N42237.AR.000197
NSB KINGS BAY
5090.3a

LETTER REGARDING DATA FROM THE PRELIMINARY AQUIFER TEST AT NSB KINGS BAY GA
1/13/1994
U S DEPARTMENT OF THE INTERIOR

United States Department of the Interior

GEOLOGICAL SURVEY
Water Resources Division
Peachtree Business Center, Suite 130
3039 Amwiler Road
Atlanta, Georgia 30360-2824

TAKE PRIDE IN AMERICA

January 13, 1994

31547.000
16.01.00.0013

Mr. David Driggers
Southern Division Naval Facilities Engineering Command
2155 Eagle Drive, P.O. Box 190010
North Charleston, South Carolina 29419-9010

Dear David:

The data from the preliminary aquifer test at Kings Bay submarine base were transmitted from ABB Environmental Services (ABB) to the USGS in early December, as you had requested. The data were reviewed and analyzed by the USGS. Descriptions and results are given on the enclosed pages.

Five methods were used to determine aquifer parameters. Values of hydraulic conductivity computed from the different analyses are surprisingly similar; range is from 5.8 to 14 feet per day, and median is 11 feet per day. The specific yield of the aquifer could not be determined, probably because pumping duration was too short (25 hours) in this preliminary test. The more detailed test of 7-day duration, planned by ABB for the near future, may yield data from which the specific yield can be determined.

ABB has informed the USGS that their analyses of these preliminary aquifer-test data will be included in a report to be printed soon. Comparison of the results from that report with those on the attached pages will be interesting. Hopefully, the results will be similar. An extra copy of the enclosure is included, in case you want to transmit it to ABB.

Sincerely,

Bud Zehner

Bud Zehner
Hydrologist

Enclosure

USGS analyses of data from aquifer test completed by ABB Environmental Services (ABB)

The data from the aquifer test completed by ABB at the Kings Bay submarine base in October 1993 were sent from ABB to the USGS by letter dated December 6, 1993. As stated in the letter, this 25-hour-long test is considered to be preliminary to a test of 7-day duration that will soon be conducted by ABB. USGS analysis of the data consisted of comparison of time-drawdown curves to plots of barometric-pressure change, followed by use of several methods to estimate aquifer parameters. Mostly, results are described. Methods and procedures are described only briefly; details may be obtained from references cited. The well-construction and initial water-level information used in the analyses (table 1) were obtained from the December 6, 1993 letter from ABB, and from a phone conversation with K. Sichelstiel of ABB in mid-December.

Table 1. Well and initial (pre-pumping) water-level information collected during aquifer test at Kings Bay in October 1993. All depths in feet, referenced to ground level. Aquifer saturated thickness is 75 feet.

Well	Distance from pumped well*	Depth of open interval	Initial depth to water
RW1**	0	20.5 - 60.5	7.42
PS1	13	30. - 35.	6.95
PS2	62	30. - 35.	5.07
PS3	65	31.4 - 36.4	6.61
PS4	400	30.1 - 35.1	8.
11-1	436	2.5 - 12.5	***
11-2	66	3.0 - 13.0	***

*Approximate, as stated in ABB letter of December 6, 1993.
**Pumped well, constant discharge 6.47 gallons per minute.
***Unknown to USGS, not used in analysis.

Plots were made of barometric-pressure and drawdown data from wells PS2 and 11-1 (fig. 1), and of drawdown data from wells PS1, PS3, PS4, and 11-2 (fig. 2). A constant 7 pounds per square inch was subtracted from barometric-pressure data, and constant 1 foot was subtracted from well PS1 water-level data, so that individual plots would have closer proximity for more detailed comparison. All observation wells apparently respond to barometric pressure change, and response is least in the shallower wells 11-1 and 11-2. The shallower two wells apparently have good hydraulic connection to the aquifer (personal commum., K. Sichelstiel, ABB, December 1993), but responded very little, if any, to pumping and were therefore not included in aquifer-test analyses. The reason for the lack of response in the two shallower wells has not yet been determined.

The water-level response to barometric-pressure change is in the expected direction; the depth to water in the wells decreases as barometric pressure decreases. The apparently "flat" part of the plot of barometric pressure prior to about 30 minutes (fig. 1), and the apparently "sharp" decrease in barometric pressure after 1000 minutes, result from the logarithmic scale of the plot.

Water levels in wells are expected to continually drop during the pumping period, but hydrographs (figs. 1 and 2) have nearly constant levels in all wells from about 150 to 300 minutes, and rising levels from about 600 to 1000 minutes. The unexpected changes may result from decreases in barometric pressure during the same two periods. Earlier drawdown data, prior to about 150 minutes, were therefore considered to be more representative of changes due to aquifer response to pumping than were the later data.

Barometric change during the recovery period showed a small, steady decrease after about 40 minutes (fig. 3), but the effect on water levels could not be determined because most water levels also showed a steady decrease during the recovery. The exception is data from well PS4, which showed inconsistent recovery.

The unexpected drop in water level in well PS4 during the first 1 to 4 minutes of recovery (fig. 3) cannot be explained by change in barometric pressure. The rise in water level during the recovery period from 100 to 280 minutes may be due in part to barometric-pressure change, but this is uncertain. With the exception of well 11-1, well PS4 is at the greatest distance (400 feet) from the pumped well, and the overall water-level change in PS4 is less than 0.2 foot. Neither drawdown nor recovery data from well PS4 were used in the aquifer-test analyses because barometric-pressure change might account for much of the small drop in water level during the pumping period (fig. 2), and because the water-level changes were small and inconsistent during recovery.

Distance-drawdown data from wells PS1, PS2, and PS3 were plotted at 10, 100, and 1000 minutes (fig. 4) to estimate the efficiency of the pumped well, and to obtain the aquifer parameters and effective radius (minimum distance at which effects of pumping are negligible) of the aquifer. The distance-drawdown curves have less separation after 100 minutes, indicating the drawdown rate was becoming stable, so the 1000-minute curve was used in the distance-drawdown analysis. The effective radius (r0) of the aquifer is about 750 feet, as shown in figure 4 where drawdown is 0 at 1000 minutes.

Drawdown very near the pumped well should have been about 1.3 to 1.4 feet, as may be seen for distances of 0.5 to 1.0 feet on the 1000-minute curve on figure 4. Actual drawdown in pumping well RW1 at 1000 minutes was 12.25 feet. Efficiency of the pumping well was therefore very low, at about (1.4/12.25)(100) = 11 percent. Both constant and time-weighted adjustments were made to the water-level data from the pumping well to account for the large well loss. The adjustments were not useful for estimating aquifer parameters, so data from well RW1 were not used in the aquifer-test analyses.

The Cooper and Jacob (1946) distance-drawdown and time-drawdown methods of analyses apply to confined aquifers. The aquifer at Kings Bay probably is unconfined. The response to pumping at Kings Bay, particularly during the first 1000 minutes of the aquifer test, is similar to that in a confined system, as will be discussed later in this letter. The Cooper and Jacob (1946) methods were therefore used to estimate aquifer parameters.

The data from wells PS1, PS2, and PS3 were used to estimate aquifer parameters by use of the distance-drawdown method; computations are on figure 4. Q is pumping rate (in cubic feet per day), t is time (in minutes) since pumping began, D is saturated thickness of the aquifer (in feet), r is distance from the pumped well (in feet), r0 is effective radius, delta-s is change in drawdown per log cycle of r, S is storativity, T is transmissivity (in feet-squared per day), and Kh is hydraulic conductivity in the horizontal (in feet per day).

Computations used to estimate aquifer parameters by use of the Cooper and Jacob (1946) time-drawdown method are on figure 5. The delta-s is drawdown per log cycle of time, and t0 is the time, in days, at which the linear extrapolation of the recovery curve intercepts the X-axis. Other terms are as defined previously.

The time-drawdown data prior to about 150 minutes (fig. 5) were used in the analysis because later data may be influenced by changes in barometric pressure, as described previously. Moreover, the data after t = 5 minutes were emphasized in fitting the straight line to the curve from well PS1 data to satisfy the condition that the term "u", which is equal to (r-squared)S/4KhDt, should be less than 0.1 for the error in Kh to be less than 5 percent - see explanation of minimum values of "u" in Kruseman and de Ridder (1991, pages 65-67). The condition of "u" less than 0.1 is satisfied after t = 17 minutes for data from wells PS2 and PS3. The PS2 and PS3 curves are sufficiently close so that the slope and t0 intercept are considered the same for both wells, and an average r = 64 feet was used as the distance from the pumped well.

Results (rounded) of the Cooper and Jacob (1946) methods of analyses are summarized in table 2. Aquifer parameters computed by use of the distance-drawdown method are the same because of the analysis procedure. Comparison of the results of the two methods show fairly consistent Kh and T values. The Kh ranges from 9.2 to 14 feet per day, and T ranges from 690 to 1040 feet-squared per day.

Table 2. Results of analyses by use of Cooper and Jacob (1946) time-drawdown and distance-drawdown methods.

