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PUMPING TEST INTERPRETATIONS IN THE ESTANCIA VALLEY, TORRANCE COUNTY, NEW MEXICO

by

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ABSTRACT

This paper presents the analysis of six pumping tests performed on five wells in the Estancia Valley, Torrance County, New Mexico. Well driller's logs and geophysical well logs were used in the interpretation. Two aquifer systems separated by a non-uniform clay bed, were identified. The aquifers appear to be partially confined, however enough data were not available to confirm this conclusion. Three wells are partially penetrating in the deeper aquifer and two partially penetrated only the shallow aquifer. For the shallow aquifer values of transmissivity of 12,000 gal./day/ft. and storativity of 1.36×10^{-4} were computed. As for the deep aquifer system, a transmissivity value of 6,000 gal./day/ft. was obtained taking into account well development and sanding up that took place during the pumping tests.

INTRODUCTION

The area studied belongs to the central part of the Estancia Valley in Torrance County, New Mexico. It is located in the township T6N, R9E, according to the U S Geological Survey, between the village of La Estancia to the West and Laguna del Perro to the East. The well field is located at the cen -

ter of this township coinciding with the intersection of the parallel 34° 45' North and the meridian 106° West of Greenwich.

The U.S.G.S. subdivides Torrance County into six areas according to geology and ground water occurrence [1] . One of these areas is the Estancia Valley which also extends into Santa Fe County to the North. This valley is characterized by numerous playas,dry lakes, and associated windblown deposits. About 60% of the county's population is concentrated in this area. The principal use of ground water is for irrigation, but also for stock and domestic uses.

The New Mexico Institute of Mining and Technology has been particularly interested in the study of this valley.Five wells and associated observation wells were drilled in the vecinity of metereologic observation stations. The area of this well field is 2 mi^2.

The information used for this report consists in driller's logs, geophysical well logs, water level records, taken over a time interval of about two years, and pumping tests. Geological information was obtained from a U.S.G.S. report [1] .

I.- PURPOSE

The purpose of this study was to obtain information about the hydraulic characteristcs of the aquifers in the Estancia Valley.

It is hoped that this information will be useful in a regional study of ground water motion.

II. DESCRIPTION OF THE AREA

a) Geology

The investigated area consists of valley fill deposits of sand, gravel and clay. From the well data, the total thickness of the sequence is about 350ft. This material consists of erosion products from the mountains surrounding the valley.

The upper part of the sequence consists of Pleistocene lake deposits ranging in thickness from 100ft. in the West to 105ft. in the East. Hydrologically these lake sediments contain a permeable layer, the Shallow aquifer, confined between clay beds.

The lower part of this sequence is an alluvial complex made up of stream sediments, clays, gravels and sands.

They contain two permeable horizons separated by a semi permeable partition about 25ft. thick. These form one aquifer system, the Alluvial Aquifer.

The alluvial unit diminishes in thickness from 269 ft. in the East to 250ft. in the North and West part of the area.

This complex of alluvial deposits is underlain by the Permian-Yeso formation. The upper boundary of the yeso formation in the area consists of a limestone of about 10ft. of thickness and below this a series of clays, shales and sandstones. Three of the five wells investigated by this study bottom in the yeso.

Deposition within the area is essentially horizontal. Grain size in the Shallow Aquifer appears to be finer on the average than in the Alluvial Aquifer.

b) Well drilling data

Five wells were investigated for this study, their location is shown in Map 1. They are described in Appendix A. These wells were drilled by New Mexico Tech. at different times starting three years ago; at least two years between drilling of the first and the last one transcurred. Their state of conservatiOn varies.

Driller's logs and original water level data were available for the following three wells: Berkshire # 1, Berkshire # 2 and School Section # 1. No data were available for the two wells penetrating only the Shallow Aquifer; Berkshire # 3 and Berkshire # 4.

All the wells were cased and some of them were cemented in the upper zone, the casing, however, is not complete in the water producing zones. It is, therefore, probable that at the time of the pumping tests the wells were partially sanded up to a greater or lesser but unknown degree, a fact that complicates the interpretation. The wells have neither gravel filters nor screens, so that washout of fines and collapse took place in most or all wells. Only one well (Berkshire # 4) has a screen.

An observation well was provided for each of the wells, at a distance 3-4 ft. They turned out to be useless because they are too shallow (see well sketches in Appendix C). No observable drawdown occurred in the observation wells.

The pumping tests suggest that the wells are partially penetrating and this is probably due to the cavings and partial collapse.

A result of this study is that the formations correlate from well to well quite consistently. However, due to lensing some of them are not continuous through out all of the area covered by the well field.

Two of the deep wells, Berkshire # 1, and # 2, cut through limestone before penetrating an impermeable clay of the yeso formation, the third deep well, School Section # 1, did not report limestone above that clay, but doubt exists about the way samples were obtained in that zone because of a cave-in from a higher zone. (Bruce DeBrine, personal communication).

As shown in Appendix A, all the wells have a clay formation in their upper part, ranging from 40 to 60 feet in thickness, which corresponds to the Upper Lake Sequence. The next lower formation is the Medial Sand Sequence. It ranges from 20 to 50 feet. This is a permeable formation of sand and gravel with thin interbedded clays.

Below this formation is the Lower Lake Sequence and the upper part of the Alluvial Unit, both made up of clay material of low permeability. The thickness of this semipermeable unit varies from 10 to 100 ft. The lower part of the Alluvial Unit is permeable and consists of sand and gravel with a thickness between 150 and 240 feet. A thin bed of low permeability clay material (25 feet thick) divides this permeable sequence in two.

Below this permeable bed, two of the wells penetrated a limestone formation, 10ft. thick. School Section # 1 lost some circulation while drilling through this limestone, suggesting the presence of fractures. And below this limestone a clay formation between 20 and 40 feet thick is present. School Section # 1 completely penetrated it and partially penetrated another permeable formation, 10 feet thick, of sand alternating with thin clay beds.

According to this sample description the Shallow Aquifer is found in the Medial Sand Sequence bounded by the Upper Lake Sequence at the top and by the Lower Lake Sequence and upper part of the Alluvial Unit at the bottom. The Alluvial Aquifer is the lower part of the Alluvial Unit, confined at the bottom by a clay formation.

c) Geophysical well logging data

Geophysical well logs were run on the three deep wells (Berkshire # 1, Berkshire # 2 and School Section # 1) by the U.S.G.S. in 1967 and 1968. They proved to be very helpful for the qualitative analysis of the formations for their correlation between the wells, and for the identification of permeable and impermeable horizons.

The following logs are available. Most useful for this study were the caliper, resistivity, S.P. and gamma logs.

TABLE 1

Distribution of Geophysical Logs.

	Berkshire #1	Berkshire #2	School Section #1
Caliper	x	x	x
Resistivity	x	x	x
Self Potential	x		x
Gamma	x	x	x
Gamma Gamma	x	x	
Neutron	x	x	x

The resistivity spacing and mud salinity are not known, and neither is the absolute value of radiation intensity in the gamma logs. Thus only qualitative interpretation could be made.

Resistivity Logs.- The resistivity logs show two high-resistivity zones approximately corresponding with the two aquifers mentioned before. The Alluvial Aquifer is more resistive than the Shallow Aquifer. The highest resistivity was measured in the lowermost part of the Alluvial Aquifer just above the limestone formation. This limestone formation has a lower resistivity than the Alluvial Aquifer.

High resistivity is usually correlated with a high permeability (sand), high conductivity with low permeability (shaliness).

Self - potential logs.- In School Section # 1 a very shaly formation of low permeability, 100ft. thick, correlates with the sample description. This self potential log also shows a very sandy zone in the lower part of the Alluvial Aquifer. In Berkshire #1, the S.P. log clearly delineates the separation between the two aquifer systems. In the Alluvial Aquifer this log shows a very sandy zone at the depth of 200ft. and another one in the lower part of the Alluvial Aquifer, separated by the 25ft. clay formation.

Gamma logs.- They correlate with the resistivity logs. The radiation intensity is lower for the permeable formation characterized by a high resistivity. The Alluvial Aquifer seems to have less radiation intensity in the zones where the resistivity is highest. Specifically, this is true in two out of three wells for the permeable zone inmediately above the limestone formation.

d) Aquifer Characteristics

From the analysis of driller's logs and geophysical well logs, the picture that emerges is that of two relatively continuous aquifers throughout the area of study. This is remarkable in view of the geologic processes of valley fill which ordinarily give rise to lens-like discontinuous layering, and the size of the area.

For the definition of the two aquifers, data from drilling samples, supplemented by the qualitative analysis of well logs, were mainly used. From these data, it appears that the Alluvial Aquifer is thicker and more permeable than the Shallow Aquifer. The Shallow Aquifer varies from well to well having only 18ft. in School Section # 1 but 51 and 37 in Berkshire # 1 and # 2 respectively. For the Alluvial Aquifer the observed thicknesses are 123, 224, and 179 feet respectively.

Besides this non uniformity in thickness it is also expected that the aquifers are heterogeneous and probably anisotropic. The pumping tests indicate that they are also probably leaky. Unfortunately, sufficient data to prove it were not available.

III. PUMPING TESTS

The pumping tests were run in two periods, from July 16 to July 19 of 1969, and from September 3 to September 10 of 1969, respectively. During the first period all the wells were tested once and in the second period School Section # 1 was tested twice.

An air injection method was used for pumping. It consisted of an air compressor with a hose to inject air at a certain distance downhole, and a discharge hose. It proved impossible to maintain a constant discharge with this device, and the discharge was so low that, in spite of great care, it could not be measured very accurately with th Parshall flume available. Furthermore, the pumping action was pulsating and caused the well to surge and to foam so that water level measurements show a large scatter.

Some tests show a decrease of discharge during pumping. The rate of discharge obtained for the tests ranged from 15 to 45 g.p.m. which is a very low value, particularly if additional effects such as leakage and partial penetration are present. In order to determine the pumping test duration required for appreciable drawdowns, calculations were made taking into account the depth to water level, casing diameter, air pressure and distances to observation wells. It was found that pumping tests of at least 3 days duration were required with a discharge considerably higher than that which could be obtained. Unfortunatly it was not possible to keep the air compressor working for extended periods, and in most cases the compressor shut itself down after a few hours of continuous operation.

Measurements of drawdown and recovery were made with a measuring tape, except during the very last stages of recovery, when a waterlevel clock recorder was used.

Because of the unconsolidated terrain and partially sanded-up condition of the wells, the tests produced some well development. For this reason some of the wells showed variations in static levels after recovery. Berkshire #1 attained a static level 2ft. below its initial value and School Section # 1 went 1 foot above its static value.

Water samples taken during the pumping tests showed a high concentration of material in suspension and no appreciable decrease in turbidity as time went by. This was the result of washout and transportation of fine material from somewhat below the level of air injection. Because of the small discharge it is unlikely, however, that any material was washed out from the bottom of the wells. Consequently, sanding up and development of the wells took place simultaneously while they were being pumped.

Appendix B shows data obtained for each well during both drawdown, and recovery tests.

IV. INTERPRETATION OF PUMPING TEST DATA

For the interpretation of the data obtained from these pumping tests it was at first assumed that the aquifers are confined and nonleaky. Non-leakage from the Shallow Aquifer is supported by the absence of water level fluctuations in the shallow Aquifer wells of small diameter while pumping the Alluvial Aquifer in nearby wells.

The interpretation had to be made exclusively with data from pumping well observations due to the fact that none of the observation wells except one (Berkshire # 3, with Berkshire # 4 pumping) showed any manifestation of ;either drawshire # 4 pumping) showed any manifestation of either drawdown or recovery during pumping tests.

For this reason, the Theis method of solution [2] was selected for the interpretation of the only observation well with drawdown data, and the Jacob method of solution [3] for the interpretation of both drawdown and recovery pumping tests in the pumping wells.

a) <u>Theis method of solution</u>

The differential equation in plane polar coordinates which governs the unsteady radial flow to a well in an extensive confined aquifer is

$$\frac{\partial^2 h}{\partial r^2} + \frac{\partial h}{\partial r} = \frac{S}{T}\frac{\partial h}{\partial t} \qquad (1)$$

where

h= piezometric head

r= radial distance from the well

t= time

S= storativity

T= transmissivity

Assuming that the well completely penetrates the aquifer and that the rate of discharge is maintained constant during the pumping of the well. Theis obtained a solution of Eq. (1), using a similarity condition between ground water flow and heat conduction. To obtain this olution the following boundary conditions were used:

$$\left.\begin{array}{llll} h \rightarrow h_o & \text{as} & r \rightarrow \infty & \\ \text{and} & & & \\ r\dfrac{\partial h}{\partial r} = \dfrac{Q}{2\pi T} & \text{as} & r \rightarrow o & \end{array}\right\} \text{for } t > o \qquad (2.a)$$

and the initial condition

$$h(r,o) = h_o \qquad \text{for } t \leq o \qquad (2.b)$$

where

h_o= initial piezometric head

Q = rate of discharge

The solution of Eq.(1), using Eqs. (2.a) and (2.b) is:

$$s = \frac{Q}{4\pi T} W(u) \qquad (3.a)$$

$$\text{with} \quad u = \frac{r^2 S}{4Tt} \qquad (3.b)$$

where

s = drawdown

W(u) = well function

To apply this solution, the aquifer must be homogeneous and isotropic in its intrinsic hydraulic characteristics and it must be horizontal and infinite. The well diameter must be infinitesimal and the water removed from storage must be discharged instantaneously with each decline of head.

