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Pump Test of an Alluvial Aquifer at Redcliff (and results)

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PUMP TEST OF AN ALLUVIAL AQUIFER AT REDCLIFF, ALBERTA

OCTOBER, 1966

Synopsis

This report describes the results of a 3-day constant-rate pump test of an alluvial aquifer on the north shore of the South Saskatchewan River in section 6, township 13, range 6, west of the 4th meridian. The purpose of the test was to assess the water-supply potential of the aquifer and, in particular, to determine its suitability for an induced-infiltration supply for the town of Redcliff. Such a supply, if feasible, could yield water in amounts capable of meeting municipal and industrial demands.

The test involved, in addition to the pumped well, four observation wells. Anomalous drawdown results were obtained in one of the wells and another failed to respond at all to the test pumping. The remaining test data indicated that there was no perceptible infiltration of water from the river and that the lateral dimensions of the aquifer were severely limited in at least one direction. There is, therefore, no possibility for the development of an induced-infiltration supply and the potential for any other groundwater development is limited.

The computed transmissibility, hydraulic conductivity, and storage coefficient based on the constant-rate test results were 61,000 imperial gallons per day per foot (igpd/ft), 6,100 imperial gallons per day per square foot (igpd/ft^2), and 0.022, respectively. These results were combined with those from a step-drawdown test to obtain a calculated 20-year single-well safe yield of 27.8 imperial gallons per minute (igpm). This estimate is probably optimistic because it assumes that the pumped-well drawdown trend in effect at the end of the pump test would be main-

tained for the rest of the 20-year production period. This is unlikely because of the probable limited areal extent of the aquifer. The estimate applies specifically to the well pumped during the test. It will not be valid for another well tapping the aquifer unless

(a) aquifer thickness and lithology are the same at both well sites,

(b) available drawdown i.e. the vertical distance from the undisturbed water table to the top of the well screen, is the same at both sites, and

(c) well construction and development are the same for both wells.

Finally, it should be pointed out that, although production can be increased by increasing the number of production wells, interference between wells will restrict the gains to be made thereby. In other words, doubling or tripling the number of wells, will fall considerably short of doubling or tripling the total safe yield. Thus, even under a wellfield type of development, the potential of the aquifer is low and is probably less than 100 igpm.

Description of the Aquifer and Locations of Wells

The aquifer tested is an alluvial deposit consisting of gravel and coarse sand along the north bank of the South Saskatchewan River in Sec. 6, Tp. 13, R. 6, W. 4th Mer., near the town of Redcliff, Alberta. The lateral extent of the aquifer is not known. From the stratigraphic logs obtained during previous test drilling (Fig. 1), the saturated thickness of the aquifer appears to be approximately 10 feet, the basal 2 feet of which consist of coarse sand or fine gravel, and the top 8 feet of coarse gravel. The aquifer is unconfined and the water levels are generally below the top of the gravel. The gravel is, in general, overlain by 5 to 15 feet of clay or silt. Figure 2, prepared by the Engineering Department of the City of Medicine Hat, shows the locations of the test holes from which the stratigraphic logs were obtained.

Table 1 lists the locations and elevations of those test holes that were used as production well and observation wells for the pump test.

Table 1. Locations and Elevations of Production and Observation Wells

Well No.	Distance from pumped well (feet)	Direction from pumped well	Elevation* (feet)
1	90	N 45° E	+80.60
2	302	N 64.5° E	+79.77
3	136	N 84° W	+80.95
5	0	-	+70.88
6	2	N 90° W	+76.73

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*All elevations are measured at the top of the casing and in reference to a benchmark at the pump house.

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River Efficiency of the Wells

Figures 3, 4, and 5 illustrate the response of the water levels in wells 1, 2, and 5, respectively, to changes in the level of the South Saskatchewan River. The river efficiency appears to be very close to 100 per cent for all three wells. During the pump test, river levels were measured at the same time as those in the wells (Appendix A) and the drawdown measurements were corrected accordingly.

Constant-Rate Test

well #5

During the constant-rate test, the well was pumped for 4,275 minutes at an average rate of 85 igpm. Because no proper device was installed to regulate the flow, a gradual decline in the pumping rate from 94 igpm at the beginning of the test to 83 igpm at the end could not be avoided (Fig. 10). This means a deviation of 13 per cent, which is generally considered above the acceptable limit for a first-class test. The results are nevertheless felt to be adequate for a reasonable assessment of aquifer potential.

Drawdown in the Pumped Well

The observed drawdowns in the pumped well were corrected for changes in water level due to changes in river level (Appendix B) and plotted against the logarithm of time (Fig. 7). The graph exhibits a steadily increasing downward slope, very similar to those for time-drawdown graphs obtained from wells pumping from a strip aquifer (an aquifer bounded by two parallel impermeable boundaries). There is no indication of stabilization of the drawdown due to infiltration from the river.

Drawdowns in Observation Well No. 3

The water levels measured in observation well No. 3 permit the evaluation of the transmissibility and storage coefficient of the aquifer. The analysis used here was the nonleaky artesian type curve method (Walton, 1962; Ferris et al., 1962).

In the case of a water-table aquifer, an adjustment must be made to the observed drawdown measurements to compensate for the decrease in transmissibility due to dewatering of the aquifer, after which the method as outlined above can be applied. The corrected drawdown is calculated from

$$s' = s - s^2/2m \tag{1}$$

where s' = corrected drawdown, in feet

m = the thickness of the aquifer, in feet.

Appendix C gives the observed water levels, the nonpumping level corrected for the change in river level, the measured drawdowns (s), and the corrected drawdowns, s'; s' is plotted against t in figure 8.

If the aquifer is not of infinite areal extent, but impermeable boundaries are present at not too great a distance from the pumping well, the drawdown curve will start to deviate from the type curve after a certain length of time. The excess drawdown can be considered as being caused by one or more "image wells," pumping at the same rate as the real well (Walton, 1962; Ferris et al., 1962).

In figure 8 the uppermost heavy line is the type curve matched to the early part of the drawdown curve. Assuming that the match is made correctly, the type curve represents that part of the drawdown which is caused by the real well. The deviation, indicated by the shaded area, represents the part of the drawdown caused by the image well(s).

In general, when the deviation is again plotted against the time, the resulting curve, or part of it, can be matched with the type curve. Because T is already known from the first match, this match must be made in such a way that the same T results, or in other words, the shift from the first to the second matched position must be made parallel to the t or u axis. In the present case, however, it was found that no reasonable match could be obtained in this manner. The assumption was then made that the observed deviation was the result of two image wells, located at approximately the same distance from the observation well, so that the influence of both image wells was felt at the same time; therefore, one half of the deviation or the effect of one image well was plotted against time (the squares in Fig. 8). Using the values of T and S obtained from the first match and u and t from the second matchpoint, the distance r between the observation well and the image well can be found.

Calculation of T, K, S, and r

From matchpoint 1:

$W(u) = 1$

$u = .1$

$s = .16$ feet

$t = 150$ minutes;

from $S = 114.6\,Q\,W(u)/T$ or $T = 114.6Q\,W(u)/S$

$T = 114.6 \times 85 \times 1/.16 = 61{,}000$ igpd/ft

$K = T/m = 6{,}100$ igpd/ft^2;

from $S = uTt/2{,}242r^2$

$S = 0.1 \times 61{,}000 \times 150/(2{,}242 \times 136^2) = .022$;

from matchpoint 2 we find

$u = .1$

$t = 1{,}380$ minutes;

and from $r = \sqrt{uTt/2{,}242S} = \sqrt{.1 \times 61{,}000 \times 1{,}380/(2{,}242 \times .022}$

$= \sqrt{170{,}000} = 412$ feet

Drawdowns in Other Observation Wells

Water levels in observation well No. 1 were measured with an automatic recorder; records obtained over a period of two weeks previous to the test showed large fluctuations in the water level, which could not be interpreted as response to changes in river level. The cause of these fluctuations could not be explained in any other way. The records obtained during the test showed clearly that the water level was responding to the pumping, but the movement of the water level was so erratic that the data could not be used for a determination of the aquifer constants.

Observation well No. 2 failed to respond to the pumping. The total drop in water level at the end of the test was only 0.05 feet. If the values of T and S obtained from observation well No. 3 are accepted as valid, the drawdown to be expected in well No. 2 is calculated as 0.45 feet.

Observation well No. 6 responded normally to the pumping. The results, however, were not further analyzed because the well was so close to the pumping well. It is very likely that the transmissibility at this point has been affected appreciably by the drilling, the development, and the pumping of the well. The transmissibility calculated from the data for this observation well would therefore have no significance for the evaluation of the potential of the aquifer.

Location of Impermeable Boundaries

Although the postulated image wells may be located anywhere on the circle of radius r = 412 feet and center at well No. 3 (Fig. 9), the fact that no drawdown occurred at well No. 2 indicates that an impermeable boundary exists somewhere between the pumping well and well No. 2. A possible location of the impermeable boundary is therefore shown in figure 9.

Step-Drawdown Test

A step-drawdown test was conducted two weeks after the main test. At this time the water level in the pumped well had recovered completely. The test consisted of the following steps:

Step 1, duration 50 minutes, pumping rate 62.5 igpm (imperial gallons per minute)

Step 2, duration 50 minutes, pumping rate 77 igpm

Step 3, duration 50 minutes, pumping rate 86 igpm

The measured drawdowns are plotted against the logarithm of the time since each step began (Fig. 6). From the graph the ratio $(s_w/Q)_n$ is calculated:

$$(s_w/Q)_1 = 2.21/62.5 = .0354 \text{ ft/igpm}$$

$$(s_w/Q)_2 = (2.66 - 2.28 + 2.21)/77 = .0337 \text{ ft/igpm}$$

$$(s_w/Q)_3 = (3.29 - 2.73 + 2.59)/86 = ..0366 \text{ ft/igpm}$$

That is, considering the accuracy of the measurements, s_w/Q may be considered a constant for pumping rates under 86 igpm or, in other words, the drawdown is proportional to the pumping rate.