TERM	WELL PS1		WELL PS2		WELL PS3	
	METHOD OF ANALYSIS		METHOD OF ANALYSIS		METHOD OF ANALYSIS	
	t-s	r-s	t-s	r-s	t-s	r-s
r	13.	-	64.	-	64.	-
t0	0.8	-	3.1	-	3.1	-
t	-	1000.	-	1000.	-	1000.
s/LCY	0.33	0.44	0.28	0.44	0.28	0.44
Kh	9.2	14.	11.	14.	11.	14.
T	690.	1040.	810.	1040.	810.	1040.

Method of analysis: t-s is time-drawdown, and r-s is distance-drawdown. The t is the time, in minutes, at which drawdown s, in feet, is determined on the distance-drawdown curve, and t0 is time, in minutes, at which the drawdown is zero on the linear extrapolation of the time-drawdown curve. The r is distance, in feet, from the pumped well. The s/LCY is drawdown per log cycle of time on the linear extrapolation of the time-drawdown curve, and is drawdown per log cycle of distance on the linear extrapolation of the distance-drawdown curve. The Kh is horizontal hydraulic conductivity, in feet per day, and T is transmissivity, in feet-squared per day.

The Neuman (1975) method of analysis is applicable to unconfined aquifers that may be either isotropic or anisotropic, in which flow is unsteady, and in which wells are fully penetrating. Wells used in the aquifer test at Kings Bay are not fully penetrating, and this point is discussed later. The method involves matching the time-drawdown plots from the aquifer test to theoretical type curves. The "B" value of the curve used in the match reflects the anisotropy of the aquifer.

The time-drawdown plots of data from wells PS1, PS2, and PS3 (figs. 6, 7, and 8) show the aquifer response that mostly represents expansion of the water and compression of the aquifer; that is, the response that is like that in a confined aquifer. The unconfined part of the response evidently did not develop due to the short duration of the pumping period. The slight increase in drawdown during the period 1000 to 1500 minutes in all three wells might be the beginning of the unconfined part of the aquifer response, or it might be a response to the increase in barometric pressure during this period, as indicated in figures 1 and 2, or both.

Only the type-curve plots of 1/UA and the "well function" W(UA,B) of Neuman (1975) were used to analyze the Kings Bay data, rather than the 1/UB and W(UB,B) curves, because of insufficient development of the unconfined part of the time-drawdown curves. Specific yield could not be determined because the 1/UB curves could not be used. Match points on time-drawdown curves and type curves (figs. 6, 7, and 8) are shown as "X" designations. The corresponding values of 1/UA, W(U), drawdown (s), and time (t) were obtained at the match points. Computations of parameters Kh, hydraulic conductivity in the vertical (Kv, in feet per day), and anisotropy (Kv/Kh) are shown on the plots.

The Streltsova (1974) method of aquifer-test analysis is similar to that of Neuman (1975), having similar aquifer conditions of being unconfined, either isotropic or anisotropic, and unsteady flow. The difference in methods is that Streltsova (1974) accounts for partial penetration of the pumped and observation wells. From data in table 1, the partial penetration factor (ratio of well length below the water table to saturated aquifer thickness) is 0.8 at the pumped well at Kings Bay, and is 0.4 at the PS1, PS2, and PS3 observation wells. The type curves of these factors, as given by Streltsova (1974), were used in the analysis.

Only the Streltsova (1974) type-curve plots of 1/UA and the "well function" W(UA,B) for a confined system, rather than the 1/UB and W(UB,B) curves for an unconfined system, were used to analyze the Kings Bay data, for the same reasons previously described for use of the Neuman (1975) method. Match points on the time-drawdown curves and type curves (figs. 9, 10, and 11) are again shown as "X" designations. The corresponding values of 1/UA, W(U), s, and t were obtained at the match points. The term bl is the length of the pumped well below the water table. From data in table 1, bl is 60.5-7.42 = 53.1 feet. The calculations of aquifer parameters are shown on the plots.

The Theis (1935) recovery method applies to unsteady flow in a confined aquifer. Most of the recovery curves from wells at Kings Bay are similar to those that would be obtained from a confined aquifer, as was previously explained in the drawdown part of the aquifer test, and were therefore used to estimate aquifer parameters. The method involves plotting the residual drawdown s' (initial water level minus water level after pumping has stopped), and the ratio of t/t'. The t' is time since the pump was shut off, and the t is time since pumping started (entire duration of pumping period, plus time t'). The slope delta-s', which is residual drawdown per log cycle of t/t', is obtained from the linear part of the plot, and is used to calculate aquifer parameters.

The calculations of aquifer parameters are shown on the recovery plots of data from well PS1 (fig. 12), PS2 (fig. 13), and PS3 (fig. 14). The later time of the recovery (smaller values of ratio t/t') were used to satisfy the condition that the term "u" be less than 0.1 for error in T to be less than 5 percent - see explanation of minimum values of "u" in Kruseman and de Ridder (1991, pages 65 through 67 and 195). For u less than 0.1, both t and t' must be greater than 2.5(r-squared)S/KhD. The S is aquifer storativity, and is assumed to have the same value in both the drawdown period and in the recovery period. Other terms are as previously defined.

S is considered to be 0.003, which is the mean of the five values on figures 4 through 8. Using this S, r = 13 feet, and the Kh and D values shown in figure 12, the t' value of data from well PS1 should be greater than [(2.5)(13)(13)(.003)]/[(7.6)(75)] = 0.0022 days, or 3.2 minutes, to satisfy the condition u less than 0.1. Considering the duration of the pumping period was 1500 minutes, the value of t should be greater than 1500 + 3.2, and the ratio t/t' should be less than 1503.2/3.2 = 470. Therefore, values of t/t' less than 470 were emphasized in the linear part of the curve shown on figure 12. Similarly, values of t/t' less than 26 were emphasized in the linear parts of the curves from well PS2 and PS3 data (figs. 13 and 14).

Results (rounded) of aquifer-test analyses by Neuman (1975), Streltsova (1974), and Theis (1935) are summarized in table 3. The Kh values (rounded) from all methods of analyses, and the means of these values for each method, are shown in table 4. All Kh values, in feet per day, have a range of 5.8 to 14, median of 11, and mean of 10.

Table 3. Summary of aquifer-test analyses by use of methods described by Neuman (1975), Streltsova (1974), and Theis (1935).

TERM	WELL PS1			WELL PS2			WELL PS3		
	METHOD OF ANALYSIS			METHOD OF ANALYSIS			METHOD OF ANALYSIS		
	NEUMAN	STRELT	THEIS	NEUMAN	STRELT	THEIS	NEUMAN	STRELT	THEIS
1/UA	10.0	100.0	-	70.0	1.0	-	95.	10.	-
W(U)	1.7	3.0	-	2.2	0.22	-	3.0	1.8	-
t	10.0	120.0	-	230.	3.2	-	240.	30.	-
s	0.39	0.7	-	0.44	0.033	-	0.45	0.28	-
B	0.01	0.01	-	0.03	0.01	-	0.01	0.01	-
s/LCY	-	-	0.40	-	-	0.29	-	-	0.30
Kh	5.8	8.0	7.6	6.6	12.	11.	8.8	12.	10.
T	430.	600.	570.	500.	900.	790.	660.	900.	760.
Kv/Kh	1/3	1/3	-	1/23	1/68	-	1/75	1/75	-

Match of drawdown and type curves used to obtain terms UA, W(U), and B (all dimensionless), t (time in minutes since pumping began), and s (drawdown in feet). The s/LCY is residual drawdown per log cycle of t/t', in which t is time since pumping began and t' is time since pumping stopped. Kh is hydraulic conductivity in the horizontal and Kv is hydraulic conductivity in the vertical, both in feet per day. T is transmissivity in feet-squared per day.

Table 4. Values of Kh determined by five methods of analyses and by use of data from three well sites. All values in feet per day.

METHOD OF ANALYSIS	Kh FROM PS1 DATA	Kh FROM PS2 DATA	Kh FROM PS3 DATA
C-J,t-s	9.2	11.	11.
C-J,r-s	14.	14.	14.
NEUMAN	5.8	6.6	8.8
STRELT	8.0	12.	12.
THEIS	7.6	11.	10.
Mean	8.9	11.	11.

Method of analysis: Neuman (1975); Streltsova (1974); Theis (1935); C-J,t-s is Cooper and Jacob (1946) time-drawdown method, and; C-J,r-s is Cooper and Jacob (1946) distance-drawdown method.

The Neuman (1975) method is similar to that of Streltsova (1974), but does not take into account partial penetration of the pumped and observation wells, as does the latter method. The values of 1/UA, W(U), t, and s obtained from curve matching are different in the two methods (table 3), but the resulting Kh values are similar. Moreover, "B" values of curves are similar in both methods, reflecting little difference in resulting calculations of anisotropy. These similarities indicate that partial penetration of the wells at Kings Bay evidently made little difference in the results of analyses of aquifer parameters.

