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DESIGN OF SHALLOW WELLS FOR DRAINAGE BY PUMPING, LEWISTON AREA, UTAH

by

Gregory L. Pearson

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

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Logan, Utah

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INTRODUCTION

After approximately 25 years of using open drains in the Lewiston Area, Utah, the water table has not changed appreciably from what it was in 1921 when Hart and Adams (4) conducted their drainage investigations. It is still only about three feet below the ground surface. This is not effective drainage, meeting neither of the two primary drainage requirements of an arid or semi-arid agricultural region, namely; preventing an accumulation of excessive water within the depth of soil required for optimum growth of plant root systems, and maintaining the water table at a depth below the ground surface greater than the maximum height capillary water can rise, carrying any harmful salts that may be present in solution.

In the only other comprehensive study of drainage conditions in the Lewiston Area, the Humphery Brothers (6) point out the need for drains placed at a depth of eight to ten feet. This requires the development of new drainage methods, since the present open and tile drains have been constructed to their maximum economical depth. Because of sloughing of the banks, six feet is near a maximum depth to which open drains can be dug without making them excessively wide. Present tile-laying machines will only work successfully in these saturated sandy soils to a maximum depth of six feet.

Open drains are objectionable in that they serve as weed traps and become filled with vegetative growth which

makes them inefficient. Also, they tend to seal up with the finer soil particles which are brought in by inflowing water and from the sloughing banks.

Because of the peculiar geological formation of the soils and subsoils, the only other method in major use for the drainage of soils, i.e. drainage by pumping from relatively thick beds of pervious surface soils, or from a confined artesian aquifer, is not feasible in this area. Therefore, the primary purpose of this investigation was to determine if a small shallow well could be developed which would allow drainage of the Lewiston Area soils to greater depths more efficiently and economically than is being done by present methods.

GEOLOGY OF THE LEWISTON AREA, UTAH

GENERAL

Underlying the sandy surface soils in the Lewiston Area, there is a bed of impermeable clay over 100 feet thick which was deposited in Lake Bonneville. The principal source of these soils was Bear River, which carried a large load of sediment. The coarser sands were dropped near the shore in the river's delta, while the finer clay sediments were carried out into the Lake and settled out to form the thick clay bed.

As the water in the lake receded, Bear River followed it on out into the valley, depositing its sands in levees on top of the previously formed clay layer. These surface sands vary in thickness from about one foot to a maximum of 20 feet.(10)(2)

EFFECT ON THE DRAINAGE PROBLEM

Williams, Maughan, and Israelsen (10) describe the effect of this peculiar geological formation on drainage conditions as follows:

> Water flows with comparative rapidity through the sandy soils--probably 10,000 times as rapidly as it flows through the clay. The result is the accumulation of water on the clay layer to produce a perched water table. Since the sand layer is thin, the water table is everywhere perilously close to the surface. The perched body of ground water is fed not only by the downward flow of irrigation water spread in the field to water the crops, but also by excessive seepage from canals. It is also augmented by natural precipitation, especially by the melting of snow in the springtime.

... With irrigation the water table has risen, and more and more of the sand levee area has required drainage. Any increased use of irrigation water under present methods will carry with it a corresponding increase in need for drainage, because the storage capacity of the sand for water is very small, and there is no chance for escape of water through the clay layer.

DRAINAGE BY PUMPING FROM HORIZONTAL WELL POINTS

PROPOSED SHALLOW WELL

The type of shallow well proposed for use consists of a standard well drive point placed in a horizontal position at the bottom of the sand layer, on top of the clay. A gravel filter must be put around the well point for efficient discharge and to prevent it from filling with sand.

JUSTIFICATION FOR TYPE OF SHALLOW WELL

Because of the shallow depths of permeable soils prevailing in this area, it is desirable that the well point be placed in a horizontal position instead of the standard vertical position, in order to increase the discharge obtained. The increased discharge is the result of the greater drawdown and the larger effective radius of the horizontal well. For permeable sands of greater depths the increased discharge would probably be insufficient to warrant the added expense of construction.

The ratio between the discharges to be expected from these two types of shallow wells is indicated by a consideration of the appropriate well discharge formula.

Using the formula illustrated in Fig. 2,

$$Q = \pi k \frac{H^2 - h^2}{2.3 \log_{10}(\frac{R}{r})}$$

Let subscript 1 refer to the vertically placed well

point and 2 refer to the horizontal well point. Then,

$$Q_2 = Q_1 \frac{H_2^2 - h_2^2}{H_1^2 - h_1^2} \times \frac{\text{Log}_{10} \frac{R_1}{r_1}}{\text{Log}_{10} \frac{R_2}{r_2}}$$

Using a 5-ft. well point (5-ft. overall length, 48" screen),

$$h_1 = 4.5 \text{ ft.} \qquad h_2 = 0.5 \text{ ft.}$$

If the water table is 3 ft. below the ground surface and

$$R_1 = R_2 = 200 \text{ ft.}^{1/}$$

$$r_1 = 0.5 \text{ ft.}^{2/}$$

$$r_2 = 1.5 \text{ ft.}^{2/}$$

then, for a depth to clay of 10 ft.

$$H_1 = H_2 = 7 \text{ ft.}$$

and

$$Q_2 = Q_1 \frac{49}{29} \times \frac{2.60}{2.12}$$

$$\therefore \quad Q_2 = 2.1\, Q_1$$

Similarly, for

12.5 ft. to clay, $Q_2 = 1.6\, Q_1$

15.0 ft. to clay, $Q_2 = 1.4\, Q_1$

20.0 ft. to clay, $Q_2 = 1.3\, Q_1$

1/ For radii from 150 to 300 ft. the change in the ratio of discharge is in the second decimal place and makes no change in the ratio given below.

2/ See section on Effective Well Radius.

JETTING METHOD TO BE USED TO SINK WELL ASSEMBLY

The method proposed for sinking the well assembly was to first construct a jetting assembly, shown in Fig. 3, consisting of a vertical riser pipe with two short arms connected into a tee at the bottom. On the under side of the arms, holes were drilled. The plan was to pump water down the riser pipe and out through the holes, causing water jets which would churn and stir up the sand under the assembly, allowing it to sink down to the underlying clay layer. It was thought that a narrow trench would have to be dug down to the water table to drop the assembly in before starting to pump.

After the jetting assembly had reached the clay, pumping was to be continued while the well-point assembly was dropped down in to the side of it. After this, the filter would be put in.

The well-point assembly could consist of either a tee assembly similar to the jetting device, the arms being replaced with well points, or be ell-shaped with one long well point as illustrated in Figs. 5 and 12.

PUMP CAPACITY REQUIRED FOR JETTING

The question arose as to whether or not sufficient pressure could be developed in the jetting assembly after it was down to the clay layer to cause vertical piping of the overlying sandy soil. That this would not be a problem in the shallow depths considered is shown if the critical

flotation gradient for these sandy soils is assumed at $i_f = 1.15$. (5) Then, with

i_f = critical flotation gradient

h = pressure head causing flow, in feet

L = length of flow path, in feet

p = pressure intensity gradient, in psi

$$i_f = \frac{h}{L} = 1.15; \quad h = 1.15\ L$$

If the pressure intensity gradient required to cause "quicksand" is used rather than pressure head gradient, then,

$$p = 0.433 \times 1.15\ L = 0.5\ L$$

Assuming 20 feet down to the clay layer, the pressure necessary to cause a quicksand condition would only be 10 psi.

The critical piping velocity is

$$v = k\ i_f = 1.15\ k$$

where k is permeability in ft./sec.

A consideration of the above figures made it obvious that the velocity and pressure necessary to create the needed quicksand condition through which the well-point assembly could be lowered were not the critical elements. The velocity of efflux of the water jets necessary to churn up the sand below the jetting assembly was plainly the critical thing in allowing it to sink.

Tests indicated that jetting velocities of 5 to 6. ft./sec. would be sufficient.

If the jetting assembly were to have arms 3 ft. long

with 143 3/8" dia. holes spaced on ½" centers, and a jetting velocity of 6 ft./sec. average was to be used, then a pump having a capacity of 0.7 cfs would be needed.

$$Q = 0.0008 \times 143 \times 6 = 0.7 \text{ cfs}$$

A gasoline-driven pump having a rated capacity of one cfs and capable of developing 60 psi was obtained and used for sinking the two experimental wells.

EXPERIMENTAL WELL NO. 1

Location

The first well was located on the Glen W. Wiser farm, approximately 95 rods east and 15 rods north of the southwest corner of section 5, Township 14 North, Range 1 east, Salt Lake Base and Meridian.