To compute the formation constants T and S, a graphical method devised by Theis is used, making super imposition between a curve obtained plotting drawdown vs time from field data and a type curve relating the well function and Eq.(3.b). Both curves are plotted on logarithmic paper.

b) Jacob method of solution

A simplification of Theis' method is possible whenever the value of u is less than about 0.01, which coincides with small values of r and/or large values of t.

Jacob [3] introduced this simplification taking the expansion in series of the well function W(u). Neglecting terms after the first two we obtained.

$$s = \frac{2.3\,Q}{4\pi T} \log \frac{2.25\,T\,t}{r^2 S} \qquad (4)$$

Eq.(4) is a straight line when it is plotted semilogarithmically with s on the arithmetic scale and t on the logarithmic scale.

The slope is $2.3Q/4\pi T$, which is measured as the drawdown per log cycle. S is found from

$$\frac{2.25\ Tt_o}{r^2s} = 1 \qquad (5)$$

where t_o = time of zero drawdown.

c) Theis recovery method

The non-equilibrium formula, Eqs. (3.a, 3.b) is also used to analize the recovery test. If the well is pumped at a constant discharge rate Q until the head has reached a value h_t and then allowed to recover to $h_t' > h_t$, it may be assumed that the same rate of recharge Q has taken place during the recovery. In this case the recovery s' is found by superposing a recharge well of strenght -Q from t to t' on a discharge well of strength Q from $t = o$ to t', where $t' > t > o$.

The solution is obtained in a similar way as for Eqs. (3.a) and (3.b). Expanding in series the well function and taking only the first two terms of the series, it is finally found that

$$s' = \frac{2.3Q}{4\pi T} \log \frac{tS_r}{t'S_d} \qquad (6)$$

where S_d and S_r are storativities for drawdown and recovery tests respectively.

Eq.(6) is also a straight line on a semilogarithmic plot, using s' for the arithmetic scale and t/t' for the logarithmic scale. Again the slope of this straight line corresponds to $2.3Q/4\pi T$ from which T is obtained. For a developed aquifer $S_r = S_d$ because inelastic effects tend to disappear when the aquifer has been pumped for some time.

d) Transmissivity and Storativity coefficients

Transmissivity and Storativity were determined by the graphical procedures discussed before in sections a, b and c.

Although an attempt was made to analyze both drawdown and recovery tests for each well, in most cases only recovery curves were usable because of excessive scatter in the drawdown data. Appendix C shows the plots of the pumping tests for each well.

Attempts to normalize the values of drawdown when the rate of discharge was not constant were unsuccessful and none of the curves of drawdown Vs time could be used to get reliable values of the coefficient of transmissivity.

The following table shows values of the transmissivity coefficient in gal/day/ft. obtained for each well, method of interpretation and dates pumped.

TABLE 2

Transmissivity in gal/day/ft.

Date	Name	Drawdown	Recovery
7/18/69	Berkshire # 1	-	1,690
7/16/69	Berkshire # 2	-	1,840
7/19/69	Berkshire # 3 *	12,200	-
7/19/69	Berkshire # 4 *	-	8,800
7/17/69	School Section # 1	-	4,740
9/3/69	School Section # 1	7,020	6,200
9/10/69	School Section # 1	5,150	5,300

*Shallow Aquifer

Values from this table can not be compared without knowing the thickness of the aquifers at each well, without this information the hydraulic conductivity K can not be computed. This information is not available because of the wells being partially sanded up at the time of the tests.

Making use of the values of the transmissivity and the initial thickness of the aquifer in wells Berkshire # 1 and # 2 a value of 8 and 10 gal/day/ft^2 respectively were found for the hydraulic conductivity of the Alluvial Aquifer. This indicates a poor aquifer. Todd 4 .

A similar calculation for School Section # 1 yields a hydraulic conductivity of 50 gal/day/ft^2. Since this aquifer appears to be relatively uniform in lithological properties throughout the region, it is likely that the discrepancy is due to the sanding up of the two wells (Berkshire # 1 and # 2) previously discussed, in the lowermost portion of the aquifer which also appears to be the most permeable one in these two wells according to the geophysical logs.

With the thickness observed in wells Berkshire # 1 and # 2 for the Shallow Aquifer, a hydraulic conductivity can be computed which varies between 240 and 330 gal/day/ft^2. This value is probably too low because of the partial penetration.

From the above considerations, a representative value of transmissivity for the Shallow Aquifer is about 12,000 gal/day/ft. and for the Alluvial Aquifer, about 6,000 gal/day/ft.

When pumping well Berkshire # 4 in the Shallow Aquifer, drawdown was observed in Berkshire # 3. Using Theis' graphical method and Jacob's method, a value of 1.36×10^{-4} for storativity was obtained for the Shallow Aquifer. This is the only storativity value that could be obtained in this study.

Calculations for the Alluvial Aquifer (indicated on the graphs of Appendix C) show that the ratio Sr/Sd varies between large and improbable limits. This is probably due to the effects of sanding up and well development that have been discussed.

Appendix C also shows computations for transmissibity.

e) Effects of leakage and partial penetration

As it has been discussed, effects of leakage between the Shallow Aquifer and the Alluvial Aquifer were not observed in the pumping tests.

However, a pronounced non-linearity in the recovery test curves for short observation times may have been caused either by leakage (perhaps from a deeper aquifer) or by partial penetration effects, or a combination of both factors. Such effects disappear as recovery goes to completion (for small values of t/t'), and it is this linear part of the curve (marked on the graphs in Appendix C) that was used for interpretation.

V. SUMMARY AND CONCLUSIONS

1. By the analysis of drilling sample logs and geophysical well logs it appears that the valley fill contains two systems of confined aquifers separated by a clay bed of non-uniform thickness, which did not show evidence of leakage in the pumping tests.

2. The pumping system used for the tests was not adequate, especially in view of the fact that the nearest well used for observation was distant about one mile from the pumping well.

3. None of the wells were cased in the aquifer zones and none had been pumped since their drilling date, therefore all the wells underwent development and simultaneously were being sanded up during the pumping tests.

4. The results obtained from the pumping tests show that the Shallow Aquifer, which is located in the Medial Sand Sequence, has a transmissivity of 12,000 gal/day/ft. and a storativity of 1.36×10^{-4}. The Alluvial Aquifer, located in the lower part of the Alluvial Unit, has a transmissivity of 6,000 gal/day/ft.

VI REFERENCES

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2. Theis, C.V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage. Transactions American Geophysical Union, Vol. 16, pp 519-524, (1935).

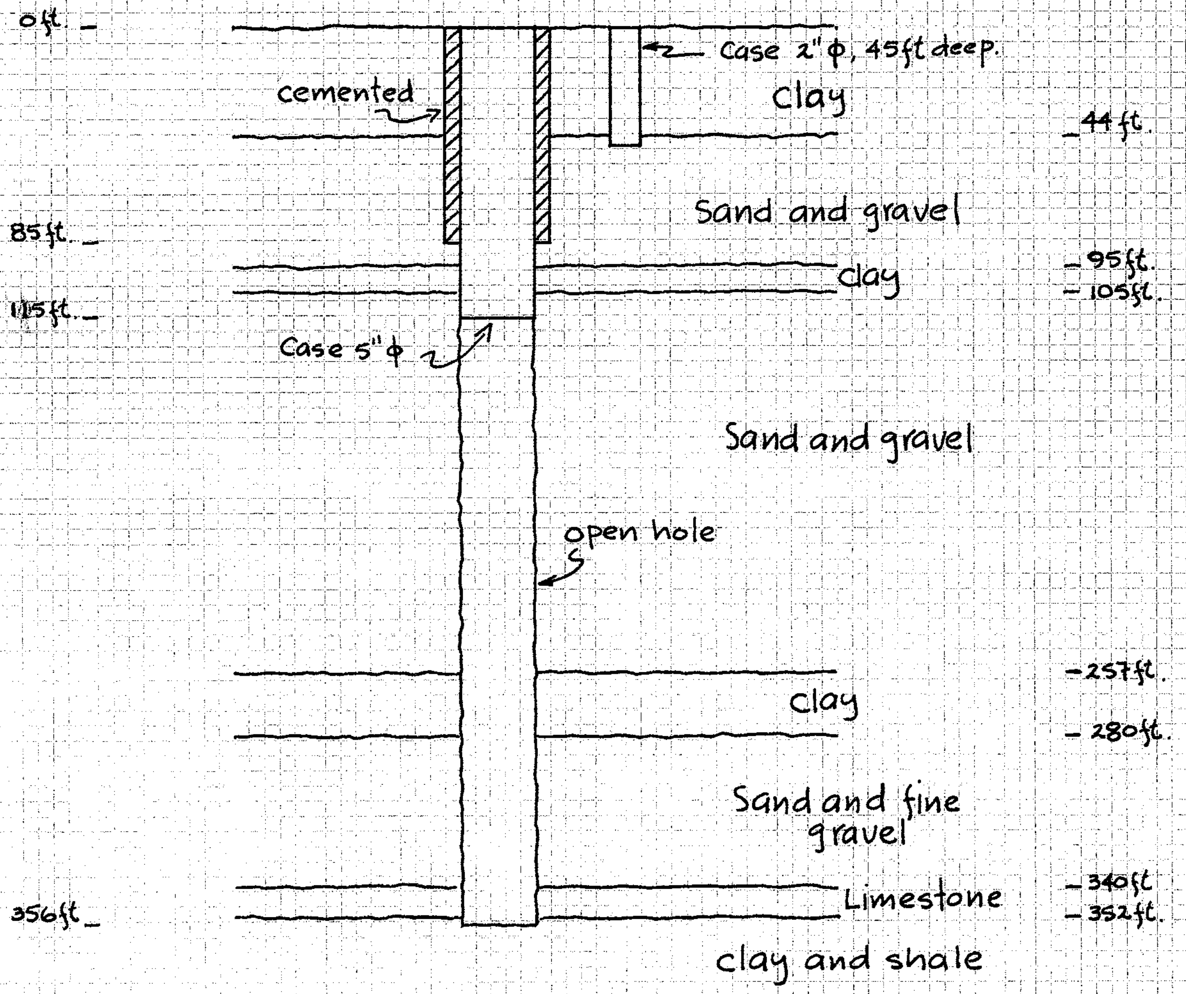
3. Cooper, H.H., and C E. Jacob, A generalized graphical method for evaluating formation constants and summarizing well-field history. Transactions American Geophysical Union, Vol. 27, pp 526-534, (1946).