The anisotropy of the aquifer at Kings Bay evidently did not significantly affect the results of analytical methods designed for use with isotropic aquifers. The Neuman (1975) and Streltsova (1974) methods are applicable to flow in anisotropic (in the vertical) aquifers, and results of analyses show estimated Kv/Kh values ranging from 1/3 to 1/75 (table 3). The Theis (1935) and Cooper and Jacob (1946) methods are applicable to flow in homogeneous and isotropic aquifers, but Kh values computed by these methods for the apparent anisotropic aquifer at Kings Bay have little difference from the Neuman (1975) and Streltsova (1974) methods.

Values of storativity computed on figures 4 through 8 are small, and probably result from expansion of water and compression of the aquifer. The values were used only to determine the linear sections of time-drawdown curves that were to be emphasized to satisfy the condition that the "u" term be less than 0.1, and were not computed in the analysis by use of the Streltsova (1974) method. The specific yield of the aquifer would be more useful in the hydrologic investigation at Kings Bay, but this parameter could not be determined because of insufficient development of the unconfined part of the drawdown curve. Results of the next aquifer test, having a planned pumping period of 7 days, may enable determination of the specific yield.

REFERENCES

Cooper, H.H., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well field history: Amer. Geophys. Union Trans, V. 27, pp. 526-534.

Kruseman, G.P., and de Ridder, N.A., 1991, Analysis and evaluation of pumping test data: International Institute for Land Reclamation and Improvement/ILRI, Wageningen, The Netherlands.

Neuman, S.P., 1975, Analysis of pumping test data from anisotropic unconfined aquifers considering delayed gravity response: Water Resources Research, V. 11, pp. 329-342.

Streltsova, T.D., 1974, Drawdown in compressible unconfined aquifer: J. Hydraul. Div., Prodc. Amer. Soc. Civil Engineers, V. 100(HY11), pp. 1601-1616.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage: Trans. Am. Geophys. Union, V. 16, pp. 519-524.

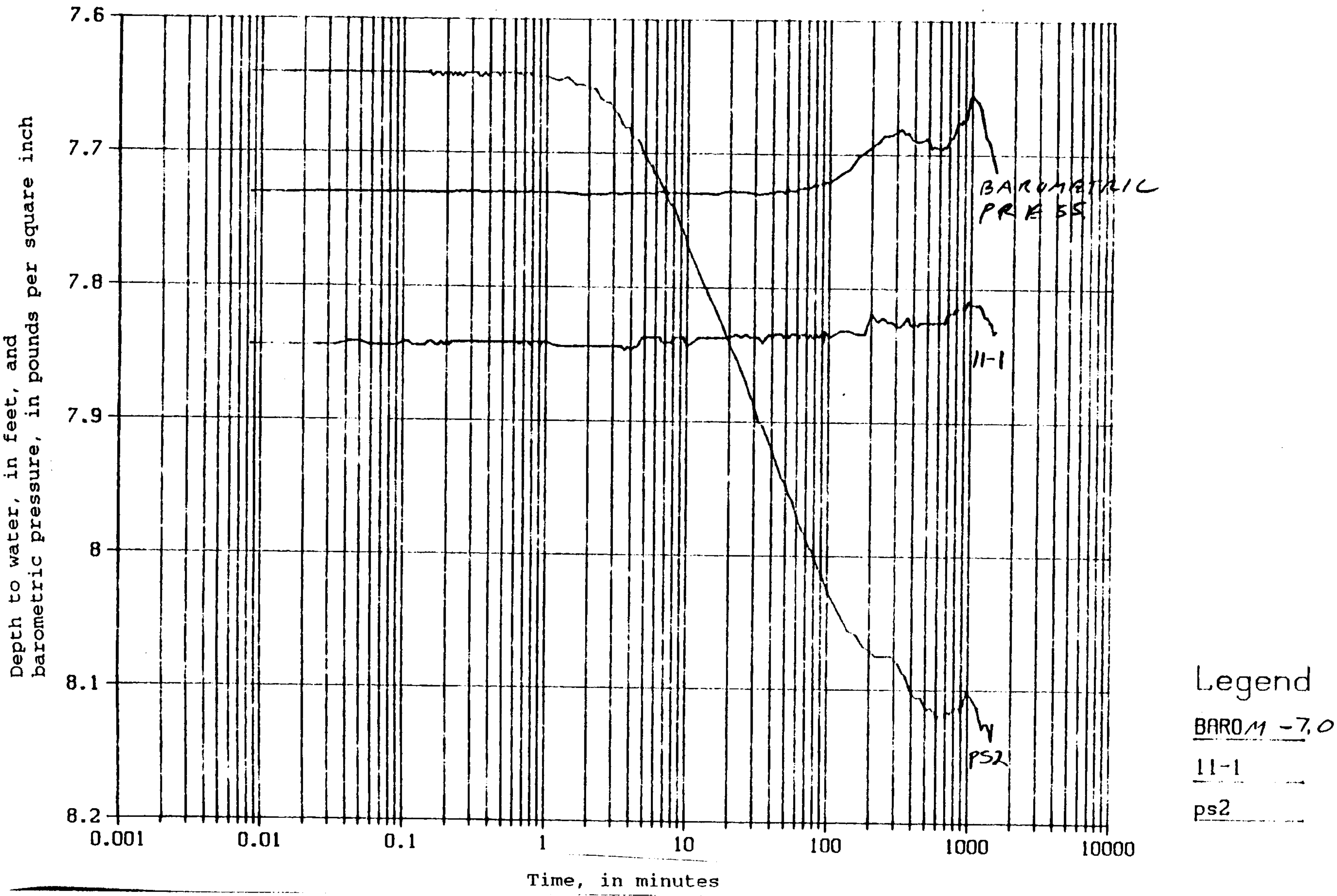


Figure 1. Barometric pressure and hydrographs of wells PS2 and 11-1 during pumping period.

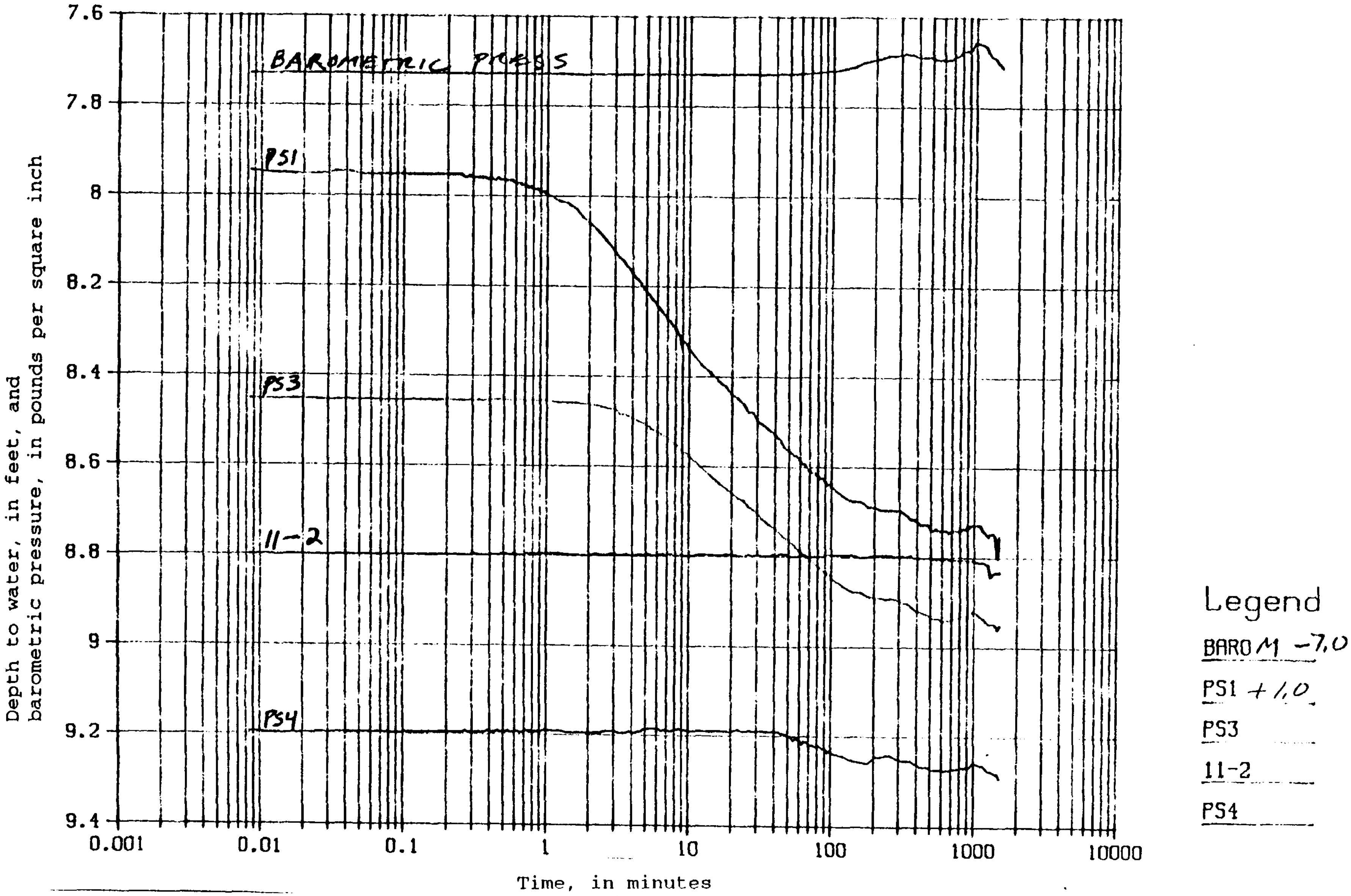


Figure 2. Barometric pressure and hydrographs of wells PS1, PS3, PS4, and 11-2 during pumping period.