Jetting Assembly

The arms of the jetting assembly were 2" black pipe, 30" long, with the ends forged closed to a wedge shape. One of them had a single row of 3/8" holes spaced on ½" centers. The other had two rows of 3/8" holes, the rows being ½" apart. The holes were on 1" centers in each row, and ½" centers between the holes in alternate rows, as illustrated in Fig. 4.

The riser pipe consisted of 5-ft. sections of 2" black pipe connected with standard pipe couplings.

Water for Jetting

The water used in jetting was pumped from the drain running east and west back of the Wiser home.

Jetting Procedure

A hole 5.5 ft. long by 2 ft. wide and 3.5 ft. deep was dug before starting to jet. A hardened sand layer was encountered between the 3 and 3.5 ft. depth.

While jetting, the assembly sank about ½ ft. per minute. It would have sunk more rapidly, but since no holes had been bored in the bottom of the tee it was necessary to wait until sufficient washing from the arms undermined the sand under the tee.

At the 10-ft. depth another hardened sand layer was encountered. Jetting through a half foot of this was slow, after which the assembly dropped to the clay layer at the 13-ft. depth.

While still pumping through the jetting device, the well assembly, consisting of a 2" Johnson well drive point, #15 slot, 5 ft. long (48" screen) and attached to the 2" riser pipe with a 90 degree ell, was dropped down the hole. The end of it caught on the hard layer at 10 ft.

It is believed that if the jetting assembly had been worked around by hand, as it was during the first ten feet, a large enough hole would have been washed to allow the well point to sink farther down.

When the well point was pulled up, it was found to have washed full of fine sand. Some of the sand had washed back up into the riser pipe.

While replacing the Johnson well point with a shorter sand point, one with a 30" fine wire mesh, 42" overall length, Fig. 6, the pump for the jetting assembly was shut off. When upward flow stopped, the sand settled down around the jet assembly and held it firmly. After the pump was started again, although the pressure was on, it was 10 or 15 minutes before upward flow commenced. Because of the "feel" of the sand when probed with a 14 ft. piezometer tube, it was believed that the arms of the jetting assembly had filled up with fine sand when the pump had been shut off and the pressure gradient reversed. When pumping was resumed only the one arm had washed clean.

With upward flow re-established, the shorter sand point was dropped in and went all the way down. While trying to get the jet assembly raised above the sand point it was discovered that the jet, while unattended, had twisted sideways. When lifted, the ends caught on the overlying hardened layer. It was believed that the arm thought to be filled with sand kept the assembly from being rotated back into position so that it could be lifted out of the hole.

The sandpoint acted as a piezometer, and water rose in it about four feet above the level of the ground.

When the fine screen sandpoint was pulled back up it was found to be relatively free of sand. After this it was put down in the hole again.

The riser pipe of the jetting assembly broke at the joint 5 ft. from the bottom. This was done while trying to work it loose.

After a pumping test had been made on the coarse natural sand left after the upward washing, 0.2 cu.yd. of filter no. 1 was put down and then on top of it 0.4 cu.yd. of filter no.2.

The 10 ft. of riser pipe which had broken off was used to jet the filter material to cause upward washing of the filter. Upward flow of water was too localized to develop a good vertically graded filter and failed to wash the necessary fines out of filter no. 2. Also there was considerable doubt that the filter was properly placed around the sandpoint.

Another pumping test was run, after which the well was left until after Experimental Well No. 2 had been completed.

Then about 5 cu.yd of filter no. 3 was used to fill up the well. It was jetted with the vertical pipe jet as before, with essentially the same results. A final pumping test was made.

Natural Soil and Filters

Fig. 7 shows by mechanical analysis the natural sorting and grading obtained with the upward flowing water. This is shown by comparing the mechanical analysis curve for the soil which was washed out of the well with the curve for the washed natural soils at the 7 and 12-ft. depths.

It was estimated that about 2 cu.yd. of fine sand washed out of the hole.

Filters no. 1,2, and 3 are also shown. Filter no. 2 as shown had too many fines in it, but it had been anticipated that these would wash out with the upward flow of the water from the jetting assembly. This was prevented when the jetting assembly was broken.

Filter no. 1 was an ordinary plaster sand, screened to pass a no. 8 sieve and be retained on a no. 40 sieve.

Filter no. 2 was the same plaster sand as no. 1, but was unscreened.

The basis for the design of filter no. 3 is given under Experimental Well No. 2.

Pumping Tests

The pumping test made on the washed natural sand before the filter was put down gave the following results. At the start 9.5 gpm were pumped at zero drawdown. After one hour and 15 minutes with a 9-3/4" drawdown, 8.5 gpm were pumped.

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After filters no. 1 and 2 had been put down, another pumping test was run. At the start 15 gpm were pumped. After $4\frac{1}{2}$ hours, with the drawdown at 36", 12 gpm were being pumped. The final test, after filter no. 3 had been added, started at 17 gpm with zero drawdown and ended at 10 gpm with a 42" drawdown.

The fines within the filter kept the water from dropping rapidly down to the bottom of the well, giving maximum drawdown immediately, as would have happened if it had been properly graded. This would have given greater discharges, and a wider radius of influence.

EXPERIMENTAL WELL NO. 2

Location

Experimental Well No. 2 was located on the Richard G. Meier farm, approximately 70 rods east and 13 rods south of the northwest corner of section 31, Township 15 North, range 1 east, Salt Lake Base and Meridian.

Jetting Assembly

The arms of the jetting assembly were of 2" black pipe 36" long with the ends forged closed to a wedge shape. As a result of the experience with Experimental Well No. 1 it was decided that the arms with two rows of holes as described under Experimental Well No. 1 should be used. The number and size of holes was modified, beginning from the outer end with small holes. The size was increased going toward the center tee as follows: 12 holes at 7/32", 13 at ¼", 14 at 9/32", and 28 at 5/16". In the tee, four 9/64" holes were spaced on one-inch centers. This hole spacing gave a fairly uniform water jet across the length of the jetting arms as illustrated in Figs. 8 and 9. Slightly larger holes could have been used in the tee. Braces were welded from the riser pipe to the jetting arms to give added strength. Also, the joints in the riser pipe were spot welded. This was done to keep the couplings from tightening up if it was necessary to use pipe wrenches on the riser pipe to rotate it back into position in case it twisted sideways as happened at Experimental Well No. 1. The riser pipe was 15 ft. long.

Water for Jetting

The water used for jetting was pumped from Drainage District No. 5's drain which runs north and south through Mr. Meier's farm.

A v-notch weir was installed in a ditch which carried the jetting water away from the well and was used to measure the discharges.

Jetting Procedure

To aid in preventing the jetting assembly from twisting sidewards, two sets of two piezometer tubes each, with 3.5 ft. between sets and one foot between tubes in each set as illustrated in Fig. 10, were jetted down into the clay.

A hole 6½ ft. long by 15" wide and 3½ ft. deep was dug through the surface soil between the piezometer sets and through the hardened sand layer which was encountered here as well as at Experimental Well No. 1.

The jetting assembly sank immediately at the rate of 2 ft. per minute down to the clay layer at the 10-ft. depth. One-half cfs of jetting water was being used. Pumping was continued for one hour until no more fine particles were washing out. Then the well-point assembly, consisting of the 5-ft. long Johnson well point, #15 slot, attached with a 90-degree ell to the riser pipe as illustrated in Fig. 11, was dropped into the hole.

Before dropping the well-point assembly, it was connected to another small pump and water was pumped down through and out of the well point. This outward flow prevented the inwash of sand such as occurred at Experimental Well No. 1.

Pumping continued through both jetting and well-point assemblies for another hour, the discharge being 2/3 of a sec.ft. The increased discharge brought up more fines. The pump supplying the jetting assembly was shut down to idling, after which 2½ cu. yds. of filter no. 3 was being shoveled into the hole. Upward washing was continued with 1/3 sec. ft. for another 45 minutes. Another 1½ cu. yds. of filter was put in, after which the jetting assembly was pulled out and pumping continued with the well point only. After 15 minutes of backwashing the hole was completely filled with the filter. Backwashing continued for another 15 minutes after which the pump was shut down.

When all water had disappeared from the top, the little pump was started up again. Immediately water appeared on top of the filter and sand boils commenced forming, showing the high permeability of the graded filter that had been developed. Before all the filter had been shoveled in, the ground for several feet around the well was becoming soft and some mud boils appeared in it because of the upward water pressure.

Natural Soil and Filters

Fig. 16 shows the mechanical analysis of the natural soil formations at the site of Experimental Well No. 2. It also shows the mechanical analysis of filter no. 3 which was used at this well. A comparison of mechanical analysis curves of the in-place filter shows the decided natural sorting and upward grading obtained by the upward flowing water.

From the results of the pumping test in which the water cleared so rapidly from silt, it is evident that there was also a horizontal grading of the filter outward from the well point.