4. Todd, D.K., Ground water Hydrology, John Wiley & Sons, Inc., p. 53, (1959).

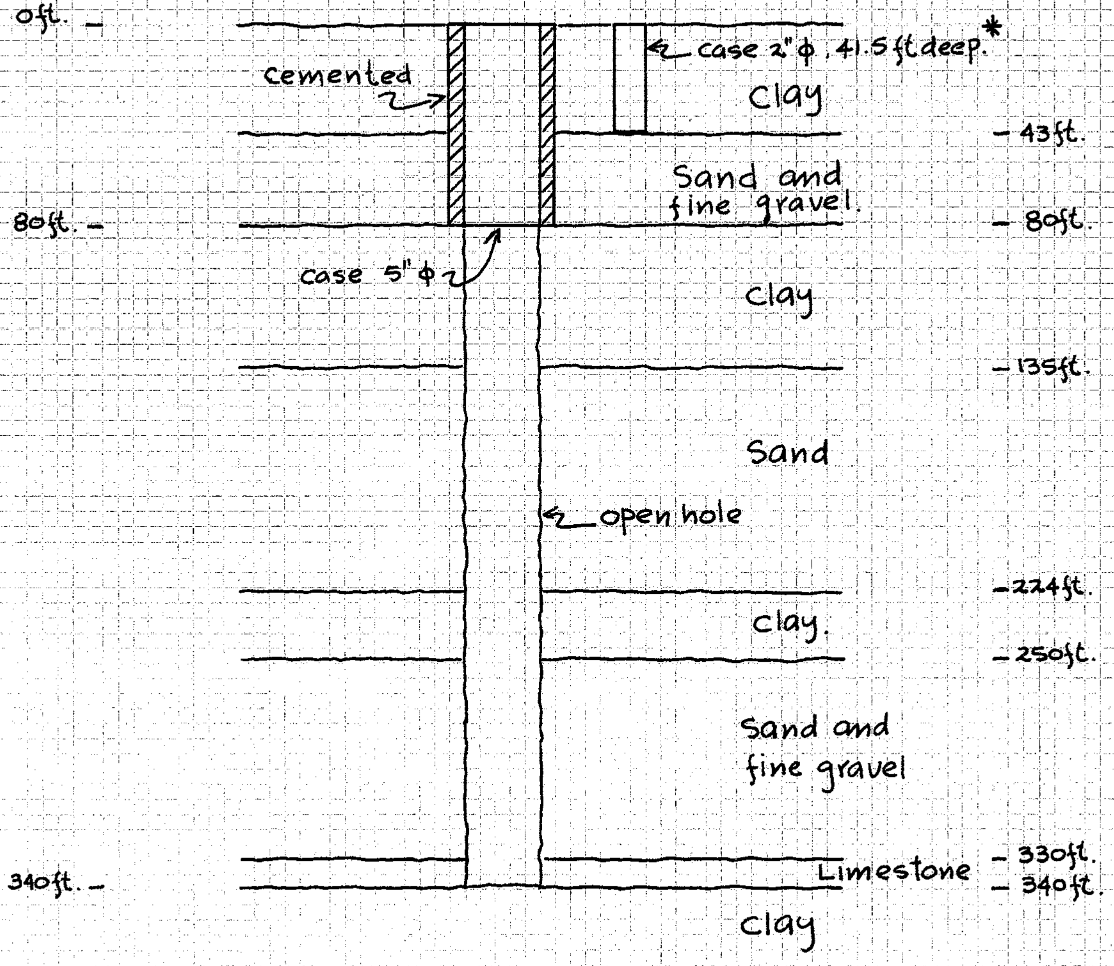
APPENDIX A

GEOLOGIC WELL SECTIONS

Well Berkshire #1

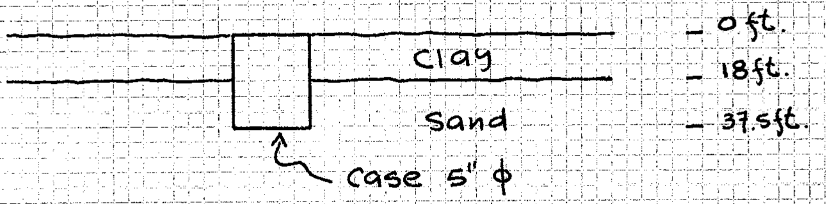


Well Berkshire #2

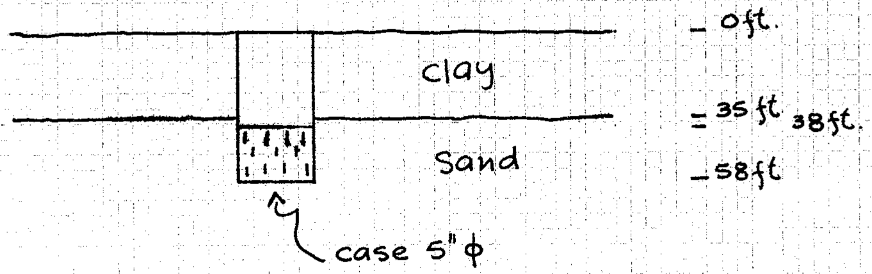


* a sand formation was found at this depth.

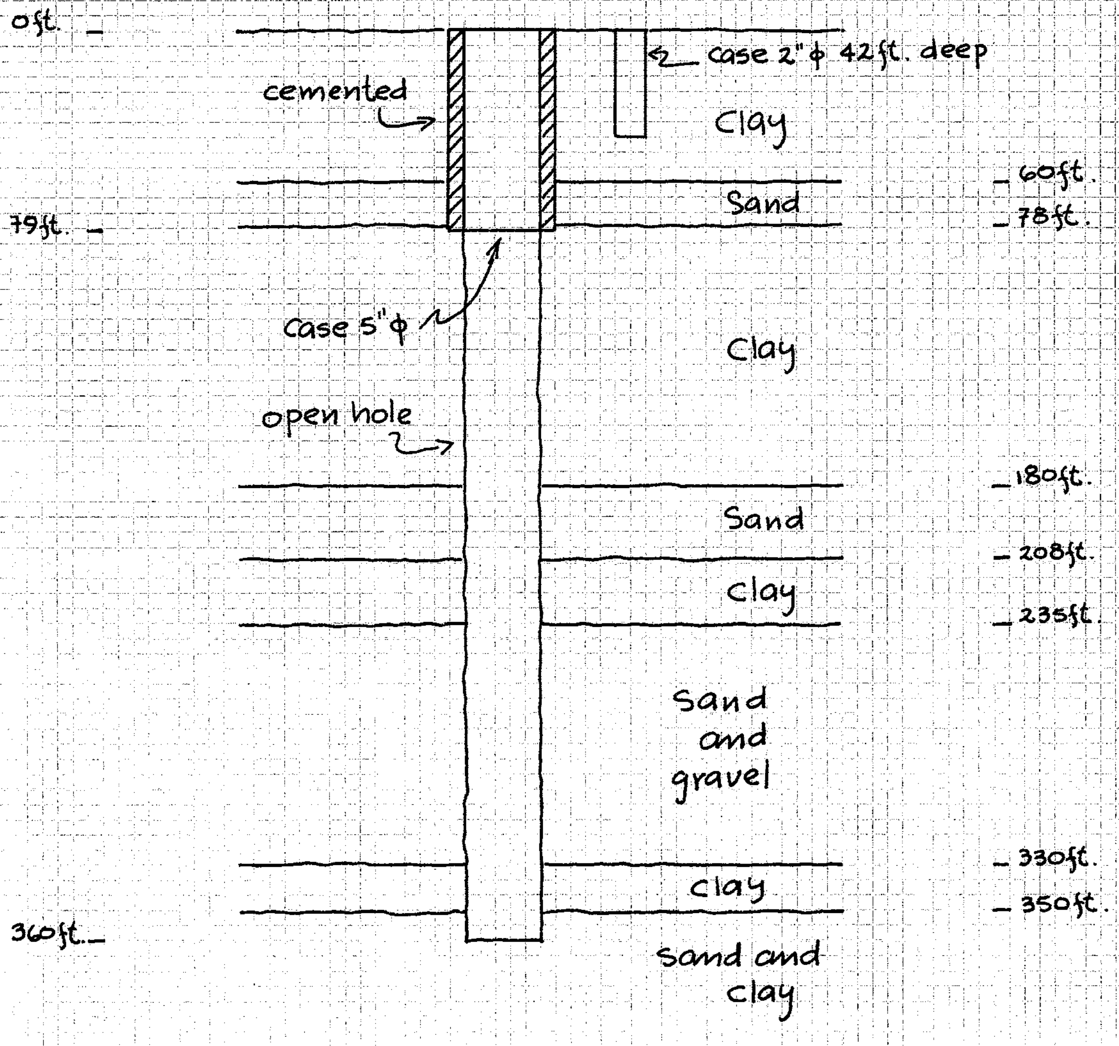
Well Berkshire #3



Well Berkshire #4



Well School Section #1



APPENDIX B

TABLES OF PUMPING TEST DATA

TABLE B1

Well Berkshire # 1

Drawdown test

Rate of discharge: 25gpm.

Date	Hour	Depth to water (ft.)	Accum. time (sec.)	Drawdown (ft.)
7/18/69	10:48	7.81 *	0	0.00
	51	41.06	180	33.25
	57	41.75	540	33.94
	11:00	42.20	720	34.39
	06	42.52	1,080	34.71
	20	41.68	1,920	33.87
	46	42.64	3,480	34.83
	12:22	41.99	5,640	34.18
	47	41.90	7,140	34.09
	13:33	41.92	9,900	34.11
	14:14	42.16	12,360	34.35

* Static level taken from earlier water level records.

TABLE B 2

Well Berkshire # 1

Recovery test Rate of recharge: 25gpm.

Date	Hour	Depth to water (ft.)	Accum. time t in sec.	Accum. time t' in sec.	Residual drawdown (ft.)	t/t'
7/18/69	14:18		12,600	0		
	19	28.58	12,660	60	20.77	211.0
	20	23.15	12,720	120	15.34	104.0
	21	19.57	12,780	180	11.76	71.0
	22	18.70	12,840	240	10.89	53.5
	23	18.07	12,900	300	10.26	42.9
	25	17.59	13,020	420	9.78	31.0
	27	16.50	13,140	540	8.69	24.3
	29	16.01	13,260	660	8.20	20.1
	31	15.61	13,380	780	7.80	17.2
	33	15.29	13,500	900	7.38	15.0
	38	14.67	13,800	1,200	6.86	11.5
	43	14.22	14,100	1,500	6.41	9.4
	48	13.84	14,400	1,800	6.03	8.0
	57	13.35	14,940	2,340	5.54	6.4
	15:08	12.94	15,600	3,000	5.13	5.2
	18	12.71	16,200	3,600	4.90	4.5
	32	12.44	17,040	4,440	4.63	3.84
	45	11.98	17,820	5,220	4.17	3.4
	17:00*	11.65	22,320	9,720	3.84	2.3
	19:00	10.97	29,520	16,920	3.16	1.75
	23:00	10.55	43,920	31,320	2.74	1.4
7/19/69	7:00	10.36	72,720	60,120	2.55	1.21
	15:00	10.29	101,520	88,920	2.48	1.14
	20:00	10.27	119,520	106,920	2.46	1.12

*Start reading levels from water level record.

TABLE B 3

Well Berkshire # 2

Drawdown test

Rate of Discharge: 15gpm.

Date	Hour	Depth to water (ft.)	Accum. time (sec.)	Drawdown (ft.)
7/16/69	11:00	13.50	0	0.00
	08	35.17	480	21.67
	22	35.95	1,320	22.45
	33	35.50	1,980	22.00
	12:24	35.65	5,040	22.15
	13:07	36.14	7,620	22.64
	28	36.31	8,880	22.81
	59	36.10	10,740	22.60

TABLE B 4

Well Berkshire # 2

Recovery test

Rate of recharge: 15gpm.

Date	Hour	Depth to water (ft.)	Accum. time t in sec.	Accum. time t' in sec.	Residual drawdown (ft.)	t/t'
7/16/69	14:00		10,800	0		
	03	30.85	10,980	180	17.35	60.9
	04	21.63	11,040	240	8.13	46.0
	05	19.74	11,100	300	6.24	37.0
	06	18.57	11,160	360	5.07	31.0
	07	18.00	11,220	420	4.50	26.7
	08	17.65	11,280	480	4.15	23.5
	13	16.46	11,580	780	2.96	14.8
	18	16.04	11,880	1,080	2.54	11.0
	28	15.64	12,480	1,680	2.14	7.42
	43	15.16	13,380	2,580	1.66	5.18
	15:01	14.86	14,460	3,660	1.36	3.95
	16:00*	14.50	18,000	7,200	1.00	2.5
	18:00	14.15	25,200	14,400	0.65	1.75
	22:00	13.92	39,600	28,800	0.42	1.37
7/17/69	6:00	13.79	68,400	57,600	0.29	1.19
	14:00	13.76	97,200	86,400	0.26	1.13
	19:00	13.74	115,200	104,400	0.24	1.1

*Start reading leveles from water level record.

TABLE B 5

Well Berkshire # 4

Drawdown test Rate of discharge: 25gpm.

Date	Hour	Depth to water (ft.)	Accum. time (sec.)	Drawdown (ft.)
7/19/69	11:55	14.97*	0	0.00
	12:02	22.54	420	7.57
	08	22.68	780	7.71
	12	22.69	1,020	7.72
	27	23.40	1,920	8.43
	30	23.36	2,100	8.39
	39	23.70	2,640	8.73
	42	23.91	2,820	8.94
	53	24.30	3,480	9.33
	13:07* *	23.46	4,320	8.49
	18	22.70	4,980	7.73
	54	22.35	7,140	7.38

*Static level taken from earlier water level records.

**Rate of discharge changed to 23 gpm.

TABLE B 6

Well Berkshire # 4

Recovery test　　　　Rate of recharge: 23gpm.

Date	Hour	Depth to water (ft.)	Accum. time t (sec.)	Accum. time t' (sec.)	Residual drawdown (ft.)	t/t'
7/19/69	14:30		9,300	0		
	38	16.95	9,780	480	1.98	20.3
	39	17.53	9,840	540	2.56	18.2
	40	16.19	9,900	600	1.22	16.5
	41	16.89	9,960	660	1.92	15.1
	42	16.83	10,020	720	1.86	13.9
	53	16.31	10,680	1,380	1.34	7.8
	15:09	16.06	11,640	2,340	1.09	5.0
	29	15.87	12,840	3,540	0.90	3.65
	35	15.78	13,200	3,900	0.81	3.4
	16:00	15.60	14,700	5,400	0.63	2.72
	18:00*	15.38	21,900	12,600	0.41	1.74
	20:00	15.25	29,100	19,800	0.28	1.48
	24:00	15.16	43,500	34,200	0.19	1.28
7/20/69	4:00	15.14	57,900	48,600	0.17	1.19
	8:00	15.12	72,300	63,000	0.15	1.15
	14:00	15.11	93,900	84,600	0.14	1.11

*Start reading levels from water level record.

TABLE B 7

Well Berkshire # 3
(Flowing well)

Observation drawdown test

Distance from pumping well: 322 ft.

Date	Hour	Depth to water (ft.)	Accum. time in days	Drawdown (ft.)	r^2/t (ft^2/day)
7/19/69	11:55	0.8	0	0.00	
	12:22	1.15	0.0187	0.35	5.59×10^6
	34	1.24	0.0271	0.44	3.85×10^6
	56	1.31	0.0424	0.51	2.47×10^6
	13:23	1.39	0.061	0.59	1.72×10^6
	58	1.47	0.0851	0.67	1.23×10^6

TABLE B 8

Well School Section # 1

Drawdown test Rate of discharge: 23gpm.

Date	Hour	Depth to water (ft.)	Accum. time (sec.)	Drawdown (ft.)
7/17/69	11:45	9.62	0	0.00
	55	34.30	600	24.68
	12:02	34.10	1,020	24.48
	13	33.73	1,680	24.11
	30	33.52	2,700	23.90
	13:03	33.63	4,680	24.01
	30	34.15	6,300	24.53

*Static level taken from earlier water level records.

TABLE B 9

Well School Section # 1

Recovery test   Rate of recharge: 23gpm.