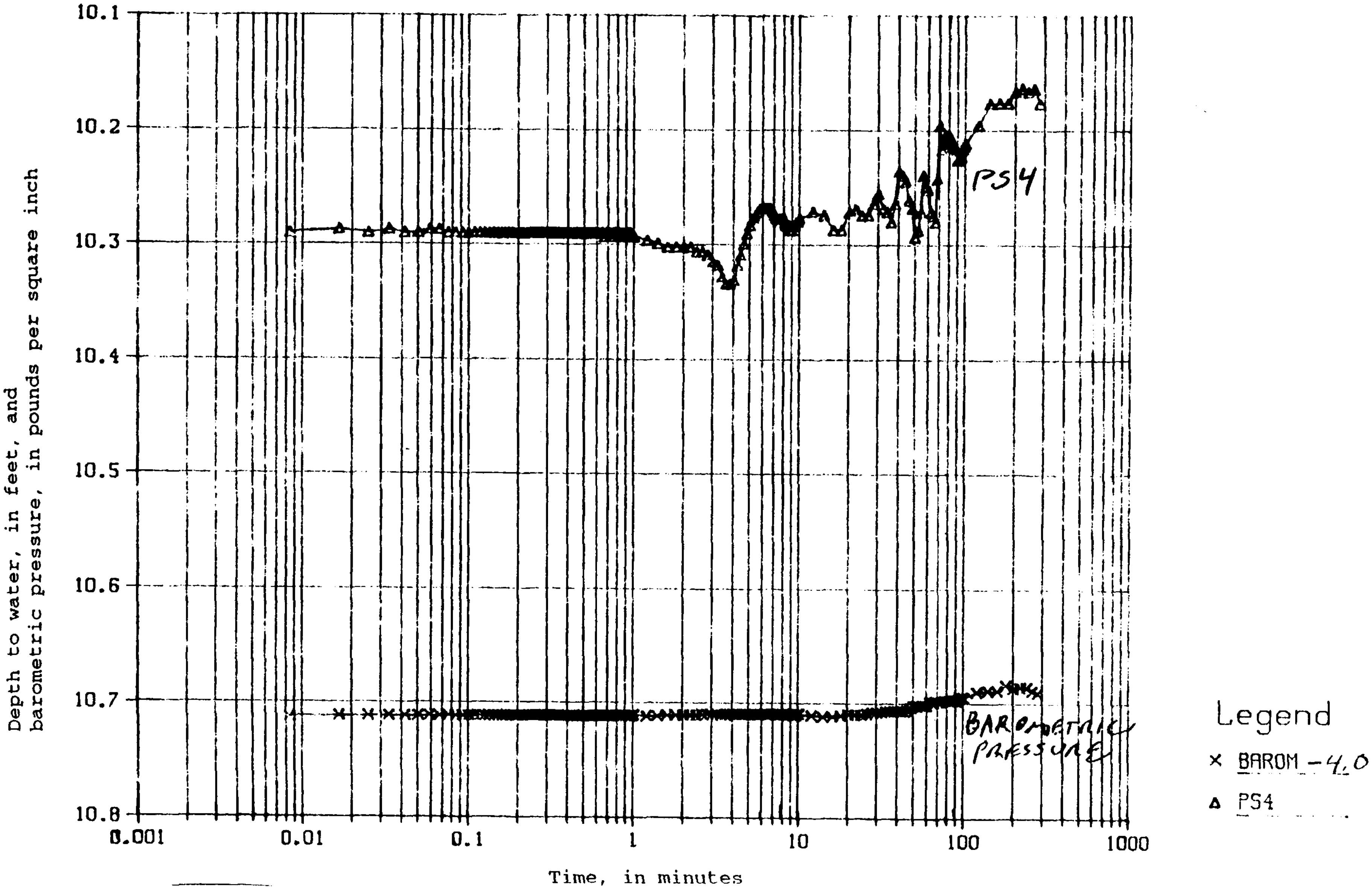


Figure 3. Barometric pressure and hydrograph of well PS4 during recovery period.

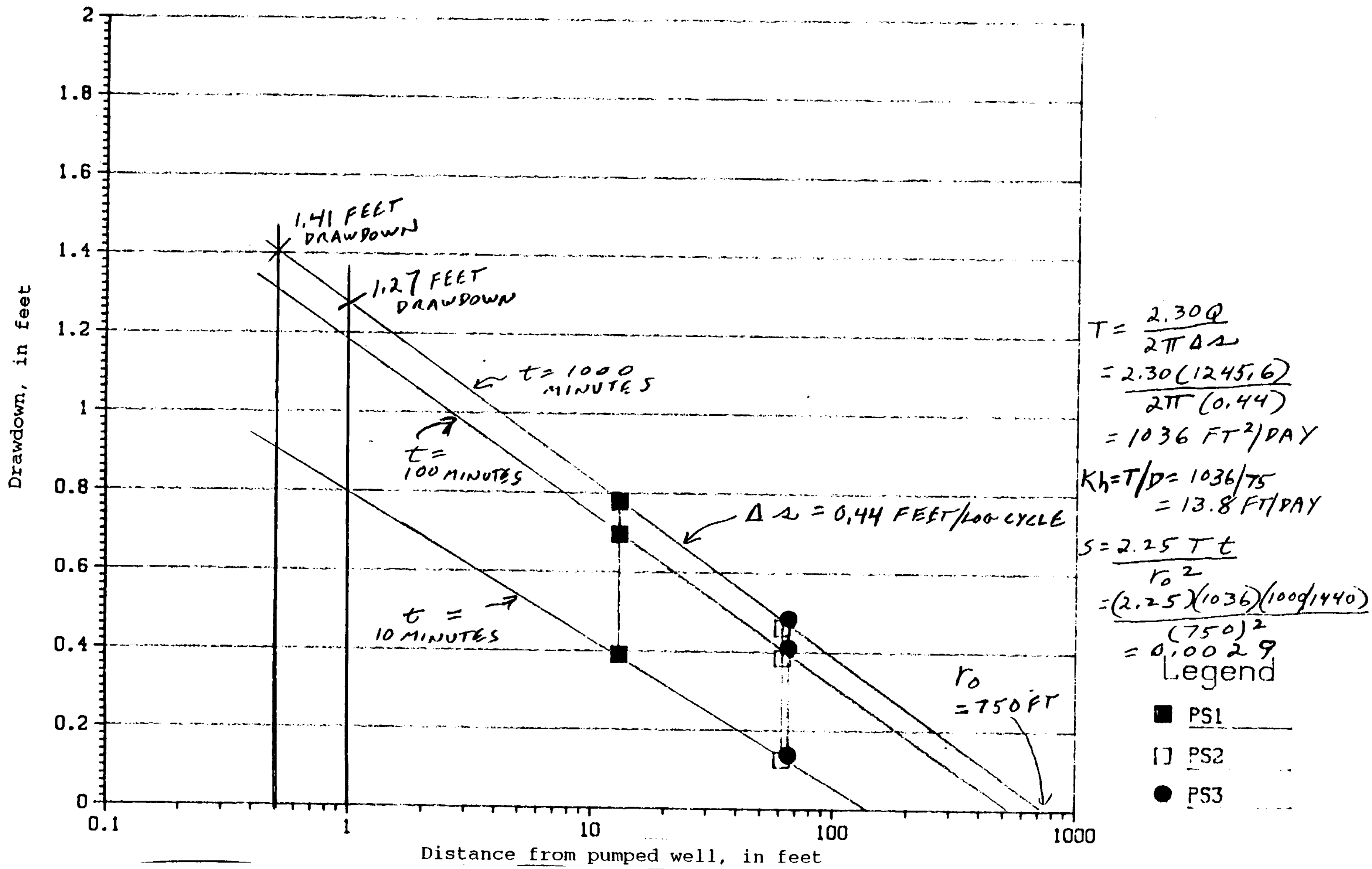


Figure 4. Distance-drawdown relations at wells PS1, PS2, and PS3, at time periods 10, 100, and 1000 minutes, Cooper and Jacob (1946) method of analysis.

