharge. Reducing the observed 561 gallons by 4 per cent gives 540 gallons per minute as the corrected discharge of the well. The water level was lowered 6.35 feet below the normal. The lift to the discharge trough was 17 feet. The engine ran at 240 revolutions and averaged 64 explosions per minute.

The amount of gasoline used was determined by measuring the depth of gasoline in the tank at intervals and noting the time at each measurement; then by plotting a curve the average rate per hour of lowering of the gasoline in the tank was obtained, and, the horizontal cross section of the tank being known, the amount of gasoline used per hour was computed to be 0.65 gallon. The cost of gasoline was 21 cents per gallon in barrel lots, making the expense of running the

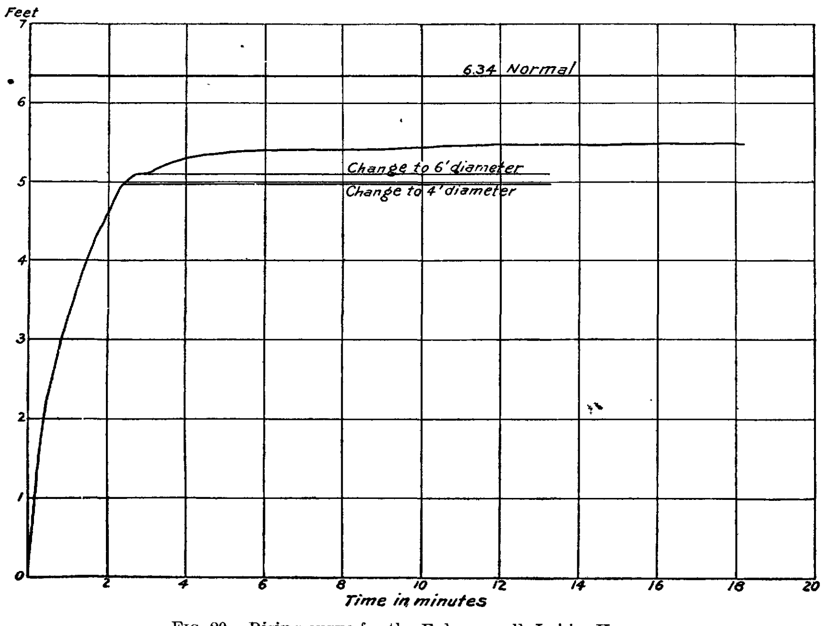


FIG. 20.—Rising curve for the Fulmer well, Lakin, Kans.

engine 13.65 cents per hour. The cost of water per acre-foot was therefore $1.37. The cost of water per 1,000 gallons was 0.42 cent, and the cost per 1,000 foot-gallons was one-fortieth of a cent.

A reservoir 100 feet wide by 240 feet long is used in connection with the plant. This reservoir was made by digging out the inside and using the material to form the banks. This produced a very porous bottom and much trouble has been experienced from seepage. To remedy this the bottom was puddled thoroughly by plowing and harrowing, then putting in chaff and straw and herding cattle and horses in the bottom for several days, but the surface of the water still drops about 6 inches per day.

One observation of the rising curve of this well was made (fig. 20). It will be noticed that there is an irregularity in the curve corresponding to a depth of about 1⅓ feet below the normal water level, caused by the sudden change in cross section from 12½ square feet to 28⅛ square feet at the top of the lower casing. From the rising curve the specific capacity may be obtained from the following formula:

$$c = 17.25 \frac{A}{t} \log \frac{H}{h}$$

At a point 4 feet above lowest position of water level the average area A of the well from 0 to this point is 17 square feet. t=1.6 minutes; H=6.35 feet; h=2.35 feet.

Then c=80 gallons per minute. This, multiplied by 6.35, the amount the water was lowered by pumping, gives 508 gallons, which is within 6 per cent of the observed discharge.

The total area of percolating surface, 7 feeders, and the bottom of the well, is 334 square feet. The above specific capacity divided by 334 gives 0.24 gallon per minute per square foot of percolating area.

The amount of water recovered can not be increased without lowering the pump, as a glance at the diagram will show, the water level being now lowered slightly below the lower shaft.

The Fulmer plant was installed in the spring of 1903 and has been in operation since April of that year. The cost of the entire plant is as follows:

Cost of Fulmer plant, Lakin, Kans.

	Cost of material.	Labor.		Total cost.
		Time, in days.	Cost.	
Well:				
Material and lumber	$18.50	*a* 3	$6.00	$24.50
Digging		*a* 45	90.00	90.00
Seven feeders at $8.40 (24 feet each, at 35 cents a foot)	58.80			58.80
Reservoir, man and team, at $3.50 a day		40	140.00	140.00
Pump, made by Mr. Fulmer, market price about	260.00			260.00
Engine:				
Cost in Kansas City	328.50			347.12
Freight	18.62			
Shed, 8 by 22 by 7 feet	35.00	*a* 5	10.00	45.00
Incidentals				34.58
Total cost	719.42		246.00	1,000.00

a Labor, $2 a day.

Mr. Fulmer uses water from the south-side ditch, and only about 15 acres of cantaloupes and fruit trees are irrigated. The capacity of the plant is about 100 acres.

TEST OF PUMPING PLANT OF J. M. ROOT, LAKIN, KANS.

This plant is located at the southeast corner of northwest ¼ sec. 4, R. 36 W., T. 25 S., Kearney County, 3 miles southwest of Lakin, Kans.

The well consists of a wooden casing, 6 feet in diameter and 12 feet long, sunk with the top flush with the ground. Inside of and below this is a 10-foot casing, 4½ feet in diameter at the top and 5½ feet at the bottom, sunk until the top is 2 feet above the bottom of the upper casing, making the total depth of the main well 20 feet. In the bottom of this main well are sunk 5 feeders in a circle about 10 inches from the edge of the lower casing. The feeders are 8 inches in diameter; two of them are 24 feet long and three are 18 feet long. The 24-foot feeders project 2 feet above the bottom, while the 18-foot feeders project only 1 foot. These feeders are made of No. 20 galvanized iron, and the perforations are the same as in Fulmer's well, previously described.