Date	Hour	Depth to water (ft.)	Accum. time t (sec.)	Accum. time t' (sec.)	Residual drawdown (ft.)	t/t'
7/17/69	13:57		7,920	0		
	59	11.86	8,040	120	2.24	67.0
	14:01	11.00	8,160	240	1.38	34.0
	02	10.72	8,220	300	1.10	27.5
	03	10.58	8,280	360	0.96	23.0
	08	10.01	8,580	660	0.38	13.0
	13	9.76	8,880	960	0.14	9.25
	25	9.57	9,600	1,680	-0.05	5.72
	15:00	9.20	11,700	3,780	-0.42	3.1
	16:00*	8.95	15,300	7,380	-0.67	2.07
	18:00	8.78	22,500	14,580	-0.84	1.54
	22:00	8.69	36,900	28,980	-0.93	1.27
7/18/69	2:00	8.69	51,300	43,380	-0.93	1.19
	6:00	8.65	65,700	57,780	-0.97	1.14

*Start reading levels from water level record.

TABLE B 10

Well School Section # 1

Drawdown test Rate of discharge: 42.9gpm.

Date	Hour	Depth to water (ft.)	Accum. time in sec.	Drawdown (ft.)
9/3/69	7:55	12.93*	0	0.00
	59	51.19	240	38.26
	8:08	52.40	780	39.47
	20	52.47	1,500	39.54
	10:00	53.58	7,500	40.65
	11:52	54.09	14,220	41.16
	13:27	54.17	19,920	41.24
	55	54.16	21,600	41.23
	14:52	54.16	25,020	41.23
	16:25	54.00	30,600	41.07

*Static level taken from earlier water level records.

TABLE B 11

Well School Section # 1

Recovery test

Rate of recharge: 42.9gpm.

Date	Hour	Depth to water (ft.)	Accum. time t in sec.	Accum. time t' in sec.	Residual drawdown (ft.)	t/t'
9/3/69	17:00		32,700	0		
	02	19.36	32,820	120	6.43	274.0
	05	16.87	33,000	300	3.94	110.0
	06	16.55	33,060	360	3.62	92.0
	10	15.96	33,300	600	3.03	55.5
	14	15.62	33,540	840	2.69	40.0
	23	15.17	34,080	1,380	2.44	24.7
	30	14.95	34,500	1,800	2.02	19.2
	36	14.79	34,860	2,160	1.86	16.2
	44	14.63	35,340	2,640	1.70	13.4
	52	14.49	35,820	3,120	1.56	11.5
	18:00	14.39	36,300	3,600	1.46	10.1
9/4/69	7:58	12.99	86,580	53,880	0.06	1.62
9/5/69	7:57	12.77	172,920	140,220	-0.16	1.24

TABLE B 12

Well School Section # 1

Drawdown test Rate of discharge: 40gpm.

Date	Hour	Depth to water (ft.)	Accum. time (sec.)	Drawdown (ft.)
9/10/69	,7:50	12.33	0	0.00
	52	41.14	120	28.81
	54	46.89	240	34.56
	8:07	48.60	1,020	36.27
	22	49.62	1,920	37.29
	9:02	50.48	4,320	38.15
	33	50.65	6,180	38.32
	10:34	50.83	9,840	38.50
	11:35	50.64	13,500	38.31
	12:38	50.91	17,280	38.58
	13:36*	44.13	20,760	31.80
	44	46.89	21,240	34.56
	15:03	46.39	25,980	34.06
	57	44.95	29,220	32.62
	16:57	45.49	32,820	33.16
	18:58	45.89	40,080	33.56
9/11/69	5:14	44.33	77,040	32.00
	6:55	44.03	83,100	31.70
	9:23	43.36	91,980	31.03
	10:37	42.94	96,420	30.61

* After this time rate of discharge decreased to 33gpm.

TABLE B 13

Well School Section # 1

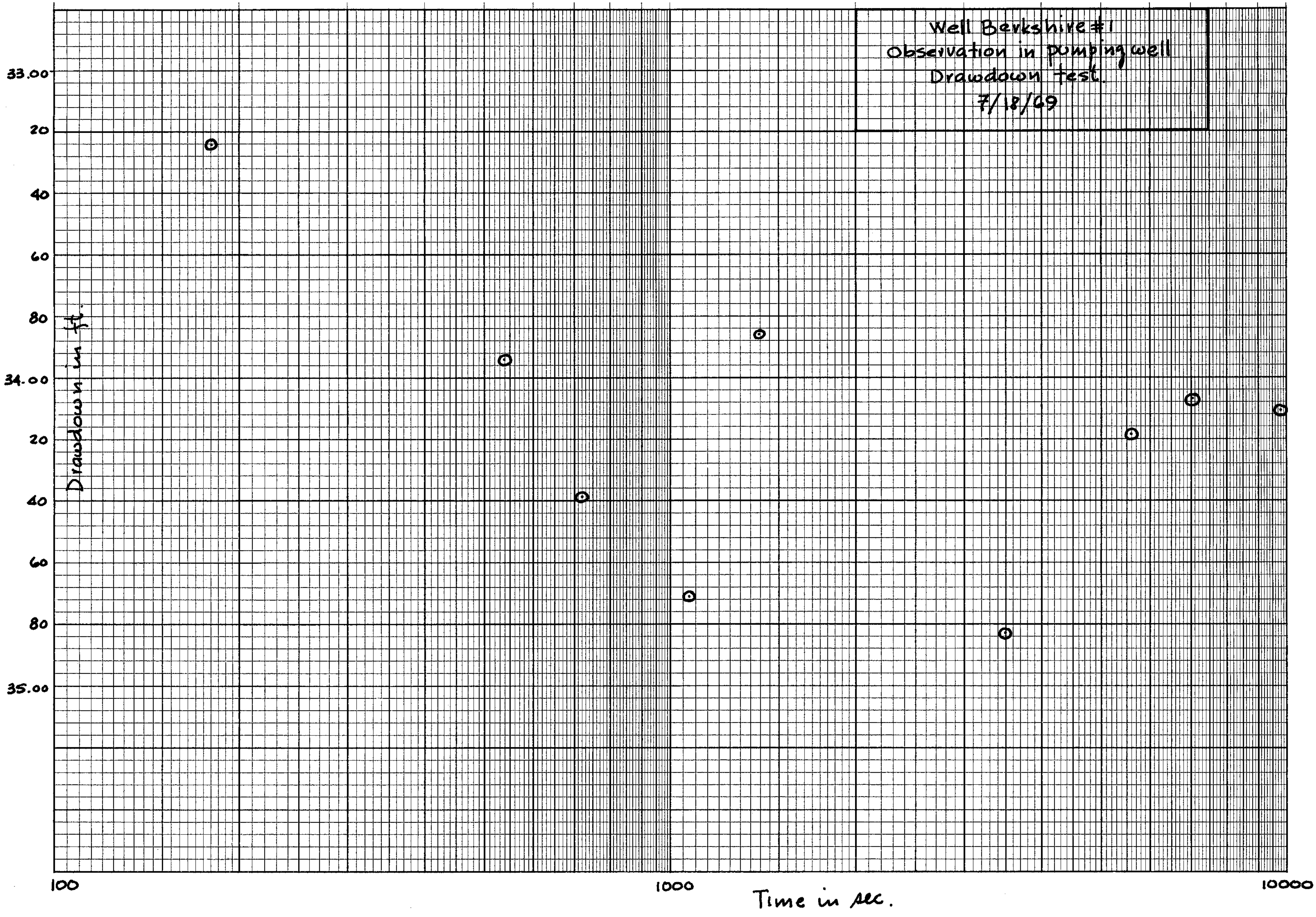
Recovery test Rate of recharge: 33gpm.

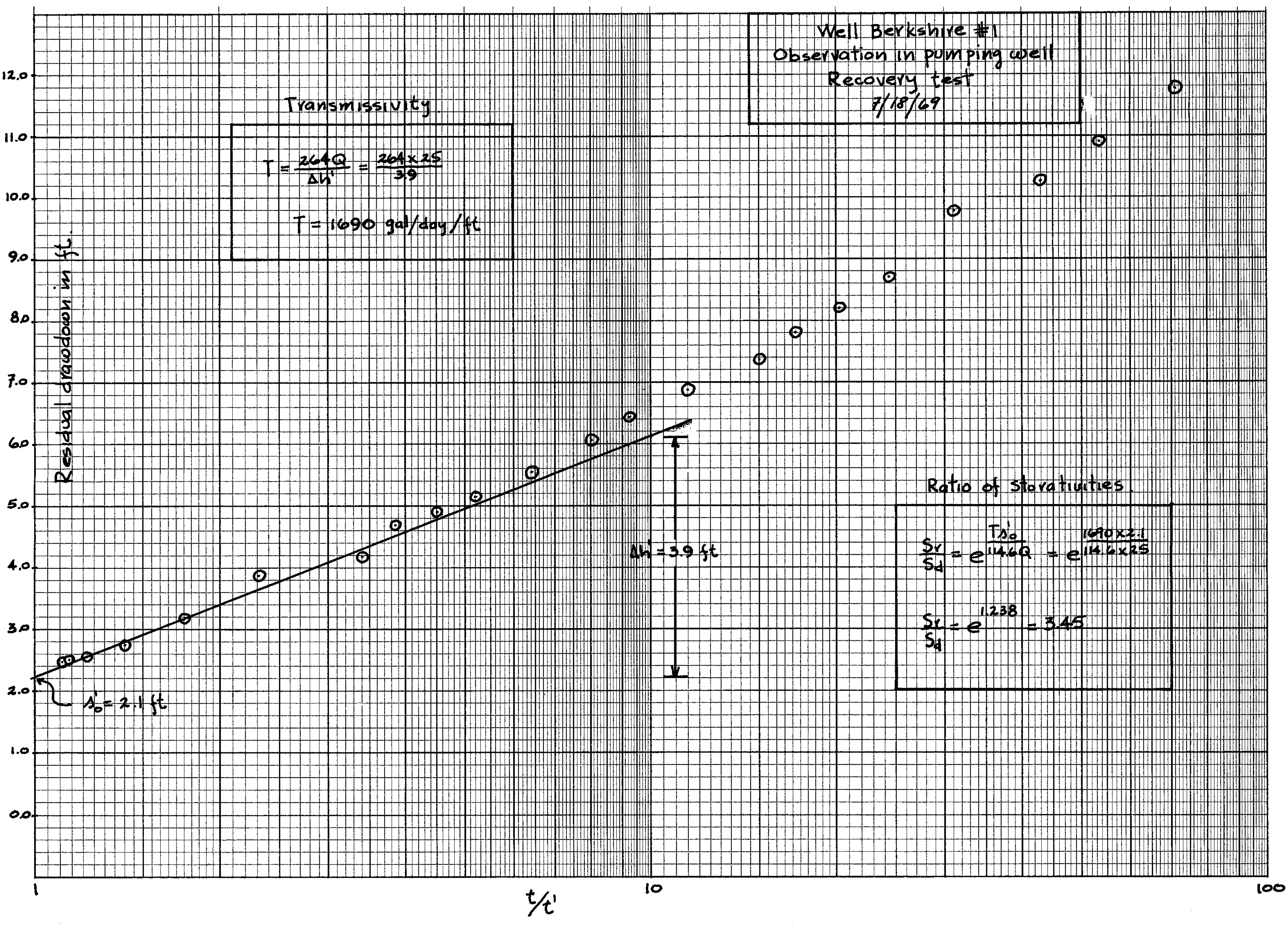
Date	Hour	Depth to water (ft.)	Accum. time t (sec.)	Accum. time t' (sec.)	Residual drawdown (ft.)	t/t'
9/11/69	12:45		104,100	0		
	13:10	13.80	105,600	1,500	1.47	70.0
	19	13.71	106,141	2,040	1.34	52.1
	38	13.52	107,280	3,180	1.19	33.7
	53	13.43	108,180	4,080	1.10	26.5
	14:04	13.36	108,840	4,740	1.03	23.0
	19	13.28	109,740	5,640	0.95	19.4
9/12/69	12:17	12.26	196,020	91,920	-0.07	2.13
	18:00*	12.17	219,600	115,500	-0.16	1.90
	24:00	12.14	241,200	137,100	-0.19	1.76
9/13/69	8:00	12.05	270,000	165,900	-0.28	1.63
	16:00	12.00	298,800	194,700	-0.33	1.54
	24:00	11.97	327,600	223,500	-0.36	1.47