Estimated Safe Yield

In order to estimate the maximum safe pumping rate of the well for a period of twenty years, the following assumptions were made:

1) that the slope of the drawdown curve (Fig. 7) established toward the end of the test (after about 1,000 minutes) remains constant thereafter;

2) that half of the total saturated thickness of the aquifer or 5 feet can be dewatered without seriously affecting the performance of the well. The maximum safe yield is then calculated by extrapolating the drawdown curve to $t = 10^7$ minutes:

$$\text{Maximum safe yield} = s_t Q/(s_{1000} + 4\Delta s) = 5 \times 85/(3.55 + 4 \times 2.93)$$
$$= 27.8 \text{ igpm}$$

where s_t = available drawdown (5 feet)

Q = the pumping rate for the test (85 igpm)

s_{1000} = drawdown at t = 1000 minutes (3.55 feet)

Δs = the slope of the last straight line segment of the time-drawdown curve (2.93 feet/cycle)

The behavior of the drawdown curve (Fig. 7) suggests that assumption (1) may be optimistic and, if so, 27.8 igpm may well be an over-estimate for the safe yield.

Comments and Conclusions

Due to the presence of impermeable boundaries close to the pumping well, limiting the extent of the aquifer, the maximum safe pumping rate for well No. 5 is much lower than was expected. To insure production of the well for a period of twenty years, the well should not be pumped at a rate exceeding 27.8 igpm continuously. The transmissibility, hydraulic conductivity and storage coefficient of the aquifer are estimated at 61,000 igpd/ft, 6,100 igpd/ft^2 and .022, respectively.

Due to the complex nature of the aquifer, the estimates presented in this report are subject to a large error; therefore, the Research Council of Alberta cannot guarantee that the amount of 27.8 gpm can be withdrawn from well No. 5 for a period of twenty years, although it considers this figure a reasonable estimate of the safe pumping rate.

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Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W. (1962): U.S. Geol. Surv. Water-Supply Paper 1536-E

Walton, William C. (1962): Selected analytical methods for well and aquifer evaluation; Illinois State Water Survey, Urbana, Bull. 49, 81 pages.

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RESULTS OF A PUMP TEST AT REDCLIFF, ALBERTA

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by

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Unpublished Report

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RESULTS OF A PUMP TEST AT REDCLIFF, ALBERTA,

OCTOBER, 1966

Introduction

This report describes the results of a pump test conducted by personnel of the Research Council of Alberta, Groundwater Division, on October 7, 1966 and following. The pumped well is situated near the pump house of the town of Redcliff, Alberta, in Sec. 6, Tp. 13, R. 6, W. 4th Mer. and 115 feet north of the low water line of the South Saskatchewan River. The purpose of the test was mainly to observe if stabilization of the water levels in the pumped well and the observation wells occurred as a result of infiltration from the river; however, stabilization of the water levels did not occur during the test. On the contrary, the water levels kept declining at a rate comparable to the decline of water levels in wells affected by impermeable boundaries. The observation well farthest east did not respond at all to the pumping. One other observation well, situated 90 feet northeast of the pumping well, exhibited large erratic movements, both during the test as well as before and after. The cause of these movements could not be established with certainty and the measurements in this well could therefore not be used for aquifer evaluation. The water levels in a third observation well and the pumping well itself were used to determine the transmissability and storage coefficient of the aquifer. A 2 1/2 hour step-drawdown test was conducted to aid in the estimation of the maximum safe yield over a 20-year period for the pumping well.

Description of the Aquifer and Locations of Wells

The aquifer tested is an alluvial deposit consisting of gravel and coarse sand along the north bank of the South Saskatchewan River in Sec. 6, Tp. 13, R. 6, W. 4th Mer., near the town of Redcliff, Alberta. The lateral extent of the aquifer is not known. From the stratigraphic logs obtained during previous test drilling (Fig. 1), the saturated thickness of the aquifer appears to be approximately 10 feet, the basal 2 feet of which consist of coarse sand or fine gravel, and the top 8 feet of coarse gravel. The aquifer is unconfined and the water levels are generally below the top of the gravel. The gravel is, in general, overlain by 5 to 15 feet of clay or silt. Figure 2, prepared by the Engineering Department of the City of Medicine Hat, shows the locations of the test holes from which the stratigraphic logs were obtained.

Table 1 lists the locations and elevations of those test holes that were used as production well and observation wells for the pump test.

Table 1. Locations and elevations of production well and observation wells

Well No.	Distance from pumped well (feet)	Direction from pumped well	Elevation* (feet)
1	90	N 45° E	+80.60
2	302	N 64.5° E	+79.77
3	136	N 84° W	+80.95
5	0	-	+70.88
6	2	N 90° W	+76.73

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*All elevations are measured at the top of the casing and in reference to a benchmark at the pump house.

River Efficiency of the Wells

Figures 3, 4, and 5 illustrate the response of the water levels in wells 1, 2, and 5, respectively, to changes in the level of the South Saskatchewan River. The river efficiency appears to be very close to 100% for all three wells. During the pump test, river levels were measured at the same time as the wells (Appendix B) and the drawdown measurements were corrected accordingly.

Step-Drawdown Test

A step-drawdown test was conducted after sufficient time had elapsed since the main test to allow water levels to recover to the nonpumping level. The test consisted of the following steps:

Step 1, duration 50 minutes, pumping rate 75 gpm (gallons per minute)
Step 2, duration 50 minutes, pumping rate 92 gpm
Step 3, duration 50 minutes, pumping rate 103 gpm

The measured drawdowns are plotted against the logarithm of the time since each step began (Fig. 6). From the graph the ratio $(s_w/Q)_n$ is calculated:

$$(s_w/Q)_1 = 2.21/75 = .00295 \text{ ft/gpm}$$

$$(s_w/Q)_2 = (2.66 - 2.28 + 2.21)/92 = .00282 \text{ ft/gpm}$$

$$(s_w/Q)_3 = (2.59 + 3.29 - 2.73)/103 = .00306 \text{ ft/gpm}$$

That is, considering the accuracy of the measurements, s_w/Q may be considered a constant for pumping rates under 103 gpm or, in other words, the drawdown is proportional to the pumping rate.

Constant-Rate Test

During the constant-rate test, the well was pumped for 4,275 minutes at an average rate of 102 gpm. Because no proper device was installed to regulate the flow, a gradual decline in the pumping rate from 113 gpm at the beginning of the test to 100 gpm at the end could not be avoided (Fig. 10). This means a deviationof 13%, which is generally considered above the acceptable limit.

Drawdown in the Pumping Well

The observed drawdowns in the pumping well were corrected for the changes in water level due to changes in river level (Appendix B) and plotted against the logarithm of time (Fig. 7). The graph exhibits a number of straight line segments, very similar to the time-drawdown graphs obtained from wells pumping from a strip aquifer (an aquifer bounded by two parallel impermeable boundaries). There is no indication of stabilization of the drawdown due to infiltration from the river; on the contrary, the slope of the graph increases steadily with increasing time. This may, however, be partly due to the fact that we are dealing with a water-table aquifer rather than impermeable boundaries. In a water-table aquifer the water table is continuously lowered by the withdrawal from the well and the effective thickness of the aquifer reduced, resulting in a steadily decreasing transmissibility.

In order to estimate the maximum safe pumping rate of the well for a period of twenty years, the following assumptions were made:

1) The slope of the drawdown curve (Fig. 7), established towards the end of the test, approximately between 1,000 and 4,000 minutes, remains constant thereafter;

2) One-half of the total saturated thickness of the aquifer or 5 feet can be dewatered without seriously affecting the performance of the well. The maximum safe yield is then calculated by extrapolating the drawdown curve to $t = 10^7$ minutes:

$$\text{Maximum safe yield} = s_t Q/(s_{1000} + 4\Delta s) = 5 \times 102/(3.55 + 4 \times 2.93)$$

$$= 33.4 \text{ gpm}$$

where s_t = available drawdown (5 feet)

Q = the pumping rate for the test (102 gpm)

s_{1000} = drawdown at $t = 1000$ minutes (3.55 feet)

s = the slope of the last straight line segment of the time-drawdown curve (2.93 feet/cycle)

<u>Drawdowns in Observation Well No. 3</u>

The water levels measured in observation well no. 3 permit the evaluation of the transmissibility and storage coefficient of the aquifer. The analysis used here was the non-leaky artesian type curve method. In this method the logarithm of the drawdown is plotted against the logarithm of time and the resulting cirve is compared to the non-leaky artesian-type curve, a logarithmic plot of $W(u)$ versus u, where

$$W(u) = \int_u^\infty e^{-x}/x \, dx$$

$$u = 2693 r^2 S/Tt \qquad (1)$$

r = distance from observation well to pumped well, in feet

S = the storage coefficient of the aquifer

T = the transmissibility of the aquifer in gpd/ft (U.S. gallons per day per foot)

t = the time after the pumping started, in minutes.