In choosing filter no. 3, the design criteria recommended by the U. S. Waterways Experiment Station at Vicksburg, Mississippi was followed. (3) (7) It is:

a. The ratio of the 15% size of the filter to the 85% size of the sand should be less than 5.0.

b. The ratio of the 15% size of the filter to the 15% size of the base should be less than 20, and the ratio of the 50% size of the filter to the 50% size of the base should be less than 25.

c. The filter should also be uniformly graded from its maximum to its minimum size, with no large excess or lack of intermediate sizes.

d. The ratio of the 15% size of the filter to 15% size of the base should be greater than 4 so that the filter will have a permeability sufficiently greater than that of the base.

They also recommend that the ratio of the D_{85} size of the filter to the slot width of the collector pipe should be greater than 1.2 to prevent excess washing of the filter into the pipe. This ratio for the filter around the well point was 12.1. The ratios for the filters and sands are shown on Fig. 16.

On the basis of the above criteria, a uniformly graded filter passing a 0.33 inch sieve and retained on a no. 40 sieve was ordered. This filter, no. 3, as delivered, was a little finer than anticipated.

Because it was realized that the filter around the well point would be much more coarsely graded than the original,

the design of filter no. 3 required that its upper limits be about 20% (arbitrarily chosen) of the limits given above.

The figure shows that the ratio of the coarsest filter sample, F-6, to the natural sand at the same depth, N-6, was well within the U. S. Waterways recommendation, except for uniform grading.

The sample of the filter at the 9-ft. depth is believed to be finer than actually existed, since while the sample was being taken with a soil auger, some caving of the fines from shallower depths was taking place. It is believed that F-6 is more nearly representative of the filter at the 9-ft. depth.

Preliminary Pumping Test

Immediately after completion of installation of well and filter, a short pumping test was run to see how effectively the filter was working. After two minutes of pumping, a discharge measurement was taken. It was 60 gpm. Three minutes after pumping was started the water became clear of silt and remained so for another two minutes, after which it began showing signs of silt again, clearing up completely after ten minutes and remaining so for the rest of the pumping test. The discharge dropped steadily during the first hour, at which time 20 gpm were being pumped. At the end of another hour and 15 minutes, it was being maintained at 17 gpm.

Since the above test had been performed while the water table was high as a result of jetting operations, several days were allowed to elapse before another test was

run to allow the water table to return to a normal position.

The well discharge was measured by noting the time it took to fill a five-gallon can.

Water Table Measurements

Two lines of 4" auger holes were bored, one running north and south and the other east and west with the well at the center. Ground surface elevations were taken at each auger hole and then measurements were made from the ground surface to the water table with steel tapes. The static water table elevations and water table elevations during pumping were as shown in tables 1,2,3 and 4.

Pumping Test

A three-day pumping test was started the morning of April 22. Initial discharge was 60 gpm and illustrates the effectiveness and high permeability of the filter. After 15 minutes of pumping the discharge had dropped to 20 gpm. At the end of six hours it was being maintained at 15 gpm.

The next morning, April 23, 13.5 gpm were being pumped. That evening it had dropped to 12.5 gpm. The second morning, April 24, 12 gpm was being pumped, and the final morning, April 25, it had dropped to 11.75 gpm. Figs 17 and 18 illustrate the positions of the ground water, both north-south and east-west lines, before and during pumping.

Fig. 19 shows the time-discharge curve.

Permeability

The Thiem method for determination of permeability coefficient of pervious surface strata as described by Justin, Hinds and Creager (9) was used to determine the

permeability of the soil at the site. Fig. 20 illustrates the equation used with this method, and is basically the same as Fig. 2. It shows the method of using two observation holes to determine permeability. Also, Q is expressed in gpm instead of cf/day.

The values for calculating the permeability are recorded in tables 5 and 6. The permeability based on the cone of depression in the north-south plane averaged 9×10^{-4} ft./sec. Based on the east-west plane cone of depression it was 11×10^{-4} ft./sec.

Effective Well Radius

Because of the departure of the experimental well from the standard vertical type, it is difficult to determine a radius so that a comparison can be made between the discharge of horizontally-and vertically-placed well points. To arrive at a radius to use, it was decided to determine the equivalent diameter of the well. This dimension is defined as the equivalent diameter of a well and gravel filter, which, when installed in a pervious foundation, will have no entrance losses into the well. (7) To obtain this, use was made of the Thiem equation of well flow from a surface stratum: (See Fig. 20)

$$k = \frac{Q \log_{10} \frac{r_2}{r_1}}{1224\ m\ (s_1 - s_2)}$$

Solving this equation for r_1 gives,

$$\log_{10} r_1 = \log_{10} r_2 - \frac{1224\ k\ m\ (s_1 - s_2)}{Q} \qquad (2)$$

Let

$$r_2 = 5 \text{ ft.}$$

$$s_2 = 6.40 \text{ ft.}$$

$$s_1 = 10 \text{ ft.}$$

$$s_1 - s_2 = 3.60 \text{ ft.}$$

$$m = 1.80 \text{ ft.}$$

$$k = 9 \times 10^{-4} \text{ ft./sec.}$$

Substituting these values in equation 2 and solving for r_1, which is the effective well radius when $s_1 = 10$ ft., the maximum possible drawdown, gives

$$r_1 = 1.67 \text{ ft.}$$

As a further check, assign a second set of values as follows:

$$r_2 = 15 \text{ ft.}$$

$$s_2 = 6.01 \text{ ft.}$$

$$s_1 = 10 \text{ ft.}$$

$$s_1 - s_2 = 4.99 \text{ ft.}$$

$$m = 2.50 \text{ ft.}$$

$$k = 9 \times 10^{-4} \text{ ft./ sec.}$$

This gives

$$r_1 = 1.80 \text{ ft.}$$

For comparison with the vertically placed well point, an effective radius of 1.5 ft. was used.

Considering the amount of filter that could be placed around the vertical well point, as compared with the horizontal point, it is believed that a conservative effective radius was chosen when 0.5 ft. was assumed for the vertical point in the section on Justification for Type of Shallow Well.

PROPOSED WELL SYSTEMS

For drainage research work, it is proposed that one of the two following pumping plans be used.

1. Pump from six well units as a group, using a one-half-horsepower centrifugal pump. Arrange well units in a straight line and space at 100-ft. intervals. The pump will be placed midway between the two center wells. The center 300 ft. will be 2½" pipe, the outside 100 ft. on each side will be 2" pipe.

2. Pump from four well units as a group, using a one-third-horsepower centrifugal pump. Arrange and space as in plan 1. The center 100 ft. will be 2½" pipe, the outside 100 ft. on each side will be 2" pipe.

It is assumed that a 200-ft. length, 3"-dia., outlet pipe line will convey the pumped water into a canal or irrigation ditch, so that it can be used for irrigation purposes. The assumption is that each well unit will require 15 ft. of 2" dia. riser pipe.

The item which is hardest to predict in estimating the cost is the most economical well spacing. For research work it is suggested that valves be placed at each well unit so that the wells may be pumped individually and in groups to determine the effect of well spacing on discharge. Also, the valves will allow head loss adjustment so that maximum drawdown can be obtained simultaneously at each well.

The well spacing given above was tentatively chosen as a result of experiments in Kansas which are reported by Carl Rohwer. (8)

COST ANALYSES OF PROPOSED WELL SYSTEMS[1]

SIX-WELL SYSTEM

The cost of the 6-well system, the cost of the pump unit designed for the capacity and lift of the system, and the assumptions noted were used in making the following cost analysis.

Capital Costs

1.	well and extras (see table 7 for itemized estimate)	$ 1,036.40
2.	centrifugal pump, ½-hp.	125.00
	Total capital cost	$ 1,161.40

Annual Operating Cost

1.	power costs for pumping 12 months @ $4.53 per 30 day month[2]	$ 54.36
2.	maintenance @ $10 per year	10.00
3.	annual payment for amortization of capital (4% interest, 20 year life)	85.46
	Total annual operating cost	$ 149.82

Cost per Acre

The assumption is made that pumping will continue throughout the year, that each well will yield an average of 8 gpm when pumped individually, or that the average yield per well will be 6 gpm when pumping the whole system.(8) This will give 36 gpm average annual discharge for the system. It is also assumed that one acre-foot of water per acre per year must

---

1/ Only meager and preliminary data concerning costs of pumping facilities and well installations and development are now available. Cost estimates are, therefore, of necessity based on approximations and assumptions, both of which will change as further factual data become available.

2/ Rate figured from schedule #24, irrigation and drainage pumping power service of the Utah Power and Light Company.

be removed by artificial drainage, and that of this 2/3 acre-foot must be removed by pumping. The other 1/3 acre-foot is assumed to be removed as spring runoff by existing open drains.