The material encountered in sinking the well was, first, about 1 foot of sand, then about 17 feet of black dirt, followed by 1 foot of yellow clay and 2 feet of sandy clay. There is no record of the material encountered in sinking the feeders.

The Pittman pump is used in this well and is of the same pattern as that described in connection with the Fulmer plant. The buckets are smaller, having a capacity of 6.3 gallons, and the bucket chain has places for 40 buckets, 24 of which were in place at the time of the test. The vacant places were left at regular intervals around the chain, but the effect was to give the chain a swinging motion, which caused the slopping out of a great deal of water. The valves in the bottoms of the buckets also leaked excessively.

Power is furnished by a vertical 2½-horsepower two-cycle Weber gasoline engine with throttle governor, built by the Weber Gas and Gasoline Engine Company, Kansas City, Mo. The engine is cooled by a small tank and exploded by an autosparker. The ratio of the gearing between the engine and the bucket chain is such that 257 revolutions of the drive wheel produce 1 revolution of the bucket chain, or 6.4 revolutions of the engine to each bucket raised, if the buckets are all on the chain.

There is no reservoir used with this plant. The discharge was measured with a fully contracted weir, with a length of crest of 1 foot. The average head observed was 0.2805 foot, giving the following discharge by the Francis formula:

$$\begin{aligned} q &= 3.33\ (b - 0.2\ \mathrm{H})\ \mathrm{H}^{\frac{3}{2}} \\ &= 3.33\ (1.0 - 0.056)\ 0.2805^{\frac{3}{2}} \\ &= 3.33 \times 0.944 \times 0.1485 \\ &= 0.4675 \text{ second-foot} \\ &= 210 \text{ gallons per minute.} \end{aligned}$$

By the formula given by Merriman for fully contracted weir of length of crest of 1 foot the discharge is computed to be 218 gallons per minute. The following computations are based on a discharge of 215 gallons per minute: As the water level was lowered 4.16 feet the specific capacity is 51.7 gallons per minute. The lift was 15.8 feet. The engine averaged 488 revolutions per minute, exploding at every revolution.

The amount of gasoline used for a three-hour run was exactly 6 quarts, or at the rate of 0.5 gallon per hour. This gasoline cost 22 cents per gallon, making the cost of fuel 11 cents per hour. The cost of water is 0.855 cent per 1,000 gallons, $2.78 per acre-foot, and one-nineteenth cent per 1,000 foot-gallons. The lack of economy in this plant is in the engine, which is old and in poor condition, and in the buckets, the valves of which leak badly. Also the water was lowered so far that the buckets did not start up full, and the swinging motion of the chain spilled a great deal. The owner has never been able to keep the plant running for more than half an hour at a time, and it took as long to put the plant in order as it did to make the test.

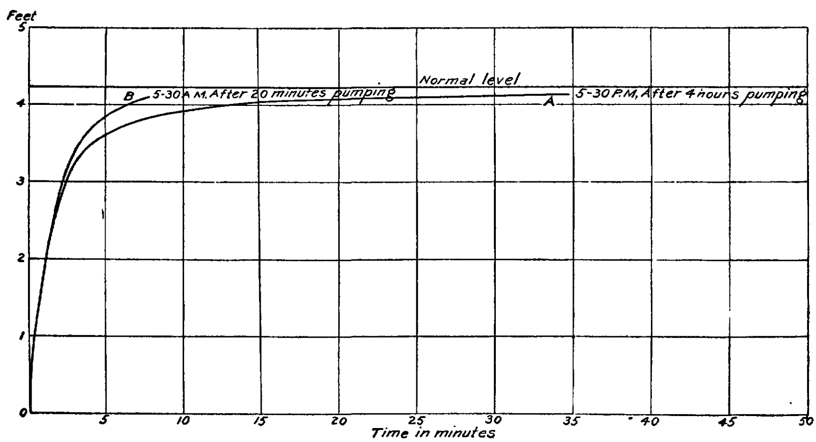


FIG. 21.—Two rising curves for the Root well: Curve A, after four or five hours of pumping; curve B, after only twenty minutes of pumping.

Two rising curves of this well were obtained, which make an interesting comparison (see fig. 21).

Curve A was taken late in the afternoon, after about four or five hours' pumping, and curve B was taken after about twenty minutes' pumping, when the water was lowered to the same depth as during the preceding afternoon.

Curve B is much steeper than curve A, showing that the water flowed into the well faster. This can be explained by the fact that during the short period of pumping (twenty minutes) the cone of influence had not extended as far as in the first case, and there was therefore less unsaturated soil to fill with water and a steeper slope of the ground-water surface.

The specific capacity of the well, determined from these curves, using the method described heretofore, is 62.5 gallons per minute. This multiplied by 4.16, the amount of lowering of the well by the pump, gives 260 gallons per minute, which is 19 per cent above the observed discharge. The percolating surface—area of feeders plus bottom of well—is 210 square feet, and dividing the specific capacity determined from the discharge by 210 we get 0.246 gallon per minute as the specific capacity per square foot of percolating area. This large error is probably caused by the steep slope given to the rising curve by the leakage of the water from the buckets. The pump must be lowered before a greater quantity of water can be recovered, as the water at present is lowered to the level of the lower shaft.

This plant has not been utilized for irrigation as yet, but its use is contemplated for irrigating about 20 acres of beets, cantaloupes, melons, and garden truck.

The Root plant was installed in the spring of 1904, being completed in the latter part of May. Its total cost was as follows.

Cost of Root pumping plant near Lakin, Kans.