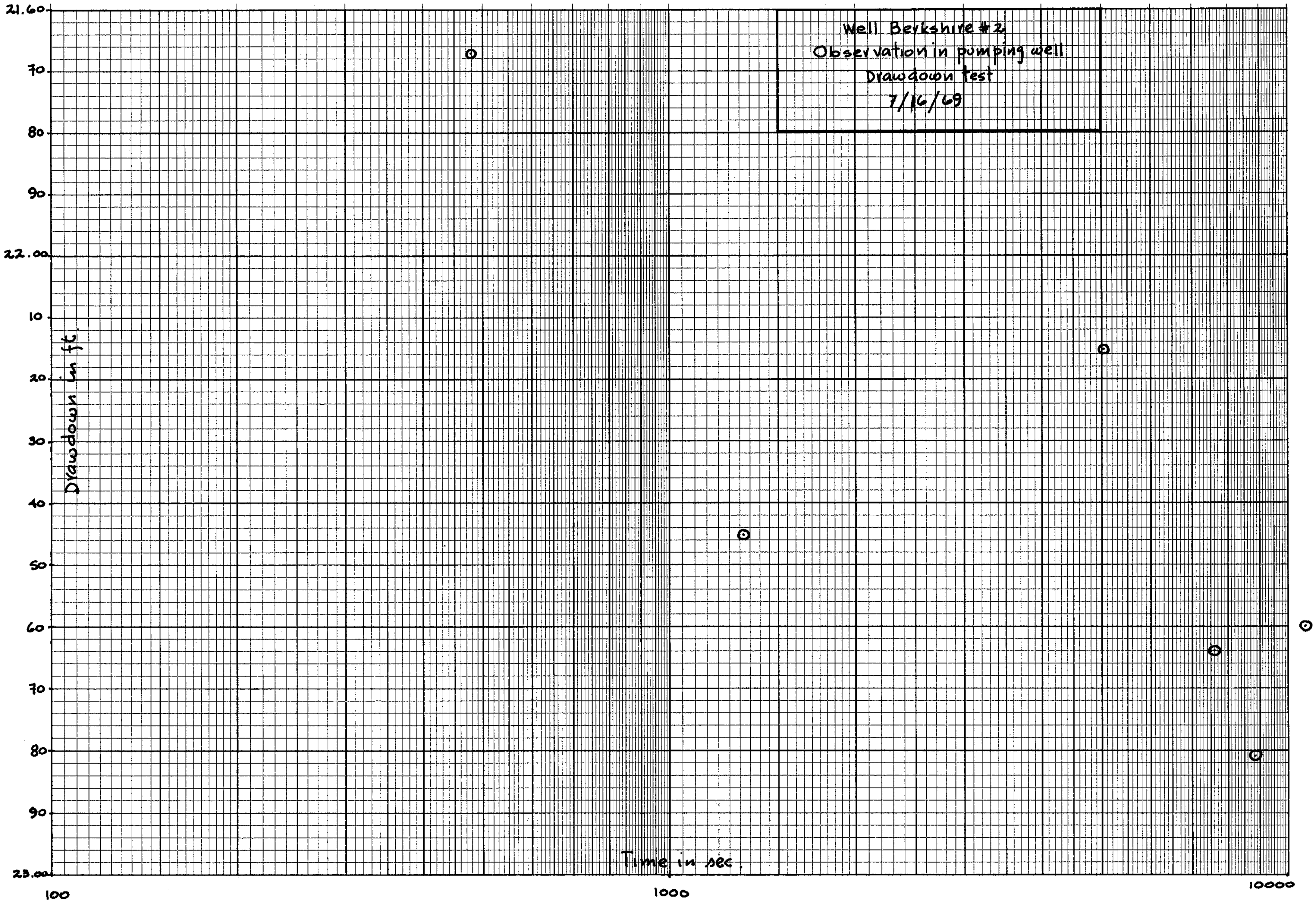
*Start reading from water level record.

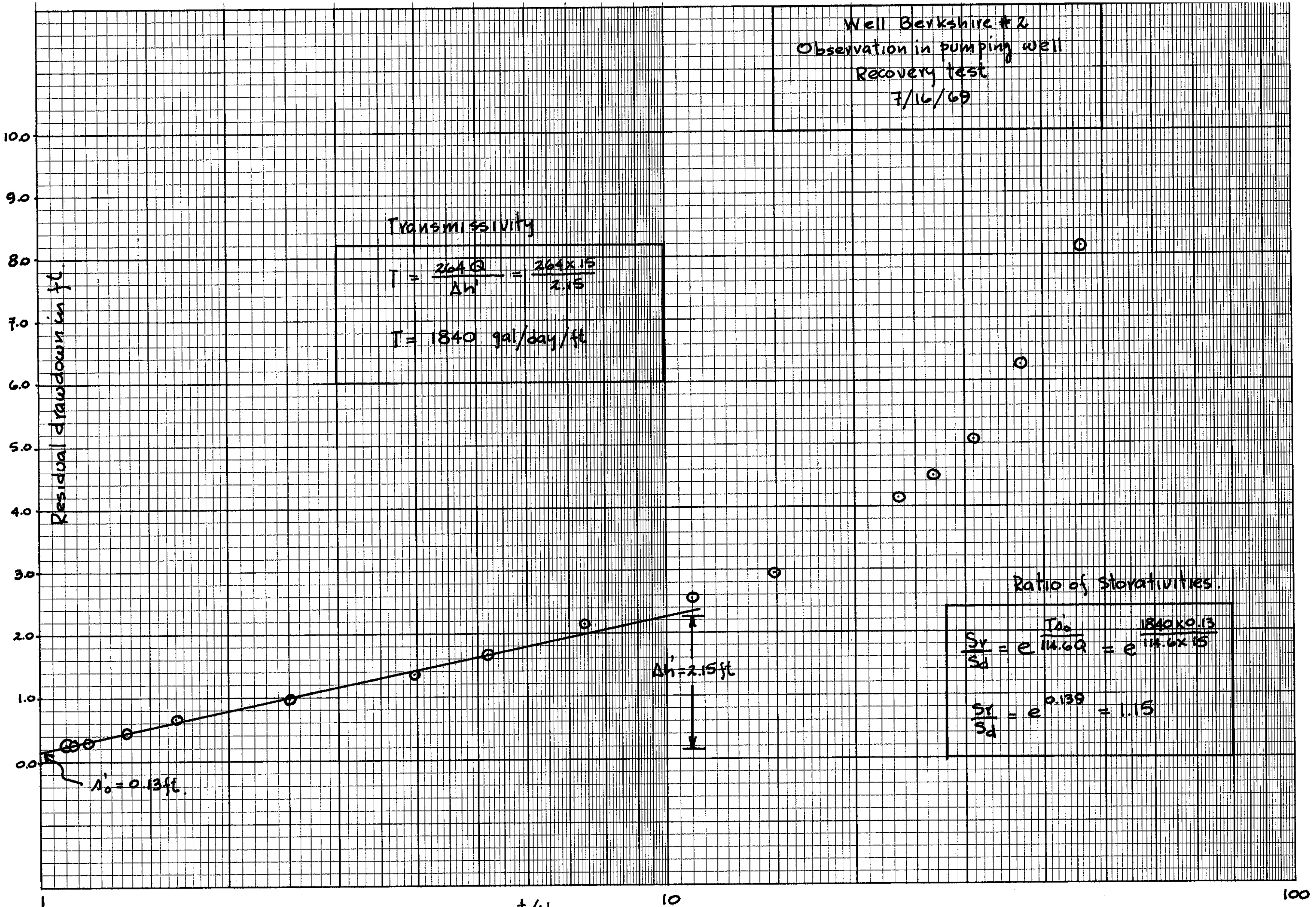
APPENDIX C

PLOTS OF PUMPING TEST DATA AND COMPUTATIONS OF HYDRAULIC CHARACTERISTICS


Well Berkshire #1
Observation in pumping well
Drawdown test.
7/18/69
33.00
20
40
60
80
34.00
20
40
60
80
35.00
Drawdown in ft.
100
1000
10000
Time in sec.


Well Berkshire #1
Observation in pumping well
Recovery test
7/18/69
Transmissivity
$T = \frac{264Q}{\Delta h'} = \frac{264 \times 25}{3.9}$
T = 1690 gal/day/ft
Ratio of storativities
$\frac{S_r}{S_d} = e^{\frac{Ts'_o}{114.6Q}} = e^{\frac{1690 \times 2.1}{114.6 \times 25}}$
$\frac{S_r}{S_d} = e^{1.238} = 3.45$
$\Delta h' = 3.9$ ft
$s'_o = 2.1$ ft
Residual drawdown in ft
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1
10
100
t/t'


Well Berkshire #2
Observation in pumping well
Drawdown test
7/16/69
Drawdown in ft.
Time in sec.
21.60
70
80
90
22.00
10
20
30
40
50
60
70
80
90
23.00
100
1000
10000



Well Berkshire # 2
Observation in pumping well
Recovery test
7/16/69

Transmissivity

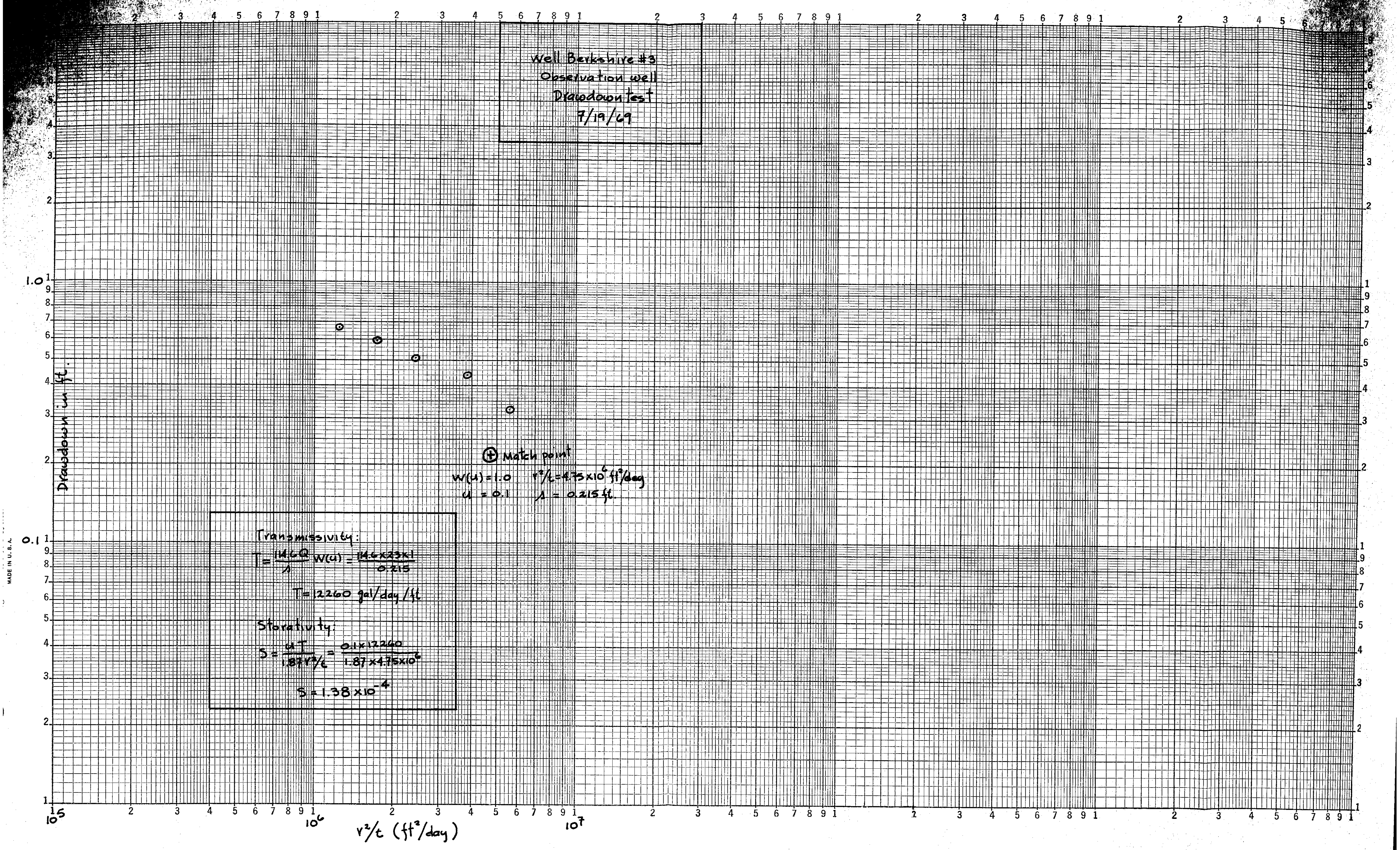
$$T = \frac{264\,Q}{\Delta h'} = \frac{264 \times 15}{2.15}$$

$$T = 1840 \text{ gal/day/ft}$$

Ratio of Storativities.

$$\frac{S_r}{S_d} = e^{\frac{T s'_o}{114.6\,Q}} = e^{\frac{1840 \times 0.13}{114.6 \times 15}}$$

$$\frac{S_r}{S_d} = e^{0.139} = 1.15$$



Well Berkshire #3
Observation well
Drawdown test
7/19/69

⊕ Match point
$W(u) = 1.0$ $r^2/t = 4.75 \times 10^6$ ft²/day
$u = 0.1$ $s = 0.215$ ft.