Since one gpm flowing one year is equivalent to 1.61 acre-feet, 36 gpm yields 58 acre-feet of water, or the excess water from 87 acres.

Assuming a 20-year life of the well system, the annual payment will be $1.72 per acre per year.

If the total capital cost plus the first year's annual power and maintenance cost is paid for the first year, then the cost per acre the first year will be $14.10. Following years, the cost would be the annual power and maintenance cost of $0.74 per acre per year.

If the value of the pumped water for irrigation is allowed, this cost reduces to $0.18 per acre per year.

Use of Pumped Water for Irrigation

Based on the Van Orden report and a verbal conversation with Mr. Nyman of the Federal Land Bank, Logan, Utah, water in the Lewiston Area has a value of at least $2.00 per acre-foot.

During a 5-month irrigation season the volume of water pumped at the rate of 36 gpm is 24.15 acre-feet. The value of this water at $2.00 per acre-foot would be $48.30. This amounts to 75% of the annual power and maintenance cost.

FOUR-WELL SYSTEM

The cost analyses of the 4-well system with pump, etc., follows:

Capital Costs

1.	well and extras (see table 8 for itemized estimate)	$ 760.68
2.	centrifugal pump, 1/3-hp.	105.00
	Total capital costs	$ 865.68

Annual Operating Cost

1.	power cost for pumping 12 months @ $3.71 per 30-day month.	$ 44.52
2.	maintenance @ $10 per year	10.00
3.	annual payment for amortization of capital (4% interest, 20-year life)	63.70
	Total annual operating cost	$ 118.22

Cost per Acre

Making the same assumptions as for the 6-well plan, the 24-gpm discharge will remove excess water from 58 acres.

Assuming a 20-year life of the well system, the annual payment will be $2.04 per acre per year.

If the capital cost plus the first year's annual power and maintenance cost is paid for the first year, then the cost per acre the first year will be $15.87. Following years the cost would be the annual power and maintenance cost of $0.94 per acre per year. Allowing for the value of the water for irrigation, this reduces to $0.39 per acre per year.

Use of Pumped Water for Irrigation

Making the same assumptions as before, the value of the water pumped each year would be $32.16. This will pay 59% of the annual power and maintenance cost.

SUMMARY

The purpose of the investigation was to determine if a method could be devised to place a well point in a horizontal position on the clay layer and develop a satisfactory filter around it. A further purpose was to determine if this could be made an effective and economical method for drainage of the shallow sandy soils in the Lewiston Area.

Two experimental wells were put down in seeking to develop a satisfactory procedure for installing horizontal, gravel-packed well points. Well No. 1 primarily answered the questions:

1. What type of jetting assembly would be satisfactory, and

2. How to put the well point down so that it would not fill with sand.

The jetting assembly as described in this report was satisfactory. However, it is suggested that in any future work the four 9/64" holes in the tee be enlarged to 3/16" diameter. This will give a more uniform water jet across the length of the jetting arms. The well point can be prevented from filling with sand if water is pumped down and out through it while being lowered into the hole.

Well No. 2 showed that:

1. The jetting assembly designed as a result of experience gained at Well No. 1 was satisfactory.

2. Filter no. 3 would develop stable filters at all depths. A comparison of F-6, the coarsest washed filter

at Well No. 2 with the washed natural sands at Well No. 1, as illustrated in Fig. 7, indicates that it would be entirely stable here also. From this it is believed that this filter is adequate for any of the soils encountered in the northwest Lewiston Area.

3. The soils in this location are highly permeable, and provided well-discharge data from which a cost estimate could be prepared.

Subject to further experimental work of the proposed well systems, the estimated cost analysis, which was based on results of the data obtained during the course of this investigation, indicates the probability that drainage by pumping from horizontal gravel-packed well points is practical and economically feasible.

BIBLIOGRAPHY

(1) Conference on Control of Underseepage. U. S. Waterways Experiment Station, Vicksburg, Mississippi. April 1, 1945.

(2) Davis, Sterling, "The Drainage Problem in the Lewiston Area, Utah." Unpublished M.S. Thesis, Utah State Agricultural College, Logan, Utah. May, 1948.

(3) Field and Laboratory Investigation of Design Criteria for Drainage Wells. U. S. Waterways Experiment Station, Vicksburg, Mississippi. Tech. Memo. No. 195-1. July, 1924.

(4) Hart, R. A. and Adams, T. C., "Drainage Investigations on Sub-Irrigated Land, Lewiston, Utah." Division of Agricultural Engineering, U.S.D.A., July, 1924.

(5) Harza, L. F., "Uplift and Seepage Under Dams on Sand." Trans. American Society Civil Engineers. Vol. 100, 1935, p. 1376.

(6) Humphrey Brothers, "Engineer's Report to Supervisor, Drainage District No. 3, Cache County, Utah, " U.S. Reclamation Service. Dec. 13, 1926.

(7) Investigation of Wooden Well Screens for Grenada, Enid and Sardis Dams. U. S. Waterways Experiment Station, Vicksburg, Mississippi. Tech. Memo. No. 3-250, pp. 16, 21. February, 1948.

(8) Rohwer, Carl, "Putting Down and Developing Wells for Irrigation." Division of Irrigation, Soil Conservation Service, U.S.D.A. Circular No. 546.pp. 17-18 February, 1940.

(9) Justin, Jel D.,; Hinds, Julian; and Creager, Wm. P., Engineering for Dams, Vol. III. New York; John Wiley and Sons, Ind., 1947. p. 652.

(10) Williams, J. Stewart; Maughan, Howard; and Israelson, O. W., "Irrigation and Drainage Problems in the Lewiston Area." Farm and Home Science, Vol. 10, No. 1, p. 9. Utah Agricultural Experiment Station. March, 1949.

(11) Van Orden, E. M., Watermaster Cub River Irrigation Co. Report to Prof. A. A. Bishop, Utah State Agricultural College, Logan, Utah.

FIGURES

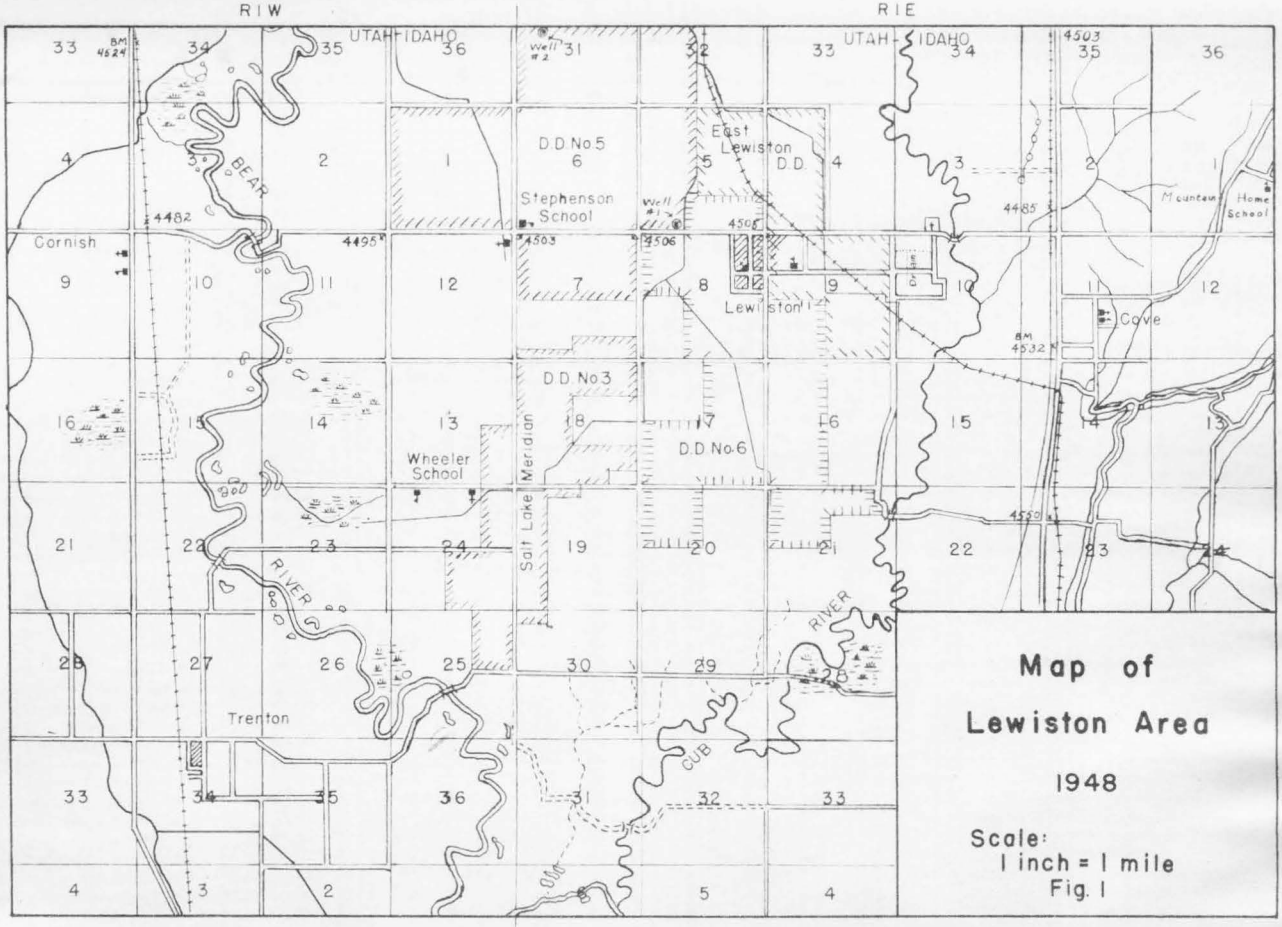
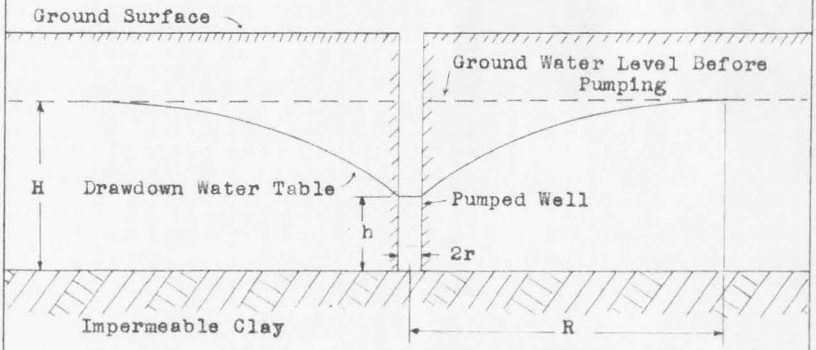

