Water-Supply and Irrigation Paper No. 184

Series { K, Pumping Water, 13
O, Underground Waters, 65

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE UNDERFLOW

OF THE

SOUTH PLATTE VALLEY

BY

CHARLES S. SLICHTER AND HENRY C. WOLFF

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THE UNDERFLOW OF THE SOUTH PLATTE VALLEY.

By C. S. Slichter and H. C. Wolff.

LOCATION AND PURPOSE OF THE INVESTIGATIONS.

Investigations were begun in the middle of July, 1905, in that part of the South Platte Valley extending from Sterling, Colo., to North Platte, Nebr. The purpose of the survey was to determine what resources, if any, existed in the underflow waters of the valley and whether it was practicable to make use of such waters, if they were found to exist in suitable quantities, for purposes of irrigation.

The greater part of the work was carried on at Ogalalla, Nebr. This point was selected for several reasons; primarily for the fact that an underflow canal on the south side of the river at this place has been in successful operation for several years and has attracted the attention of those interested in irrigating the bottom lands of the valley. It was thought that valuable information might be obtained from observations on the operation of this canal, concerning not only the practicability of recovering ground water by the gravity method, but also the extent of the deposits of water-bearing gravels and the ease with which they yield water under small heads. Again, while the conditions found existing at this point are probably not in all respects typical for the valley in western Nebraska, the results obtained can be applied to any part of the valley.

In the eastern part of Colorado and in the western part of Nebraska the South Platte Valley ranges from 6 to 8 miles in width. Near Ogalalla it narrows down to about 2 miles and holds approximately this width to Sutherland, Nebr., a distance of about 32 miles. Below Sutherland the valleys of South Platte and North Platte rivers unite and form a broad, low tract of land west of the city of North Platte.

From Sterling, Colo., to Ogalalla the direction of the South Platte Valley is about N. 80° E.; from Ogalalla to North Platte the direction is almost due east.

In western Nebraska the river has cut to a depth of 150 to 300 feet in the Ogalalla formation, with steep bluffs on the north side, but with more gentle slopes rising to the rolling uplands on the south. The Ogalalla formation is a deposit of sand, gravel, and calcareous grit, from which the river sands were, for the most part, derived by the washing out of the fine sand, silt, and cementing material.

Lodgepole Creek, the only tributary of any size, joins the South Platte from the west near the Colorado-Nebraska State line. This stream has cut down into the Brule clay and is fed by spring water from the overlying Ogalalla formation. At places the surface flow is entirely taken out for purposes of irrigation.

The river itself occupies a sandy stretch from 1,500 to 2,500 feet in width. During low stages the river flows in this wide bed in numerous interlocking small streams, among which it is difficult to select the principal channel. Much of the bottom land near the river is low and swampy. These low bottoms vary greatly in width at different places, and at points where the width is considerable they leave but a small area of land suitable for irrigation. Above the bottom lands the valley slopes gently away from the channel, here and there in two or three distinct levels, but at many places in a gradual rise without noticeable benches, to the base of the escarpment that borders the uplands on either side of the river. The uplands or table-lands within which the river has cut its valley have the well-known level topography of the High Plains of western Kansas and Nebraska.

Numerous irrigation canals have been taken out of South Platte River at various points in Colorado and Nebraska. As a rule these canals carry water to the bottom lands only. At no place between Sterling and North Platte has it been practicable to construct a canal to convey water to the uplands, owing to their elevation. Where the irrigation systems have been properly constructed and maintained the results have been very satisfactory, except during the middle and end of the irrigating season, when the farmers complain of the shortage of water—a complaint frequently heard in irrigation districts. In order to augment the low-stage supply of water several reservoirs have been constructed in the South Platte Valley in Colo ado.

WATER-BEARING GRAVELS.

Inasmuch as irrigation must of necessity be confined to the bottom lands of the valley, it is especially important to know to what extent these lands can be irrigated by means of water drawn from the underflow of the river. This point was kept well in mind during the investigations.

The gradient of the river channel along this portion of its course averages about 8 feet to the mile. The alluvial deposits consist of a coarse sand, with which are mixed gravels of various sizes up to pebbles 1 inch in diameter. The larger pebbles are not deposited in separate streaks, but are scattered through and mixed with the coarse sand of the river deposits. In this respect the sands of the South Platte differ materially from the sands of Arkansas River in western

Kansas, in which the larger pebbles are usually absent. Moreover, the South Platte sands are fairly free from deposits of quicksand and fine silt.

The presence of the large pebbles in the coarse sands of the South Platte deposits renders this material an excellent water-bearing gravel, especially well adapted for the construction of wells of large capacity. By the use of proper strainers the smaller particles can be removed from the immediate neighborhood of a well, so that the water can be collected through the coarser material that is left. Gravel of this kind was found wherever sought between Sterling and North Platte, and it is believed that there is no considerable area in this part of the valley which is not underlain with similar gravel.

In order to determine the amount of water that can be obtained from such gravels by means of suitably constructed wells and pumping machinery, it was planned to test wherever practicable the capacity of existing wells in the valley. It was found, however, that so few pumping plants had been constructed that it was not possible to get together a very large amount of data bearing on this point; but such tests as could be made indicate that wells of high capacity can be very economically constructed and that no difficulty will be experienced in the recovery of water in quantities suitable for irrigation.

The reconnaissance work indicated that there is very little difference in the water-bearing gravel between Sterling, Colo., and Ogalalla, Nebr. The valley varies considerably in width, but the water-bearing material seems to be fairly uniform.

From fig. 1 (p. 10) it will be seen that the river gravels are not very deep or extensive at Ogalalla; all the test wells, with one exception, were driven completely through the deposit. At station 1, 200 feet south of the north bank of the river, good water-bearing gravel was found at a depth of 85 feet, where driving ceased. The average depth of the gravel between stations 9 and 4 was found to be about 40 feet. At the edges of the valley, beyond these stations, the gravels probably thin out very abruptly, for at the section line shown at the right of the figure and in the bluffs shown at the left appears the undisturbed formation within which the valley is cut.

Fine material was encountered in but a single instance, about 200 feet south of the south bank of the river. This station was located in a portion of the old river bed, now a swamp in process of being filled up by decaying vegetation, blowing sand, and silt deposited by the river at times of flood. The upper 25 feet of sand within the river bed is very much cleaner and its effective size probably much greater than that found elsewhere in this part of the valley. At a depth of about 25 feet there is a marked change, the sands below containing a slightly increased proportion of smaller grains, together with a very small amount of argillaceous material. The line of separation of the upper from the lower sands is about on a level with the lower limit of the river deposits on either side of the channel. The origin of the two classes of deposits probably lies in part in the fact that the fine material brought in by the lateral component of the underflow works its way downward to the deep deposits by the constant subdivision and mingling of the water as it flows through the capillary spaces between the sand grains, and in part in the tendency of the ground water, which flows in from both sides, to come eventually to the surface and wash out and carry downstream with it a considerable amount of fine material. The gravels in all cases where test wells were put down have a sharply defined lower limit, resting upon a soft formation of sand (usually very fine) and calcareous grit. In places, however, the material is so firmly cemented that it offered considerable resistance to the driving of the test wells. This underlying material is practically impervious, as in only a few cases was it possible to draw water from it, and even then only with great difficulty.

CONDITIONS AT STERLING, COLO.

At Sterling the valley of the South Platte is very wide. A pumping plant constructed for the purpose of irrigation is located on the Johnson ranch, on the east side of the river. The dug well used in connection with this plant was so poorly sheeted up that large quantities of sand entered the pump, making the test unsatisfactory. It will be very easy, at small expense, to so modify the well that the sand will be kept away from the pump, after which there will be no difficulty about obtaining a large supply of water.

In the vicinity of Sterling the water-bearing gravels extend to a depth of 40 to 80 feet below the surface, and there is unquestionably an ample supply of water for a large number of moderate-sized pumping plants. It is believed that the best method of recovering the ground water at this point is by means of wells and pumping machinery, either owned by the individual farmers or operated by electricity from a central plant. Considerable interest is taken at the present time in this locality in the growing of sugar beets, and a large sugar factory has already been constructed. It may be practicable to distribute power from this factory during the irrigation season to a number of farmers who live in the neighborhood, for the purpose of procuring a sufficient supply of ground water for the irrigation of the beet and other crops suitable to this locality. It is not believed advisable to put in large pumping stations designed to take out a large amount of ground water at any one place. It seems evident that it is more economical to restrict the amount of ground water taken out at any one place to about 2,500 gallons a minute, rather than attempt to get a greater supply. A number of moderate-sized plants will be found to be much more economical and satisfactory in the long run than a few large plants.

INVESTIGATIONS AT OGALALLA, NEBR.

VELOCITY AND DIRECTION OF THE UNDERFLOW.

At Ogalalla a series of test wells was sunk in a nearly north and south line across the valley and careful determinations were made of the extent and quality of the water-bearing material and of the actual rate of movement of the underflow.

The rate of movement of the ground water was determined by the electrical method.[a] The investigation showed that there is a true underflow at this point, the ground waters moving downstream with a velocity varying from 2.3 to 13.6 feet per twenty-four hours. The average velocity of eight determinations was found to be 6.4 feet per twenty-four hours, with an average direction of about N. 88° E. Fig. 1 gives a cross section of the valley, looking downstream, showing the location of the test wells, the extent of the alluvial deposits, and the position of the water plane. The numbers within the circles give the velocity of the underflow in feet per twenty-four hours at the various stations for a depth corresponding to the position of the numbers. These velocities are also given in Table I. With the exception of the three highest velocities (13.6 and 12 feet per twenty-four hours, found near the surface of the river channel, and 9.2 feet per twenty-four hours, found at station 9) the rate was very uniform, ranging from 2.3 to 4.4 feet per day. The water-bearing gravels of this section may be classified with reference to velocities of underflow into four distinct portions—the portion north of the river, within which the mean of the velocities was 6.8 feet per day; the portion south of the river, within which the mean of the two velocity determinations gave 3.55 feet per day; the portion within the river channel down to a depth of 25 feet, within which two tests were made giving the two highest velocities; and the portion within the river channel below the 25-foot line, within which the remaining two of the eight velocity determinations gave a mean flow of but 2.55 feet per day. From Table I it will be seen that the two velocities found within each section are nearly equal, but differ very much from velocities found in other sections. The lowest velocity was found at station 1, 85 feet below the river bed, the deepest point at which a velocity test was made. The high velocities at the shallow depths within the river channel may be due to the fact that the sand of the upper 25 feet is exceedingly clean and contains practically no very fine material.

[a] Water-Sup. and Irr. Paper No. 110, U. S. Geol. Survey, 1905, pp. 17-31.