The drawdown is then given by:

$$s = (114.6Q/T)W(u) \qquad (2)$$

where

s = the drawdown in the observation well, in feet

Q = the pumping rate, in gpm (U.S. gallons per minute).

Theoretically, when the aquifer is of infinite areal extent, the time-drawdown curve exactly matches a portion of the type curve and the match is unique. The method for finding T and S then consists in matching the drawdown curve and the type curve, obtaining the matchpoint coordinates $u, W(u)$, t, and s for an arbitrary matchpoint and substituting these values in (1) and (2).

In the case of a water-table aquifer, an adjustment must be made to the observed drawdown measurements to compensate for the decrease in transmissibility due to dewatering of the aquifer, after which the method as outlined above can be applied. The corrected drawdown is calculated from

$$s' = s - s^2/2m \qquad (3)$$

where s' = corrected drawdown, in feet

m = the thickness of the aquifer, in feet.

Appendix C gives the observed water levels, the nonpumping level corrected for the change in river level, the measured drawdowns (s), and the corrected drawdowns, s'; s' is plotted against t in figure 8.

If the aquifer is not of infinite areal extent, but impermeable boundaries are present at not too great a distance from the pumping well, the drawdown curve will start to deviate from the type curve after a certain length of time:

"The influence of impermeable boundaries on the response of an aquifer to pumping can be evaluated by means of the image-well theory described by Ferris, which may be stated as follows: The effect of an impermeable boundary on the drawdown in a well, as a result of pumping from another well, is the same as though the aquifer were infinite and a like discharging well were located across the real boundary on a perpendicular thereto and at the same distance to the boundary as the real pumping well. Thus, the effects of impermeable boundaries on the drawdown in a well can be simulated by use of hypothetical image wells." (after Walton). In Figure 8 the uppermost heavy line is the type curve matched to the early part of the drawdown curve. Assuming that the match is made correctly, the type curve represents that part of the drawdown which is caused by the real well. The deviation, indicated by the shaded area, represents the part of the drawdown caused by the image well(s).

In general, when the deviation is again plotted against the time, the resulting curve, or part of it, can be matched with the type curve. Because T is already known from the first match, this match must be made in such a way that the same T results, or in other words, the shift from the first to the second matched position must be made parallel to the t or u axis. In the present case, however, it was found that no reasonable match could be obtained in this manner. The assumption was then made that the observed deviation was the result of two image wells, located at approximately the same distance from the observation well, so that the influence of both image wells was felt at the same time; therefore, one half of the diviation or the effect of one image well was plotted against time (the squares in Fig. 8) by substituting in (1) the values of T and S obtained from the first match and u, W(u), t, and s from the second matchpoint, the distance r between the observation well and the image wells can be found.

Calculation of T, S, and r

From matchpoint 1:

$W(u) = 1$

$u = .1$

$s = ..16$

$t = 150$

equation (2):

$$s = 114.6QW(u)/T \text{ or } T = 114.6QW(u)/s$$

$T = 114.6 \times 102 \times 1/.16 = 73,200$ gpd/ft

equation (1): $u = 2693r^2S/Tt$ or $S = uTt/2693r^2$

$S = 0.1 \times 73,200 \times 150/2693 \times (136)^2 = .022$

From matchpoint 2: $u = .1$

$t = 1380$

From equation (1): $r = uTt/2693S = .1 \times 73,200 \times 1380/2693 \times .022$

$= 170,000 = 412$ feet

Location of Impermeable Boundaries

Although the postulated image wells may be located anywhere on the circle of radius r = 412 feet and center at well #3 (Fig. 9), the fact that no drawdown occurred at well #2 indicates that an impermeable boundary exists somewhere between the pumping well and well #2. A possible location of the impermeable boundary is therefore shown in figure 9.

Comments and Conclusions

Due to the presence of impermeable boundaries close to the pumping well, limiting the extent of the aquifer, the maximum safe pumping rate for well #5 is much lower, as was expected. To insure production of the well for a period of twenty years, the well should not be pumped at a rate exceeding 33.4 gpm continuously. The transmissibility and storage coefficient of the aquifer are estimated at 73,200 gpd/ft and .022, respectively.

Due to the complex nature of the aquifer, the estimates presented in this report are subject to a large error; therefore, the Research Council of Alberta cannot guarantee that the amount of 33.4 gpm can be withdrawn from well #5 for a period of twenty years, although it considers this figure a reasonable estimate of the safe pumping rate.

Appendix A. River levels during pump test

(with reference to the stage at the beginning of the test)

Time since start of test (mins.)	River stage (ft.)	Time since start of test (mins.)	River stage (ft.)
1	-.01	100	0
2	+.01	120	+.007
3	-.01	140	-.003
4	+.01	160	+.007
5	+.01	180	+.007
6	+.012	215	+.017
7	+.01	245	+.012
8	+.01	275	+.017
9	-.003	310	+.017
10	-.003	370	+.017
12	0	430	+.09
14	-.002	485	+.10
16	-.003	575	+.15
18	-.002	700	+.18
20	0	825	+.24
25	+.007	980	+.24
30	-.002	1200	+.24
35	+.007	1390	+.18
40	+.007	1640	+.18
45	+.007	1940	+.17
50	0	2340	+.17
60	+.012	2765	+.22
70	-.003	3180	+.26
80	0	3660	+.30
90	0	4275	+.44

Appendix B. Drawdowns in the pumping well

Time since start of test (mins.)	Nonpumping level, corrected for change in river stage (ft.)	Water level (ft.)	Draw-down (ft.)
1	61.28	59.61	1.67
2	61.30	59.61	1.69
3	61.28	59.62	1.66
4	61.30	59.59	1.71
5	61.30	59.58	1.72
6	61.30	59.56	1.74
7	61.30	59.55	1.75
8	61.30	59.53	1.77
10	61.29	59.47	1.82
12	61.29	59.48	1.81
14	61.29	59.40	1.89
16	61.29	59.39	1.90
18	61.29	59.40	1.89
20	61.29	59.37	1.92
25	61.30	59.30	2.00
30	61.29	59.26	2.03
35	61.30	59.23	2.07
40	61.30	59.21	2.09
45	61.30	59.19	2.11
50	61.29	59.16	2.13
60	61.30	59.09	2.21
70	61.29	59.08	2.21
80	61.29	59.02	2.27
90	61.29	58.98	2.31
100	61.29	58.96	2.33
120	61.30	58.89	2.41
140	61.29	58.84	2.45
160	61.30	58.77	2.53
180	61.30	58.74	2.56
215	61.31	58.64	2.67
245	61.30	58.64	2.66
275	61.31	58.57	2.74
310	61.31	58.57	2.74
370	61.31	58.50	2.81
430	61.38	58.46	2.92
485	61.39	58.43	2.96
575	61.44	58.35	3.09
700	61.47	58.20	3.27
825	61.53	58.08	3.45
980	61.53	58.00	3.53
1200	61.53	57.80	3.73
1390	61.47	57.58	3.89
1640	61.47	57.40	4.07
1940	61.46	57.14	4.32
2340	61.46	57.10	4.36
2765	61.50	56.73	4.77
3180	61.55	56.62	4.93
3660	61.59	56.45	5.14
4275	61.73	56.44	5.29

Appendix C. Observation well #3

Nonpumping level: 61.25 feet above reference point

TTime since pumping started (min.)	Water level measured (ft.)	Nonpumping level corrected for river response (ft.)	Drawdown measured (ft.)	Drawdown corrected $s' = s - s^2/20$ (ft.)
1	61.25	61.24	-0.01	-0.01
2	61.25	61.26	0.01	0.01
3	61.25	61.24	-0.01	-0.01
4	61.25	61.26	0.01	0.01
5	61.24	61.26	0.02	0.02
6	61.24	61.26	0.02	0.02
7	61.24	61.26	0.02	0.02
8	61.24	61.26	0.02	0.02
9	61.23	61.25	0.02	0.02
10	61.23	61.25	0.02	0.02
12	61.22	61.25	0.03	0.03
14	61.21	61.25	0.04	0.04
16	61.20	61.25	0.05	0.05
18	61.20	61.25	0.05	0.05
20	61.20	61.25	0.05	0.05
25	61.18	61.26	0.08	0.08
30	61.18	61.25	0.07	0.07
35	61.16	61.26	0.10	0.10
40	61.16	61.26	0.10	0.10
45	61.14	61.26	0.12	0.12
50	61.12	61.25	0.13	0.13
60	61.10	61.25	0.16	0.16
70	61.06	61.25	0.19	0.19
80	61.03	61.25	0.22	0.22
90	61.00	61.25	0.25	0.25
100	60.98	61.25	0.27	0.27
120	60.88	61.26	0.38	0.28
140	60.89	61.25	0.36	0.36
160	60.85	61.26	0.41	0.39
180	60.82	61.26	0.44	0.43
215	60.75	61.27	0.52	0.51
245	60.71	61.26	0.55	0.54
275	60.68	61.27	0.57	0.59
310	60.65	61.27	0.62	0.60
370	60.59	61.25	0.66	0.64

Time since pumping started (min.)	Water level measured (ft.)	Nonpumping level corrected for river response (ft.)	Drawdown measured (ft.)	Drawdown corrected $s' = s - s^2/20$ (ft.)
430	60.53	61.34	0.81	0.78
485	60.48	61.35	0.87	0.84
575	60.40	61.40	1.00	0.95
700	60.32	61.43	1.11	1.05
825	60.26	61.49	1.23	1.16
980	60.18	61.49	1.31	1.22
1200	60.06	61.49	1.43	1.33
1390	59.97	61.43	1.46	1.36
1640	59.87	61.43	1.56	1.44
1940	59.76	61.42	1.66	1.52
2340	59.63	61.42	1.79	1.63
2765	59.54	61.47	1.93	1.74
3180	59.45	61.51	2.06	1.84
3660	59.38	61.55	2.17	1.93
4275	59.34	61.69	2.35	2.07

$r = 770$ ft = distance from No 3 to recharge image well.

$$s = \frac{\overset{114.6}{\cancel{267}} \cdot Q \; W(u)}{T}$$ for the drawdown to reach a ^measurable^ value of

0.2 ft $W(u) = \frac{0.2 \times 61{,}000}{\cancel{114.6} \times 85} = 1.25$ $u = 0.19$

$$0.19 = \frac{2244 \times 770 \times 770 \times 0.022}{61000\, t} \quad t = \frac{2244 \times 7.7 \times 7.7 \times 0.022}{6.1 \times 0.19} = 250$$

that is after 2500 minutes, the recharge from the river should be readily measurable in the ~~obs~~ No 3 well.