R1W
R1E
T15N
T14N
UTAH
IDAHO
BEAR
RIVER
CUB
RIVER
Salt Lake Meridian
Cornish
Trenton
Wheeler School
Stephenson School
D.D. No.5
D.D. No.3
D.D. No.6
East Lewiston D.D.
Lewiston
Cove
Mountain Home School
Well #2
Well #1
BM 4624
BM 4532
4482
4495
4503
4506
4508
4485
4503
4508
Map of
Lewiston Area
1948
Scale:
1 inch = 1 mile
Fig. 1

Fig. 2

Pumping From Surface Stratum



$$Q = \pi k \frac{H^2 - h^2}{2.3 \log_{10} \frac{R}{r}}$$

Q = rate of extraction in cubic feet per day

k = coefficient of permeability in feet per day

r = radius of well in feet

R = radius of circle of influence in feet

h = distance from well bottom to draw down curve in feet

H = distance from well bottom to original water table in feet

Fig. 3. Jetting assembly showing the white bands around the riser pipe at 5-ft. intervals.

Fig. 4. Another view of the jetting assembly, showing holes in the jetting arms.

Fig. 5. Ell-shaped well-point assembly, #15 slot, 48" screen, Ed. E. Johnson Co. well point.

Fig. 6. Fine wire mesh sand point, 30" perforated and 42" overall length.

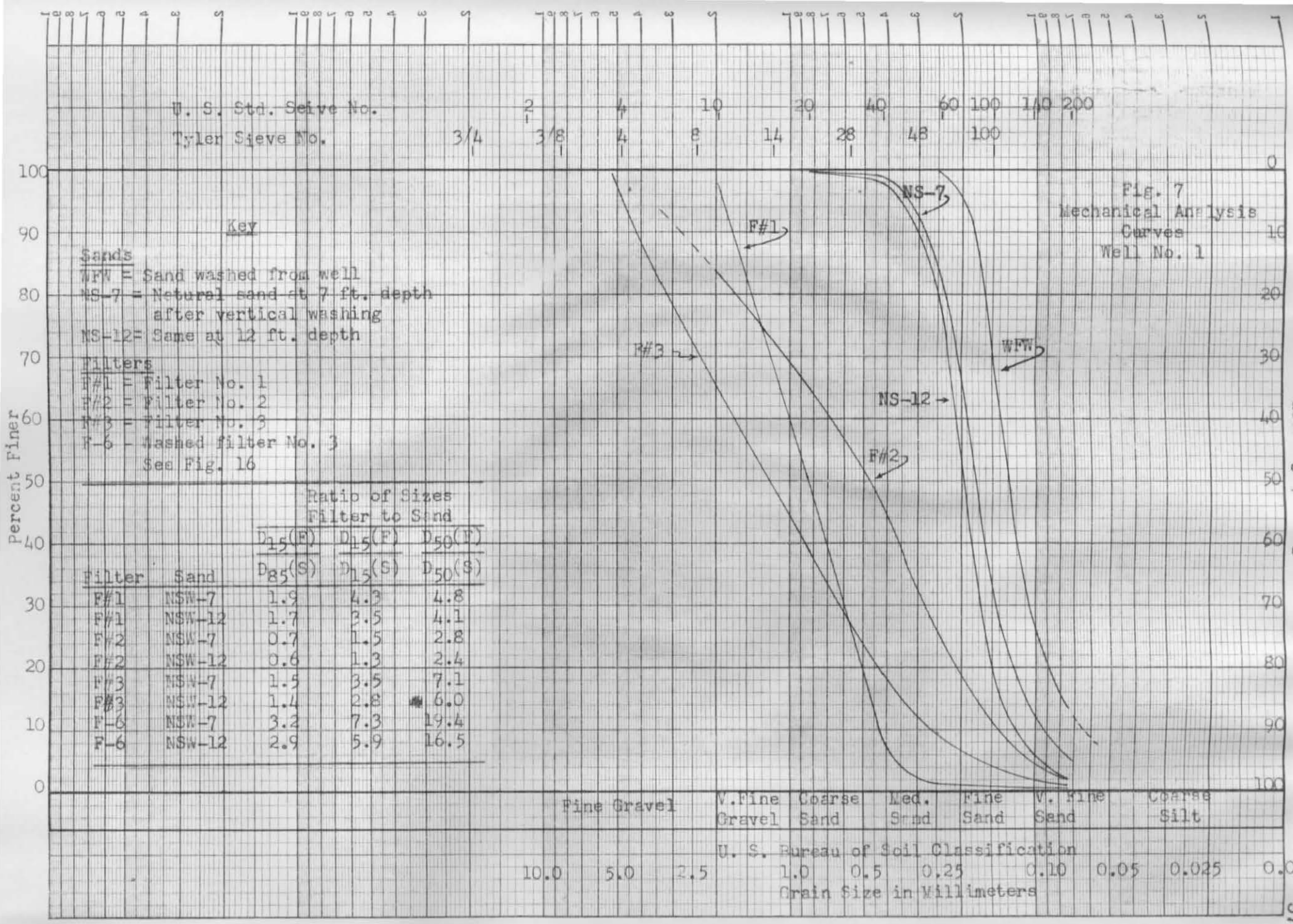


Fig. 7
Mechanical Analysis
Curves
Well No. 1

Key

Sands
WFW = Sand washed from well
NS-7 = Natural sand at 7 ft. depth after vertical washing
NS-12 = Same at 12 ft. depth

Filters
F#1 = Filter No. 1
F#2 = Filter No. 2
F#3 = Filter No. 3
F-6 - Dashed filter No. 3 See Fig. 16

Filter	Sand	Ratio of Sizes Filter to Sand $\frac{D_{15}(F)}{D_{85}(S)}$	$\frac{D_{15}(F)}{D_{15}(S)}$	$\frac{D_{50}(F)}{D_{50}(S)}$
F#1	NSW-7	1.9	4.3	4.8
F#1	NSW-12	1.7	3.5	4.1
F#2	NSW-7	0.7	1.5	2.8
F#2	NSW-12	0.6	1.3	2.4
F#3	NSW-7	1.5	3.5	7.1
F#3	NSW-12	1.4	2.8	6.0
F-6	NSW-7	3.2	7.3	19.4
F-6	NSW-12	2.9	5.9	16.5

Fig. 8. Pumping through the jetting assembly before sinking Well No. 2.

Fig. 9. Another view of the jetting assembly showing the length of the jetting arms.

Fig. 10. Jetting assembly has just reached the clay. One-half cfs of jetting water is flowing away in the ditch shown at the bottom of the picture. Two sets of piezometer tubes were used to keep the jetting assembly from twisting.