	Cost of material.	Labor.		Total cost.
		Time in days.	Cost. [a]	
Well:				
Lumber	$27			$27
Feeders	42			42
Labor—				
Prospecting for location, digging big hole		2	$4	4
Making big curb		9	18	18
Sinking big curb		12	24	24
Sinking feeders		17	34	34
Pump	100			100
Engine	100			100
Installing			6	6
Shed:				
Lumber, nails, and window	33			33
Paint and painting	4			4
Labor			10	10
Total	306		96	402

[a] Labor, $2 a day.

TEST OF WELL AT KING BROTHERS' RANCH, GARDEN, KANS.

This well is located near the west side of sec. 30, R. 33 W., T. 22 S., about 12 miles northwest of Garden, Kans.

The well consists of a shaft, about 5 feet square, sunk 41.4 feet, to within 1.2 feet of the water level. From the bottom of this shaft a 15-inch, perforated, galvanized-iron casing extends down to a depth of 40.5 feet from the normal surface of the ground water.

It was put down by King Brothers to determine the amount of ground water which could be recovered at this point from a single well and its influence on other wells.

Fifteen feet from the first well a second well was sunk to a depth of 91 feet, 7.9 feet lower than the first well. This second well was put down for the purpose of determining the effect on the water plane of lowering the water in the first well by pumping.

A No. 4 Byron-Jackson centrifugal pump was placed at the bottom of the shaft of the first well and connected by a long belt running over 2 idle wheels to a 14-horsepower thresher engine on the surface of the ground. The discharge was measured by a fully contracted weir with a crest of 1 foot. The head at the time of maximum discharge, when the water in the well was as far down as the pump could lower it, was 0.25 foot, corresponding to a flow of 183 gallons per minute. This maximum rate was very difficult to maintain for any length of time, because of the temporary manner in which the machinery was installed. The belt was liable to slip and allow the water to rise several feet; also the idle wheels at the top of the shaft over which the belt ran were poorly mounted, and at times a stop was necessary to cool off a hot box at that place.

The above discharge was measured when the water level in the well was lowered 20.3 feet by the pump. Dividing the discharge by the distance gives the specific capacity of the well, or the amount of water furnished for 1 foot of lowering, as 9 gallons per minute. The total percolating area of well strainer exposed to the water was 85 square feet. From this it appears that the specific capacity of the well strainer is 0.106 gallon per square foot per minute.

As this was a test of the capacity of the well only, and not of the pumping plant, no indicator cards nor other device was used to get the efficiency of the plant, and no measure was made of the coal burned. The mechanical efficiency would undoubtedly have been low, as there was a constant slipping of the belt, and the idle wheels were home-made, running in wooden bearings, which were smoking constantly.

The maximum lowering of the water in the main well was 20.2 feet, and the corresponding depression of the water plane, 15 feet away, as indicated by the test well, was 3.5 feet. This shows the steep slope of the water plane and the comparatively small radius of the base of the cone of influence.

Readings were taken of the water level in the main well and the test well, and the discharge was noted at intervals. The accompanying curve, fig. 22, shows rising curves for the main well and the test well plotted together. A study of the curve brings out several facts that might well be expected. The rise of the test well lags slightly behind that of the main well. The curve of the main well shows an irregularity due to the caving in of material around the strainer.

King Brothers contemplate sinking 20 of these wells in a north and south line. They propose to connect them all with a tunnel just above the water plane and lay a main suction pipe in this tunnel, with branches tapping all the wells. The pumps will be located in the shaft already dug, and connected by a belt to the power plant on the surface.

The owners paid 40 cents a foot for sinking the wells and furnished one man. The price paid for the 15-inch, No. 16, iron casing was $1 a foot. They contemplate using wooden casing in the remainder of

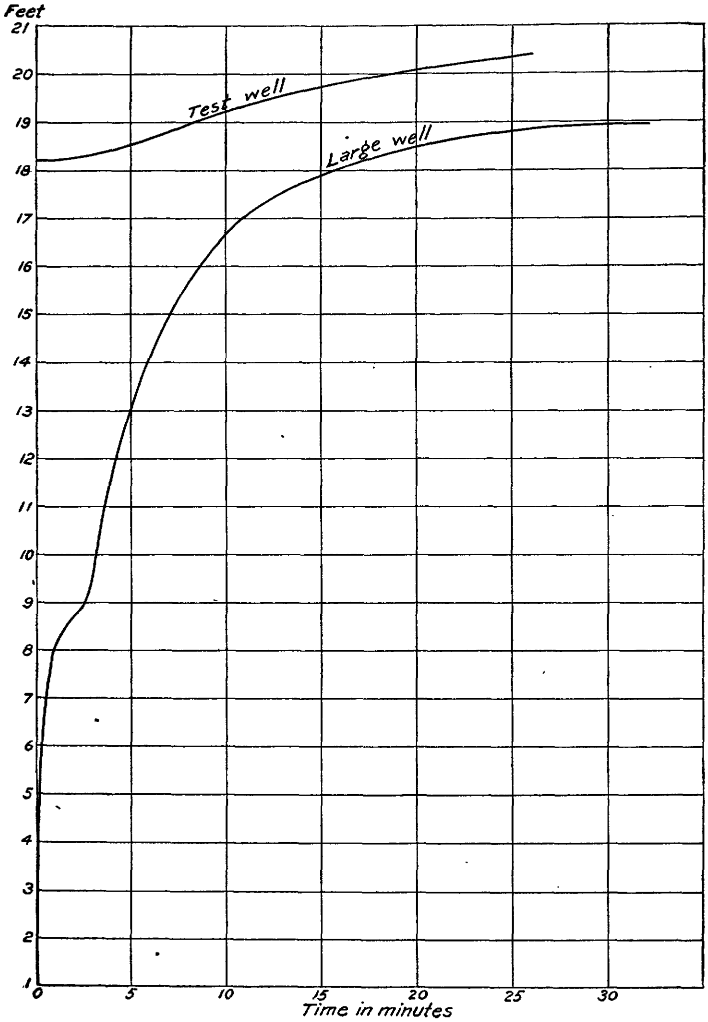


FIG. 22.—Rising curves for main well and test well, King Brothers' plant, Garden, Kans.

the wells. This will be made of pine lumber 1 inch by 3 inches. It will take 16 such boards to make the circular casing, at a cost of $3.50 per hundred linear feet of lumber. One man, at $1.50, can make and perforate about 25 feet of this casing in a day. This would make the cost of wooden casing 62 cents per foot.