2nd residual curve

t	s
460	0.017
480	0.027
570	0.04
700	0.054
820	0.075.

$$r^2 = \frac{560 \times 61000}{0.022 \times 2244} \qquad r = 830$$

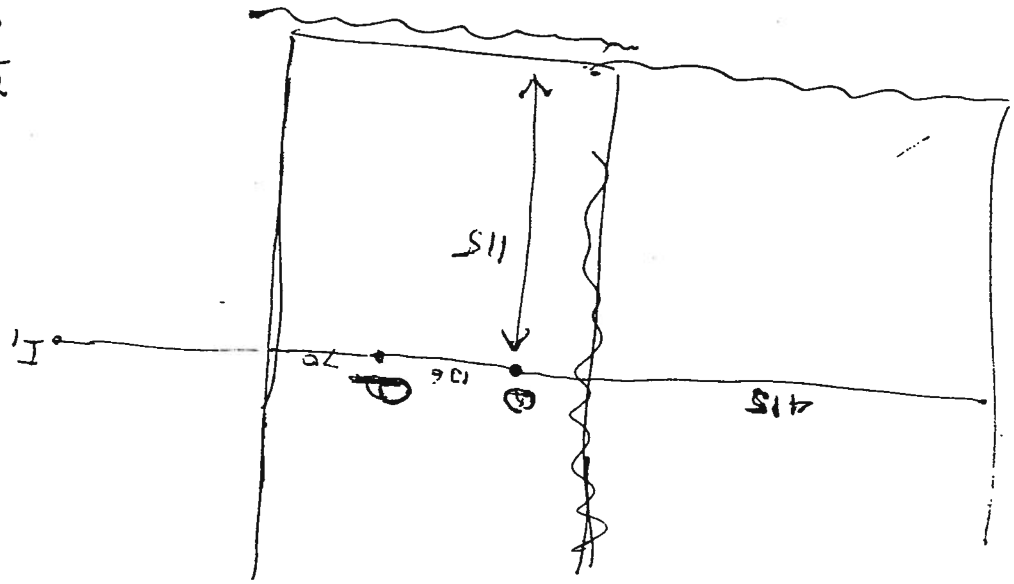
---

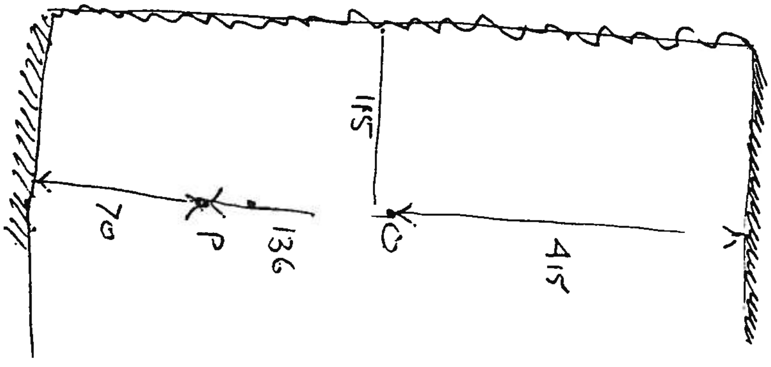
for 2nd boundary.

830

1 min = 4 ft.

$$\begin{array}{r} 73 \\ 4 \\ \hline 292 \end{array}$$





T = 61,000

S = 0.022

drawdown curves.

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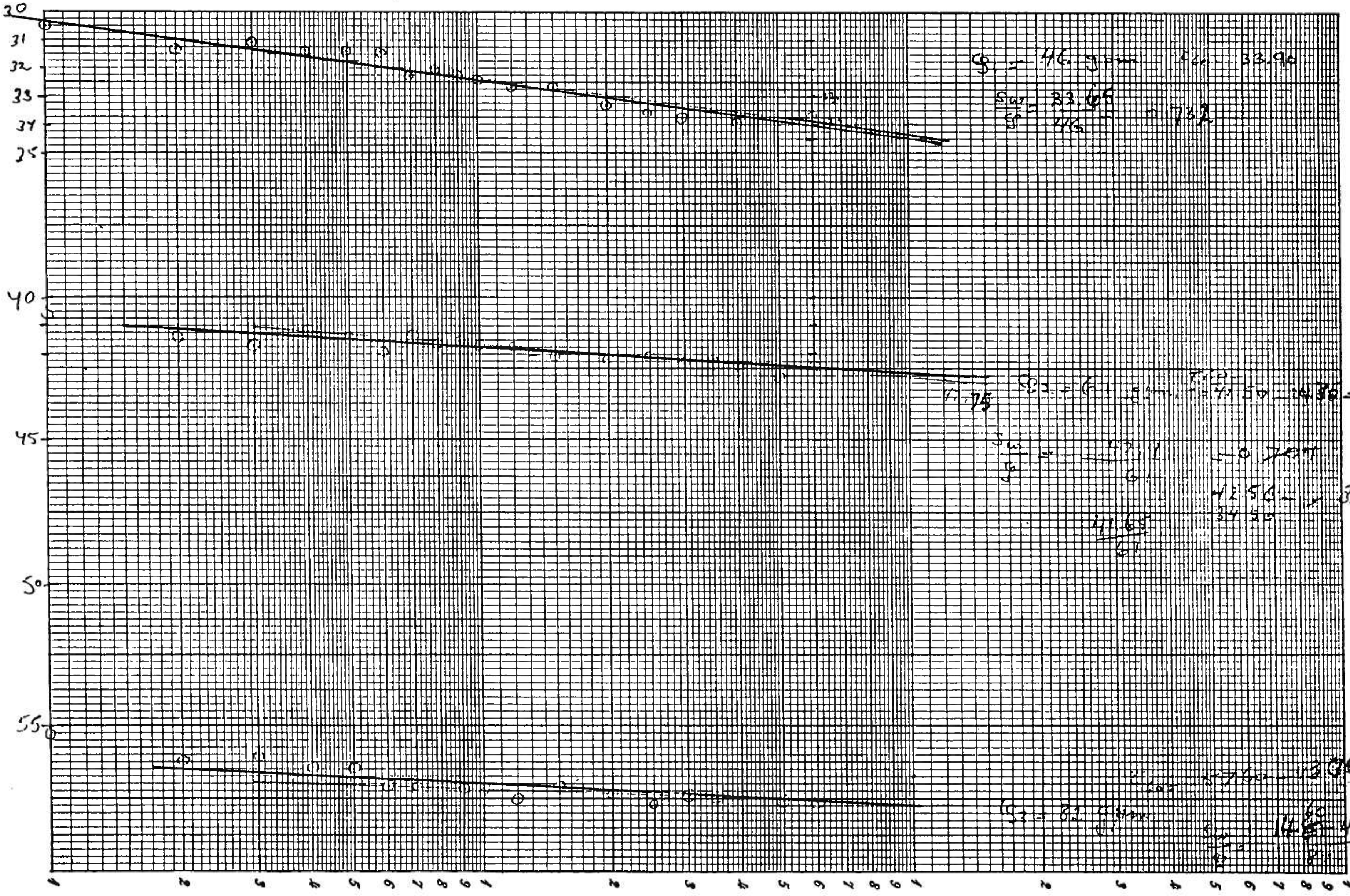
732
704
701
37
712



732
683
713
2128
7.09.

= 6.75
~~9.00~~

6.83

3.00.