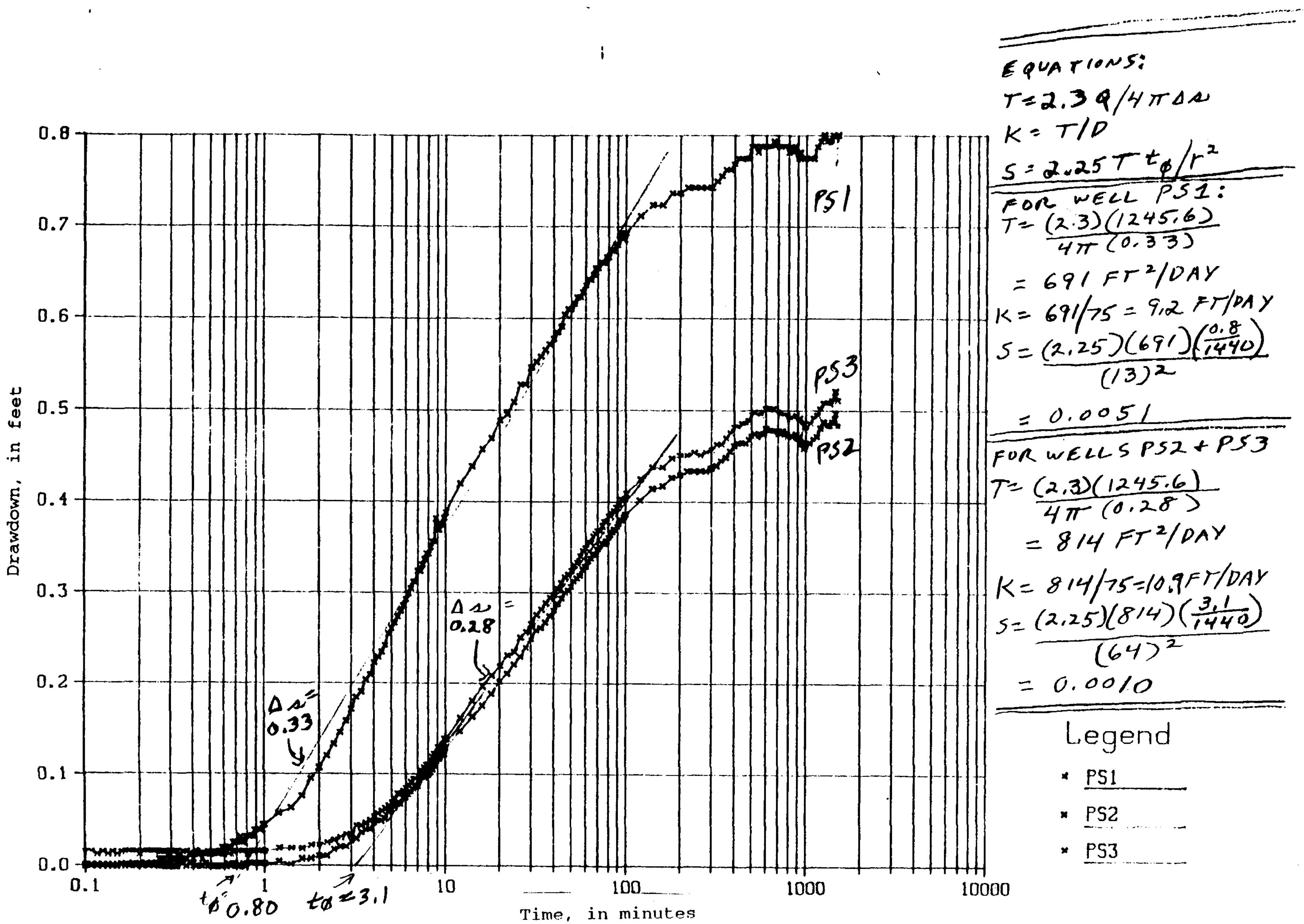
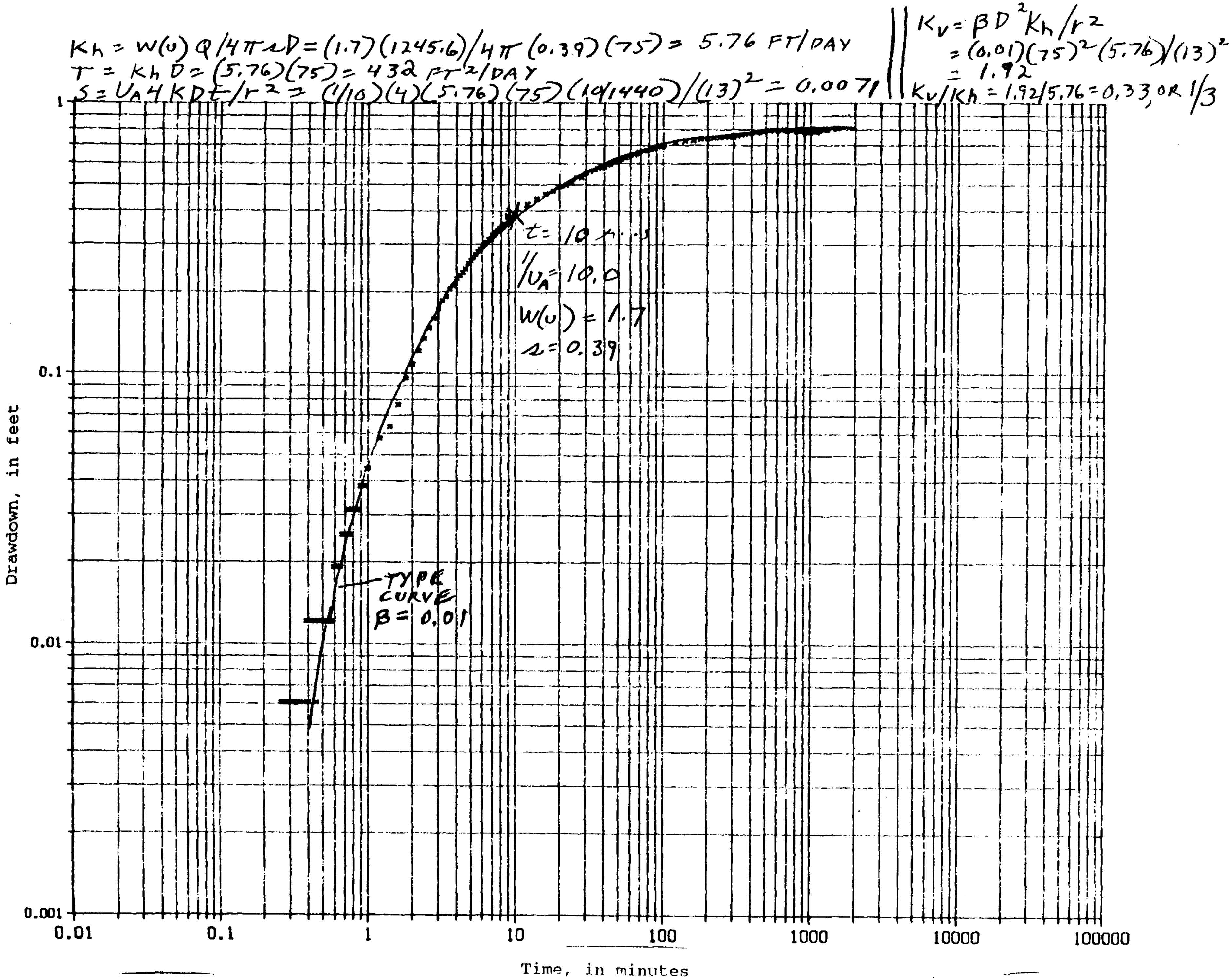


Figure 5. Time-drawdown relations at wells PS1, PS2, and PS3, Cooper and Jacob (1946) method of analysis.



ure 6. Time-drawdown relation at well PS1, Neu (1975) method
f analysis.