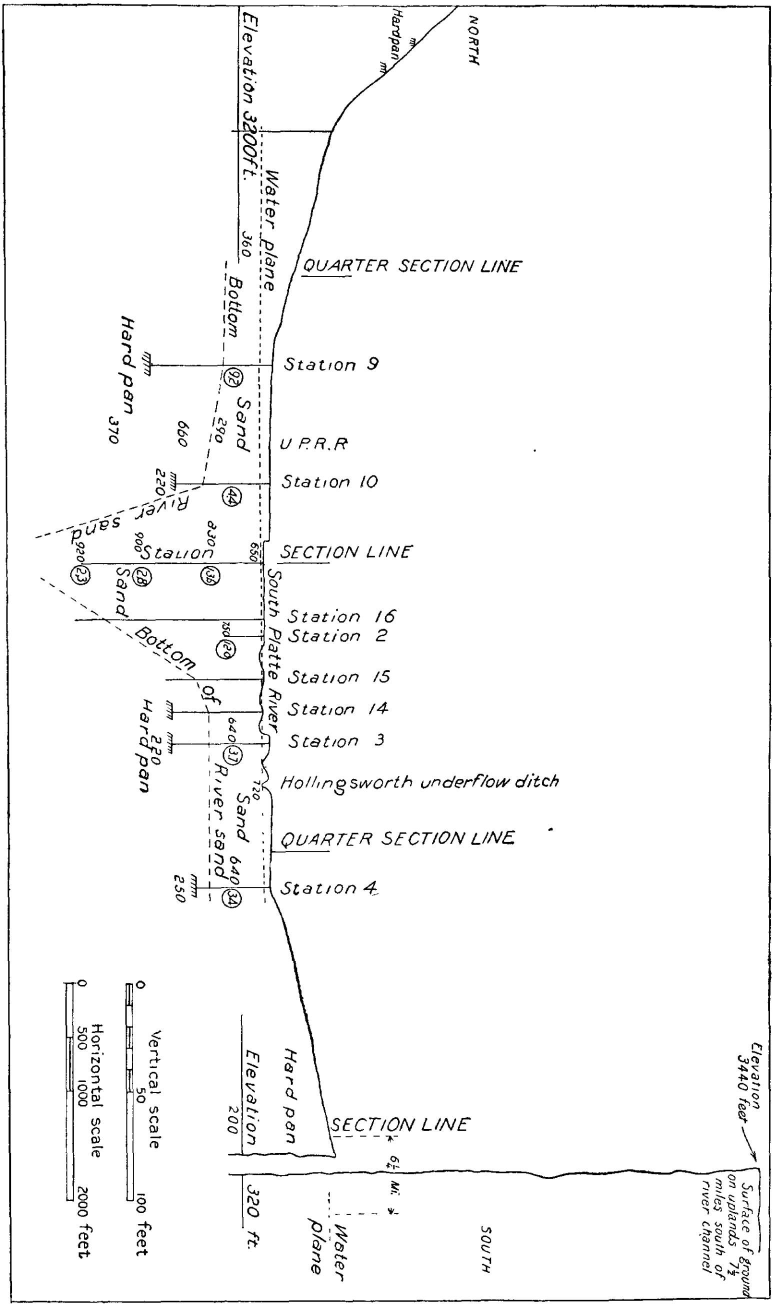

FIG. 1.—Cross section of the South Platte Valley at Ogalalla, Nebr. The numbers inclosed in circles give the velocity of ground water in feet per twenty-four hours; the numbers not inclosed indicate the total amount of dissolved solids in the water, in parts per million, at the points where the figures are placed.

TABLE I.—*Velocity of ground water at Ogalalla, Nebr.*

Date.	No. of station.	Velocity per 24 hours.	Mean velocity per 24 hours.	Direction of flow (east of north).	Depth.	Location.
1905.		*Feet.*	*Feet.*	°	*Feet.*	
August 16	9	9.2	6.8	112	16	1,600 feet north of north bank of river.
August 17	10	4.4		100	16	550 feet north of north bank of river.
August 1	1	13.6	12.8	84	22	In river channel, 200 feet from north bank.
Do	2	12.0		90	16	In river channel, 900 feet from north bank.
August 6	1	2.8	2.55	84	55	In river channel, 200 feet from north bank.
August 11	1	2.3		84	85	Do.
August 15	3	3.7	3.55	100	17	100 feet south of south bank of river.
August 5	4	3.4		54	16	1,400 feet south of south bank of river.
Average	....	6.4	....	88	....	

The direction of flow for all tests made within the present river channel was found to be downstream. At this point the river flows slightly north of east. At station 10, located 550 feet north of the north bank of the river, the direction of flow was S. 80° E., giving a component flow toward the river at this point of 0.76 foot per twenty-four hours; at station 9, located 1,600 feet north of the north bank of the river, the direction of flow was S. 68° E., giving a component flow toward the river of 3.2 feet per day, and at station 4, located 1,400 feet south of the south bank of the river, the component flow toward the river was at the rate of 2 feet per twenty-four hours. At station 3 the flow was away from the river, probably owing to local deposits of fine sand and silt, since this station was located in a portion of the old river bed. It will be seen from these results that, at least during low stages of the river, the ground waters contribute very largely to the surface flow. A line of levels run across the valley at this point gave the same indications, for it was found that the water plane sloped toward the river channel from both the north and south sides.

During the summer months of 1905 the South Platte was at no time perfectly dry at Ogalalla. There were several small channels within the river bed, some carrying as much as several hundred second-feet of perfectly clear water. These interlocking small channels of the river are cut down 2, 3, and even 4 or 5 feet below the general river bottom, and are fed for the most part by still smaller channels. These smaller rills when traced upstream gradually disappear, and they can be observed to originate in ground water coming to the surface from the underflow. It is claimed by the older residents of this vicinity that these smaller channels did not exist within the river in former years, but that its bed was a flat, sandy stretch from bank to bank. The river has a large number of islands throughout its course through the western part of Nebraska, on which are growing not only grasses and willows, but even small cottonwood trees. In time of flood these islands deflect the current, causing more scour in one part of the river than in another, hence numerous small channels are found cut down in the river bed when the water lowers. Now that these islands are formed, the smaller living streams will continue to exist within the river itself unless the water plane falls much lower than it is at present.

QUANTITY OF THE UNDERFLOW.

The maximum amount of underflow waters passing through the gravels in the valley of the South Platte at Ogalalla can be readily estimated. The cross section at this point is about the smallest that is found between North Platte and Sterling, but the slope of the water plane is greater than the average throughout the valley. The total cross section of gravels capable of transmitting water is less than 330,000 square feet. The average velocity of the ground water in this material does not exceed 7 feet per twenty-four hours. From this it can be readily concluded that the total amount of ground water passing between the river bluffs at Ogalalla does not exceed 10 second-feet.

While this amount of water is not large, it nevertheless indicates that a considerable quantity of ground water can be safely removed from these underflow gravels, because the supply is renewed at frequent intervals by floods in the river and by the rainfall upon adjacent lands. Any extended use of the ground waters of the valley by means of pumps and wells would tend to lower the water plane, but this in turn would decrease materially the enormous amount of water that now goes to waste in the surface flow of the river and in the evaporation from the sands and soils in the wide river bed and the adjacent low bottom lands. This evaporation undoubtedly reaches 12 inches per month during July and August of an average year.

CHEMICAL ANALYSES OF WATER.

A few simple chemical tests were made of the water drawn from nearly all the test wells sunk in the valley and from existing wells wherever it was thought that such analysis would throw light on the origin or movement of the ground waters.

Portable field apparatus was at hand for the determination of chlorine, alkalinity, and hardness by titration, respectively, with N/10 $AgNO_3$, N/10 HCl, and standard soap solution. The total solids in solution were determined by means of the Whitney electrolytic bridge.

In fig. 1 (p. 10) the numbers not inclosed within circles represent the total solids in solution, expressed in parts per million, at the points corresponding to the position of the numbers in the drawing. The surface water of the river contains about 100 parts per million more dissolved solids than the average water taken from the river gravels on the two sides of the channel. The strongest waters are, however, found in that portion of the river bed at and below the 25-foot level, where the slowest movements of the ground waters occur. The total solids in solution in this part of the bed average 880 parts per million and the chlorine content is higher than at any other place in the valley, the average being 36.9 parts per million. Both total solids and chlorine increase slightly with depth within the zone of surface gravels, but as soon as the deposit of river gravels is completely penetrated a sudden change takes place in the quality of the water. These deeper waters are much softer than those in the river sands above them. By referring to the analyses, Table II, and the cross section, fig. 1, it will be observed that the waters below the sand contain from 220 to 250 parts per million of total solids. The one exception is a well in the town of Ogalalla, which draws water from the deposits just below the surface gravels.

The tests of water from the deposits below the river sands run very uniform with tests of water from wells on the uplands both north and south of the river. These waters are uniformly very much better than the upper "sheet water" of the valley.

TABLE II.—*Analyses of South Platte Valley waters.*

NEAR STERLING, COLO.

Date.	Chlorine (parts per million).	Alkalinity, as $CaCO_3$ (parts per million).	Hardness, as $CaCO_3$ (parts per million).	Total solids (parts per million).	Temperature (° F.).	Depth (feet).	Location.
1905.							
July 22	Trace.	172.5	213	240	....	31	Dr. Johnson's well in sand hills south of Sterling.
Do	3	182.5	208	310	....	17	Dr. Johnson's well in valley south of Sterling.
Do	42.6	172	386	730	....	....	River water, Sterling.

NEAR OGALALLA, NEBR.

Date.	Chlorine (parts per million).	Alkalinity, as $CaCO_3$ (parts per million).	Hardness, as $CaCO_3$ (parts per million).	Total solids (parts per million).	Temperature (° F.).	Depth (feet).	Location.
1905.							
August 2	7.1	126.5	161	220	....	39	North Platte River water, north of Ogalalla.
Do	10.6	239	223	390	....	(?)	One-fourth mile south of North Platte River, directly north of Ogalalla.
July 27	7.1	194	194	290	62.2	(?)	Well 1½ mile north of South Platte River.
Do	14.9	209	272	360	68.5	24	Well at court-house, Ogalalla.
Do	12.4	185	250	290	....	25	Nelson's well on Main street, Ogalalla.
August 18	29.1	[a] 387.5	182	400	64	56	Station 9.
July 27	28	197.5	281	600	....	40	Well at Martin Hotel.
Do	14.2	154	267	370	65	75	Union Pacific Railroad well, Ogalalla.
Do	28	145	325	650	75.5	....	River water, north side.
August 4	38.3	167	403	900	57	55	Station 1.
July 31	35.5	175	381	830	66.5	22	Do.
August 10	36.9	140	356	920	58	85	Do.
August 1	27.7	136	324	750	66	16	Station 2.
August 21	12.4	156.5	205	220	59	44	Station 3.
August 3	31.9	152.5	312	640	61	17	Do.
Do	26.3	191	306	640	60	16	Station 4.
August 14	10.6	169	99	250	60	35	Do.
Do	8.9	164	104	200	....	60	Well on section line one-half mile south of bridge at Ogalalla.
August 20	9.2	165	110	230	....	200	Southeast corner of NE. ¼ sec. 14, T. 12 N., R. 39 W.
July 27	33.4	150	366	720	69.8	....	Hollingsworth's seepage ditch, at bridge.

[a] High alkalinity due to calcareous sediment.

TABLE II.—*Analyses of South Platte Valley waters*—Continued.

IN SAND HILLS NORTH OF PAXTON, NEBR.

Date.	Chlorine (parts per million).	Alkalinity, as $CaCO_3$ (parts per million).	Hardness as $CaCO_3$ (parts per million).	Total solids (parts per million).	Temperature (° F.).	Depth (feet).	Location.
1905.							
August 31	None.	91.5	58	80	....	15	In valley of West Birdwood Creek, 7 miles below Big Spring.
Do	....do	91.5	60	90	....	....	Big Spring, at head of West Birdwood Creek.
Do	....do	69	40	70	....	193	2½ miles north of Big Spring.

AT NORTH PLATTE, NEBR.

Date.	Chlorine (parts per million).	Alkalinity, as $CaCO_3$ (parts per million).	Hardness as $CaCO_3$ (parts per million).	Total solids (parts per million).	Temperature (° F.).	Depth (feet).	Location.
1905.							
September 11	3	70.5	6	60	....	140	Near center of W. ½ sec. 30, T. 15 N., R. 29 W.
Do	3	75.5	8	100	....	80	Southeast corner of SW. ¼, sec. 12, T. 14 N., R. 30 W.
Do	11.3	139.5	158	300	....	....	North Platte River water.
September 7	46.8	192.5	316	600	....	....	City waterworks well.
Do	74.6	162.5	282	820	....	6	Near center of sec. 4, T. 13 N., R. 30 W.
Do	4.6	178	142	210	....	40	Near center of sec. 22, T. 13 N., R. 30 W.
Do	8.5	176.5	186	280	....	230	NW ¼ SW ¼ sec. 4, T. 12 N., R. 30 W.

The facts brought out by these analyses show that the ground waters on either side of the valley are not derived from the underflow of the river and that the popular belief that the ground waters of the South Platte seep through the narrow divide into the North Platte is entirely erroneous. The only reason for such belief seems to be the fact that the North Platte, at a distance of only 7 miles, is about 60 feet lower than the bed of the South Platte, and that it carries water for a longer period during the summer months.