703
704.
737
2144
715

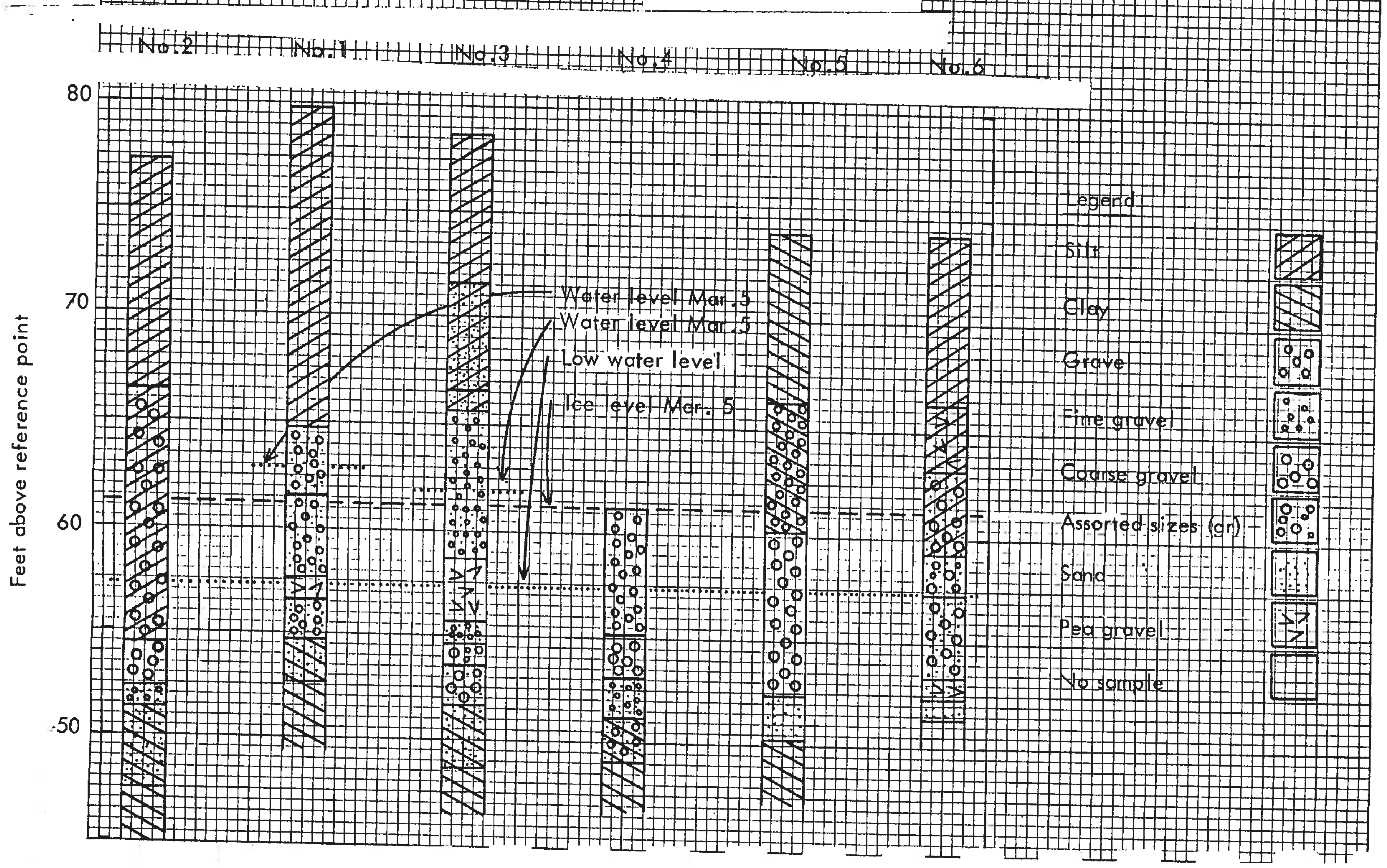
6c
= 14.85

= 5?
8

= 71.