Fig. 11. Ready to drop the well-point assembly into the hole. The large pump supplying the jet assembly is pumping out of an open drain. The small gasoline pump was used in the pumping tests.

Fig. 12. Another view of the well-point assembly. Compare the position of the boards in this picture with Figs. 13, 14, and 15. This shows caving of the soil on the right side of the well. More time spent in preliminary pumping than necessary.

Fig. 13. Pumping up through the filter using the well point. The jet assembly has been withdrawn.

Fig. 14. After pumping was stopped, water flowed downward through the filter.

Fig. 15. Sand boils appeared on top of the filter immediately after the pump was started, showing that a pervious filter had been obtained.

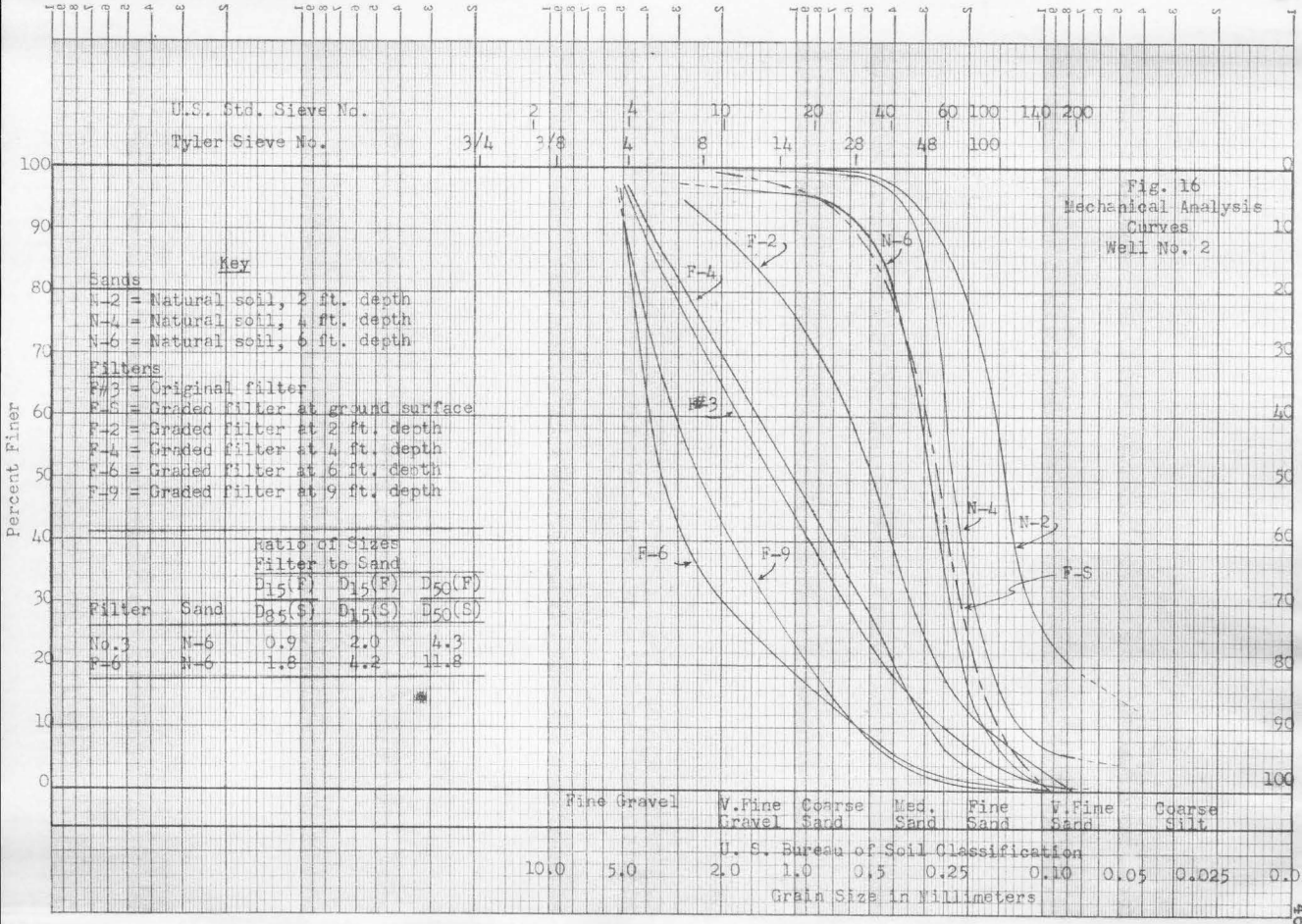


Fig. 16
Mechanical Analysis Curves
Well No. 2

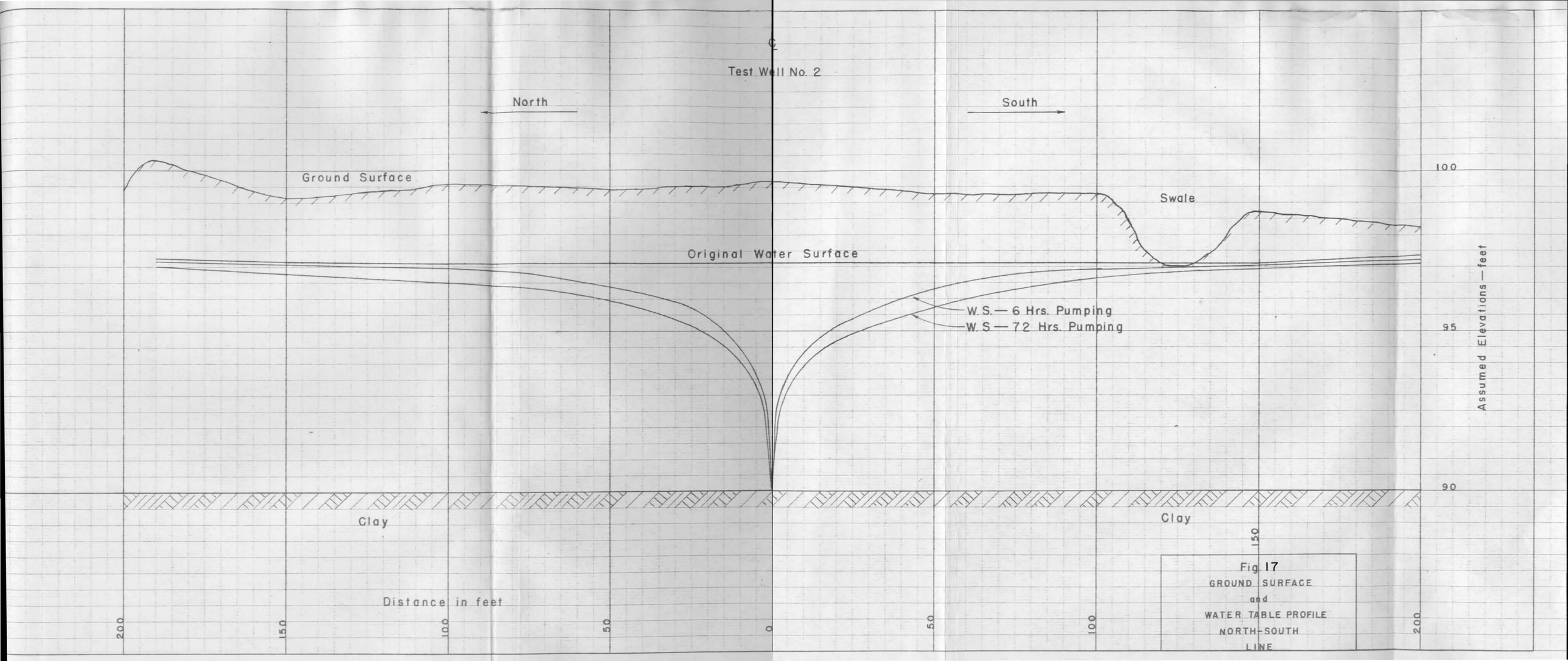


Fig. 17
GROUND SURFACE
and
WATER TABLE PROFILE
NORTH-SOUTH
LINE

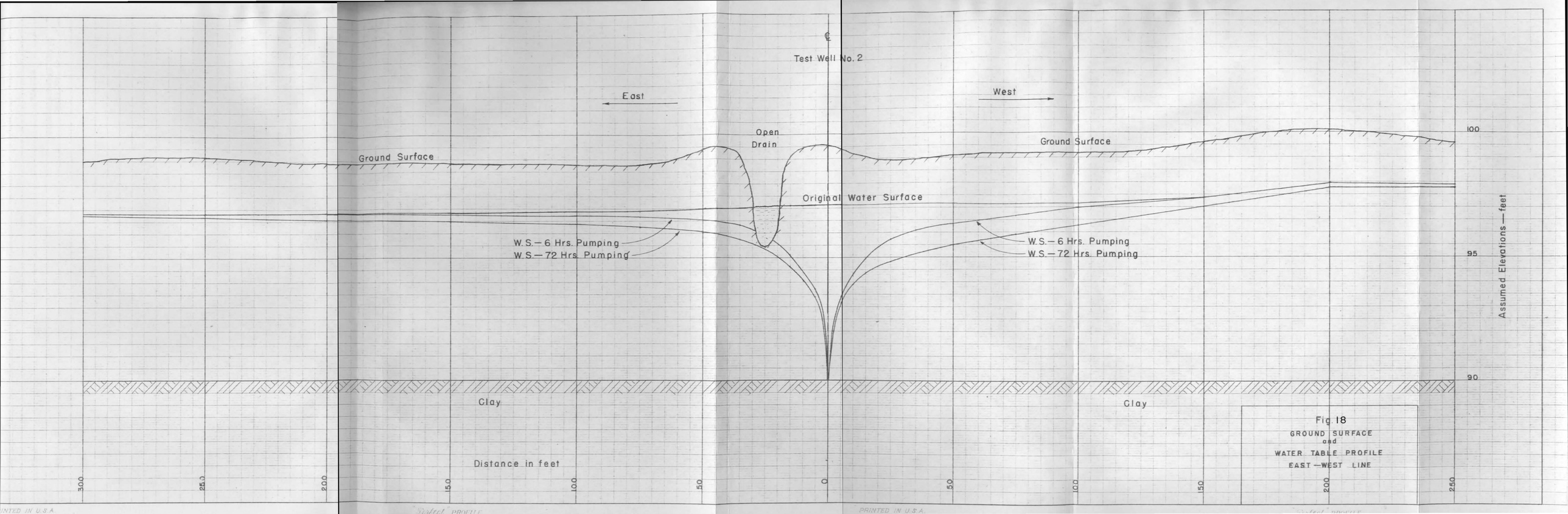


Fig. 18
GROUND SURFACE
and
WATER TABLE PROFILE
EAST—WEST LINE

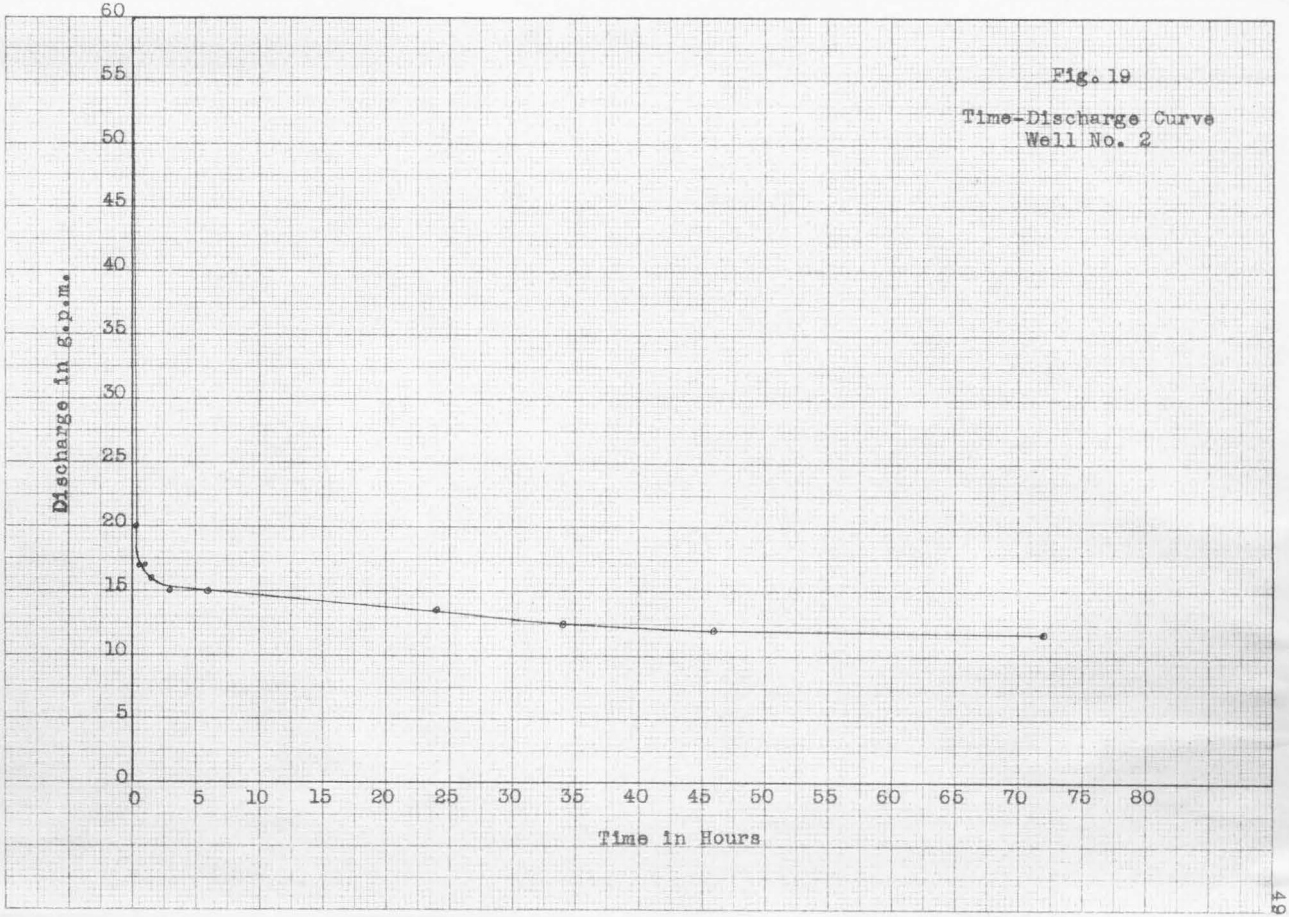
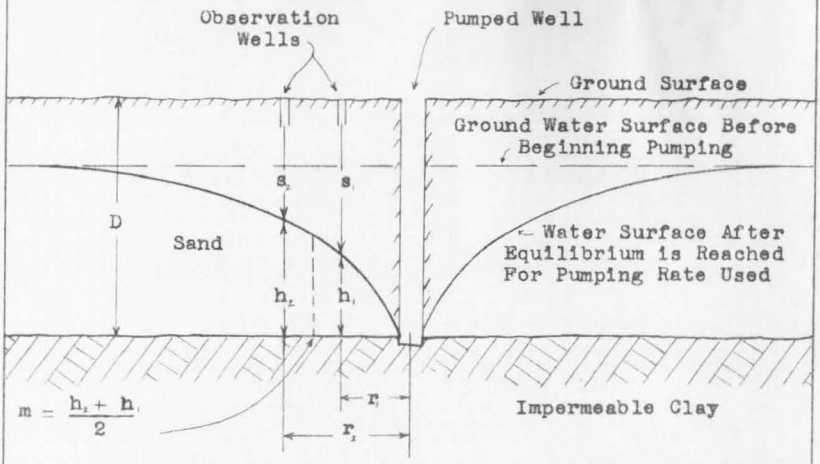


Fig. 19

Time-Discharge Curve
Well No. 2



$$m = \frac{h_2 + h_1}{2}$$

$$= D - \frac{s_2 + s_1}{2}$$

$$k = \frac{Q \log_{10} \frac{r_2}{r_1}}{1224\ m\ (s_1 - s_2)}$$

where k = coefficient of permeability in feet per second

Q = rate of pumping in gallons per minute