After the tunnels and wells are dug King Brothers purpose to contract for the installation of a compound Corliss engine and centrifugal pump at about $9,500. They expect the plant to raise 4,000 gallons of water per minute, with a 60-foot lift, this being at the rate of 2,000,000 foot-pounds per minute on 4,800 pounds of coal per twenty-four hours. If the coal contain 12,500 British thermal units, and if the boiler efficiency be assumed at 75 per cent, engine 13 per cent, and belt 90 per cent, the pump would be required to have an efficiency of 70 per cent to realize the above expectation. These figures require that the plant turn out 5.9 per cent of the energy in the fuel in the form of useful work.

TEST OF CITY WATERWORKS WELL, GARDEN, KANS.

The first test began at 4.25 a. m. June 28, 1904, when one pump was started. The second pump was started at 5.50 a. m. The hydrants used in flushing the sewers were opened at about 7.30 a. m. and closed at 10.35 a. m. The east pump was stopped at 11.15 a. m.; the west pump was operated constantly all day. On account of the flushing of the sewers an exceptionally large amount of water was pumped during this test.

Gage heights in the well were read every five minutes, and the number of cycles of each pump was recorded every tenth minute for the ten preceding minutes. The pumping machinery consists of two compound steam duplex pumps, with cylinders 8 inches by 12 inches, which are very old and worn. The test was continued until 12.40 p. m. At 8 p. m. the test was again taken up, this being the time when the sprinkling of lawns is stopped. The cycles of the engine were counted and well heights taken as before.

Pumping is stopped at 9 p. m. Sprinkling of lawns is allowed from 7 to 11 a. m. and from 4 to 8 p. m. Most of the rise of water in the well occurs before 9 p. m., when the pump is stopped. A plug was made for the feeder and inserted July 7, but it did not fit tight enough to stop the flow. The rising curve was taken July 7 in the evening and also July 8, when the plug was driven down so as to be water-tight. July 11 the rising curve was again taken when the water was lower.

The well is 16.2 feet inside diameter and 20 feet deep. The bottom is about 8.9 feet below the normal level of the ground water. There is a 10-inch feeder in the bottom of the well, which extends to a depth of 42 feet below the ground and about 3 feet above the bottom of the large well. It is open at the bottom and perforated 10 inches up from the bottom. The water level is about 11 feet below the ground level.

Data of city waterworks well, Garden, Kans.

	Feet.
Elevation of top of well roof	2,837.26
Distance to top of gage	10.35
Distance, top to 0	13.25
	23.60
Elevation, water normal	8.72
Normal elevation of water	2,822.38
Ground level	2,832.00

Elevation of bottom of well 2,813.66=0 of gage.

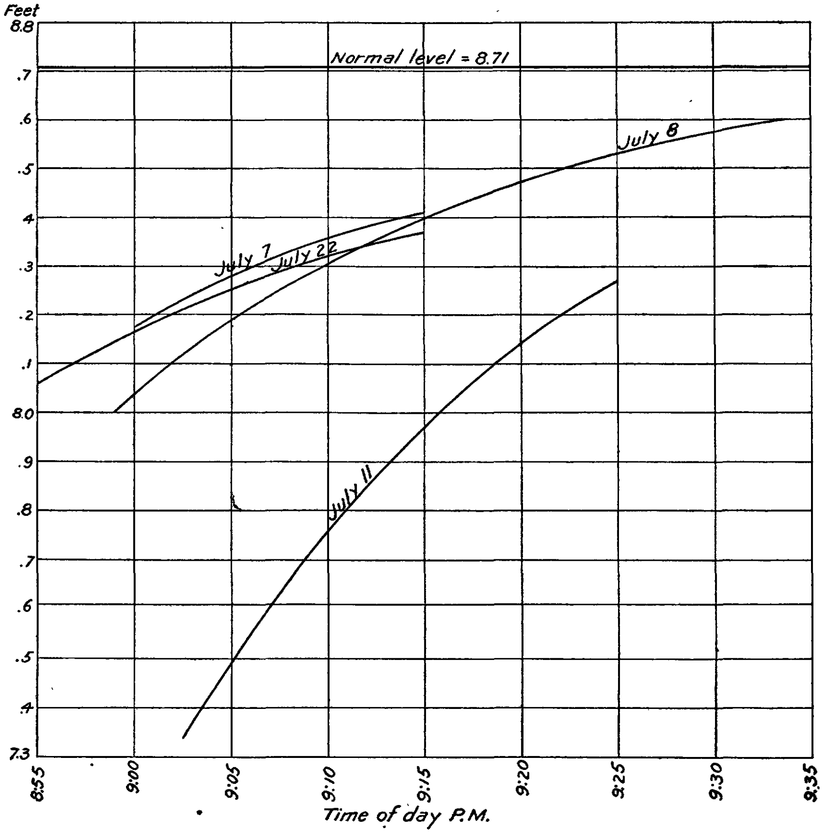


FIG. 23.—Rising curves for city waterworks well, Garden, Kans.

The rising curves obtained for this well on June 28, July 7, 8, and 11 are reproduced in fig. 23. Fig. 24 gives the engine cycles and elevation of water in the well for several hours of heavy pumping on June 28, 1904, while the sewers were being flushed. The displacement in the two cylinders of one of the pumps amounts to 1.362 cubic feet. The curve in fig. 24 enumerates the cycles of pumps, so that the total discharge of the pumps can be obtained, if no allowance be made for slip, by multiplying the number of cycles by 1.362. The discharge, computed in this way, amounts to 685 gallons a minute.