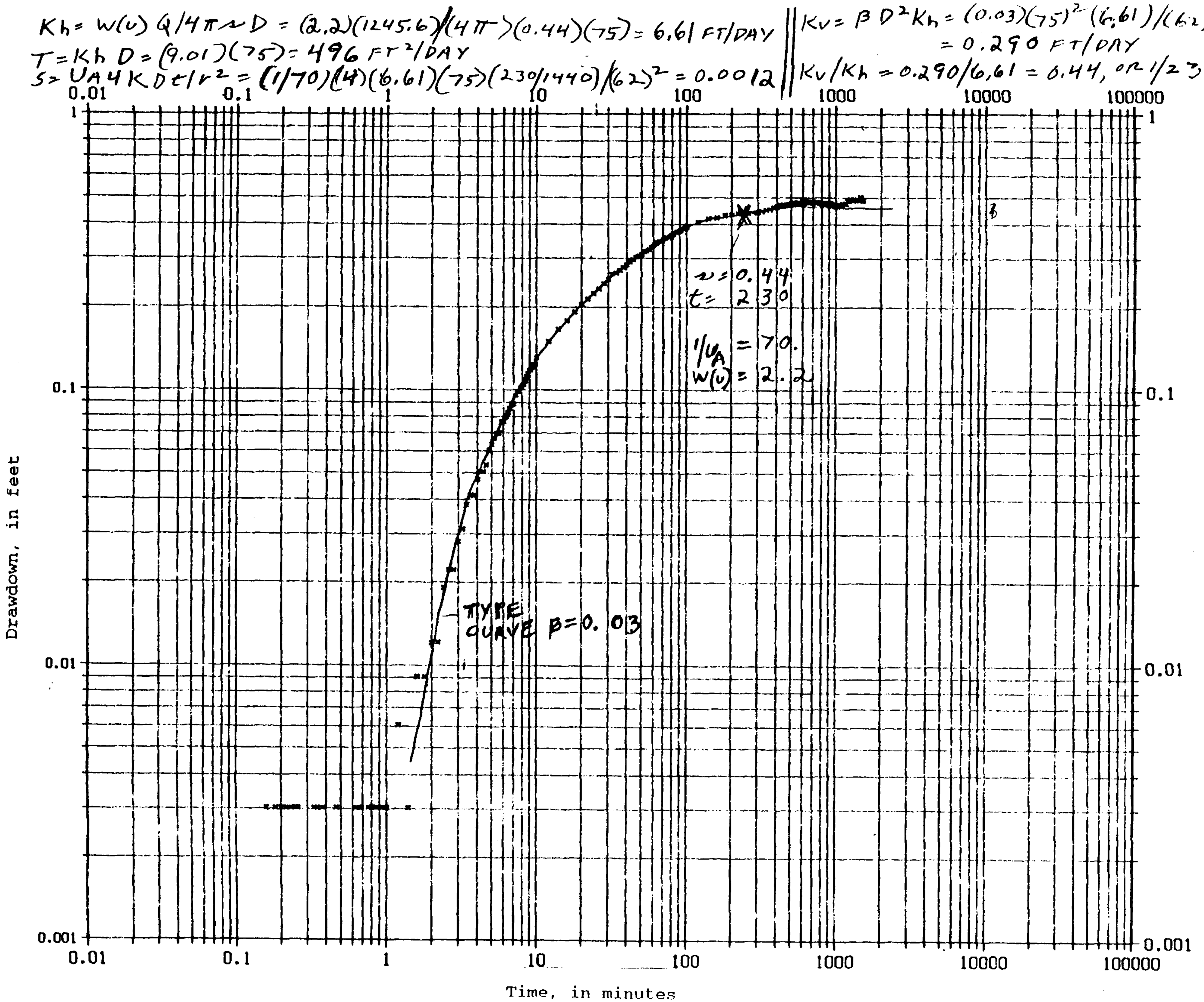


Figure 7. Time-drawdown relation at well 1 Neuman (1975) method of analysis.

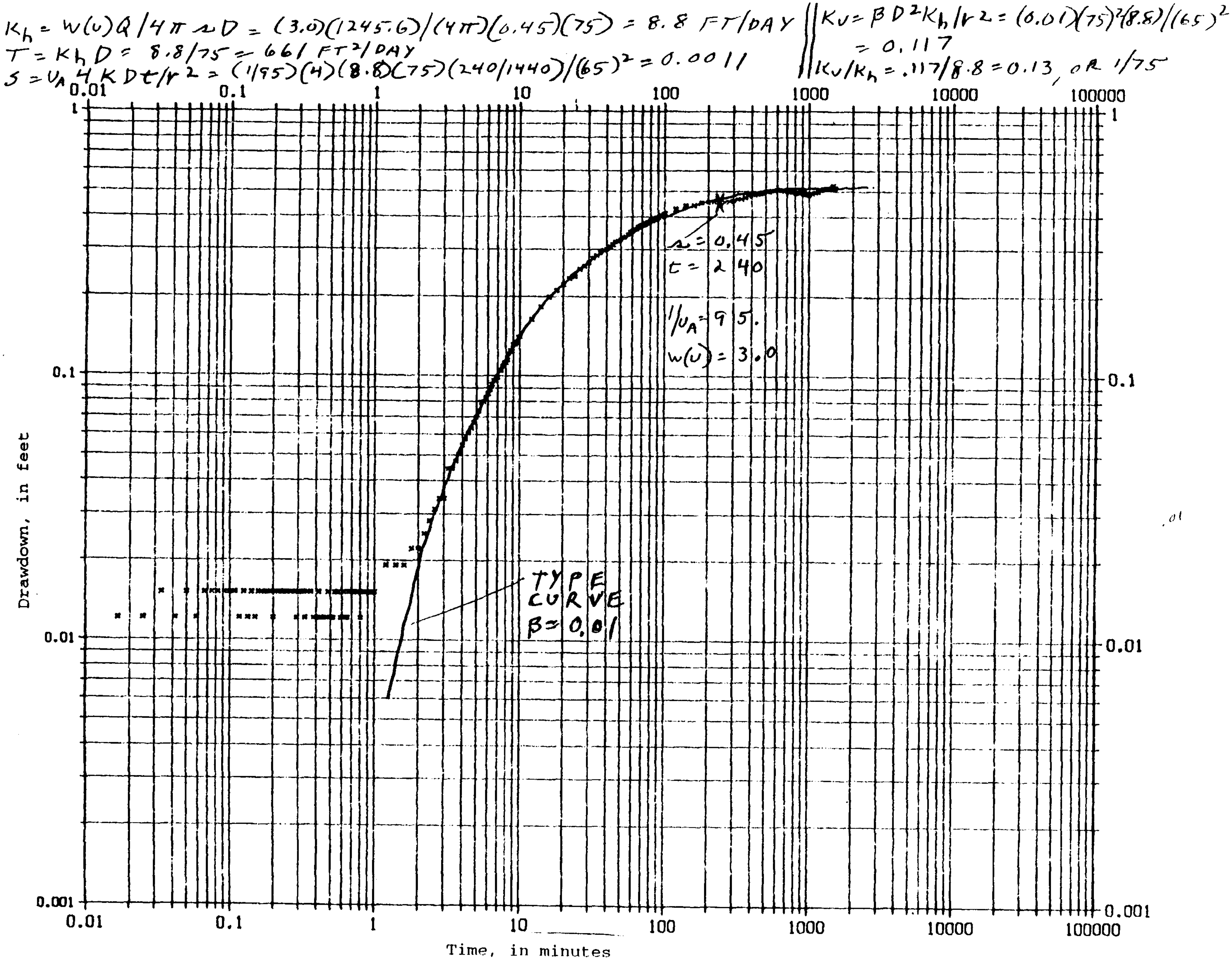


Figure 8. Time-drawdown relation at well PS3 ... uman (1975) method of analysis.