r_1 and r_2 = distances from pumped well to two observation wells, in feet

h_1 and h_2 = depth of water in observation wells during pumping, in feet

s_1 and s_2 = distances from datum plane to drawdown curve at observation wells, in feet

D = distance from clay layer to datum plane, in feet

m = average vertical thickness of the saturated portion of the water-bearing bed between the two observation wells, in feet

Fig. 20

Pumping from Surface Stratum
Thiem Formula

TABLES

Table 1. Water table elevations at Well No. 2, before and during pumping test. Discharges are also shown. Initial discharge was 60 gpm. North line. Assumed elevations.

Station	Elevation ground surface	Static water table elevation	Time from beginning of pumping				
			6 hrs.	24 hrs.	34 hrs.	46 hrs.	72 hrs.
			Discharge in gpm				
			15	13.5	12.5	12	11.75
	feet	feet	Elevation Water Table While Pumping - Feet				
North 05	99.71	97.15	93.67	93.67	93.65	93.48	93.38
10	99.54	97.12	94.42	94.42	94.37	94.16	94.06
15	99.56	97.12	94.98	94.81	94.68	94.60	94.50
25	99.47	97.12	95.76	95.39	95.37	95.22	95.17
50	99.38	97.09	96.34	96.15	96.09	96.02	95.88
75	99.48	97.10	96.81	96.61	96.56	96.48	96.36
100	99.57	97.07	96.95	96.72	96.67	96.61	96.47
150	99.16	97.14	97.08	97.00	97.00	96.93	96.78
190	100.30	97.26	97.13	97.11	97.11	97.05	97.01

Table 2. Water table elevations at Well No. 2, before and during pumping test. Discharges are also shown. Initial discharge was 60 gpm. South line. Assumed elevations.