The amount of slip is enormous. Using the rising curve for June 28, we may place H=0.65, h=0.46, and A=204.5 square feet in the formula for specific capacity. This gives a specific capacity

$$c=53 \text{ gallons a minute.}$$

This result is much below the normal on account of the excessive amount of pumping on that day, due to the flushing of sewers. The maximum amount of lowering of the water in the well was 5.48 feet,

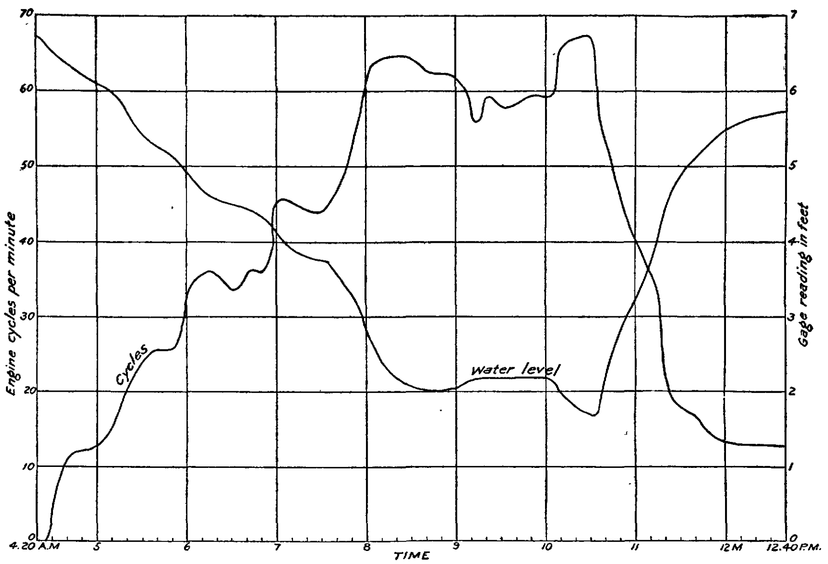


FIG. 24.—Elevation of water in city well, Garden, Kans., and engine cycles of steam pump during heavy pumping while flushing sewers, June 28, 1904.

which occurred at 10.30 a. m., when the pump cycles numbered 67 per minute. Multiplying 5.48 by 53, the total discharge at that time is found to be 290 gallons a minute. The slip of the pump must therefore have amounted to 57 per cent at this time.

Using the rising curve of July 7, the specific capacity of the well is found to be 67 gallons a minute. The following table shows the specific capacities computed for the several dates:

Specific capacity of city waterworks well, Garden, Kans., 1904.

Rising curve.	Specific capacity per minute.
	Gallons.
June 28, 8.55 to 9.05 p. m.	53
July 7, 9 to 9.10 p. m.	67
July 8, 9 to 9.10 p. m.	78
July 11, 9.05 to 9.15 p. m.	80

These results furnish interesting comparisons. The low specific capacity on June 28 was obtained after the prolonged and excessive pumping for flushing of the sewers. There was a light rain on the night of July 6, and a heavy rain on the night of July 7, which influenced both the consumption of water in the city, and in a slight degree the amount of ground water available.

On July 8 and 11 the feeder in the bottom of the well was plugged. The plug did not leak, but the casing of the feeder must have leaked badly since no influence upon the specific capacity of the well can be detected.

In Water-Supply Paper No. 67,[a] a rising curve for this same well is given, as observed by Johnson in 1900. From that curve it is possible to compute the specific capacity of the well in 1900. The following determinations are based upon various intervals after pumping has stopped, as indicated in the table. The specific capacity of a well always appears to be lower than its true value, if the very last portion of the rising curve be used, since at this period a large fraction of the water is being utilized in filling up the ground around the well.

Specific capacity of city waterworks well, Garden, Kans., 1900.

Intervals.	Specific capacity per minute.
	Gallons.
0–10 minutes	73.0
0–20 minutes	71.0
0–30 minutes	66.4
0–50 minutes	63.0
20–40 minutes	59.0
40–50 minutes	55.0

These results seem to be identical with those obtained in 1904.

The average specific capacity (77 gallons a minute) as determined in 1904 indicates that the maximum yield of the well, if the water in the well be lowered 8 feet, is 615 gallons a minute. The pumps in use at present can not pump much more than half of this amount of water on account of the worn condition of pistons and cylinders.

The total percolating surface of the well bottom and strainer of the feeder is 247 square feet. From this it can be deduced that the specific capacity of the well is 0.31 gallon a minute per square foot of percolating surface.

[a] Slichter, C. S., The motions of underground waters: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, p. 68.

TEST OF HOLCOMB'S PUMPING PLANT.

A very important attempt to recover water from the underflow was begun in the 1904 season by the owners of the Riverside stock ranch, about 7 miles west of Garden, Kans. A well 200 feet long and 5 feet wide, excavated to a depth of 9 to 10 feet below the water plane was constructed of sheet piling, and 11 galvanized-iron feeders were inserted in the bottom of the wells to a depth of about 20 feet. A 75-horsepower Corliss engine with condenser, a 90-horsepower boiler, and a No. 15 Byron-Jackson centrifugal pump were put in position at the north end of the well. Foundations for the engine and pump and buildings to cover the machinery were constructed in a very substantial manner. As soon as the engine and pump are in satisfactory working order it is purposed to sink a large number of additional feeders in the bottom of the well in the expectation of increasing its capacity to 6,000 gallons per minute. The approximate cost of the plant is about $8,000 for machinery and $4,000 for the well. Trinidad slack coal is used for fuel at a cost of $4 to $4.50 per ton.