Transmissivity:

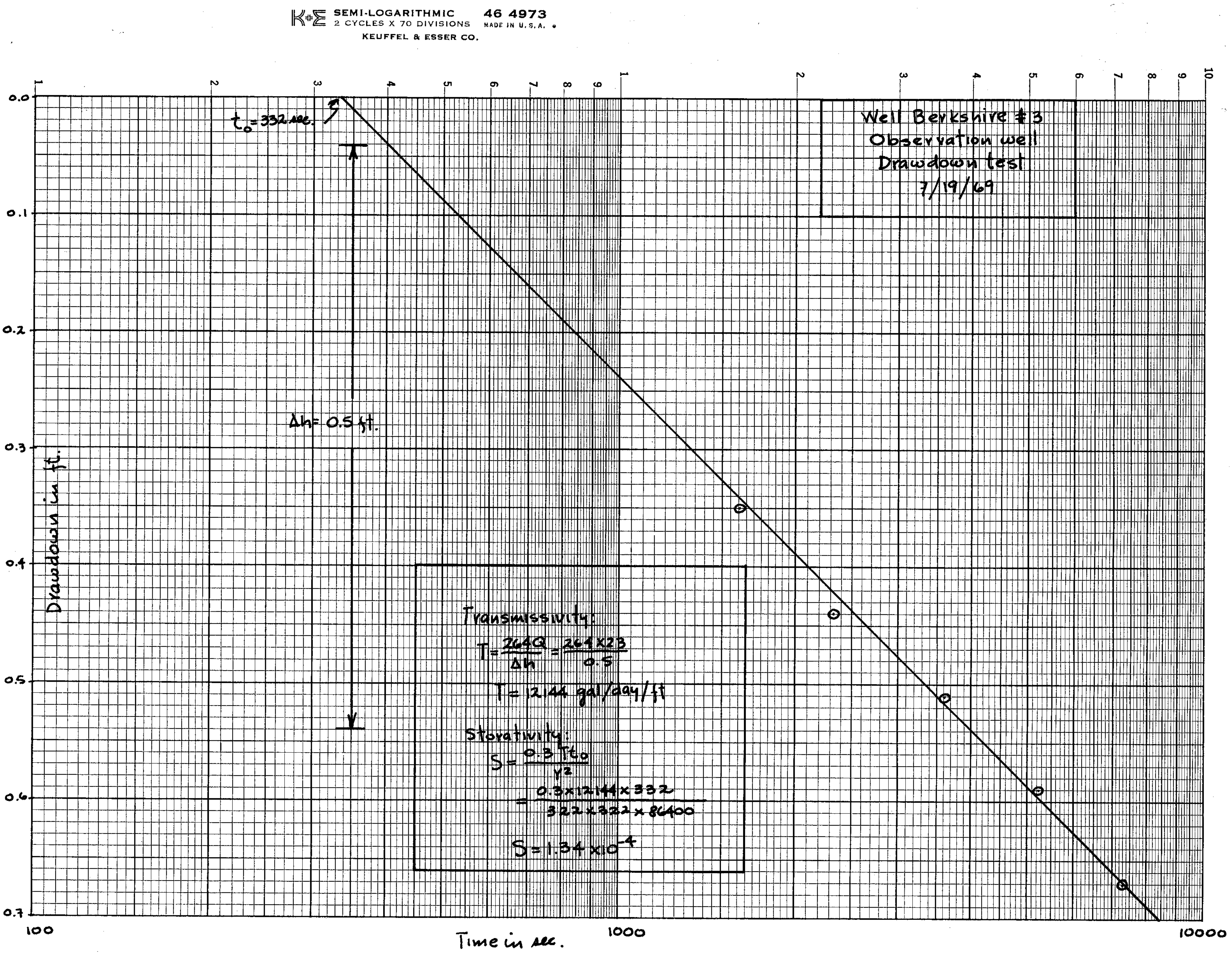
$$T = \frac{114.6Q}{s} W(u) = \frac{114.6 \times 23 \times 1}{0.215}$$

$T = 12260$ gal/day/ft

Storativity:

$$S = \frac{uT}{1.87 r^2/t} = \frac{0.1 \times 12260}{1.87 \times 4.75 \times 10^6}$$

$S = 1.38 \times 10^{-4}$



Well Berkshire #3
Observation well
Drawdown test
7/19/69

Transmissivity:

$$T = \frac{264Q}{\Delta h} = \frac{264 \times 23}{0.5}$$

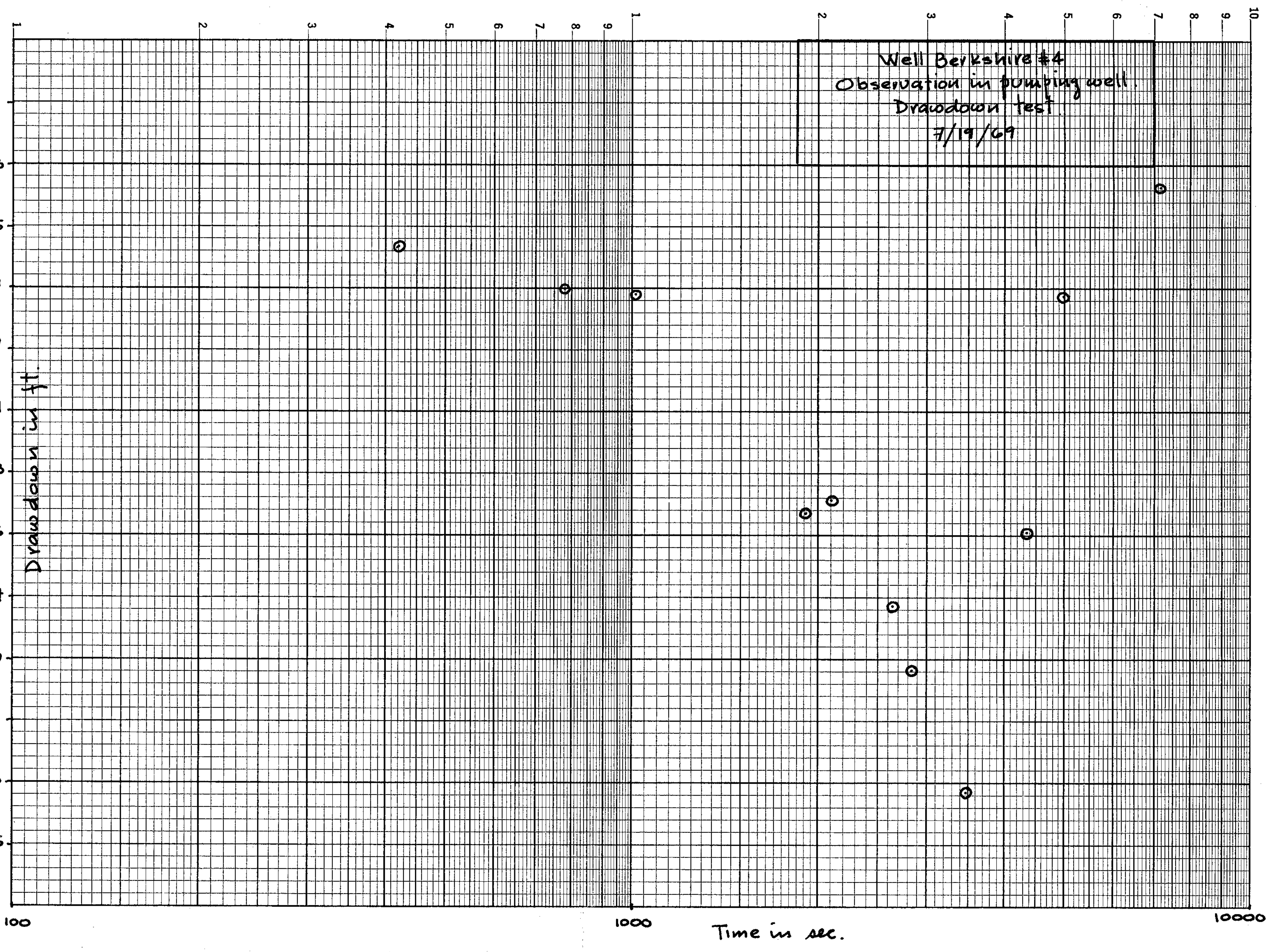
$$T = 12144 \text{ gal/day/ft}$$

Storativity:

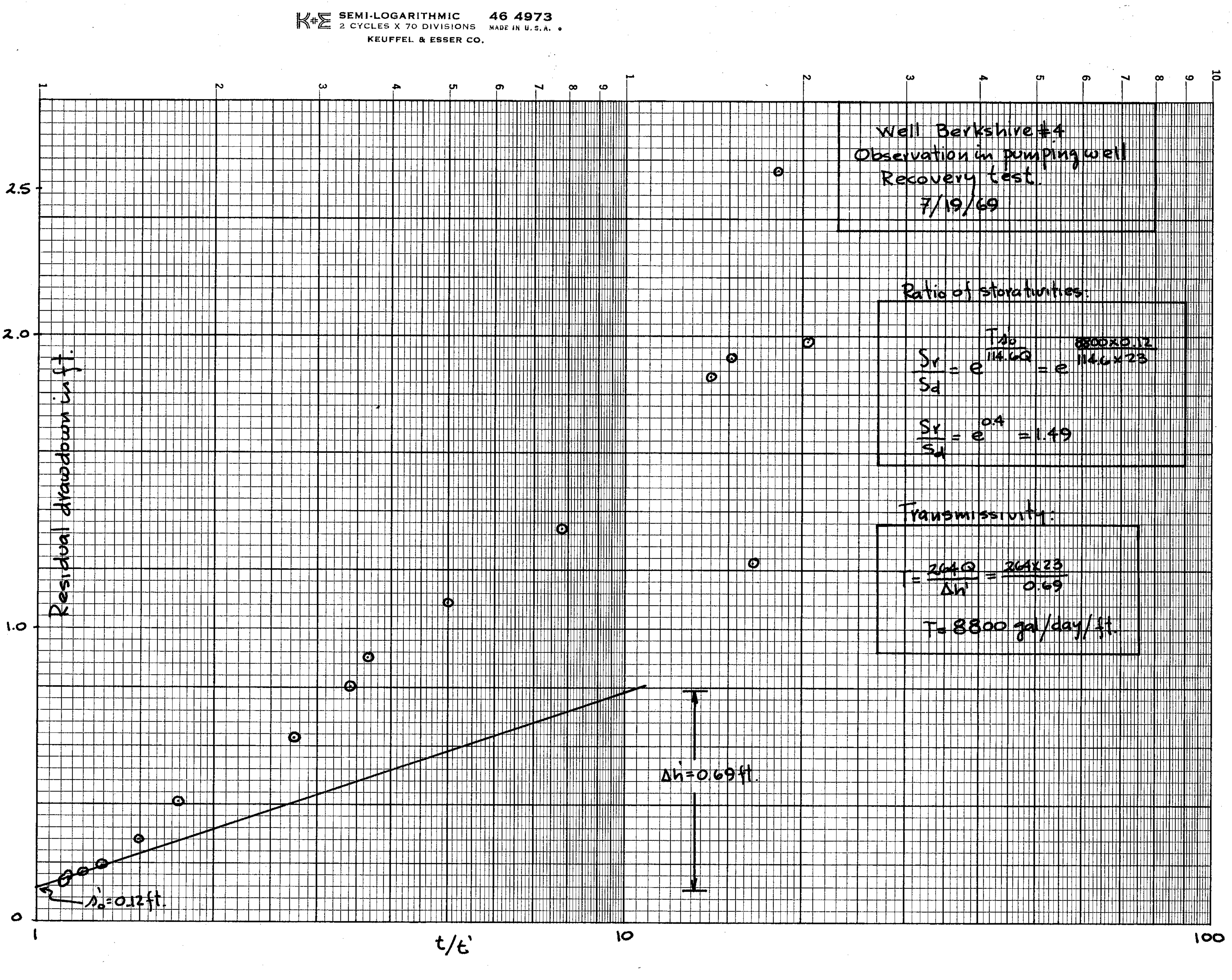
$$S = \frac{0.3\,T t_o}{r^2}$$

$$= \frac{0.3 \times 12144 \times 332}{322 \times 322 \times 86400}$$

$$S = 1.34 \times 10^{-4}$$



Well Berkshire #4
Observation in pumping well.
Drawdown test
7/19/69



Well Berkshire #4
Observation in pumping well
Recovery test.
7/19/69

Ratio of storativities:

$$\frac{S_r}{S_d} = e^{\frac{T s_0'}{114.6Q}} = e^{\frac{8800 \times 0.12}{114.6 \times 23}}$$