713
204

Figure 1. Stratigraphic logs of test holes



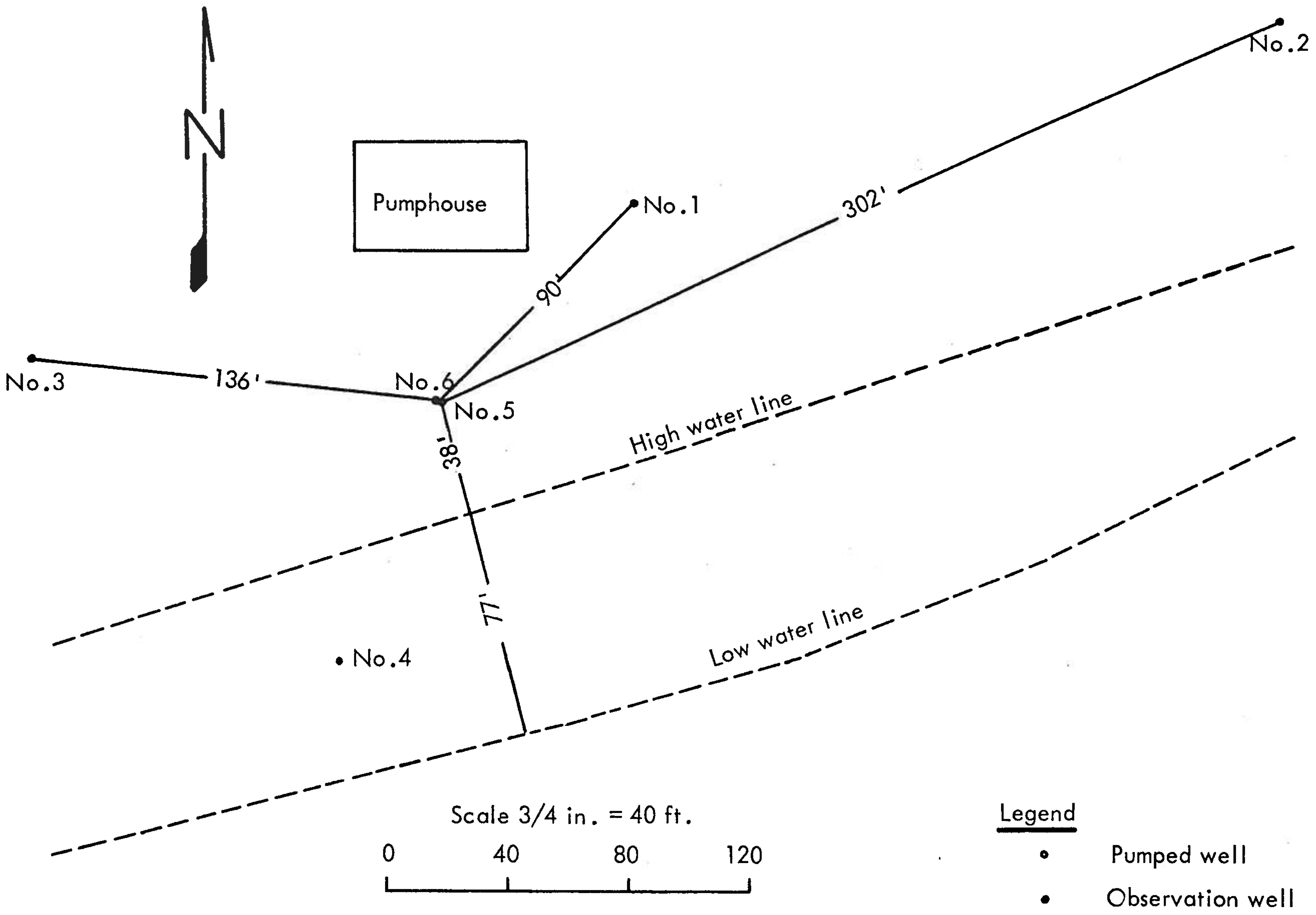


Figure 2. Location of wells, Redcliff pump test, October 1966

Figure 3. Test-hole water levels - Observation Well No. 1

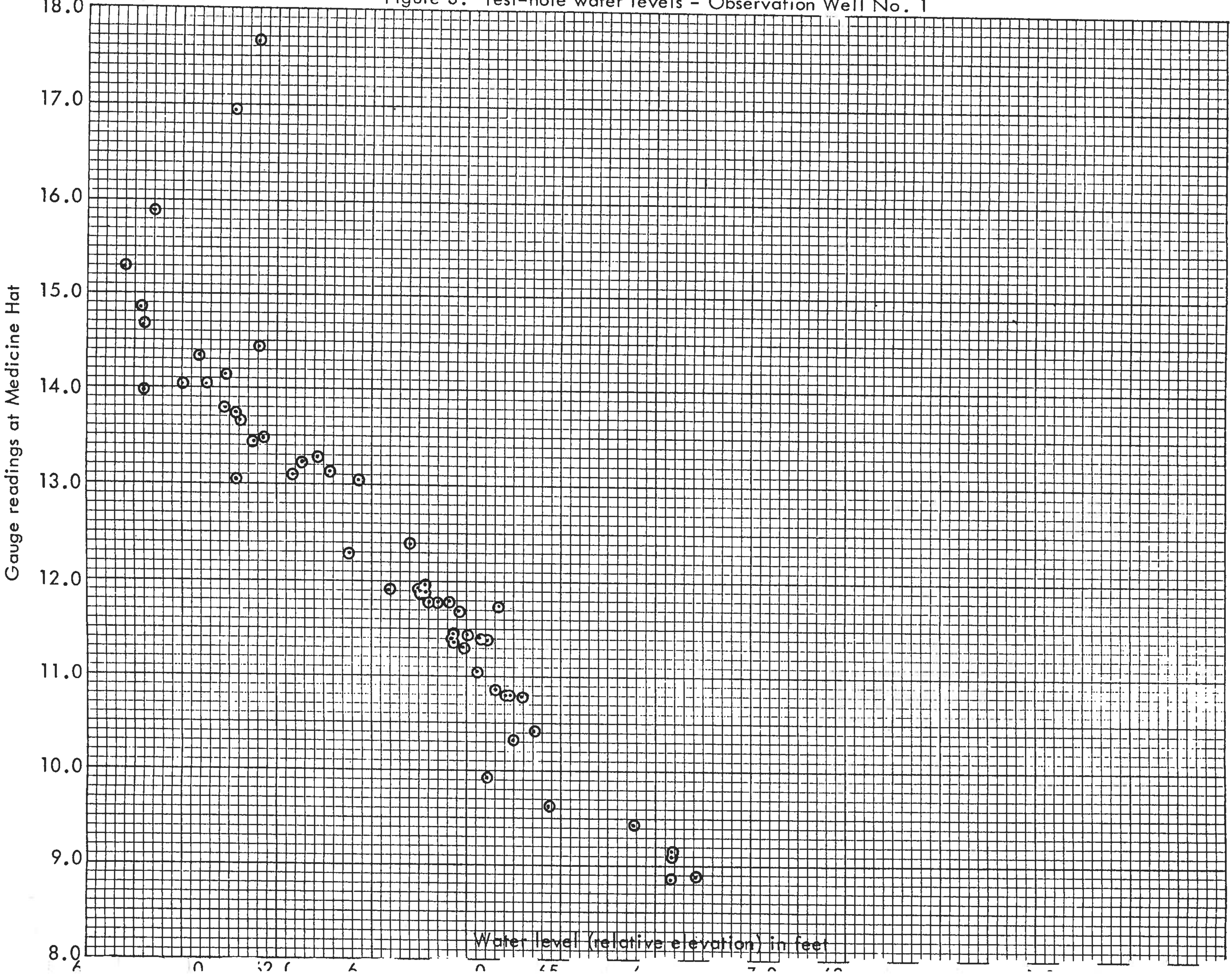


Figure 4. Test-hole water levels - Observation Well No. 2

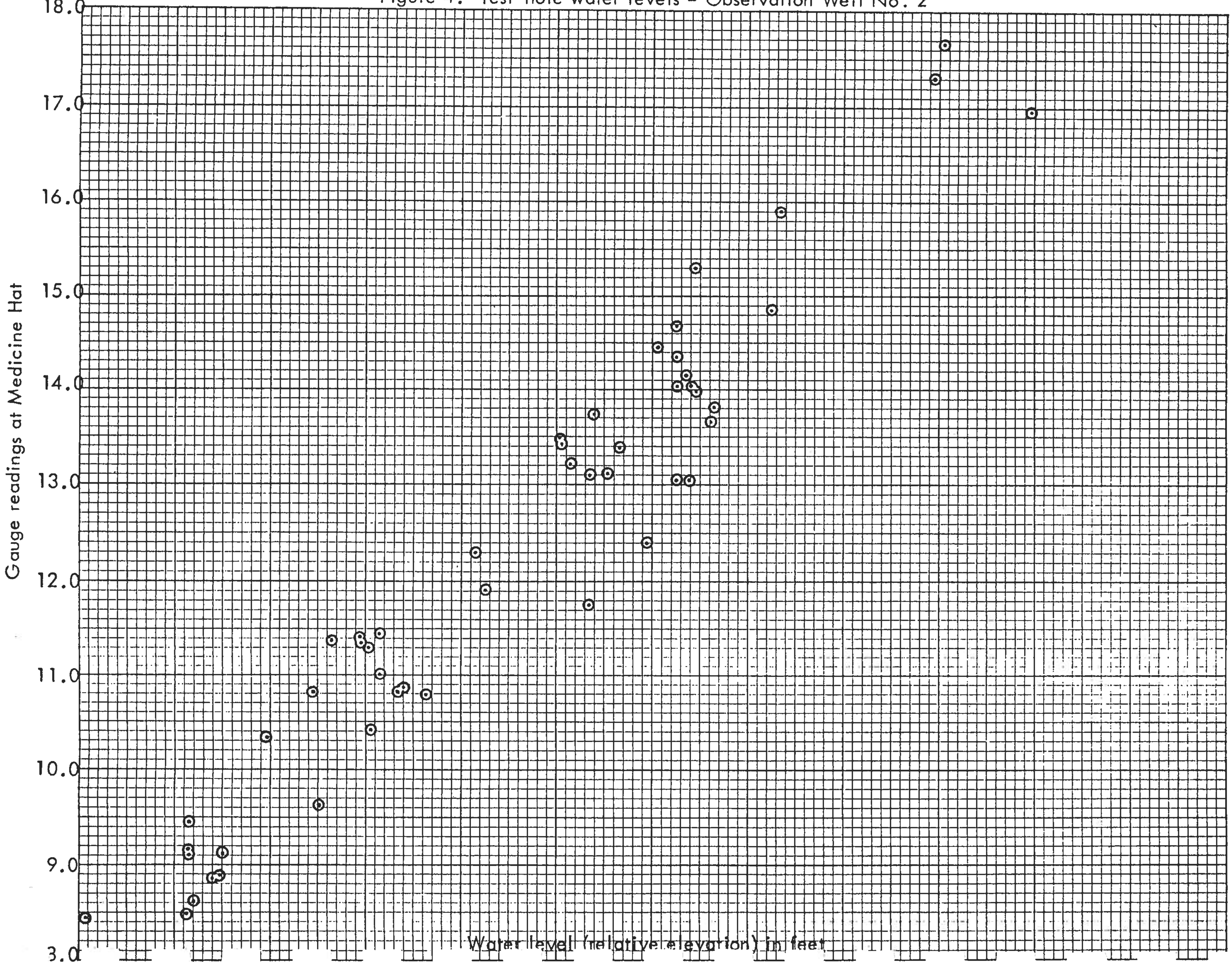