The construction of this pumping plant has attracted very wide attention and if it proves to be a success it will mean a great deal for the progress of irrigation in the bottom lands of Arkansas Valley. There is some question whether 6,000 gallons per minute can be obtained from the present well, even with a very large number of additional feeders, but it will be entirely practicable to increase the length of the well without very much additional expense. The present well, with ten 20-foot feeders, 16 inches in diameter, would furnish about 6,000 gallons per minute, if we can rely upon a specific capacity of one-third gallon per minute for each square foot of strainer. This would require, however, the lowering of the natural level of the water to a distance of 10 feet, which is somewhat more than would be best for the most economical running of the plant. [a]

Both suction and discharge pipe of the centrifugal pump are made of No. 16 galvanized iron, riveted and soldered. A 20-inch flap valve is placed at the upper end of the discharge pipe, dispensing with the use of a foot valve. The pump is primed before starting by opening a 1-inch valve in a lead pipe from the main pump to the air pump. When the proper vacuum is shown by the gage the 1-inch valve is closed and the engine started.

A test run of the plant was made for five days, from July 18 to 23, 1905. The engine was started at the lowest speed at which it would work the pump satisfactorily. After running at this rate for forty-eight hours the speed was increased until nearly the full capacity of the well had been reached.

The amount of water pumped during the test averaged about 2,300 gallons a minute, or 5 cubic feet of water a second. This is equivalent

[a] Actual test of the plant shows that this amount of water can not be recovered without extending the well.

to a daily discharge of 10 acre-feet, or a sufficient amount of water to cover 10 acres of land 1 foot deep. As is well known, the present well is not sufficiently large to supply the pump and engine with all of the water that they are designed to handle; in fact, the pump and engine are capable of handling three times the amount of water at present available for long-continued runs. It is expected that by clearing out the feeders at present in the well, and by enlarging the well, the capacity of the plant will be greatly increased; but even at the present low rate of delivery, and consequent rather low efficiency of the machinery, the cost of water delivered is comparatively low.

The average amount of coal consumed was 2,450 pounds per twenty-four hours, or about 1¼ tons per day. At $4 a ton the daily cost of coal was $5 per twenty-four hours. The cost of labor for the day and night man, each at $1.25 per day, makes the cost for coal and labor $7.50 per twenty-four hours. The cost of lubricating oil and miscellaneous supplies may be estimated at $1 a day, making a total cost of $8.50 per twenty-four hours. At this rate the cost of water was 85 cents per acre-foot, not including interest on the plant nor any allowance for depreciation and repairs on the machinery and well. If these latter items be included, the cost of water would be very materially increased.

It seems, however, unfair to estimate these charges at the present time, as the expense of erecting the plant was incurred on the basis of securing a very considerably larger amount of water than is at present delivered; for that reason the interest charges would be very high, if charged against the present amount. It seems very probable that if the supply of water from the well is sufficiently increased the plant will ultimately be capable of delivering water into the ditch at a cost not to exceed $1 per acre-foot, including a moderate charge for interest and depreciation on machinery, but not including any profit.

The following tables show the fuel consumed and the data obtained during the test. The well was not of sufficient size to supply the pump with water, and toward the end of the run difficulty was experienced in operating the plant. Occasionally the water became so low that air would be taken into the suction pipe, and the plant would have to be stopped to prime the pump. In order to secure proper returns, it will be necessary to enlarge the well to about three times its present capacity, otherwise the engine and pump will be entirely too large for the well.

Consumption of coal at test of Holcomb pumping plant.

	Pounds.
July 20, 6 a. m. to 6.30 p. m	1,386
July 20, 6.30 p. m. to July 21, 6.20 a. m	1,386
July 21, 6.20 a. m. to 6 p. m	1,134
July 21, 6 p. m. to July 22, 6 a. m. [a]	1,260
July 22, 6 a. m. to 6.30 p. m	1,134
July 22, 6.30 p. m. to July 23, 6.30 a. m. [b]	1,134
July 23, 6.30 a. m. to 2.40 p. m	832
	8,266

Data of test of Holcomb pumping plant.

[From 7.54 a. m., July 18, to 2.40 p. m., July 23.]

Date.	Hour.	Discharge of flume.		Depth of water below its initial position.	Speed in revolutions per minute.	
		Cubic feet per second.	Gallons per minute.		Engine.	Pump.
				Feet.		
July 18	7.54 a. m	0	0	0	0	0
July 18	8 a. m	13.33	5,980	4.40	75	350
July 18	8.45 a. m	7.42	3,330	7.25	73	344
July 18	9.30 a. m	7.38	3,310	7.27	73	345
July 18	11.20 a. m	6.29	2,820	7.44	73	344
July 18	2.25 p. m	5.87	2,630	7.61	73	330
July 18	4.25 p. m	5.32	2,380	7.61	73	344
July 18	5 p. m	4.89	2,190	7.62	73	344
July 19	7.15 a. m	4.67	2,090	7.80	73	344
July 19	9.30 a. m	4.72	2,110	7.74	72	344
July 20	7 a. m	5.30	2,380	7.87	74	346
July 20	7.45 a. m	4.67	2,090	8.40	75	352
July 21	6 a. m	5.82	2,610	8.50	74	345
July 21	8 a. m	5.68	2,540	9.50	77	360
July 21	8.20 a. m	5.30	2,380	9.53	77	360
July 22	7 a. m	5.03	2,250	9.30	76	357
July 23	....do	5.15	2,310	9.60	77	361

TEST OF PRODUCER-GAS PUMPING PLANT NEAR ROCKY FORD, COLO.

The future of irrigation in the bottom lands of Arkansas Valley will be greatly influenced by the cost of power for pumping water. One of the possible ways of cutting down this cost is by the use of producer-gas in gas engines, as mentioned in Chapter V.