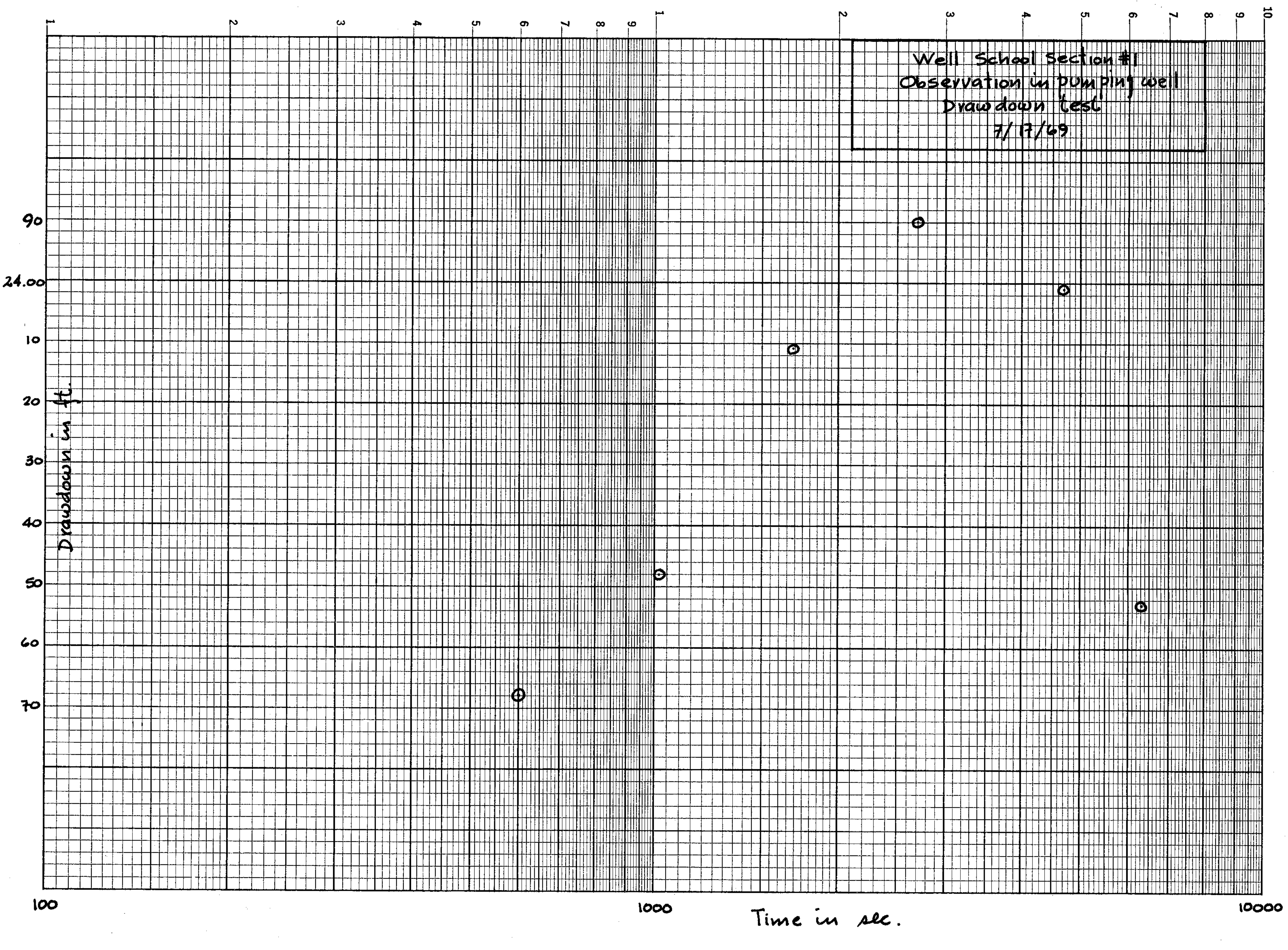
$$\frac{S_r}{S_d} = e^{0.4} = 1.49$$

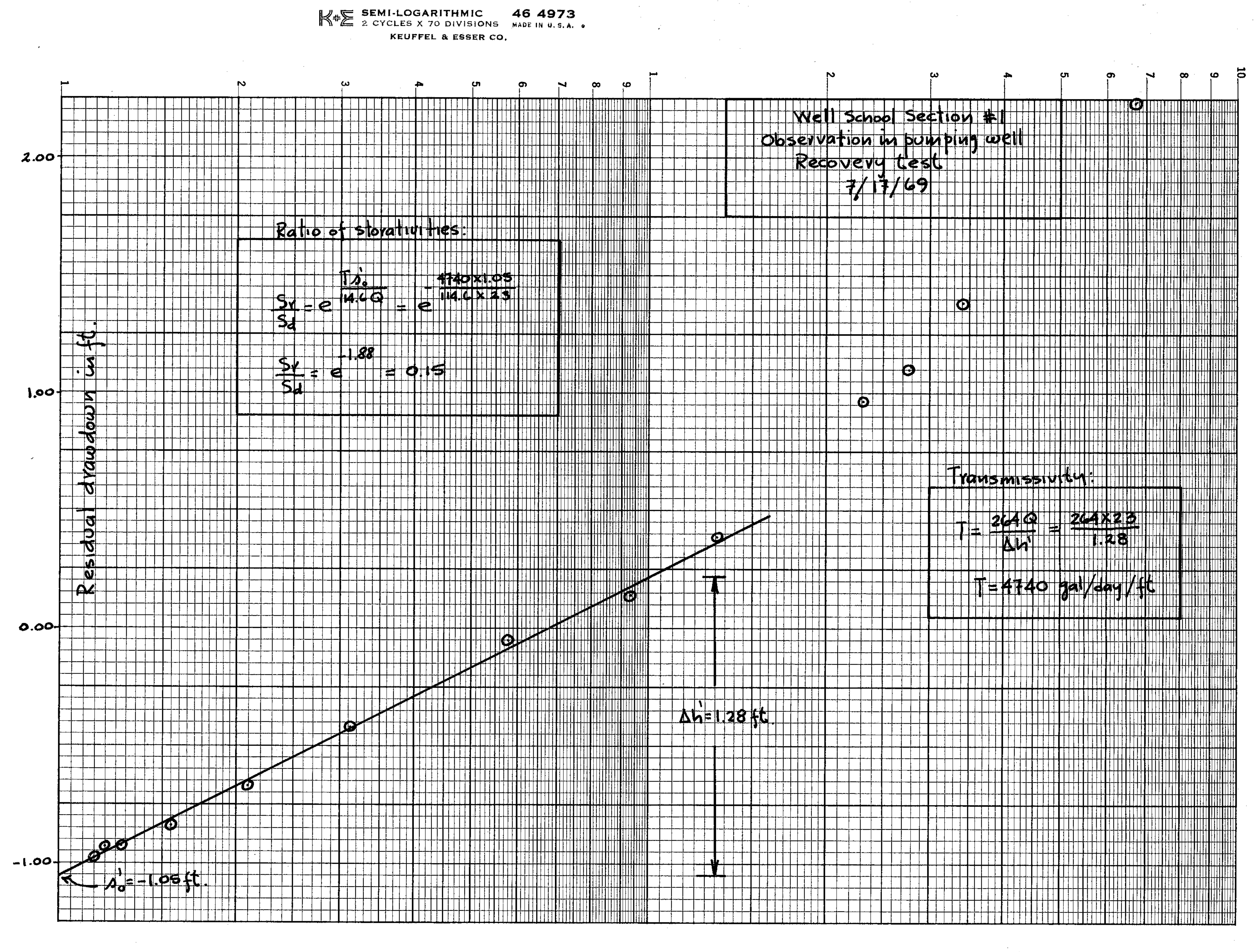
Transmissivity:

$$T = \frac{264Q}{\Delta h'} = \frac{264 \times 23}{0.69}$$

T=8800 gal/day/ft.

K+E SEMI-LOGARITHMIC 46 4973
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.





Well School Section #1
Observation in pumping well
Recovery test
7/17/69

Ratio of storativities:

$$\frac{S_r}{S_d} = e^{-\frac{Ts_o'}{114.6Q}} = e^{-\frac{4740 \times 1.05}{114.6 \times 23}}$$

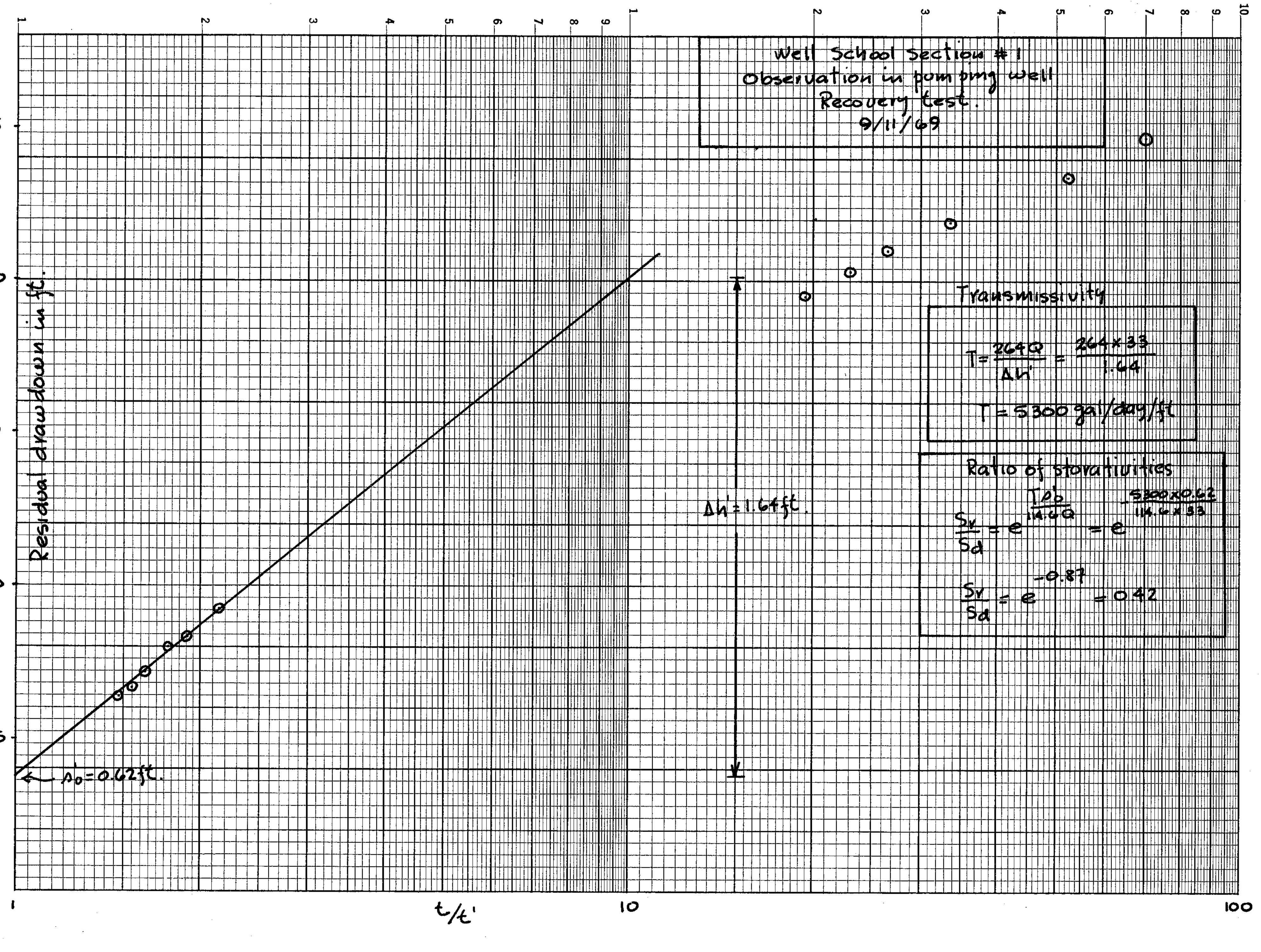
$$\frac{S_r}{S_d} = e^{-1.88} = 0.15$$

Transmissivity:

$$T = \frac{264Q}{\Delta h'} = \frac{264 \times 23}{1.28}$$

T = 4740 gal/day/ft

K+E SEMI-LOGARITHMIC 46 4973
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.



Well School Section #1
Observation in pumping well
Recovery test.
9/11/69

Transmissivity

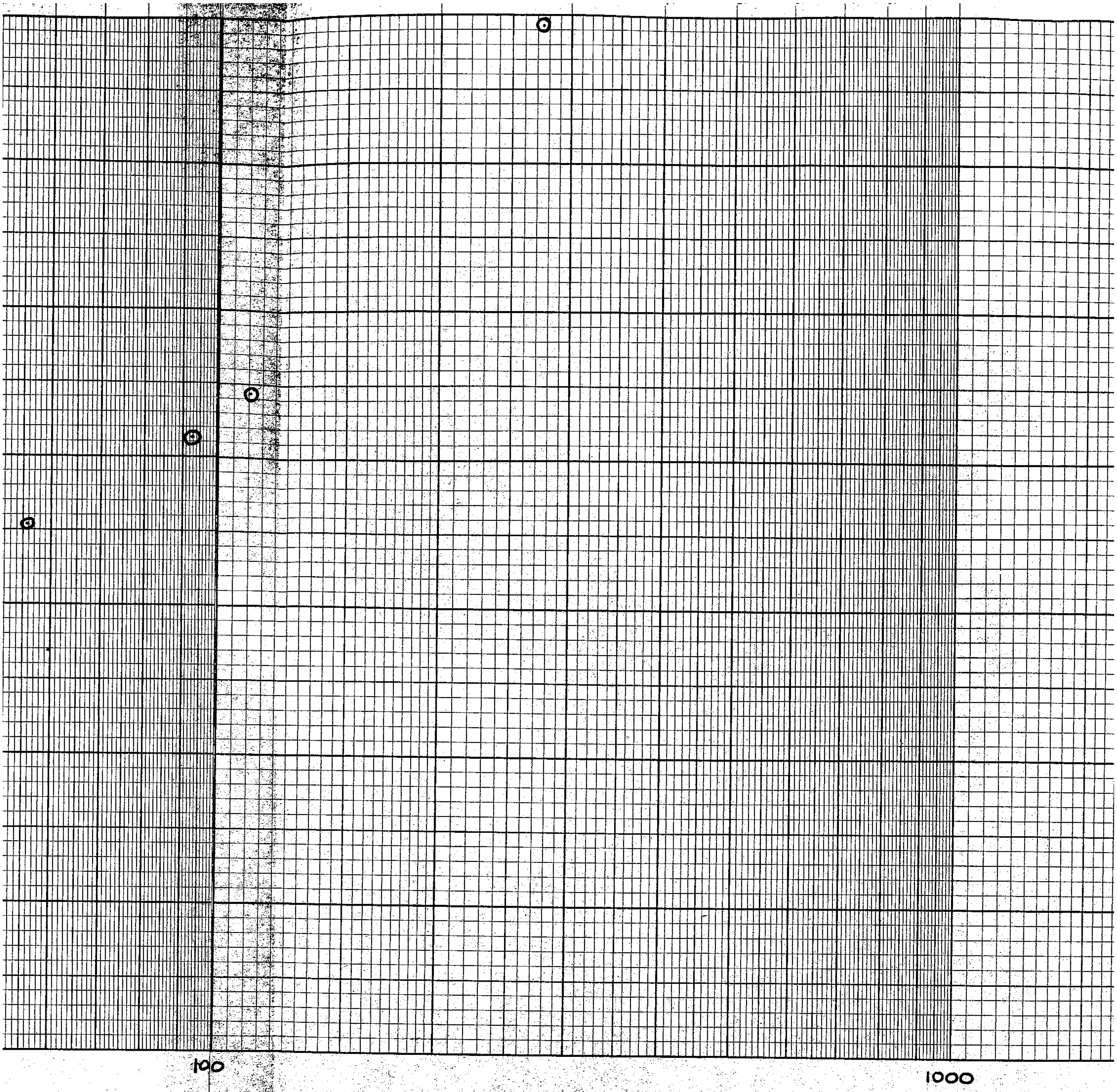
$T = \frac{264Q}{\Delta h'} = \frac{264 \times 33}{1.64}$