Figure 5. Test-hole water levels - Observation Well No. 5

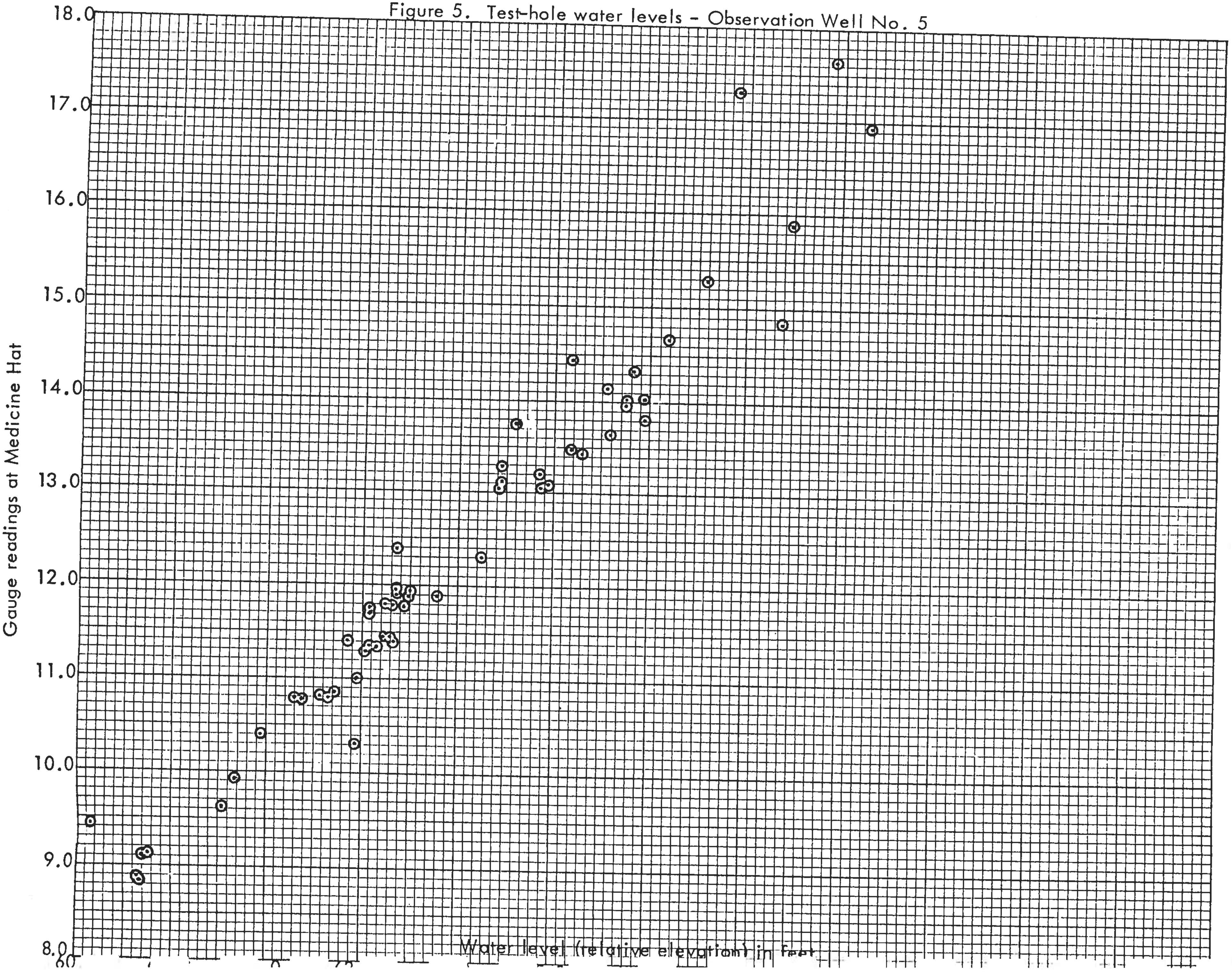


Figure 6. Time versus drawdown curve for the pumped well

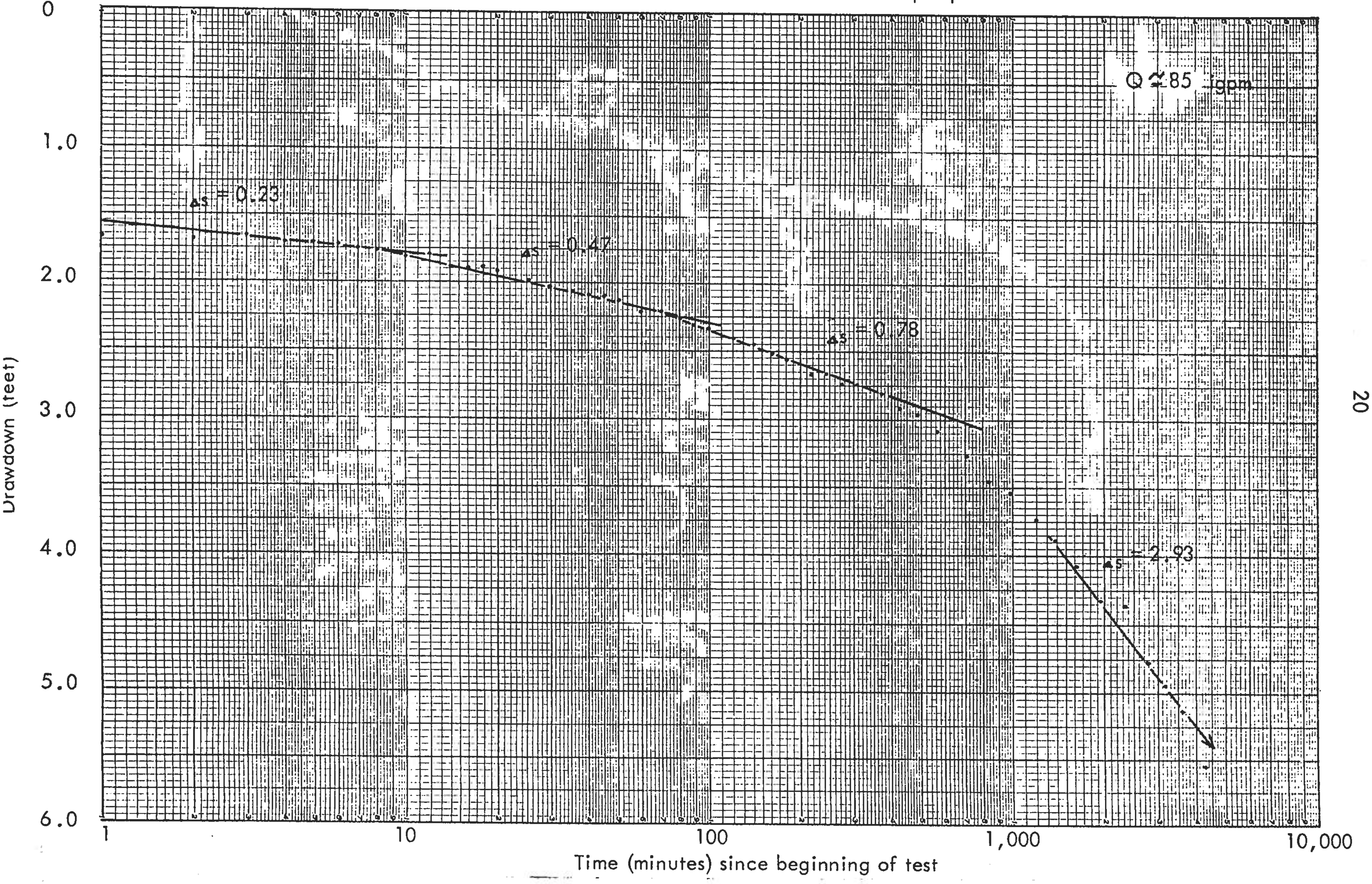
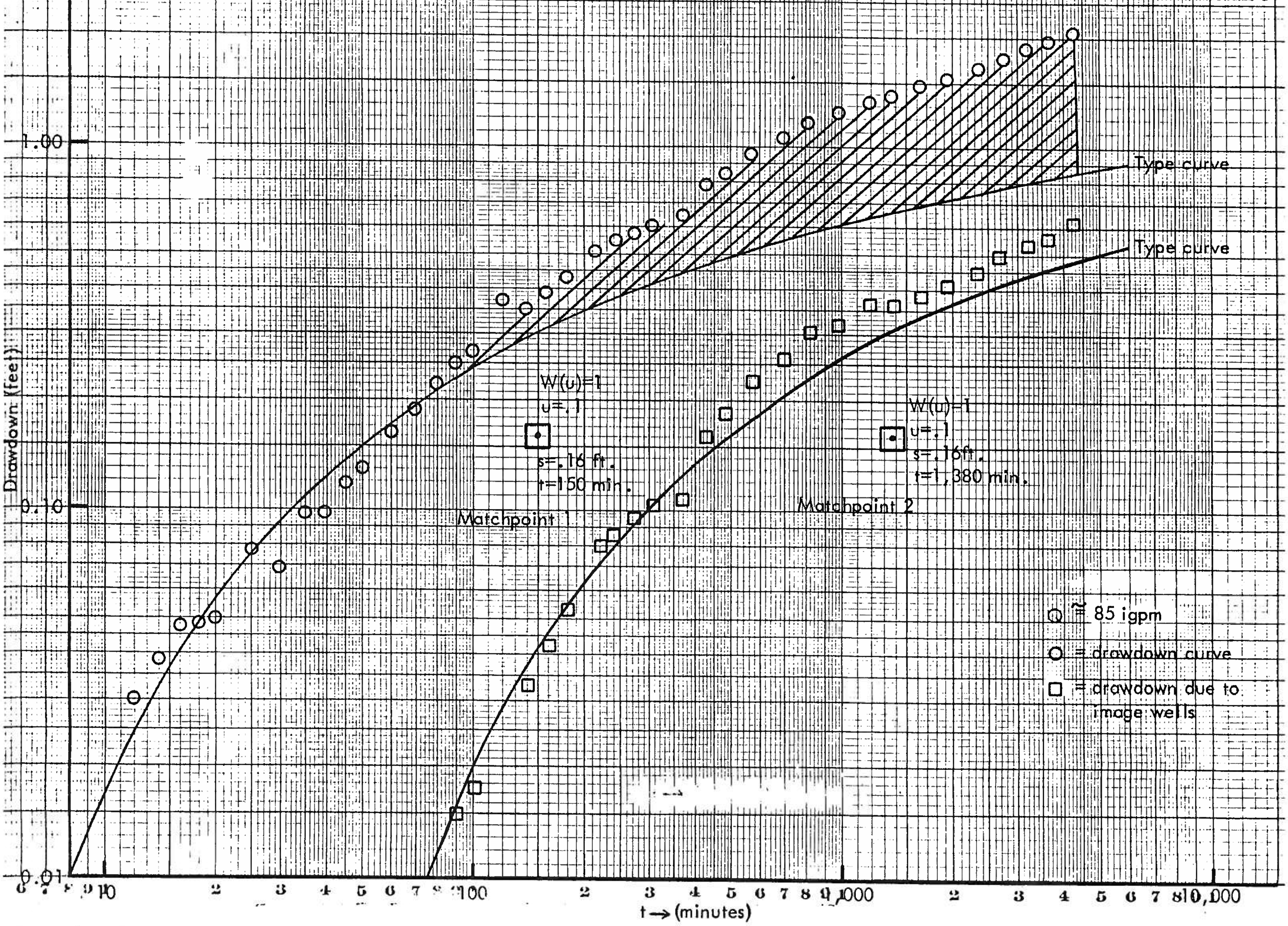


Figure 7. Analysis of pump-test data from Observation Well No. 3

(136 feet west of pumping well)