A 35-horsepower producer-gas plant has been installed by Mr. A. W. Shelton, about 6 miles northeast of Rocky Ford, Colo. It consists of a 40-horsepower Pintsch suction gas producer, a 35-horsepower single-cylinder gas engine, and a 12-inch Byron-Jackson vertical-shaft centrifugal pump. The water is pumped from a canal through 15-inch concrete tile (200 feet of intake and 300 feet of discharge) to an eleva-

[a] Stopped 35 minutes. [b] Stopped 36 minutes.

tion of 16 feet above the level of the water in the canal, called the first discharge, and at another point to an elevation of 28 feet above the level of the water in the canal, called the second discharge.

A test was made of this plant, extending from December 2 to 6, 1905. The results of the test of the engine and producer-gas apparatus are given herewith. Unfortunately the cement-discharge pipe gave out when the plant was first started, so that water could not be pumped during the test, and the hydraulic data for this plant are therefore not available.

In connection with the generation of the gas a vaporizer, scrubber, and purifier are used. Water is evaporated at atmospheric pressure to generate the steam required in the producer. The vaporizer is located directly on top of the producer. The scrubber is of the form in which a spray of water trickles down through coke, the water running out at the bottom of the scrubber. After being scrubbed the gas passes through a purifier box, next through a gas governor, and then to the engine.

The engine used was one of the Olds gasoline type, somewhat modified for the use of producer-gas. The engine governor was not the one belonging to the engine.

A belt was connected from a 30-inch pulley on the engine to a pulley on the vertical shaft of the centrifugal pump. A clutch at the engine shaft allowed the pump to be disconnected at will.

A small pulley, fastened to the shaft opposite the pulley end, carried a belt which drove a 3 by 5 inch "Baker" feed-water pump. This pump, making about 45 revolutions a minute, drew water from the well and discharged it into a 3 by 8 feet by 30 inches storage tank near the roof of the building and above the producer. A pipe leading from the bottom of this tank furnished all the water used to operate the plant, viz, water for the engine jacket, steam, and scrubber. During the brake tests it also supplied cooling water for the brake. The water, after being used, passed through the seals and then into the well from which it was drawn.

Preliminary brake tests of gas engine at pumping plant of A. W. Shelton, near Rocky Ford, Colo., December 4, 1905.

Test.	Net load, in pounds	Speed, in revolutions per minute.	Explosions per minute.	Mean effective pressure, in pounds per square inch.	Brake horsepower.	Indicated horsepower.	Mechanical efficiency (per cent).	Maximum pressure of explosion, in pounds per square inch.	Maximum pressure of compression, in pounds per square inch.
1	151	199	99.5	44.0	26.7	34.0	78.5	225	140
2	169	200	100.0	45.6	30.0	35.4	84.9	235	133
3	174	199	99.5	50.0	30.7	38.7	79.4	235	148

Diameter of piston ....14 inches.
Length of stroke ....20 inches.
Length of brake arm ....56 inches.

Brake constant $=\frac{2\times\pi\times56}{12\times33000}=$ .... .000888

Engine constant $=\frac{20\times\pi\times14\times14}{12\times4\times33000}=$ .... .00778

Brake horsepower= .... Net load×Speed× .000888
Indicated horsepower= ....Mean effective pressure×Explosions× .00778

Mechanical efficiency $=\frac{\text{Brake horsepower}}{\text{Indicated horsepower}}$.

Indicator spring, pounds per square inch, =160 for Test No. 1, 250 for Test No. 2, and 250 for Test No. 3.

Of the gas producer a test of three hours' duration was made. The gas governor was not in operation. The producer was filled with coal at the beginning, as well as at the end of the run. As the engine was not operating well the load had to be taken off for a time.

Test of gas producer at pumping plant of A. W. Shelton, near Rocky Ford, Colo., December 4, 1905.

Time.	Net brake load.	Revolutions per minute.	Explosions per minute.	Temperature °F.					Coal.
				Jacket water.			Engine room.	Outside air.	
				Entering.	Leaving.	Range.			
P. m.	*Pounds.*								*Pounds.*
1.35	181	204	102	45	154	109	60	50	....
1.50	181	208	104	45	160	115	60	50	....
2.05	181	....	....	....	166	....	60	49	....
2.20	181	206	103	45	165	120	64	48	....
2.35	181	206	103	45	165	120	64	48	21
2.50	181	206	103	45	208	163	64	47	24
3.05	Load partly off.	204	102	45	208	163	....	46	....
3.20		202	101	45	....	....	....	46	....
3.35		....	....	....	....	....	....	45	....
3.50		....	....	....	....	....	....	44	17
4.05	181	213	117	45	....	....	....	43	18
4.20	181	220	110	45	....	....	....	42	....
4.35	181	....	....	45	....	....	....	41	21
Av.	125	207	105	45	175	132	62	46	....
Total ..	....	....	....	....	....	....	....	....	104

Summary of test of gas producer at pumping plant of A. W. Shelton, near Rocky Ford, Colo., December 4, 1905.

Duration of test ....3 hours.
Net brake load (maximum) ....181 pounds.
Net brake load (average) ....125 pounds.
Revolutions per minute (average) ....207.
Explosions per minute (average) ....105.
Temperature of water entering jacket (average) ....45° F.
Temperature of water leaving jacket (average) ....175° F.
Range of jacket-water temperature ....132° F.

Temperature of engine room (average)	62° F.
Temperature of outside air (average)	46° F.
Total coal consumed	104 pounds.
Pressure maximum explosion	258 pounds per square inch.
Pressure maximum compression	145 pounds per square inch.
Pressure, suction at exit of producer	2 inches water.
Pressure, suction at exit of scrubber	2.125 inches water.
Pressure, suction at exit of purifier	2.25 inches water.
Pressure, mean effective	51.6 pounds per square inch.
Indicated horsepower $(51.6 \times 105 \times .00778) =$	42.2.
Brake horsepower (maximum) $= (181 \times 207 \times .000888) =$	33.2.
Brake horsepower (average) $= (125 \times 207 \times .000888) =$	22.9.
Mechanical efficiency (maximum) $\frac{33.2}{42.2}$	78.9 per cent.
Mechanical efficiency (average) $\frac{22.9}{42.2}$	54.2 per cent.
Pounds of coal per brake horsepower per hour, based on maximum brake horsepower $\left(\frac{104}{3 \times 33.2}\right)$	1.05.
Pounds of coal per brake horsepower per hour, based on average brake horsepower $\left(\frac{104}{3 \times 22.9}\right)$	1.51.