Two samples of water from North Platte River were analyzed—one taken at the bridge directly north of Ogalalla August 2, 1905, when there was considerable water flowing in the river, only a few points of the river bottom near the north bank being above water; the other taken at the bridge at North Platte September 11, 1905, when the river had fallen considerably, the water covering not more than one-third of the river bed. The total solids in solution in these two samples were 220 and 300 parts per million, respectively, as compared with 650 parts per million for the water from South Platte River. This difference of composition may in part be due to the fact that the North Platte is fed to some extent by soft water coming from the sand hills north of the river. From the analyses in Table II it will be seen that all samples of water coming from these sand hills are very soft, the total solids in solution ranging from only 60 to 100 parts per million. The softness of this water is due directly to the character of the soil of the catchment area, which is nearly pure quartz sand that immediately absorbs the rainfall and that contains little soluble matter to be taken up.

The sand-hill area in western Nebraska consists of dunes ranging from a few feet to several hundred feet in height, between which are valleys and depressions from a few acres to several sections in extent. This area has no run-off, and of the 17 inches of annual precipitation the greater part enters the sand and raises the water plane much above the level of North Platte River. This water under head seeps out from the sand hills and enters the river, giving rise in places to creeks of considerable size, the largest of which are Blue Creek in Deuel County and Birdwood Creek in Lincoln County.

UNDERFLOW DITCH AT OGALALLA.

One of the interesting developments in the South Platte Valley is an underflow ditch on the south side of the river at Ogalalla, owned by Dr. A. Hollingsworth. This canal was constructed in 1895 and has been in use ever since. It extends along the south bank of the river bed, is about 12 feet wide at the bottom and about 6,500 feet long, and reaches a total depth in its upper portion of 5 feet below the bed of the river. A map of this ditch is given in the lower part of fig. 2 (p. 17); in the upper part are represented in profile the bottom of the ditch and the river bed. The profile of the river bottom was made from elevations of the surface of the water in the river, determined August 13, 1905. The river at this time was nearly dry, the water flowing in only a few small channels, as described above. The line of levels run on this day, from the section line shown at the left of the figure to the section line 2 miles below, gave a drop of 16.7 feet in the river water, or a slope at this point of 8.35 feet to the mile. The distance from the head of the ditch to the line of test wells, as shown in the figure, is 800 feet; below this, the distance between points shown by consecutive dotted lines is 1,000 feet measured along the line of the ditch. For the first 1,000 feet above (west of) weir No. 1, the bottom of the ditch is about on a level with the bottom of the river. For the next 4,000 feet (west) its grade drops to 3.8 feet per mile; and from thence to its head it again has approximately the grade of the river. From its head to within about 1,000 feet of the bridge the ditch is cut in sand, and thence down to the point where it is carried up above the water plane it passes through a kind of clay loam, through which there must be considerable seepage before the water reaches the point of application. On account of an unusually ample rainfall during the summer of 1905 the water recovered by the ditch was not used for irrigation, but was permitted to run back into the river, so that no opportunity was offered for measuring the loss from the lower part of its course.

The flow of the canal is obstructed by rank vegetation growing within it. A large amount of seepage was observed to enter from the south margin of the canal.

TABLE III.—*Flow of water in Hollingsworth ditch.*

Date	Time.	Flow over weir No. 1.	Flow over weir No. 2.	Flow over weir No. 3.	Elevation of water in river (datum 3,208.51 feet above mean sea level.)	Remarks.
1905.		*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	
August 6	4 p. m	3.77			1.20	Weir No. 1 put in ditch.
August 7	5 p. m	2.83	2.28			Weirs Nos. 2 and 3 put in ditch.
August 9	11 a. m	3.06	2.86	2.22	1.05	
August 10	12 m	3.03	2.82	2.13	84	
August 11	12 m	2.67				
August 12	12 m	3.39			.89	Heavy rain night of August 11.
August 13	8 a. m	3.36	3.16	2.11		August 12 very cloudy, with local showers.
August 14	12 m	3.12			.77	
August 15	8 a. m	3.36	3.14	2.16	.70	
Do	9.30 a. m	3.34			.70	
Do	12 m	2.97			.67	
Do	4 p. m	3.06				
Do	6 p. m	3.16			.64	
August 16	8.30 a. m	3.12			.60	
Do	10 a. m	3.06			.60	
Do	12 m	2.77			.58	
Do	2.30 p. m	2.68			.55	
Do	7 p. m	3.02			.53	
August 17	8 a. m	3.20	3.14	2.12	.53	
Do	12 m	2.96			.50	
Do	2.30 p. m	2.67			.50	
Do	4 p. m	2.72			.50	
Do	5.30 p. m	2.94			.50	
August 18	8.30 a. m	3.06	2.94	2.03	.50	
Do	10.45 a. m	2.96			.48	
Do	4.45 p. m	2.86			.47	
August 19	8 a. m	2.96				
Do	3.30 p. m	2.67				Weir No. 2 removed from ditch August 19, 3.30 p. m., lowering the water back of it 1.33 feet.
August 20	8.30 a. m	3.59				
Do	11 a. m	3.40				
Do	3 p. m	3.27				
Do	8 p. m	3.55				
August 21	8 a. m	3.49				
Do	9.30 a. m	3.38				
Do	12 m	3.21				
Do	3.30 p. m	3.21				
Do	4.15 p. m	3.22				
Do	7 p. m	3.31				

The discharge from this ditch, measured with a current meter August 5, 1905, was found to be 3.78 second-feet. Later three weirs were placed at different points in the ditch and continuous records were kept for several days. These measurements are given in Table III and are represented graphically in fig. 3 (p. 18). Weir No. 1 was put in at the bridge, near the mouth of the ditch (see fig. 2), August 6, 1905. The discharge from the ditch measured over the weir August 6 was found to be 3.77 second-feet, checking the measurement made the previous day with the current meter. Weirs Nos. 2 and 3 were put in place, at locations shown on fig. 2, August 7, 1905, after which the discharge over weir No. 1 fell from 3.77 to 2.83 second-feet at a corresponding hour of the day. This diminution of 0.9 second-foot was due to the backing up of the water behind the two additional weirs, thus decreasing the effective head which forces the water into the

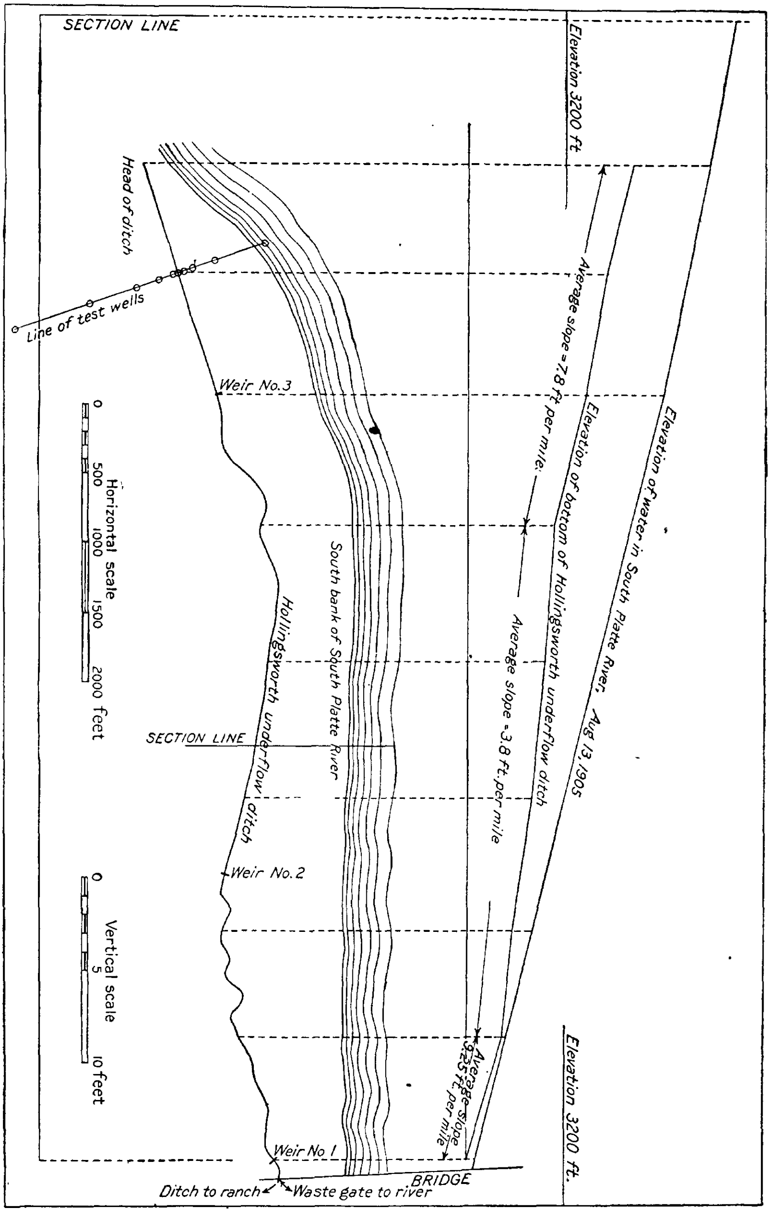

FIG. 2.—Map of Hollingsworth underflow ditch, Ogalalla, Nebr. The lower portion of the diagram shows the location of the ditch with reference to the south bank of the river; the upper portion shows the elevation of the bottom of the ditch and of the running water in the river August 13, 1905. The location of weirs placed in the canal for the purpose of measuring the flow is shown on the map; also the location of a line of test wells put down to determine the elevation of the water plane near the ditch.

ditch. Weir No. 2 was removed August 19, 1905, and the discharge over weir No. 1 rose from 2.67 second-feet at 3.30 p. m. to 3.27 second-feet at 3 p. m. August 20—nearly the former amount, notwithstanding the facts that weir No. 3 was still in place and that the river had gone down 0.8 foot. The removal of weir No. 2 lowered the surface of the water immediately back of it 1.33 feet.

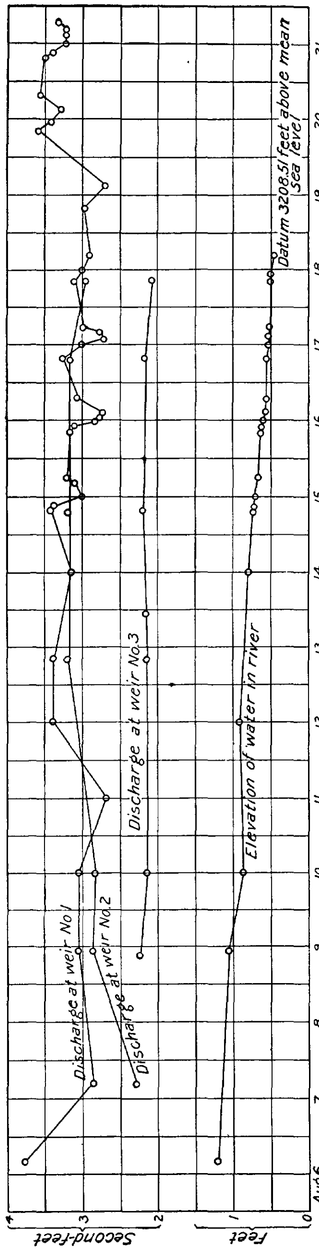

FIG. 3.—Diagram showing discharge over weirs Nos. 1, 2, and 3 in the Hollingsworth underflow ditch and the elevation of the water in the river between August 6 and 21, 1905. Small circles indicate the observed values. These are connected by straight lines, although more frequent observations would have shown a diurnal fluctuation in the discharge and the straight lines would have been replaced by curves.

It was found that the discharge from the ditch changed appreciably with a slight change of elevation of the river water. For example, from 8 a. m. August 15 to 8.30 a. m. August 18 the river fell 0.2 foot, the discharge over weir No. 1 fell 0.3 second-foot, over weir No. 2, 0.2 second-foot, and over weir No. 3, 0.13 second-foot.