Station	Elevation ground surface	Static water table elevation	Time from beginning of pumping				
			6 hrs.	24 hrs.	34 hrs.	46 hrs.	72 hrs.
			Discharge in gpm				
			15	13.5	12.5	12	11.75
	feet	feet	Elevation Water Table While Pumping - Feet				
South 05	98.94	97.07	93.58	93.46	93.48	93.26	93.19
10	98.90	97.15	94.15	94.15	94.09	93.98	93.86
15	99.55	97.10	94.93	94.63	94.63	94.47	94.38
25	99.43	97.12	95.35	95.27	95.04	95.00	94.93
50	99.26	97.10	96.30	96.05	95.92	95.86	95.72
75	99.25	97.09	96.75	96.54	96.43	96.39	96.27
100	99.26	97.05	96.89	96.82	96.74	96.72	96.63
150	98.69	97.11	97.02	97.07	97.02	97.02	96.94
200	98.22	97.39	97.22	97.30	97.18	97.22	97.10

At station 125 ft. S. there was a pond, water elevation of which was 97.10 ft.

Table 3. Water table elevations at Well No. 2, before and during pumping test. Discharges are also shown. Initial discharge was 60 gpm. East line. Assumed elevations.

Station	Elevation ground surface	Static water table elevation	Time from beginning of pumping				
			6 hrs.	24 hrs.	34 hrs.	46 hrs.	72 hrs.
			Discharge in gpm				
			15	13.5	12.5	12	11.75
	feet	feet	Elevation Water Table While Pumping - Feet				
East 05	99.58	97.12	93.72	93.66	93.71	93.52	93.41
10	99.45	97.11	94.33	94.28	94.26	94.20	94.05
15	99.07	97.10	95.11	94.97	94.86	94.78	94.66
35	99.11	97.03	96.32	96.07	96.01	95.92	95.74
50	99.45	96.99	96.53	96.33	96.33	96.18	96.04
75	98.80	96.88	96.65	96.49	96.45	96.36	96.24
100	98.80	96.90	96.76	96.59	96.55	96.47	96.38
150	98.85	96.83	96.73	96.66	96.60	96.56	96.48
200	98.94	96.84	96.82	96.69	96.67	96.61	96.55
250	99.15	96.80		96.80	96.80	96.73	96.69
300	98.99	96.83		96.83	96.83	96.76	96.72

Elevation of bottom of drain at station 25 ft. E was 95.41 ft. The elevation of water in drain was 97.09 ft.

Table 4. Water table elevations at Well No. 2, before and during pumping test. Discharges are also shown. Initial discharge was 60 gpm. West line. Assumed elevations.

Station	Elevation ground surface	Static water table elevation	Time from beginning of pumping				
			6 hrs.	24 hrs.	34 hrs.	46 hrs.	72 hrs.
			Discharge in gpm				
			15	13.5	12.5	12	11.75
	feet	feet	Elevation Water Table While Pumping - Feet				
West 05	99.39	97.14	93.43	93.31	93.31	93.14	93.10
10	99.20	97.12	94.24	94.12	94.12	93.99	93.91
15	99.07	97.13	94.94	94.61	94.65	94.49	94.36
25	98.93	97.18	95.72	95.18	95.14	94.91	94.81
50	99.09	97.15	96.34	95.92	95.84	95.69	95.51
75	99.17	97.13	96.67	96.34	96.23	96.09	95.90
100	99.17	97.15	97.00	96.67	96.59	96.46	96.27
150	99.62	97.39	97.33	96.27	97.23	97.14	97.00
200	100.10	98.00	97.98	97.91	97.91	97.85	97.79
250	99.55	97.88		97.88	97.88	97.84	97.76

Table 5. Permeabilities at Well No. 2 as Determined by the Thiem Formula --North-south Vertical Plane.

Horizontal distance from axis of well feet		Distance from datum plane to drawdown curve feet		Average thickness water-bearing sands between obser. wells feet	Permeability of soil formation ft./sec.
r_1	r_2	s_1 1/	s_2 1/	m	k
15	25	5.04	4.44	5.26	9×10^{-4}
15	50	5.04	3.68	5.64	8×10^{-4}
15	100	5.04	3.08	5.94	9×10^{-4}
15	150	5.04	2.95	6.00	10×10^{-4}
25	50	4.44	3.68	5.94	8×10^{-4}
25	100	4.44	3.08	6.24	9×10^{-4}
25	150	4.44	2.95	6.30	10×10^{-4}
50	100	3.68	3.08	6.62	9×10^{-4}
50	150	3.68	2.95	6.69	12×10^{-4}
				Average	9×10^{-4}

1/ Average of the north and south readings. The symbols are described in Fig. 20. An average discharge of 15 gpm was used for all calculations.

Assumption: (1) That the clay layer, land surface, and original water surface are horizontal
(2) That the distance from the land surface/datum plane to the clay layer is 10 ft.

Table 6. Permeabilities at Well No. 2 as Determined by the Thiem Formula -- East-west Vertical Plane.

Horizontal distance from axis of well feet		Distance from datum plane to drawdown curve feet		Average thickness water-bearing sand between obser. wells feet	Permeability of soil formation ft./sec.
r_1	r_2	s_1 1/	s_2 1/	m	k
5	15	6.43	4.98	4.30	9×10^{-4}
15	50	4.98	3.56	5.73	8×10^{-4}
15	75	4.98	3.34	5.84	9×10^{-4}
15	100	4.98	3.12	5.95	9×10^{-4}
50	75	3.56	3.34	6.55	15×10^{-4}
50	100	3.56	3.12	6.66	13×10^{-4}
50	150	3.56	2.96	6.74	14×10^{-4}
50	200	3.56	2.60	6.92	11×10^{-4}
75	100	3.34	3.12	6.77	10×10^{-4}
100	200	3.12	2.60	7.14	10×10^{-4}
				Average	11×10^{-4}

1/ Average of the east and west readings. The symbols are described in Fig. 20. An average discharge of 15 gpm was used for all calculations.

Assumption: (1) That the clay layer, land surface, and the original water surface are horizontal.

(2) That the distance from the land surface datum plane to the clay layer is 10 ft.

Table 7. Capital Cost Estimate for Six-Well System

Quantity	Item	Unit Cost	Total
Equipment and Supplies			
6	2" well points, #15 slot, Ed. E. Johnson Company	$ 8.50	$ 51.00
290 ft.	2" black pipe	0.44	127.60
300 ft.	2½" black pipe	0.62	186.00
200 ft.	3" black pipe	0.91	182.00
8	2" black ells	1.16	9.28
5	2½" black tees	2.94	14.70
6	2½" to 2" black reducers	1.74	10.44
6	2" black couplings	0.83	4.98
6	2" gate valves	8.50	51.00
1	3" gate valve	12.00	12.00
30 cu. yds.	gravel filter, del. at site	2.20	66.00
Rental			
1	pump for jetting, one cfs capacity	25.00	25.00
Labor			
2	men, 8 days per day	8.00	128.00
	Sub-total		868.00
	add 5% for miscellaneous items		43.40
			911.40
Power			
1	centrifugal pump, ½-hp.	125.00	125.00
	Total		$ 1,036.40

Table 8. Capital Cost Estimate for Four-Well System

Quantity	Item	Unit Cost	Total
Equipment and Supplies			
4	2" well points, #15 slot, Ed. E. Johnson Company	$ 8.50	$ 34.00
260 ft.	2" black pipe	0.44	114.40
100 ft.	2½" black pipe	0.62	62.00
200 ft.	3" black pipe	0.91	182.00
6	2" black ells	1.16	6.96
3	2½" black tees	2.94	8.82
4	2½" to 2" black reducers	1.74	6.96
4	2" black couplings	0.83	3.32
4	2" gate valves	8.50	34.00
1	3" gate valve	12.00	12.00
20 cu.yds.	gravel filter, del. at site	2.20	44.00
Rental			
1	pump for jetting, one cfs capacity	20.00	20.00
Labor			
2	men, 6 days	per day 8.00	96.00
	Sub-total		624.46
	add 5% for miscellaneous items		31.22
			655.68
Power			
1	centrifugal pump, 1/3-hp.	105.00	105.00
	Total		$ 760.68