$K_h = QW(u)/4\pi b_1 s = (1245.6)(3.0)/4\pi(53.1)(0.7) = 8.0$ FT/DAY

$T = KD = (8.0)(75) = 600$ FT^2/DAY

$K_v = \beta D^2 K_h / r^2 = (0.1)^2 (75)^2 (8.0)/(13)^2 = 2.66$ FT/DAY

$K_v/K_h = 2.66/8.00 = 0.33$ OR $1/3$

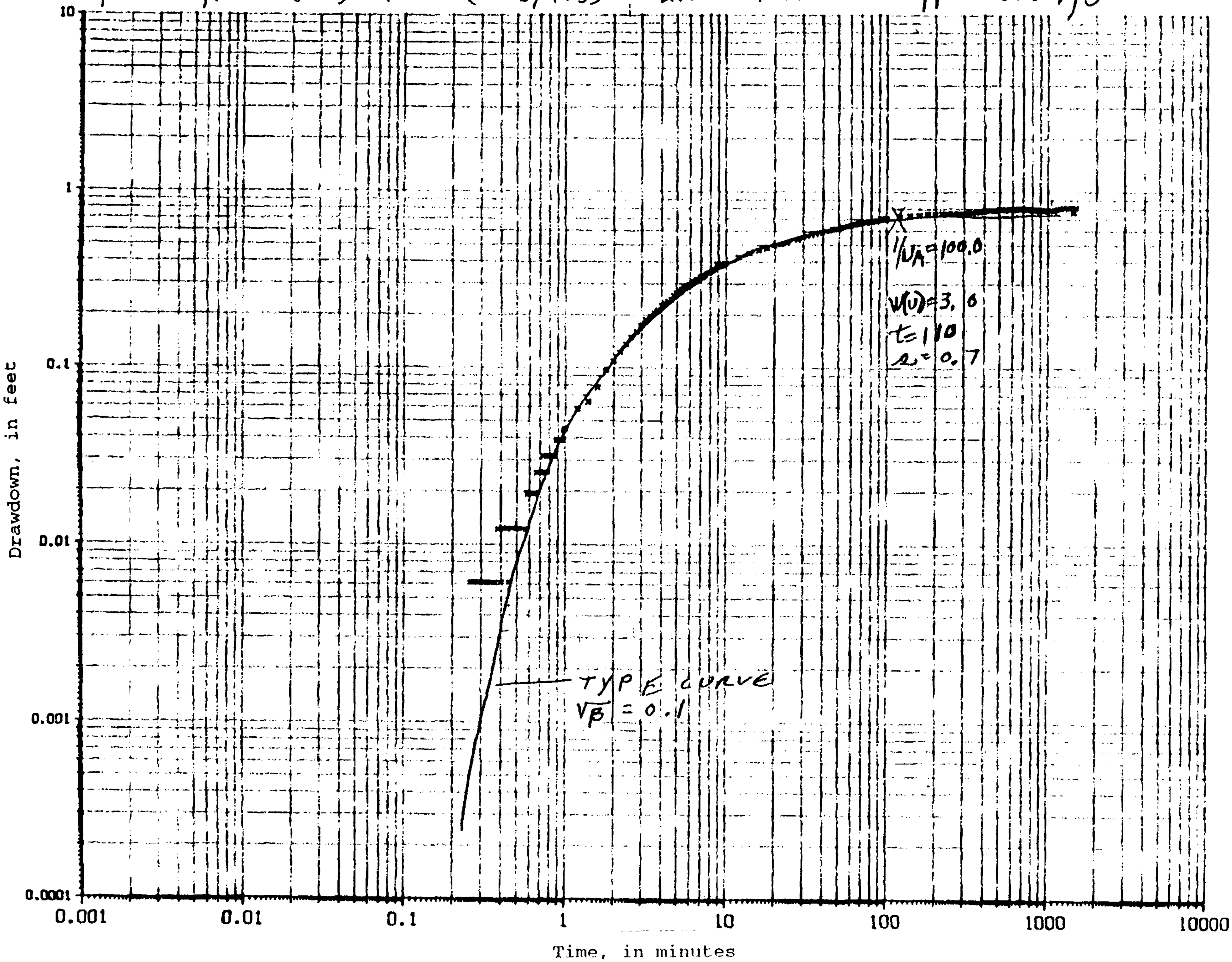


Figure 9. Time-drawdown relation at well PS Streltsova (1974) method of analysis.

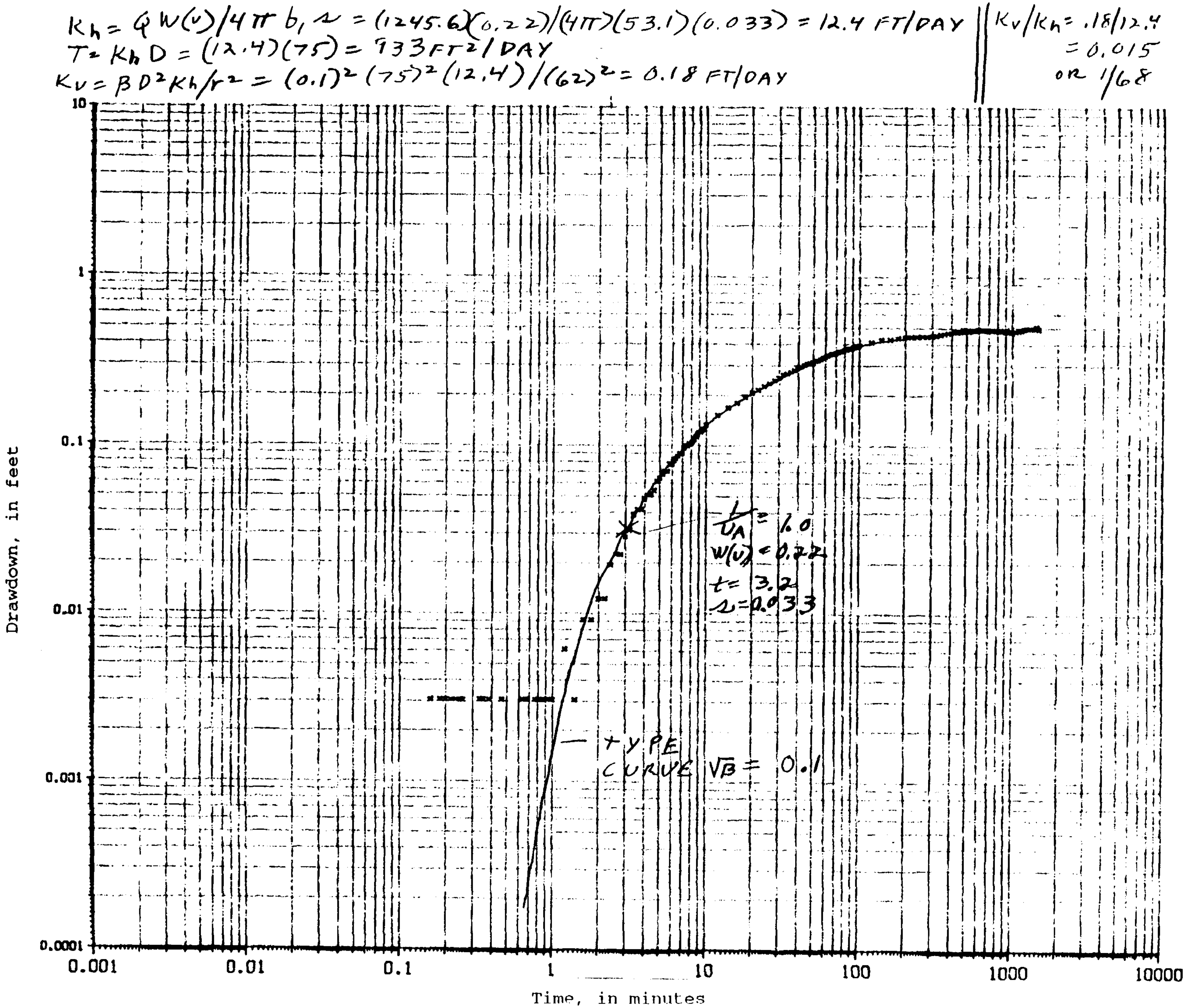


Figure 10. Time-drawdown relation at well PS. Streltsova (1974) method of analysis.

$K_h = Q W(u) / 4\pi b, s = (1245.6)(1.8)/(4\pi)(53.1)(0.28) = 12.0$ FT/DAY

$T = K_h D = (12.0)(75) = 900$ FT^2/DAY

$K_v = \beta D^2 K_h / r^2 = (0.1)^2 (75)^2 (12.0)/(65)^2 = 0.16$ FT/DAY

$K_v / K_h = 0.16/12.0 = 0.013$ OR $1/75$

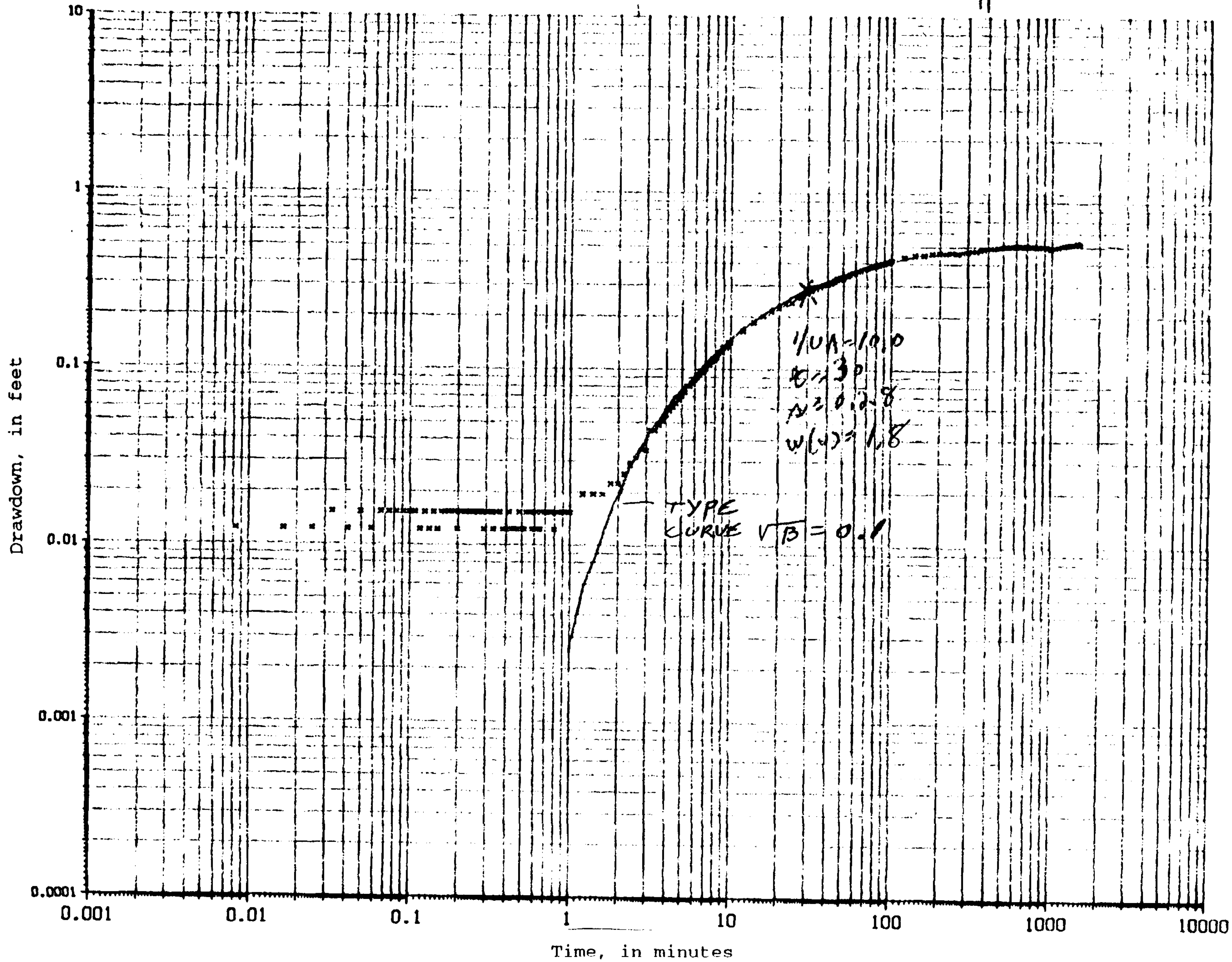


Figure 11. Time-drawdown relation at wel :3, Streltsova (1974) method of analysis.