From these data the specific capacity of the gravels in the bottom of the ditch was found to be between 0.01 and 0.02 gallon per minute per square foot of percolating surface under a head of 1 foot, a value much less than was expected. This result may be partially explained by the fact that no work had been done on the ditch since the previous irrigation season. In consequence a rank growth of vegetation sprang up not only along the banks but far out into the water and at places extended from bank to bank. There was also a tightly attached covering of moss or algæ over the entire bottom of the ditch.

The above results, while signifying little concerning the water-bearing qualities of the gravel, show that a very little extra expenditure of work on the ditch would greatly increase its yield. Doctor Hollingsworth says that loosening the moss from the bottom of the ditch by dragging a log through it with a team of horses increases its discharge at least 50 per cent.

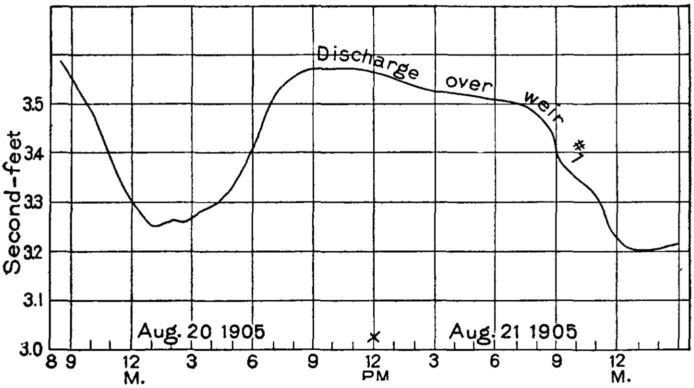

FIG. 4.—Diagram showing discharge of Hollingsworth underflow ditch from 8 a. m. August 20 to 3 p. m. August 21, 1905, made from autographic record of a self-recording water register placed above the weirs. The diagram shows the decreased flow from the ditch during the midday hours.

It was further determined, from the measurements obtained, that the flow from the ditch fell off greatly during the middle of the day, but remained nearly constant from the late afternoon until the late morning hours of the next day. The flow at midday was about 12 per cent less than the flow during the night. The cause of this fluctuation was investigated, and the conclusion was reached that the decrease was not primarily due to evaporation from the water surface and the gravels near the ditch, but mainly to the enormous use of water by vegetation growing in and along its banks. An automatic gage was put in the ditch a few feet above weir No. 1, from which a continuous record of the discharge over this weir could be computed. The results of these autographic records are given in figs. 4, 5, and 6, together with the change in temperature of the air and of the water in the ditch.

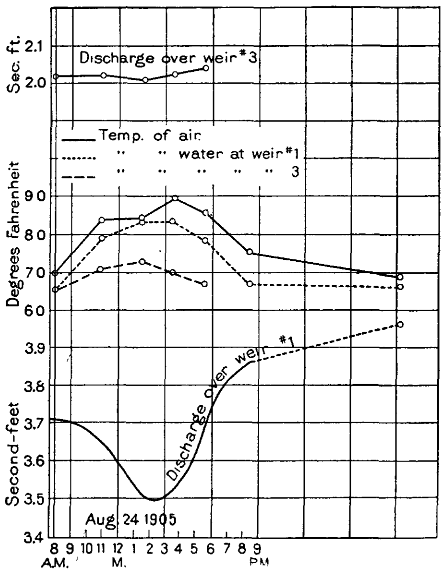

FIG. 5.—Diagram showing discharge of Hollingsworth underflow ditch and the temperature of the water and the air August 24, 1905. This diagram shows the decreased flow in the middle of the day.

An estimate of the evaporation from the surface of the water in the canal can readily be made. The length of the canal is 6,500 feet and its average width is 12 feet, making the area of surface 78,000 square feet. Evaporation experiments were conducted by the writer during the summer of 1905 at Deerfield, Kans., 200 miles south of Ogalalla, the conditions being essentially the same at the two points. The results are given in Table IV:

TABLE IV.—*Evaporation in inches of water at Deerfield, Kans., from August 6 to September 3, 1905.*

	For 28 days.	Average for 1 day.
Open water	10.90	0.39
Cultivated soil, 1 foot to water	4.88	.17
Uncultivated soil, 1 foot to water	5.83	.21
Uncultivated soil, 2 feet to water	2.23	.08
Uncultivated soil, 3 feet to water	.80	.028

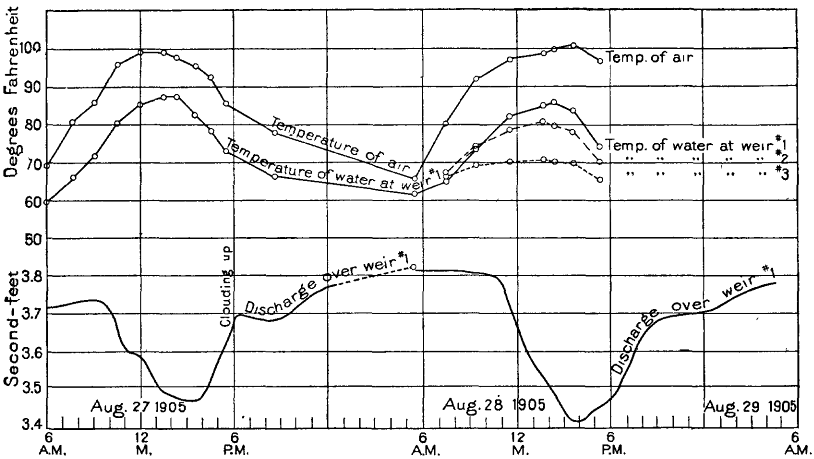

FIG. 6.—Diagram showing discharge of Hollingsworth underflow ditch and the temperature of the water and the air August 27 and 28, 1905. The discharge over the weir was measured by an automatic recording water register. The curve shows the sharp drop in the discharge in the middle of the day and the nearly uniform discharge during the night.

The result from open water is equivalent to an average evaporation of 0.0325 foot per day, or a total average evaporation of 2,535 cubic feet of water per day from the surface of the water in the underflow canal. If it be assumed that this loss took place during eight hours of midday, it should have shown itself by a falling off in the discharge from the underflow canal of 0.084 second-foot. The actual observed loss amounted to 0.3 second-foot. Thus direct evaporation can account for barely 23 per cent of the observed loss. The evaporation from the wet banks of the canal may possibly have increased the loss to the equivalent of 0.1 second-foot, still leaving two-thirds of the amount to be accounted for by the use of water by vegetation and other losses.

A line of test wells (fig. 2, p. 17) at right angles to the ditch, 800 feet from its head, was put down for the purpose of determining the depression of the water plane in the neighborhood of the ditch. The profile of the water plane found in these wells is given in fig. 7.

The point of especial interest in connection with the Hollingsworth underflow ditch is the fact that it is probably the only construction of its kind near any of the streams of the western plains which can be considered a success. As previously stated, nearly all such ditches in other localities in the Western States have proved to be failures.

The conditions at this particular point are especially favorable. The fact that the size of the development is small has also contributed to its success. The slope of South Platte River at Ogalalla is unusually large, amounting to about 1.6 feet per thousand. The

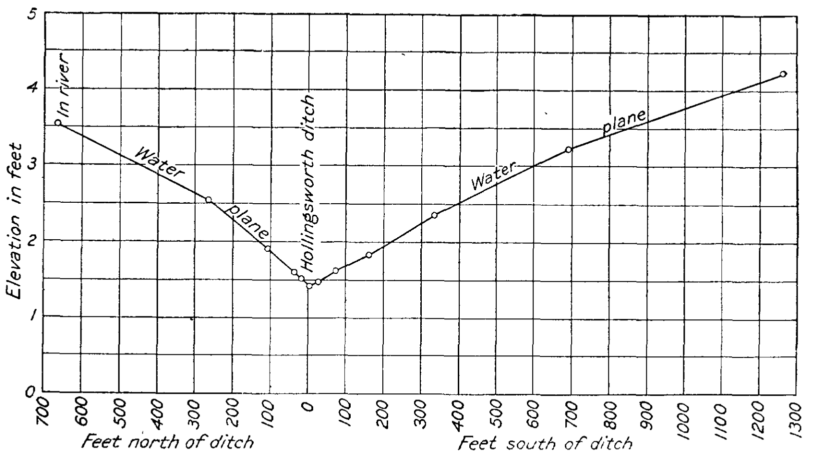

FIG. 7.—Profile of water plane at line of test wells near the head of the Hollingsworth underflow ditch The position of this cross section is given on the map (fig. 2, p. 17).

minimum slope of the underflow ditch is 0.7 foot per thousand. The cost of construction was about $3,000, including at the standard rate the time of the owner and of his teams used in the construction. The ditch requires cleaning at frequent intervals—at least once every two years—in order to remove the vegetation and the sand which tends to gradually ooze up from the bottom and fill the canal. From a financial standpoint the underflow ditch is about on a par with a pumping plant of the same capacity in the same location. The cost of operation is not very different from the cost of operating a Corliss condensing engine and centrifugal pump connected to a battery of driven wells, and there is little difference in the first cost. A pumping plant in one respect would be very much more satisfactory, inasmuch as there is constant danger that the underflow ditch will become a total loss at any time, owing to an unusually heavy flood in the river breaking over the banks and filling it or washing it out.

DISADVANTAGES OF UNDERFLOW CANALS.

As stated above (p. 18), the percolation into the Hollingsworth infiltration canal, for each square foot of percolating surface, amounted to only 0.01 to 0.02 gallon per minute, under 1 foot head. Tubular wells constructed in the same gravels show a specific capacity of 0.25 to 0.5 gallon of water per minute for each square foot of strainer surface, under 1 foot head. The low specific capacity of the underflow canal is due not only to the obstruction of the sand, through which the water must pass by vegetation and slime, but mainly to the fact that stratified gravels do not readily transmit water across or perpendicular to the direction of the bedding. When tubular wells are put down vertically in bedded gravel, the coarser streaks of gravel drain the water into the well strainer and the capacity of the well is determined largely by the coarsest layers of the gravels encountered. In the underflow ditch the water must reach the surface by passing across the various beds of gravel, and the finest layer of sand controls the rate at which the water can enter the canal. On this account wells that penetrate gravels perpendicular to the bedding are much preferred to horizontal wells or to underflow canals that must follow the direction of the bedding. For the same reasons a deep tubular well of small diameter will furnish much more water than a shallow dug well of large diameter.

An underflow ditch is also undesirable on account of the inelasticity in the amount of water which it will yield. The distance to which the water level is lowered by the underflow canal is fixed at the time of construction, and the daily yield can not be increased beyond a certain maximum; in fact, at the very time when the most water is needed—say in the month of August—the yield of the underflow canal will be near its minimum value. When water is recovered by pumping from tubular wells, the vacuum of the pumps can be increased for short intervals of time to correspond to the increased demand for water.

It should also be noted that very few infiltration or underflow canals are in actual use for irrigation purposes. There are many pumping plants in use for irrigation which have turned out to be both practicable and financially profitable; but the attempts to secure ground water by gravity have usually proved disappointing and there are numerous abandoned underflow canals in many parts of the West. An underflow ditch was constructed in 1890 in the valley of Arkansas River near Hartland, Kans., about 12 miles west of Deerfield, for the purpose of furnishing water to the Great Eastern canal. In the summer following its construction the flow from the canal amounted to a little over 5,000 gallons per minute. Water from the river overflowed the ditch during a flood and partially filled it with sediment; at the same time the gravels in the bottom of the canal showed a tendency to work themselves upward by slow movement to the level of the ground water, cutting down materially the head under which the water entered the canal. The ditch proved a complete failure and a great disappointment to the people. A large underflow ditch constructed at great expense near Dodge, Kans., had practically the same history as the one at Hartland. The Denver Union Water Company put an underflow gallery in Cherry Creek, at a cost of $200,000, and succeeded in developing only 5 second-feet of water. An expensive infiltration canal near Sacaton, Ariz., on the Gila Indian Reservation, was wholly unsuccessful. A gravity infiltration canal constructed on Cimarron River near Englewood, Kans., consisted of 900 feet of stave pipe and 2,000 feet of open canal. A flood in the river filled the canal with sand and mud soon after its completion, and it was a total failure.