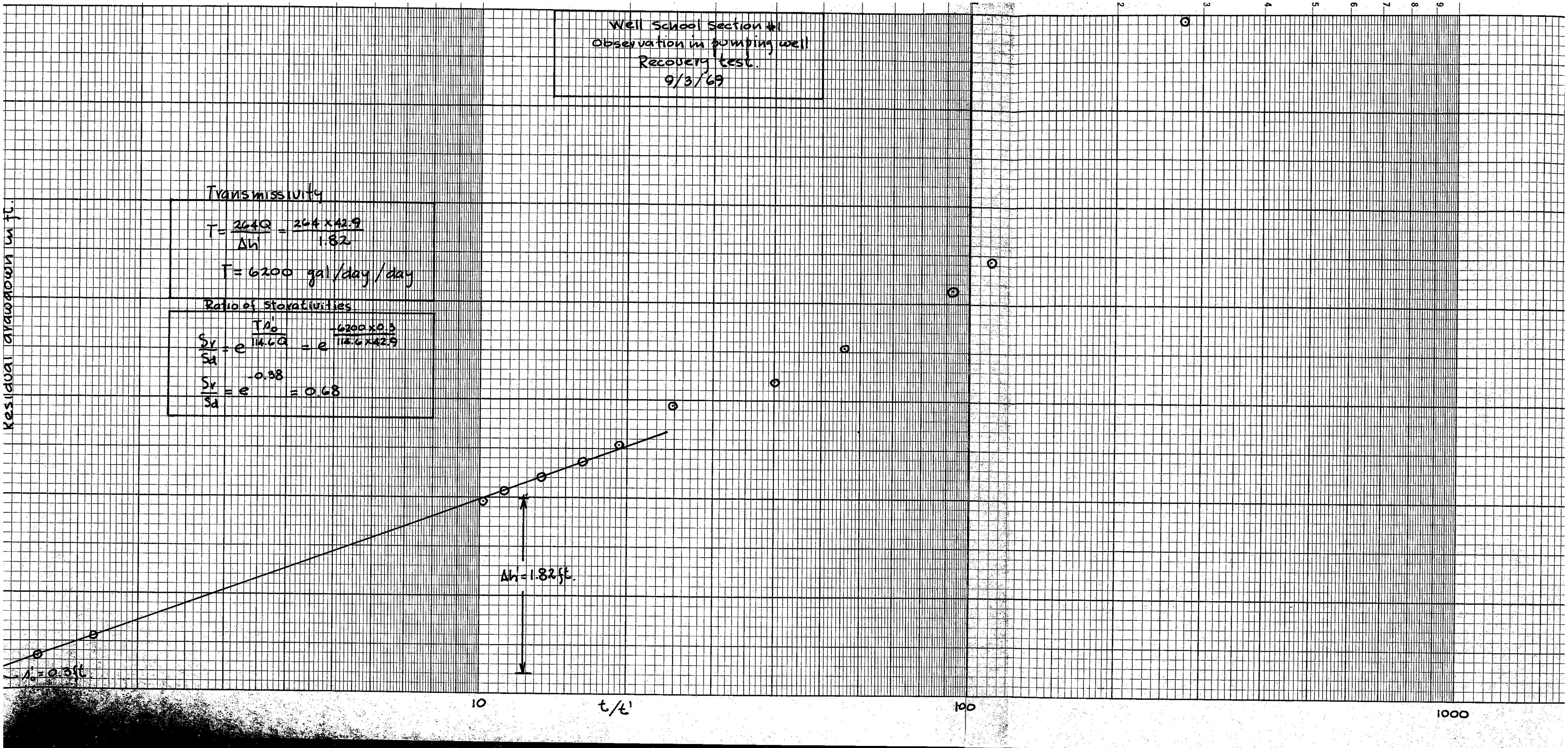
$T = 5300$ gal/day/ft

Ratio of storativities

$\frac{S_r}{S_d} = e^{\frac{T s_0'}{114.6Q}} = e^{-\frac{5300 \times 0.62}{114.6 \times 33}}$

$\frac{S_r}{S_d} = e^{-0.87} = 0.42$


100
1000



Well school section #1
Observation in pumping well
Recovery test.
9/3/69

Transmissivity

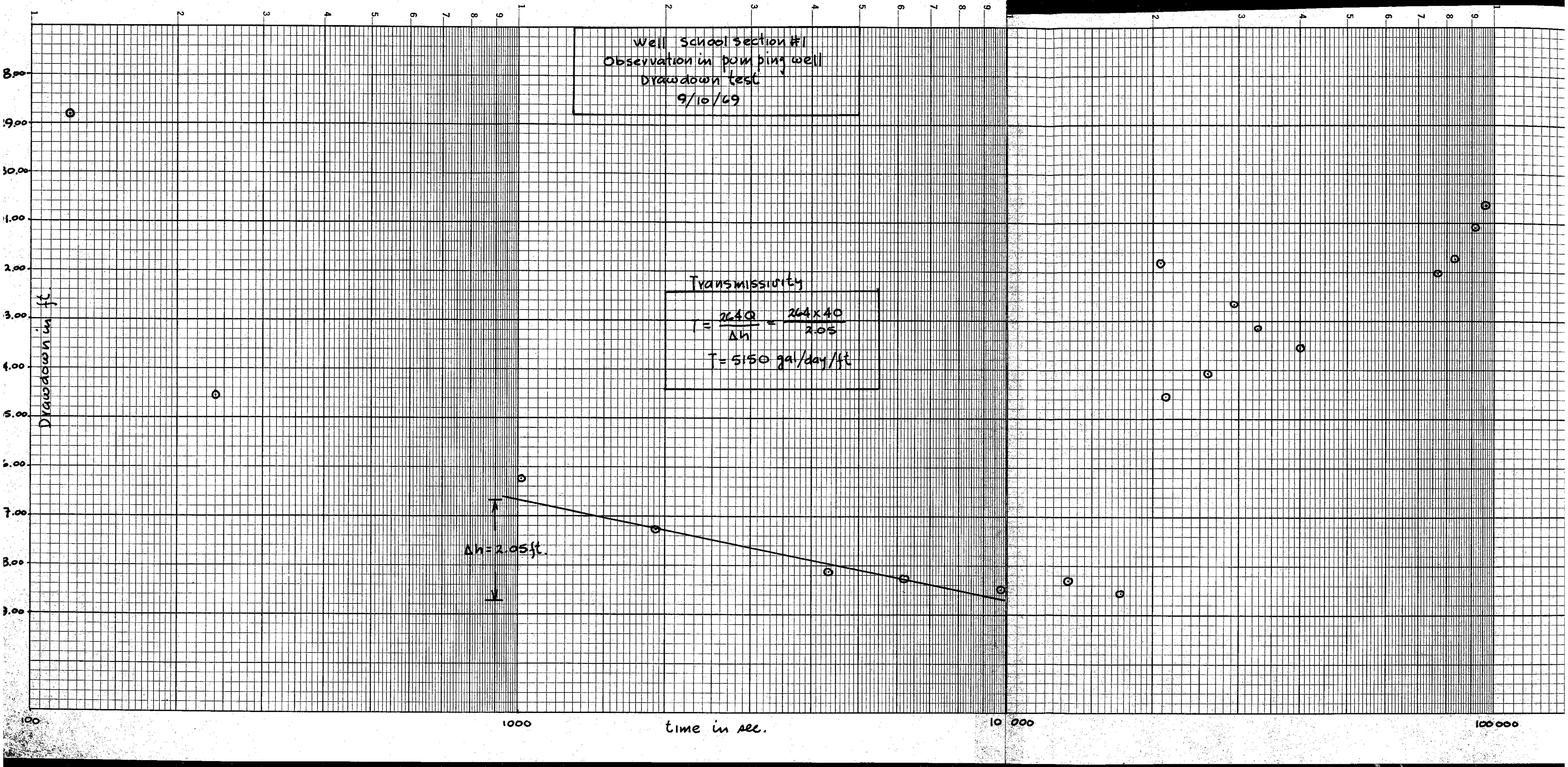
$$T = \frac{264Q}{\Delta h'} = \frac{264 \times 42.9}{1.82}$$

T = 6200 gal/day/day

Ratio of storativities

$$\frac{S_r}{S_d} = e^{\frac{T s_o'}{114.6Q}} = e^{\frac{-6200 \times 0.3}{114.6 \times 42.9}}$$

$$\frac{S_r}{S_d} = e^{-0.38} = 0.68$$

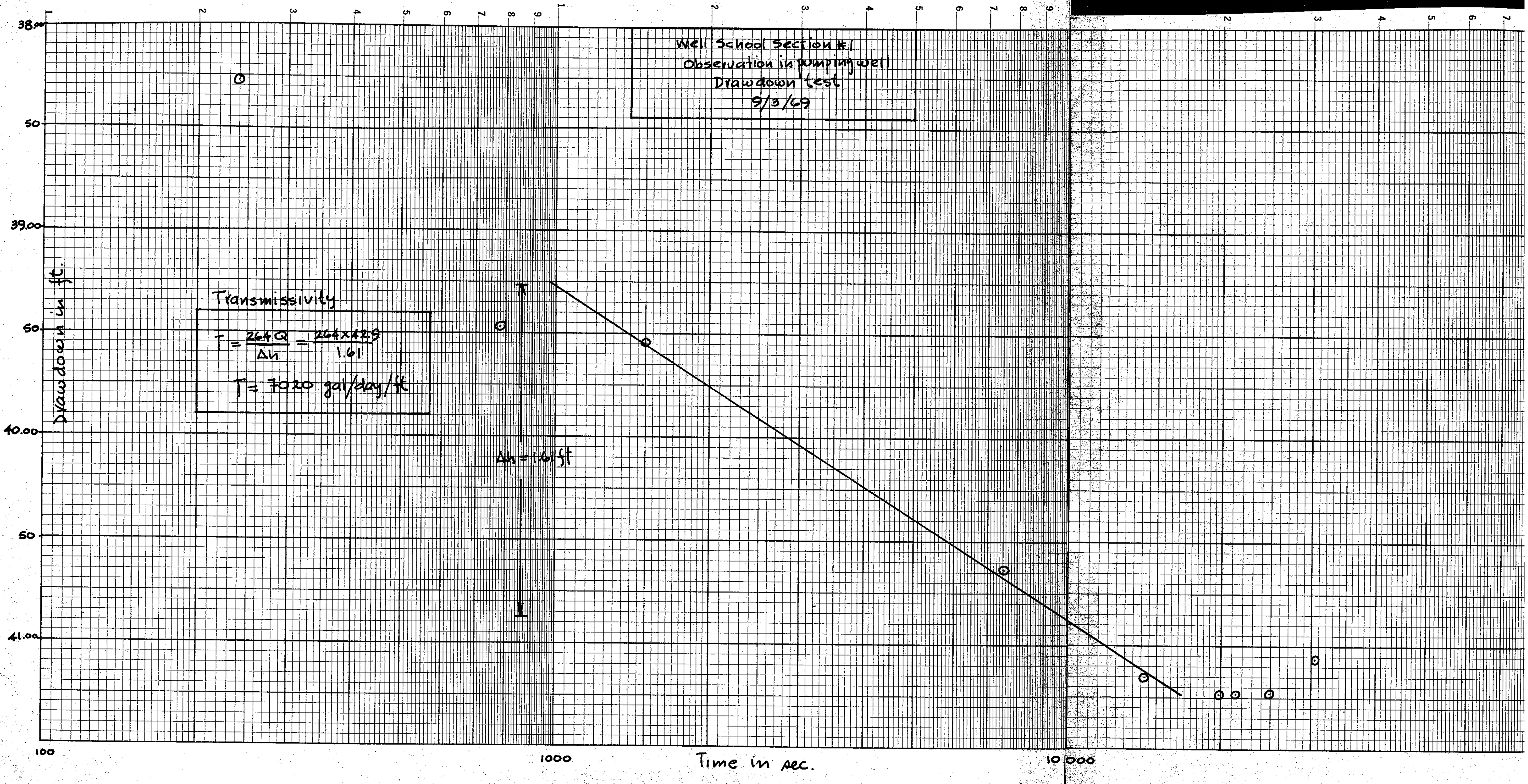


Well School section #1
Observation in pumping well
Drawdown test
9/10/69

Transmissivity

$$T = \frac{264Q}{\Delta h} = \frac{264 \times 40}{2.05}$$

T = 5150 gal/day/ft



Well School Section #1
Observation in pumping well
Drawdown test
9/3/69

Transmissivity

$$T = \frac{264Q}{\Delta h} = \frac{264 \times 42.9}{1.61}$$

$$T = 7020 \text{ gal/day/ft}$$