Test of gas engine at pumping plant of A. W. Shelton, near Rocky Ford, Colo., as shown by sample indicator card.

Duration of test (10 a. m. to 5 p. m.)	7 hours.
Rated horsepower of engine	35.
Weight of engine	11,000 pounds.
Mean effective pressure (average of 54 cards) [a]	43.7 pounds per square inch.
Indicator spring	160 pounds per square inch.
Load on brake	175 pounds.
Revolutions per minute	201.6.
Explosions per minute	100.8.
Brake horsepower $(175 \times 201.6 \times .000888)$	31.4.
Indicated horsepower $(43.7 \times 100.8 \times .00778)$	34.3.
Mechanical efficiency $\left(\frac{31.4}{34.3}\right)$ [a]	91.5 per cent.
Kind of producer	Pintsch.
Producer rated horsepower	40.
Temperature of water entering jacket	49.8° F.
Temperature of water leaving jacket	165.8° F.
Range of jacket-water temperature	116° F.
Temperature of outside air	46.8° F.
Temperature of engine room	72.0° F.
Pressure of maximum explosion	260 pounds per square inch.
Pressure of maximum compression	150 pounds per square inch.
Pressure of maximum steam	Atmospheric.
Pressure of maximum suction at producer exit	2.2 inches water.
Pressure of maximum suction at scrubber exit	2.2 inches water.
Pressure of maximum suction at purifier exit	2.4 inches water.

[a] The high mechanical efficiency is probably due to an error in the indicated horsepower. The mean effective pressure appears to be too low. The reducing motion used was made of wood and had become considerably worn when this test was made.

Data concerning coal used in test of producer-gas pumping plant of A. W. Shelton, near Rocky Ford, Colo.

Kind	Colorado anthracite, Floresta mine.
Cost at plant per ton	$6.
Size	Pea.
Total quantity fired	325 pounds.
Total refuse (clinkers, ash, and unburned coal)	66 pounds.
Total clinkers	5 pounds.
Total unburned coal	43 pounds.
Total ash (siftings)	18 pounds.
Calorific value of coal per pound	13,850 B. T. U.
Pounds of coal per brake horsepower per hour, as fired and uncorrected for unburned coal in refuse $\left(\frac{325}{7\times31.4}\right)$	1.48.
Pounds of coal per brake horsepower per hour (corrected for unburned coal in refuse)	1.24.

Approximate analysis of coal used at producer-gas pumping plant of A. W. Shelton, near Rocky Ford, Colo.

	Per cent.
Moisture	2.2
Volatile matter	7.6
Fixed carbon	83.8
Ash	6.4

Water used per hour in producer-gas pumping plant of A. W. Shelton, near Rocky Ford, Colo.

	Pounds.
By jacket	1,200
By brake	930
By scrubber (approximately)	1,300
By vaporizer	16

Efficiencies at various loads of producer gas pumping plant of A. W. Shelton, near Rocky Ford, Colo.; test of December 6, 1905.

Time.	Net brake load (lbs.).	Revolutions per minute.	Explosions per minute.	Jacket water. Temperatures. Inlet.	Outlet.	Range.	Pounds per hour.	Mean effective pressure (pounds per square inch).	Indicated horsepower.	Brake horsepower.	Mechanical efficiency (per cent).
9.50	27	205	45.0	44	104	60	1,260	44.1	15.4	4.9	30.0
10.13	50	203	52.2	44	107	63	1,570	41.1	17.9	9.0	50.2
10.42	75	203	59.4	42	112	70	1,300	44.9	20.7	13.5	65.2
11.06	100	203	69.3	42	117	75	1,340	44.1	23.8	18.0	75.6
11.30	125	203	83.0	42	126	84	1,340	43.7	28.2	22.5	79.8
12.25	150	199	96.0	42	136	94	1,570	42.4	31.6	26.5	83.8
1.18	175	201	100.5	42	145	103	1,570	39.9	31.2	31.2	....
1.40	200	189	95.0	42	140	98	1,570	39.9	29.5	33.6	....
2.00	215	178	89.0	42	148	106	....	41.3	28.6	33.9	....
....	[a]225	....	....	....	....	....	....	....	....	....	....

[a] Engine would not carry load.

Analysis of gas from gas producer at pumping plant of A. W. Shelton, near Rocky Ford, Colo.

	Per cent.	B. T. U. per 100 cubic feet of gas at 60° F.
CO_2	6.3	
O	1.0	
CO	23.2	7,513
CH_4	0.0	
H	18.6	6,107
N	50.9	
	100	13,620

It will be observed from the results obtained in the test that 1.24 pounds of coal per hour produced 1 brake horsepower. At $6 a ton the cost of fuel was therefore three-eighths of a cent per brake-horsepower hour. At this rate power was obtained at a cost for fuel equivalent to gasoline at 3 cents per gallon. One-half cent per brake-horsepower hour for labor and five-eighths cent per brake-horsepower hour for supplies, depreciation, and repairs should cover all other charges. The total cost of power should not exceed, therefore, 1½ cents per brake-horsepower hour, or about $4.50 per day of ten hours, for the present plant. In this length of time the plant should furnish about 8 acre-feet of water on the 16-foot lift, or at a cost of about 58 cents per acre-foot.

The first cost of the pumping plant in round numbers, was $3,300 for the producer, engine, and pump; $200 for the building, and $1,500 for the intake and discharge pipe and flumes.

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[Water-Supply Paper No. 153.]

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