INVESTIGATIONS AT NORTH PLATTE, NEBR.

SLOPE OF THE WATER PLANE.

Several miles of levels were run at North Platte to determine the slope of the water plane toward the bottom lands, both south and north of South Platte and North Platte rivers, and to determine whether or not the position of the water plane had changed since 1890, when W. W. Follett plotted the elevation of water in a north-south line of wells crossing the Platte Valley at this point. In the lower part of fig. 8 the wells used by Mr. Follett are represented by dots and those used by the field party in 1905 are represented by small circles. In the upper part of the figure is represented the elevation of the water in these wells.

South of the river the water plane was found at about the same elevation as determined by the line of levels run by Mr. Follett; but on the north side, within the sand-hill district, the water plane was about 18 feet lower than it was in 1890. The lowering of the ground water on the north side of the river, where its source is the rainfall upon the sand area, may be due partly to the fact that within this period there has been an unusually large number of years when the precipitation was much less than the normal. The amount of ground water removed from the wells is insignificant. The sand-hill country is used for cattle grazing, and while the number of cattle on the range is probably not as great at present as formerly, during dry years it is always greatly overgrazed. This may be the principal cause of the lower water level.

Stearns's well, shown at the north end of the line of levels, was drilled during the spring of 1905.

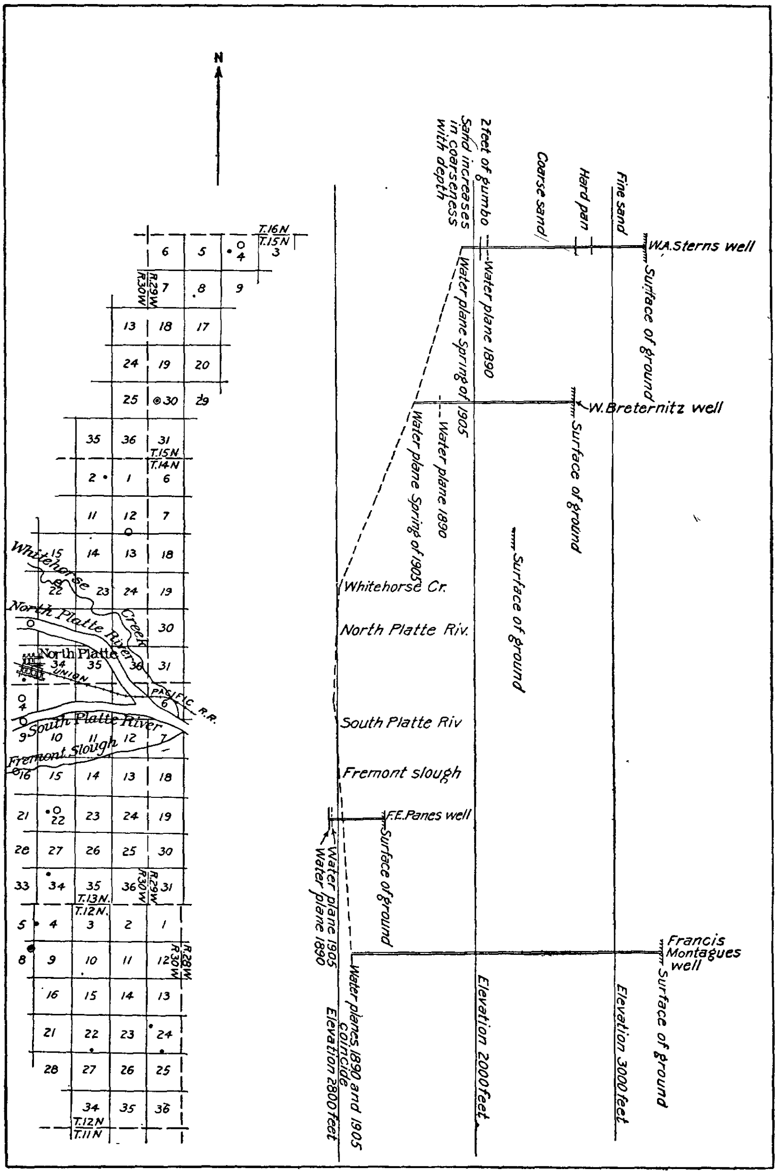

FIG. 8.—Diagram showing change in elevation of the ground water at North Platte, Nebr., between 1890 and 1905. The location of the wells used by W. W. Follett in 1890 to determine the elevation of the water plane is shown on the map by black dots. The circles show the location of the wells used to determine the elevation of the water plane in 1905.

NORTH PLATTE CITY WATERWORKS PUMPING PLANT.

In the plant of the North Platte waterworks two 10½-inch duplex double-action steam pumps are connected to a gang of 28 6-inch wells and deliver water under direct pressure. In fig. 9 the wells are numbered from 1 to 28. The second number for each well represents its depth in feet. Wells 1 to 22 have screens made of perforated brass about 4 feet long; wells 23 to 28 have 12-foot Cook strainers; all are provided with a 4-inch suction pipe.

September 15 and 16, 1905, observations were made at this plant to determine, if possible, the approximate specific capacity of the gravels in this part of the valley. On these days the south pump (H) only was running, and wells 6, 13, 14, 17, 18, 19, 20, 21, and 22 were gated off, leaving only 19 wells from which water was pumped. Well 14 was open and offered an opportunity for measuring the fluctuation of the water level at this point due to different rates of pumping at different hours of the day. These measurements are given in column 4 of Table V.

TABLE V.—*Observed and computed data from test of city waterworks pumping station at North Platte, Nebr., September 15–16, 1905.*

1.	2.	3.	4.	5.	6.	7.	8.
	Observed data.					Computed data.	
Time.	Time for 20 cycles of pump.	Vacuum gage.	Depth of water below top of abandoned well.	Length of stroke of pump. North cylinder.	Length of stroke of pump. South cylinder.	Depth of water below normal. In abandoned well.	Depth of water below normal. In pumped wells.
	Seconds.	*Inches mercury.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
September 15:							
11 a.m.	39.2	11	5.38				
12 m.	37.2	11.5	5.66				
1 p.m.	35.8	11.4	5.84	0.86	0.93	1.54	3.15
2 p.m.	32.8	12.4	6.03	.90	.96	1.73	3.55
3 p.m.	30.7	13	6.25				
4 p.m.	33.2	12.6	6.41	.88	.96	2.11	4.35
5 p.m.	30.7	12.9	6.54	.89	.98	2.24	4.60
6 p.m.	31	12.9	6.64				
7 p.m.	29.8	13.1	6.73	.90	.97	2.43	4.97
8.15 p.m.	45	10.7	6.30	.78	.88		
10.10 p.m.	106	9	5.10	.58	.84		
12 night.	100	9	4.76	.58	.81	.46	.90
September 16:							
2 a.m.	91	9	4.66	.58	.82	.36	.70
4 a.m.	93	9	4.63	.60	.82		
6.30 a.m.	67.3	9	4.62	.64	.85		
8.30 a.m.	61.4	9.5	4.86				
9.30 a.m.	43	10	5.06	.82	.88	.76	1.55
10.20 a.m.	43	10.4	5.15				

NOTE.—Specific capacity of gravels = 0.31 gallon per minute. Assumed slip of pump = 10 per cent.

The readings of a vacuum gage inserted in the suction pipe just before it enters the pump are given in column 3 of Table V. These readings are very rough, since the gage fluctuated badly with the stroke of the pump, and the true vacuum could only be estimated. But from the large number of gage readings taken over a considerable range, together with the readings taken on the open well, the computed values in columns 7 and 8 of the table can not be far from correct. Fom the data in columns 5, 6, and 8 the specific capacity of the sands was found to be about 0.3 gallon per minute, the slip of the pump being assumed to be 10 per cent. The specific capacity of a well is a numerical statement of the readiness with which the well furnishes water. It expresses the amount of water furnished per square foot of strainer surface, if the water level is lowered but 1 foot. This amount is large in the case of a good well and small in the case of a poor well.[a] In the present case each square foot of strainer surface in the wells furnished an average of 0.3 gallon of water per minute under 1 foot head. This is a large amount and indicates an excellent grade of water-bearing material. This specific capacity can probably be relied on for wells in the South Platte Valley. The waterworks at North Platte are in constant operation, so that the specific capacity measured above is the value after long-continued pumping has taken place, and hence a minimum amount.

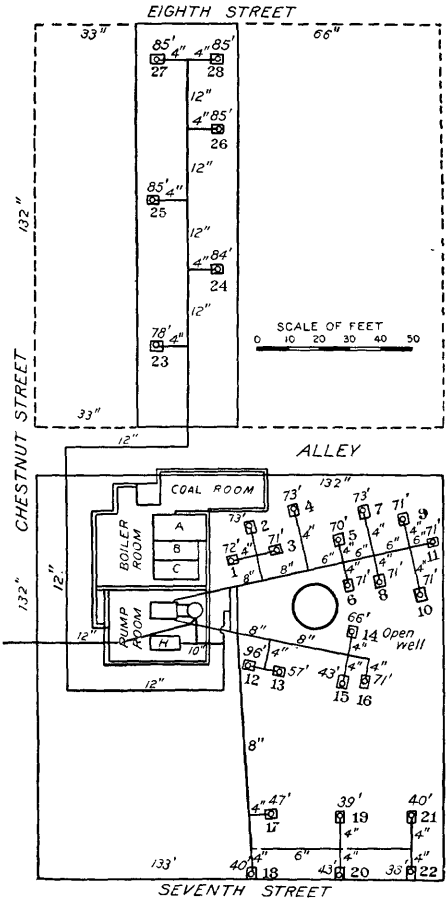

FIG. 9.—Map of the city waterworks pumping plant at North Platte, Nebr. The position of the wells and suction pipe is indicated in the diagram. The second number for each well indicates its depth where known.

SPRINGS AND ARTESIAN WATER OF BIRDWOOD CREEK.

Birdwood Creek, a perennial stream with a low-stage flow of about 150 second-feet and with a drainage area almost entirely within the sand hills, enters North Platte River about 16 miles west of North Platte, Nebr. The head of the stream is nearly 20 miles to the north. It has only two branches; one is a very small stream entering the creek near its head; the other, West Birdwood Creek, flows in an easterly direction a distance of nearly 14 miles and joins the main

[a] See Water-Sup. and Irr. Paper No. 140, U. S. Geol. Survey, 1905, p. 86.

stream 11 miles above its mouth. The flow of West Birdwood Creek at the junction is nearly as great as that of the main stream itself, and perhaps for this reason the stream is locally spoken of as having an east and a west fork. Above the forks the two branches of Birdwood Creek are cut down from 100 to 200 feet into the sand-hill deposit, with no valley bottom, the steep banks in most places extending down to the water's edge. The stream flows in this deep cut some distance below the general level of the water plane. This conclusion is justified by the fact that for nearly its entire course there is a strong seepage from both banks extending many feet above the bed of the creek.

Birdwood Creek is fed entirely by seeps along its banks and by numerous springs, some of which, at the head of the west branch and about 7 miles below the head of the east branch, are of enormous size. The description of these springs by the residents of the valley indicated that there was some probability of the ground waters being under artesian head. This matter was accordingly investigated by sinking a 2-inch well in one of the large springs at the head of the west branch, near the center of sec. 4, T. 16 N., R. 35 W. An artesian head, increasing with depth, developed during the sinking of this well; at a depth of 40 feet the water rose over 20 feet above the bed of the creek.

The log and distance to water for two wells located near the head of West Birdwood Creek were furnished by the owners. One well, 3 miles directly south of the big springs, on the ranch of Mr. F. L. Jones, in the SW. ¼ sec. 21, T. 16 N., R. 35 W., is in coarse gravel which begins at a depth of 275 feet. Above the gravel are several thin layers of hardpan, and above the hardpan is a very fine sand extending continuously to the surface. In this well the water plane is at a depth of 60 feet. The second well is on the ranch of Mr. C. W. Alexander, 2½ miles north and 1 mile west of the big spring, near the northwest corner of the SE. ¼ SE. ¼ sec. 21, T. 17 N., R. 35 W. This well was put down through 169 feet of very fine sand, 12 feet of hardpan, and for 12 feet into coarse gravel. From these data, and from elevations taken from a contour map of this region, fig. 10 was drawn. From this diagram it will be seen that the maximum artesian head which can be developed at this point should be about 25 feet—a pressure nearly equal to that found by sinking the test well in the spring. It may also be observed that the coarse gravels should be encountered at a depth not exceeding 160 feet.