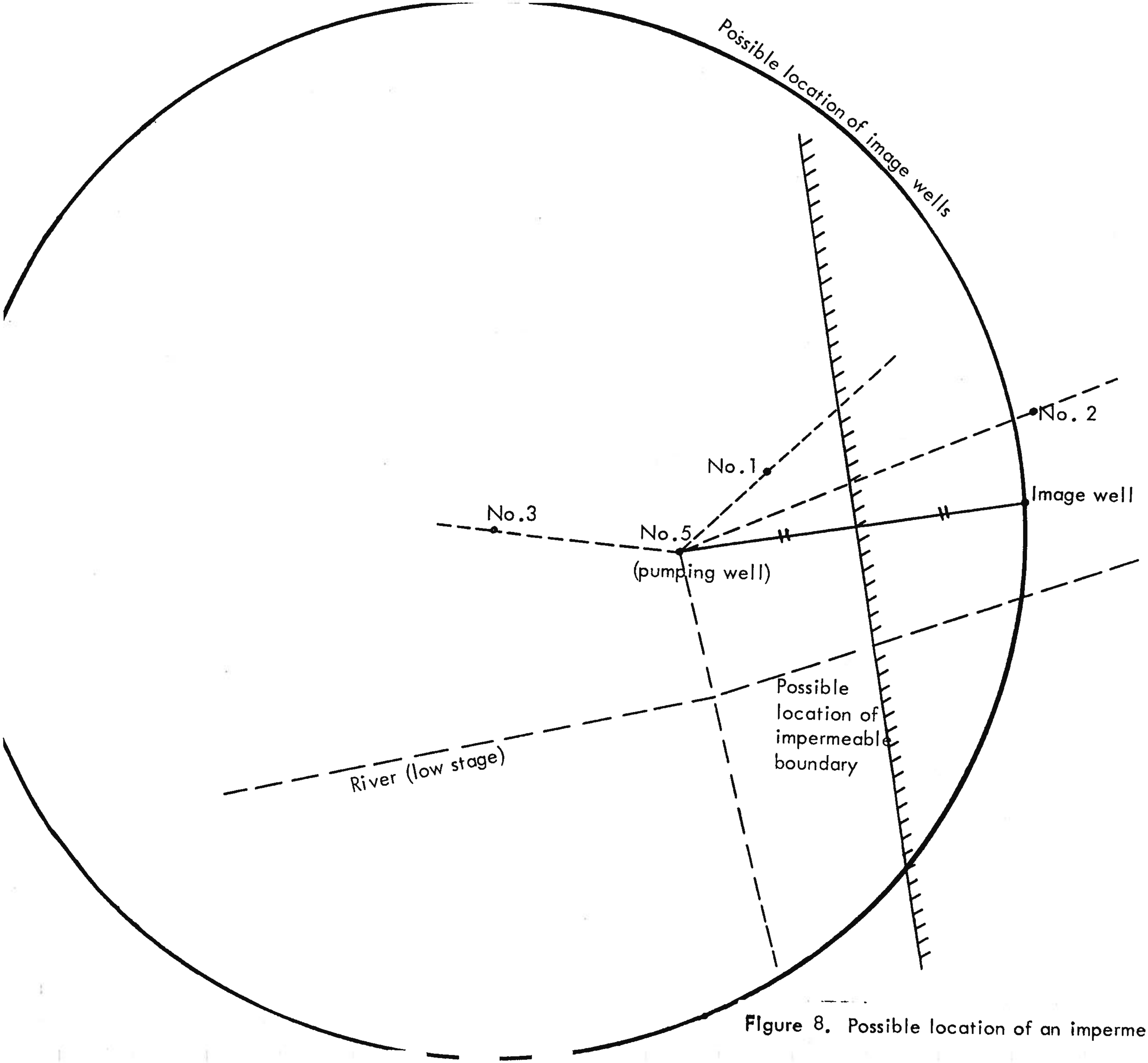


Figure 8. Possible location of an impermeable boundary

Figure 9. Analysis of step-drawdown test data

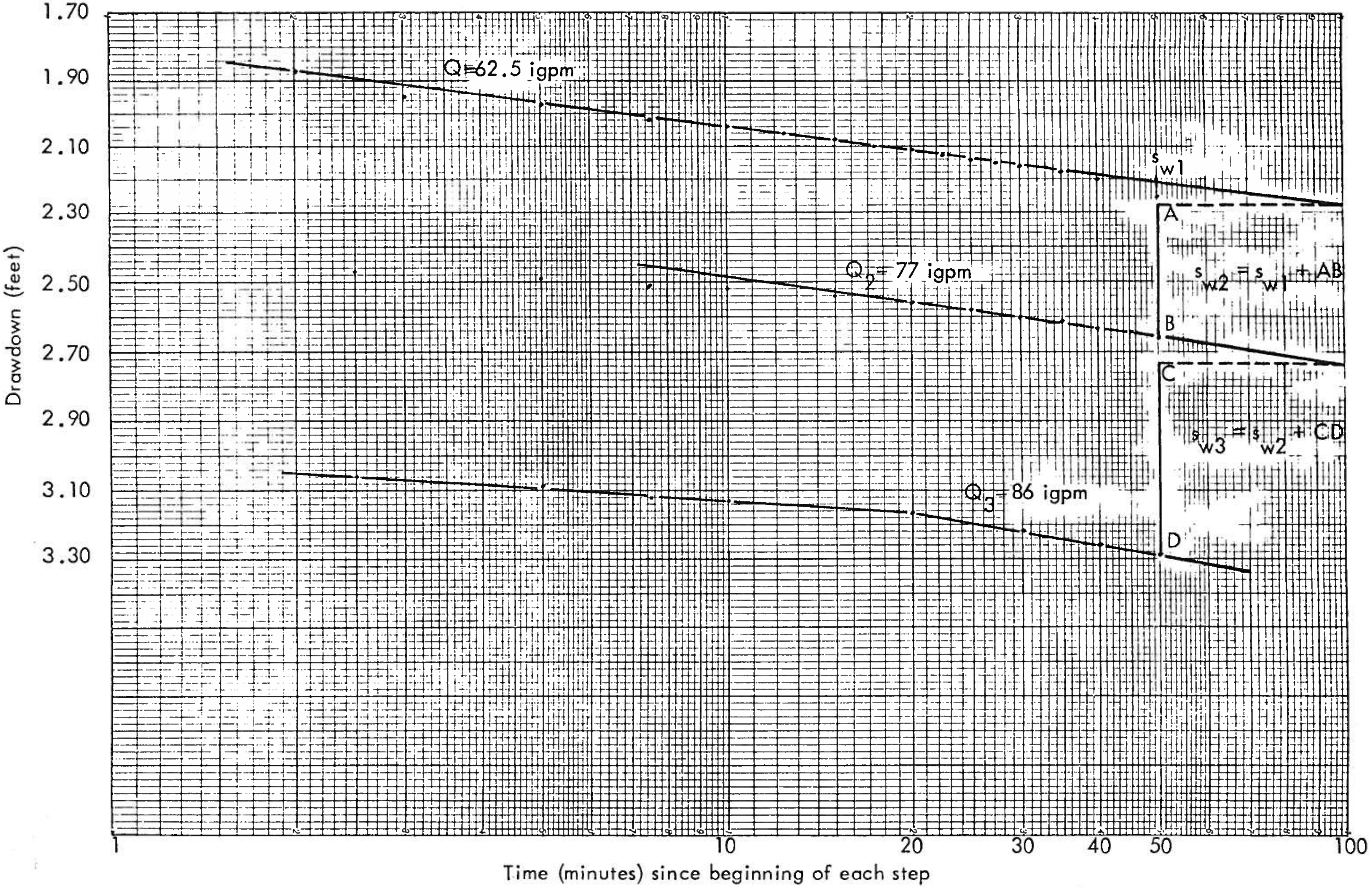
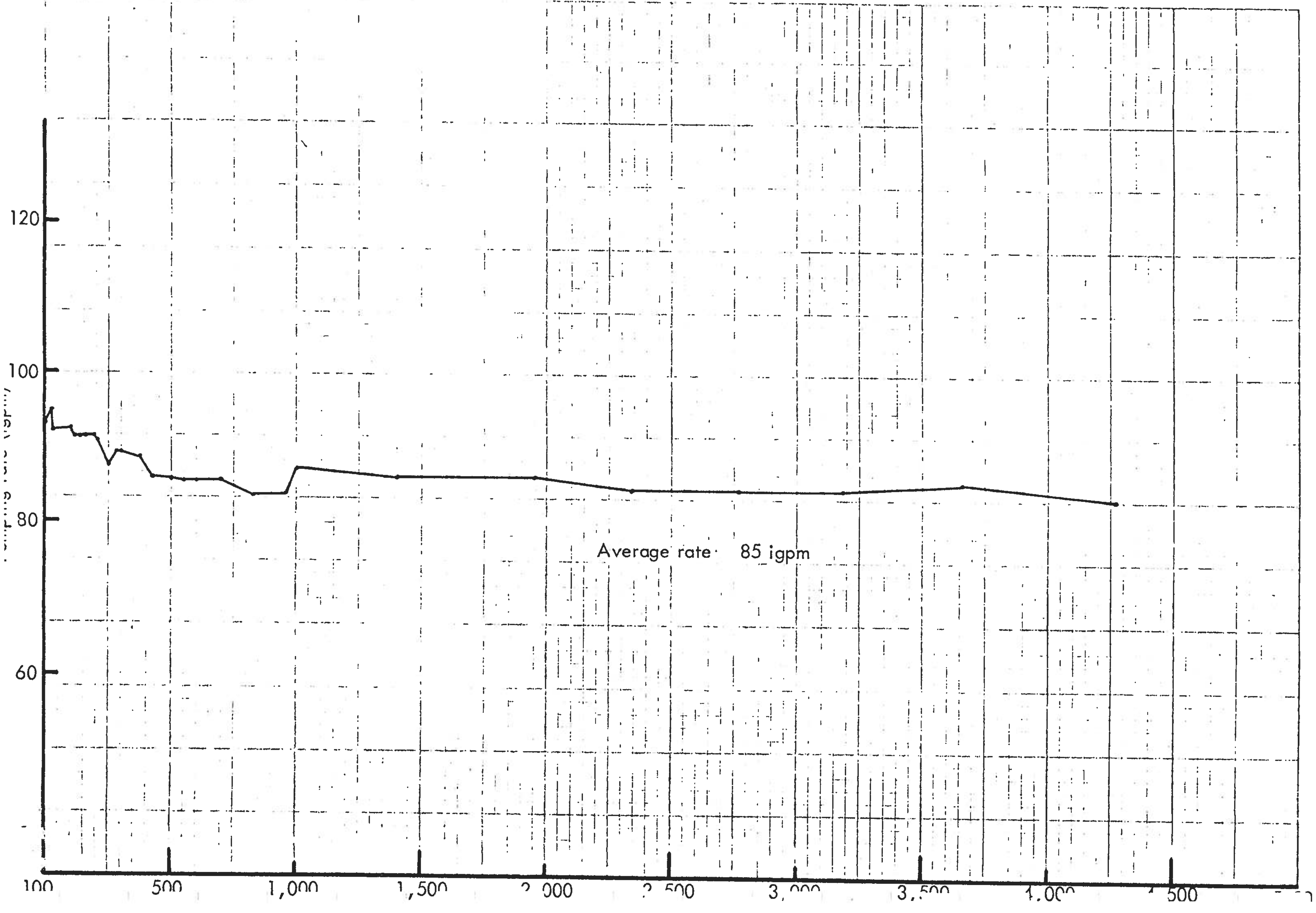


Figure 10. Variation in pumping rate during test



Average rate · 85 igpm