The waters of Birdwood Creek are taken out just above its mouth on North Platte River and diverted into an irrigation canal, which serves the bottom lands of the river. The discovery of the artesian head of the water in Birdwood Creek makes it possible to augment greatly the low-stage flow of this stream and the supply of water for the existing irrigation canal, or a new one. It will be an inexpensive matter to sink a number of 12-inch wells to the artesian water at suitable localities along the stream, and to provide these wells with

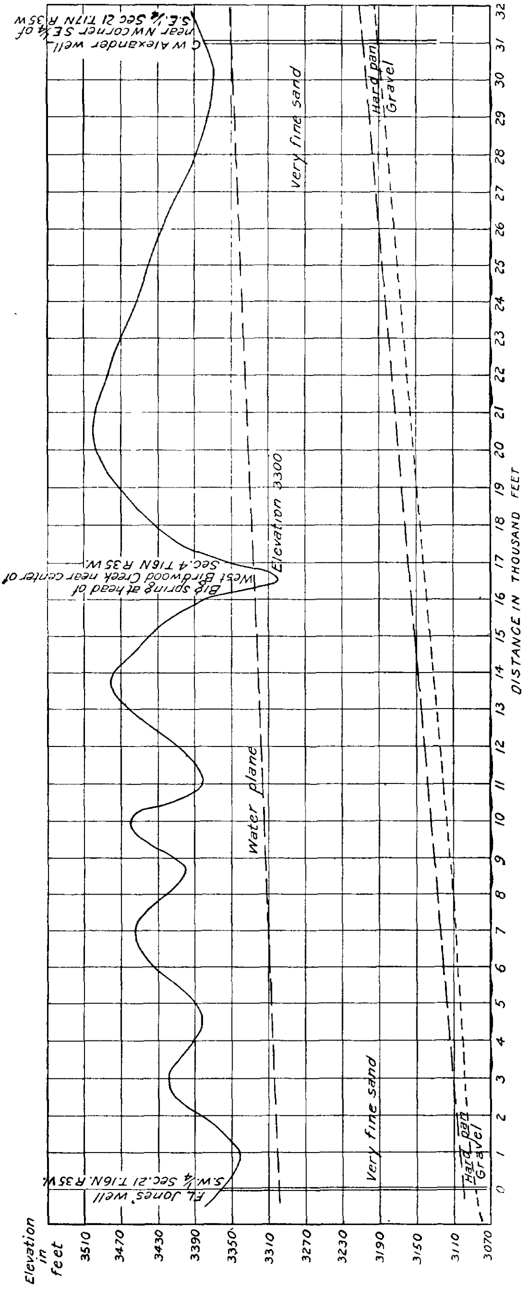

FIG. 10.—Diagram showing the position of the water plane and the coarse water-bearing gravel near the head of West Birdwood Creek. The diagram shows that wells sunk in the valley of Birdwood Creek to the depth of the coarse gravels would have an artesian head of about 25 feet.

gates or valves which can be opened during low stages of flow. It is very probable that the present minimum flow of Birdwood Creek could be doubled by such means.

SUGGESTIONS FOR THE CONSTRUCTION OF SMALL PUMPING PLANTS.

The investigations in the South Platte Valley indicate that there is an ample supply of ground water for a large number of small pumping plants located in almost any part of the bottom lands. It is possible to count on an average depth of 40 to 60 feet of good water-bearing gravels. These deposits contain a sufficient amount of coarse material to render it unnecessary to use fine-meshed strainers in the wells. In a large portion of the bottom lands the distance to water is between 5 and 15 feet, making it easy to pump the water and place it on the surface of the ground economically. The cost of pumping will be controlled, primarily, by the cost of fuel and the distance it is necessary to lift the water. Whether a pumping plant will be a profitable investment depends, of course, very largely on the crops that can be grown and marketed at a fair price.

KIND OF WELLS ADAPTED TO THE SOUTH PLATTE GRAVELS.

The most economical well to construct for the purpose of procuring ground water in the large quantities needed for irrigation purposes is one from 12 to 15 inches in diameter and extending into the water-bearing gravels a distance of 30 to 60 feet, depending on the thickness of the gravels at the place where the well is drilled. Strainers for these wells can be made of slotted galvanized iron. The perforated metal should be placed opposite all the coarse gravels, below a depth of 10 feet below the surface of the water. These strainers can be made by any mechanic by punching heavy galvanized iron with slots about one-eighth by 1 inch in size and then riveting the sheets into cylinders of the proper diameter. The cylinders should be rolled so that the burr made by punching the slots will come on the outside of the finished casing and so that the slots will be arranged vertically in the finished well. A much better strainer can be made if the metal is purchased in sheets already perforated. For this purpose steel sheets 48 by 60 inches, perforated with hit and miss slots, three-sixteenths by 1 inch, and galvanized after the perforations are made, will be found to be ideal strainers. When rolled into cylinders these sheets form a casing about 15 inches in diameter. In constructing the well the perforated sections should be put in place, one above another, to a point about 10 feet below the water level, from this depth upward the casing should not be perforated.

AMOUNT OF WATER THAT CAN BE OBTAINED.

Wells constructed as described in the preceding section can be relied on to furnish at least one-fourth gallon of water per minute for each square foot of strainer surface in the well when the water in the well is lowered 1 foot by pumping. If the water in the well is lowered

10 feet by pumping, the amount of water recovered should amount to at least ten times as much, or 2½ gallons per minute per square foot of strainer. If a 15-inch well is drilled in good water-bearing gravel to a depth of 40 feet, the lower 30 feet of which is strainer surface, and if the pump lowers the water in the well 10 feet, the amount of water supplied by the well should amount to at least 300 gallons per minute. It is believed that this estimate is conservative. A careful test of the waterworks at North Platte, Nebr., showed that the strainers in the wells were furnishing 0.3 gallon of water per minute per square foot of strainer surface, when the water in the wells was lowered 1 foot by pumping.

For small pumping plants a single well of the depth indicated above would probably be sufficient for the supply; but if the good water-bearing gravels do not extend to the requisite depth, it would be necessary, of course, to increase the number of wells and connect several of them by suitable means to the pump.

DISTANCE BETWEEN WELLS.

If it is necessary to construct several wells in order to obtain the amount of water required for an irrigation plant, it becomes important to consider the best and most economical arrangement of the wells. Two different methods will be found available for this purpose. If the amount of water required is not greatly in excess of that which can be supplied by a single tubular well, it is often found practicable to construct a large dug well 6 to 10 feet in diameter to a depth of 5 to 10 feet below the water level, inserting in the bottom of the dug well several feeders of perforated galvanized iron, as described above. This method has the advantage of permitting the pump that is to recover the water to be submerged in the water of the well. A well of this sort is shown in fig. 11.

In order to sink a dug well the proper distance below the water level, it is necessary to construct a wooden, brick, or concrete crib that will sink as the material is removed from its interior. The crib of the well shown in fig. 11 is made of wood, and is larger at the lower than at the upper end to facilitate sinking.

Another method of recovering a large quantity of water is to sink a battery of wells and connect them by suction pipe to the pump. This method is adapted to secure a greater supply than the large dug well. Various arrangements of the wells can be made. Three, four, or more wells can be arranged in a straight line 20 or 30 feet apart, and connected by suction pipe to a pump placed near the center of the row of wells. In fig. 12 is shown an arrangement suitable for a battery of eight to twelve wells. These wells are arranged in pairs, placed close together, each pair of wells being 40 to 60 feet from the next pair on the same suction line. The object of placing the wells

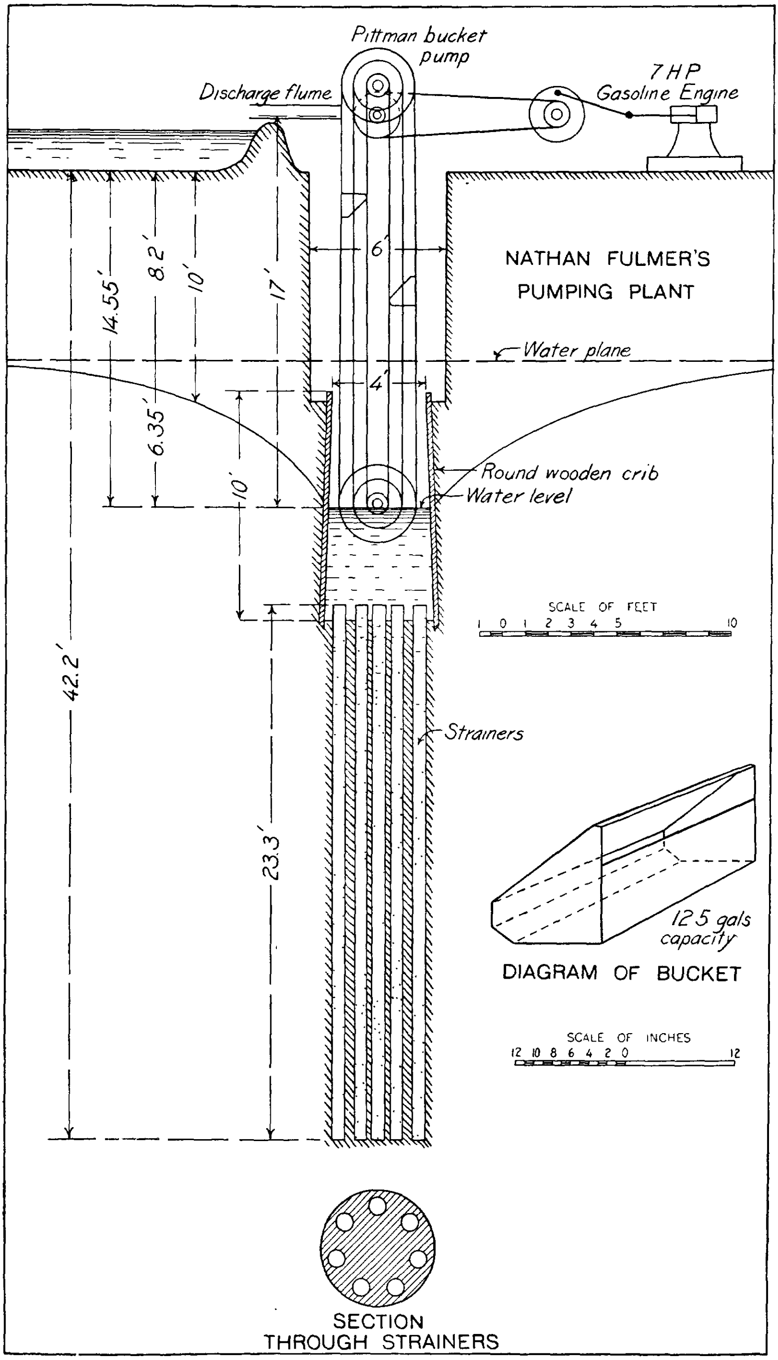

FIG. 11.—Diagram of a pumping plant in the Arkansas Valley in which the water is recovered from a dug well having a wooden crib, in the bottom of which are placed seven galvanized-iron strainers or feeders. A chain-and-bucket pump is used on this well. Better results would undoubtedly be obtained by using a vertical-shaft centrifugal pump submerged in the open well.

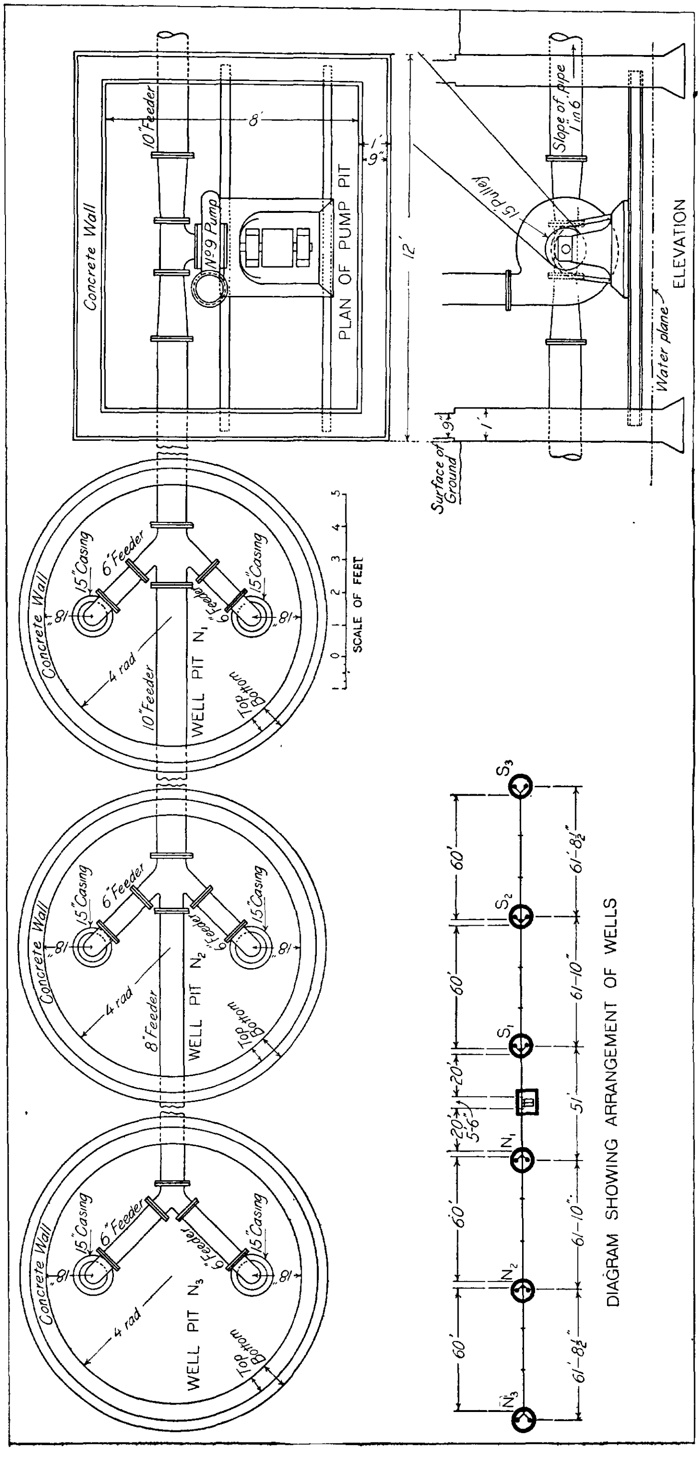

FIG. 12.—Suggested arrangement of wells and pump for a plant designed to recover 2,500 gallons of water per minute. In places where the gravels are deep and unusually coarse the wells at the end of the line of suction pipe may be omitted. The plant ccnsists of a central concrete pump house and a group of 12 wells arranged along the suction pipe leading to the pump. The suction pipe should be placed underground as near to the level of the ground water as practicable.

close together in pairs is for the purpose of removing a large amount of the fine sand from the water-bearing gravel. This can be done in gravels like those found in the South Platte Valley by pumping vigorously from one of the pair of wells and at the same time running clear water into the neighboring well. By this means it should be possible to clear out all the fine material between the two wells. A pumping plant like that shown in fig. 12 should supply from 2,500 to 3,500 gallons of water per minute, if the water-bearing gravels are of the kind usually found in the South Platte Valley, without lowering the water more than 10 feet.

KIND OF PUMP.

Probably the most satisfactory pump for use in irrigation is the centrifugal pump. It should be remembered, however, that there are a great many kinds of small centrifugal pumps on the market which are designed for a great variety of purposes. It does not pay to purchase any but the very best machinery for the pumping of water, as poorly designed machinery soon proves too expensive. The various kinds of pumps differ greatly in this respect. The centrifugal pump used by the irrigator should be of the inclosed-runner type, provided with self-oiling bearings of the oil-ring type. There are several excellent makes of centrifugal pumps on the market, and any of them will do good work if the size and design of the pump fit the conditions under which it must work. The maker of the pump should have full information of all the conditions under which it is to be installed, including the distance that the pump must discharge the water above its outlet, also the amount of suction or the distance the water must be lifted below the pump inlet. The following points are important to those about to install pumping plants:

The efficiency of the centrifugal pump under actual working conditions is higher for large pumps than for small ones. Pumps having a discharge pipe less than 3 inches in diameter will show a low efficiency.

A centrifugal pump will work better and be more efficient if the length of the suction pipe is kept as low as possible, relative to the length of the discharge pipe. On this account the pump should be placed as near the level of the water as the securing of a good foundation will permit.

If the pump is to be driven by means of a belt it should be provided with a large pulley. The pulley usually supplied with the pumps is so small that a great amount of slipping takes place between the belt and the pulley, and the efficiency of the pump is greatly decreased on that account. Of course, it is necessary to secure the proper proportion between the sizes of driving and driven pulleys, but both should be larger than are usually furnished with pumps and engines.

The suction pipe on the pump and the discharge pipe should be large. A No. 4 centrifugal pump that draws water from a single well should have at least a 6-inch suction pipe, and the discharge pipe should gradually increase from 4 inches in diameter at the discharge opening of the pump to 8 inches 3 feet above the discharge opening and continue this size until the flume or discharge conduit is reached. The discharge pipe can be made of riveted galvanized iron, and the suction pipe can be made either of standard pipe or good well casing.

A centrifugal pump loses its efficiency at once if it leaks air around the stuffing box or if there is an air leak at any place in the suction pipe. Many centrifugal pumps are now provided with a water seal around the stuffing gland that insures the absence of leaks at this point.

A good centrifugal pump with inclosed impeller or runner should show an efficiency of about 60 per cent on a 30-foot lift. Single-stage centrifugal pumps, constructed with bronze impellers, made in two pieces so that the interior could be machined and smoothed, have shown an efficiency of about 80 per cent.

METHOD OF PRIMING PUMPS.

A large number of pumping plants are installed with foot valves at the bottom of the suction pipe. When these are provided a centrifugal pump is always ready to start after it is once primed. The foot valves usually interfere very materially with the flow of water into the pipe, and it is undoubtedly more economical to omit them and place a flap valve at the upper end of the discharge pipe, which can be lowered when it is desired to start the pump. An ordinary cast-iron house pump connected to the top of the casing of the centrifugal pump can be used to prime the pump with water before starting.

PIPE FITTINGS.

The suction pipe usually installed by constructors of pumping plants is not only too small for the best results, but the elbows and tees used are very poorly adapted to the purpose intended. It is a common practice to use steam-pipe fittings for this purpose. In consequence the water is required to turn at sharp angles at the tees and elbows and the best results can not be obtained. In order to avoid this difficulty "long-sweep" fittings should be purchased. These are standard trade goods and can be obtained from any of the large dealers in pipe fittings. Fig. 13 shows the difference in the two kinds of fittings.

SOURCE OF POWER.

A favorite engine for small pumping plants is the gasoline engine. Where the price of gasoline is high it is very easy to make the cost of water prohibitive by the use of such power. Whether or not it pays to pump water by gasoline is a matter which depends very largely on the distance the water must be lifted, but also on the kind of crop that is to be irrigated. Gasoline, even at a high price, is usually a cheaper fuel than coal in an ordinary steam engine of small horsepower. For plants requiring from 20 to 30 horsepower producer-gas generators can be installed, which will keep the cost of pumping down to a minimum. A suction gas producer, using anthracite pea coal for fuel, should furnish power at the rate of 1 horsepower per hour for each pound and a half of coal consumed. At $8 per ton the cost of coal should be equivalent to gasoline at 4 to 6 cents per gallon.

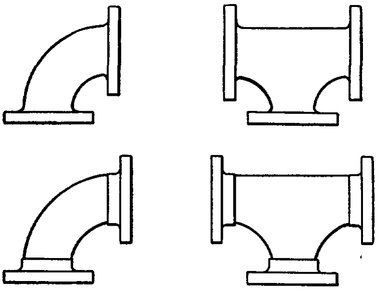

FIG. 13.—Diagram showing the relative shape of standard and "long-sweep" pipe fittings. The upper part of the diagram shows standard fittings and the lower part long-sweep fittings.

In large plants, requiring from 50 to 100 horsepower or more, a condensing Corliss engine is sufficiently economical where the cost of coal does not exceed $3.50 to $4 per ton.

ECONOMICAL DISTANCE WATER MAY BE LIFTED.

It is very unlikely that it will pay to pump water under present conditions in the South Platte Valley, a total distance of more than 30 feet, including the suction lift of the pump. If the pump lowers the water in the wells 10 feet and if the distance to water is 10 feet below the surface and the discharge pipe is brought into a reservoir or flume 5 feet above the surface, the total lift will be 30 feet, if 5 feet be added to cover loss of head due to friction in suction and discharge pipes. It will probably not pay to pump water to a greater height at any place in the valley, except for the irrigation of garden truck and other high-priced crops.

STORAGE RESERVOIRS.

In order to irrigate economically from pumping plants it is usually desirable to pump the water into a reservoir having a capacity equal to the amount of water the plant can furnish in six to eight hours. Such a reservoir is absolutely necessary for the best results with small pumping plants. If the supply of water exceeds 500 gallons per minute it is possible to dispense with the reservoir, especially if the supply greatly exceeds this amount. Plants furnishing over 1,000 gallons per minute can usually be best operated without a reservoir.

COST OF PUMPING.

The cost of recovering ground water from wells is made up of four principal items—(1) cost of fuel and supplies, (2) cost of labor, (3) charge for depreciation and repairs, (4) interest on the first cost of the plant or the capital invested. The first and third of these items are partially under the control of the owner of the plant. If the installation is carefully designed and its parts well proportioned, the cost of fuel can be kept at a minimum, and similarly the charge for depreciation and repairs will be kept low if good machinery is purchased in the first place and careful attention is given to its maintenance when in operation and when idle. The charge for depreciation will be as great, if not greater, when the plant is not running as when it is running. If the machinery is neglected and carelessly exposed when idle, the rate of depreciation will greatly exceed the rate when it is in use. The charge for depreciation and repairs should not be estimated at less than 10 per cent of the first cost of the plant.

Table VI gives an estimate of approximate cost for fuel and maintenance of a pumping plant having a capacity of 1,000 gallons of water per minute for total lifts of 10, 20, and 30 feet. In column 2 of this table is given the hydraulic horsepower, which is the theoretical power required to lift the given quantity of water the distance stated in column 1. The actual brake horsepower of the engine should be about double the amount given in column 2. The horsepower required by the engine is stated in column 3 in two ways—first, the amount of power that would be required in a well-designed pumping plant, where care has been given to all the matters previously referred to, such as the use of large suction and discharge pipes and proper selection of pump and machinery. The best that can be expected of a small pumping plant is to recover 50 per cent of the power delivered to the belt by the engine as useful work in lifting the water. The losses that occur will consist of losses in the belt, amounting to from 5 to 10 per cent, losses in the pump, amounting to about 40 per cent, and friction losses in the suction and discharge pipes, varying from 5 to 20 per cent. In order to secure an economically running plant it is important that the engine should be large enough to do the work, but at the same time not too large. Great losses occur in gasoline engines if their capacity is largely in excess of the work required. The horsepower stated as a maximum in column 3 indicates the largest that should be used for the given lift.

TABLE VI.—*Approximate cost of fuel required to pump 1,000 gallons of water per minute, for various lifts.*

1.	2.	3.		4.	5.	6.	7.	8.
Total lift.	Hydraulic horsepower.	Engine brake horsepower. Minimum.	Engine brake horsepower. Maximum.	Cost per hour of fuel, with gasoline at 16 cents per gallon	Cost per hour of fuel, with gasoline at 20 cents per gallon.	Cost per hour for coal at $8 per ton in suction gas-producer plant.	Cost per hour for coal at $4 per ton in condensing steam engine.	Cost of depreciation and repairs on machinery, etc., per year.
Feet.				*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Dollars.*
10	2.8	6	7	11.2	14	4.2	6	70
20	5.6	11	14	22.4	28	8.4	12	140
30	8.4	16	21	33.6	42	12.6	18	210

NOTE.—One thousand gallons of water per minute pumped continuously for eleven hours is equivalent to 2 acre-feet of water.

In columns 4 and 5 the cost of fuel for delivering the horsepower stated in column 3 is expressed in cents per hour, based on the price of gasoline indicated in these columns. In column 6 is given the cost of fuel if hard coal costing $8 per ton be used in a suction producer-gas plant. In column 7 is given the cost of fuel per hour if soft coal at $4 per ton be used in a condensing Corliss engine. In column 8 is given a rough estimate of the cost per year for depreciation and repairs on a well-constructed plant.

In order to determine approximately the cost of pumping water any distance between 20 and 30 feet, a proportional part of the cost for 10 feet can be added to the cost for 20 feet. Thus, to get the cost of pumping water a distance of 25 feet, half of the numbers in the first line of the table can be added to those in the second line. The table should be used for estimating the cost of pumping water only for lifts lying between 20 and 30 feet. The cost for 10 feet is given for the purpose of making estimates, but it should not be supposed that the cost for this low lift would be merely half of that for the 20-foot lift, as friction and other losses would tend to make the cost for the low lift higher than that stated in the table.

Tests of a number of pumping plants in the Rio Grande Valley are reported in Water-Supply and Irrigation Paper No. 141. On page 34 of that paper will be found a table giving the fuel cost, interest, and labor cost estimated for each acre-foot of water recovered. Similar facts concerning the cost of pumping water in existing small pumping plants in the Arkansas River Valley in western Kansas will be found in Water-Supply and Irrigation Paper No. 153. A table summarizing the results is given on page 55 of that paper, and on page 82 will be found a test of a producer-gas pumping plant at Rocky Ford, Colo.

At almost any point in the river valleys of the western plains complete pumping plants, including wells, machinery, and buildings, can be constructed for about $100 per horsepower required. In some exceptional cases the cost may run as low as $60 per horsepower.

APPENDIX.

In the following tables are given statistics of wells in the territory along the line of the Union Pacific Railroad in the South Platte Valley from North Platte to Sidney, Nebr., and from Julesburg to Sterling, Colo., which have been drilled for the purpose of obtaining a water supply for private individuals and for the railroad. This information was obtained through the courtesy of the engineering department of the Union Pacific Railroad.

TABLE VII.—*Statistics of wells along the line of the Union Pacific Railroad in western Nebraska and eastern Colorado.*

Locality.	No. of well.	Diameter. (*Ft.*)	Diameter. (*in.*)	Depth.	Average consumption per day.	Normal depth to water.	Depth to water when pumping.	Strainers.
		Ft.	*in.*	*Feet.*	*Gallons.*	*Feet.*	*Feet.*	
North Platte	1		6	94	216,100 (wells 1–12)	....	....	Cook. (wells 1–12)
Do	2		6	94				
Do	3		6	94				
Do	4		6	84				
Do	5		6	88				
Do	6		6	92				
Do	7		6	92				
Do	8		6	92				
Do	9		6	92				
Do	10		6	92				
Do	11		6	92				
Do	12		6	92				
Hershey	....		6	48	[a]120,000 (both wells)	3	12	Cook No. 8, 5½ inches by 12 feet.
Do	....	[b]13	0	13		6	....	
Paxton	....	[c]10 [d]9	6 6	15.5	34,100	4.9	8	
Ogallala	1		6	75	51,300	5.5	30	Cook No. 8, 4½ inches by 14 feet.
Do	2		5½	75	[a]194,400 (wells 2–5)	5.5	30	Cook No. 8, 5 inches by 12 feet. (wells 2–5)
Do	3		5½	75		5	30	
Do	4		5½	75		5.5	30	
Do	5		5½	75		5 5	30	
Big Spring	....	12	0	13.2	....	4.6	6	
Julesburg	....	12.2		17	64,500	7.6	14	
Chappell	....	12	6	28.5	10,000	22	24	
Lodgepole	....	9	6	17.5	15,000	12.5	16	
Sidney	1	[c]12 [d]11	0 0	33	107,800	27	([e])	
Do	2	16	0	40	....	27	([e])	
Sterling	....		[f]6–5	600	32,000	....	....	Cook, from 90 to 110 feet.
Do	....	[g]11	0	15.5	....	7	....	
Iliff	....	11	0	15.5	6,500	8	....	
Crook	....	15	6	16	....	7.3	....	
Sedgwick	....	11	0	18	3,000	....	8	

[a] Estimated flow.
[b] Old well (dug); used for emergencies only.
[c] Top.
[d] Bottom.
[e] Pumps dry.
[f] Artesian well. Casing, 90 feet 6-inch; 20 feet 5½-inch; 300 feet 5-inch; 190 feet uncased (diameter 5 inches.
[g] For emergencies only.

TABLE VIII.—*Analyses of waters along the line of the Union Pacific Railroad in western Nebraska and eastern Colorado.*

[Parts per million.]

Locality.	Source.	Date.	Oxides of iron and alumina (Fe_2O_3+ Al_2O_3).	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Chlorine (Cl).	Sulphate radicle (SO_4).	Carbonate radicle (CO_3).	Probable incrusting solids.	Total mineral solids.
Big Spring	Well 13 feet deep	Feb. 27, 1902		40	42	6.9	10	4.2	26	74	172	202
Do	do	Sept. 21, 1904	2.6	46	40	9.7	10	8.3	16	80	186	215
Chappell	Dug well 28 feet deep	Mar. 4, 1902	2.7	51	52	10	39	6.1	36	127	222	326
Do	do	Sept. 22, 1904	1.9	54	64	13	38	12	41	141	261	367
Crook	Well 15 by 20 feet	Aug. 8, 1902	4.4	21	77	22	106	64	274	82	348	653
Hershey	New well 6 inches by 48 feet	Mar. 15, 1902	4.3	30	99	19	43	25	223	91	412	535
Do	do	Sept. 20, 1904	1.7	29	98	17	55	24	224	100	390	550
Iliff	Well 12 by 18 feet	Oct. 1, 1902	6.3	27	271	61	273	74	982	235	1,114	1,930
Do	Test well 1¼ inches by 19 feet; 617 feet east of water tank.	Aug. 2, 1904		42	255	82	593	76	1,430	382	882	2,865
Do	Test well 1¼ inches by 17 feet; 309 feet west of water tank.	Aug. 1, 1904		62	236	60	457	30	1,101	327	885	2,284
Do	Well, present supply	Aug. 30, 1904	3.8	26	259	66	383	73	1,249	204	1,108	2,247
Julesburg	Dug well 17 feet deep	Feb. 27, 1902	3.6	49	68	12	36	18	71	120	271	368
Do	Well 12 by 20 feet	Feb. 23, 1903	1.5	49	78	16	41	23	106	122	321	477
Do	do	Nov. 4, 1905	1.4	51	65	12	40	19	66	123	260	[a]335
Lodgepole	Private well 6 inches by 54 feet	Feb. 28, 1902	2.0	56	51	11	28	7.2	21	120	230	[b]383
Do	Test well 6 inches by 57 feet	Mar. 22, 1902	3.8	65	49	12	48	20	47	119	235	319
Do	Well 18 feet deep	Feb. 28, 1902	3.4	55	50	11	31	12	33	115	225	360
Do	do	Sept. 21, 1901	1.2	65	60	13	34	10	30	137	261	400
North Platte	North Platte River, east side	Jan. 3, 1901	5.1	42	63	13	29	13	85	99	264	351
Do	Judge Penniston's well	do		50	41	9	24	15	51	72	190	245
Do	South Platte River	Jan. 14, 1901		16	105	36	101	33	405	98	497	763
Do	Wells at round house, present supply	Aug. 27, 1901	6.5	52	54	11	48	28	117	74	252	399
Do	North Platte River (filtered sample), at railroad bridge, east of station.	Mar. 28, 1902	7.3	33	61	15	43	24	116	91	267	398
Do	Wells at round house	Apr. 30, 1903	4.4	49	77	15	54	34	156	98	332	488
Do	do	Nov. 4, 1905	1.4	51	72	16	69	31	182	100	309	[c]527
Ogalalla	Dug well 12 feet deep	Feb. 27, 1902	1.3	27	98	24	102	25	361	93	425	731
Do	South Platte River, south of station	Mar. 20, 1902	1.3	24	116	38	105	35	417	116	540	853
Do	Test well 6 inches by 23 feet	Mar. 18, 1902	19	37	66	14	59	22	201	66	309	484
Do	Test well 6 inches by 50 feet	do	3.8	56	50	10	22	13	45	93	228	294
Do	New well 6 inches by 76 feet	Mar. 19, 1902	3.9	51	51	9.7	29	7.3	65	91	223	309
Do	New well 6 inches by 75 feet	Apr. 25, 1902		47	45	11	15	4.7	31	91	193	245
Do	New well 5½ inches by 75 feet	Aug. 1, 1902	2.0	46	44	10	28	9.7	34	100	198	274
Do	do	do	7.3	56	46	11	31	12	39	104	229	307
Do	Fire wells	June 21, 1904		43	54	14	21	18	65	88	242	303

[a] NO_3=10.

[b] Organic matter=17.

[c] NO_3=7.9.

TABLE VIII.—*Analyses of waters along the line of the Union Pacific Railroad in western Nebraska and eastern Colorado*—Continued.

[Parts per million.]

Locality.	Source.	Date.	Oxides of iron and alumina (Fe_2O_3+ Al_2O_3).	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Chlorine (Cl).	Sulphate radicle (SO_4).	Carbonate radicle (CO_3).	Probable incrusting solids.	Total mineral solids.
Paxton	Dug well 15 feet deep	Mar. 13, 1902	3.4	20	140	34	129	47	519	106	616	999
Do	2-inch well at schoolhouse, one-half mile from tank.	do	4.2	26	55	10	23	18	90	66	226	293
Do	South Platte River, 1,000 feet south of track	do	10.4	40	119	41	118	57	435	125	623	947
Do	North Platte River (filtered sample), 4 miles north of station.	Mar. 29, 1902	8.0	39	58	14	30	10	103	84	259	346
Do	New well	Oct. 4, 1903	8.5	45	130	36	117	46	531	66	635	979
Do	do	Oct. 2, 1905	1.5	26	82	19	70	29	243	88	352	[a] 567
Do	do	do	.34	22	82	19	73	29	251	85	345	[a] 570
Do	do	Nov. 4, 1905	2.3	43	157	43	205	62	576	194	657	[a] 1,294
Sedgwick	Well 11 by 18 feet	Aug. 11, 1902	6.5	42	101	23	79	33	287	102	440	674
Sidney	Tank, source unknown	Sept. 15, 1897	[b] 6	48	84	21	25	38	95	117	371	434
Do	Dug well 33 feet deep	Feb. 28, 1902	2.1	60	47	12	3	5	36	79	236	245
Do	Dug well 35 feet deep	Mar. 22, 1903	2.2	61	47	12	23	13	36	99	226	293
Do	New well 16 by 37 feet	Mar. 25, 1903	7.5	54	57	13	11	10	41	94	257	288
Do	do	Nov. 8, 1905	.....	67	60	17	30	14	71	123	292	388
Sterling	J. M. Judd's well, 140 feet deep	May 14, 1901	2.1	22	35	10	118	67	65	134	147	453
Do	Flowing well	July 25, 1901	6.5	23	8	3.7	565	348	18	451	64	[c] 1,462
Do	New well 500 feet deep	Aug. 8, 1901	2.2	5.9	3.2	.....	618	436	20	428	16	1,514
Do	Well 6 inches by 600 feet	Oct. 1, 1902	3.3	34	86	24	279	118	460	167	354	1,111

[a] NO_3=10. [b] FeO_2. [c] Organic matter=38.

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[Water-Supply Paper No. 184.]

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