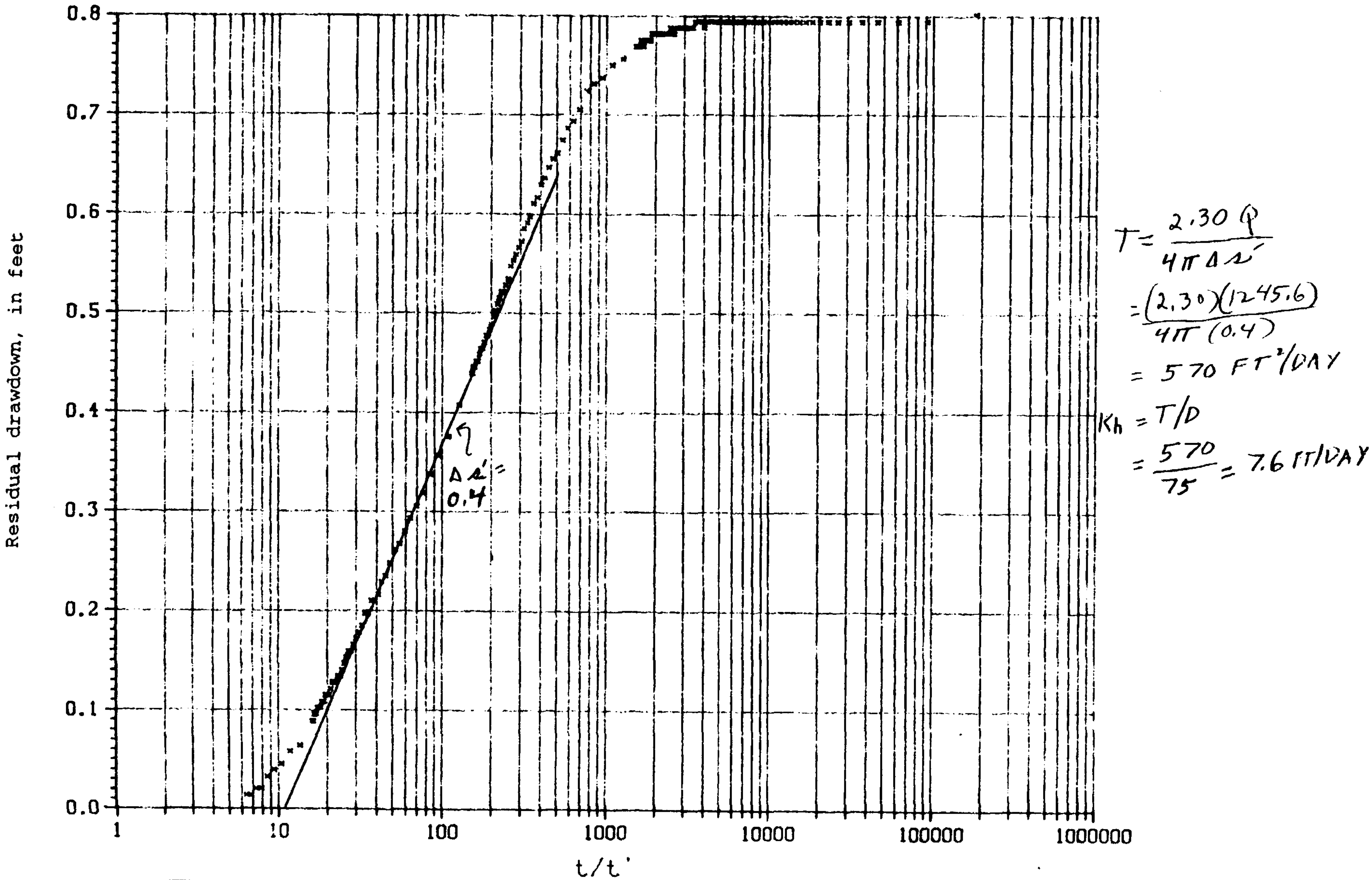


Figure 12. Time-recovery relation at well PS1, Theis (1935) method of analysis.

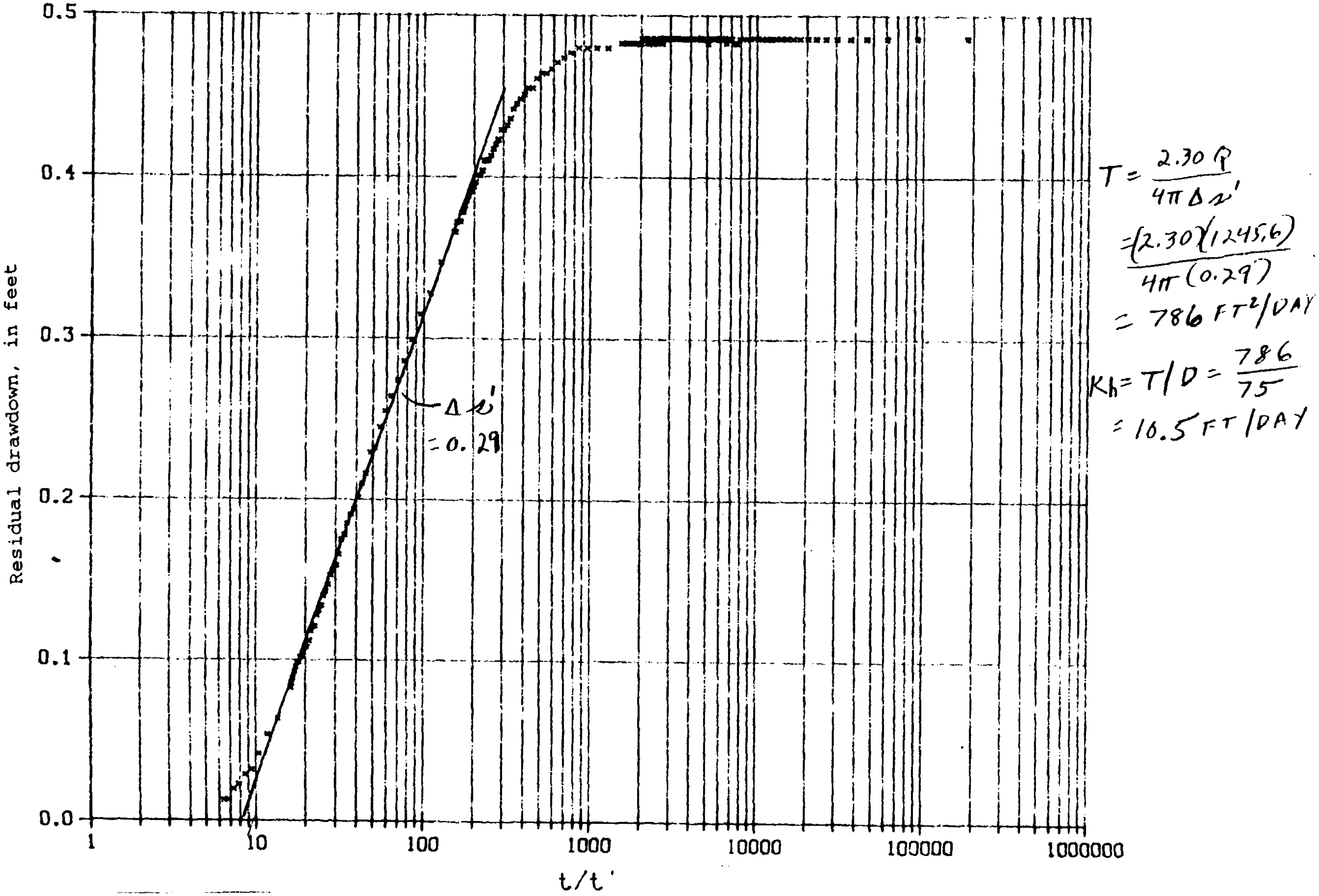


Figure 13. Time-recovery relation at well PS2, Theis (1935) method of analysis.

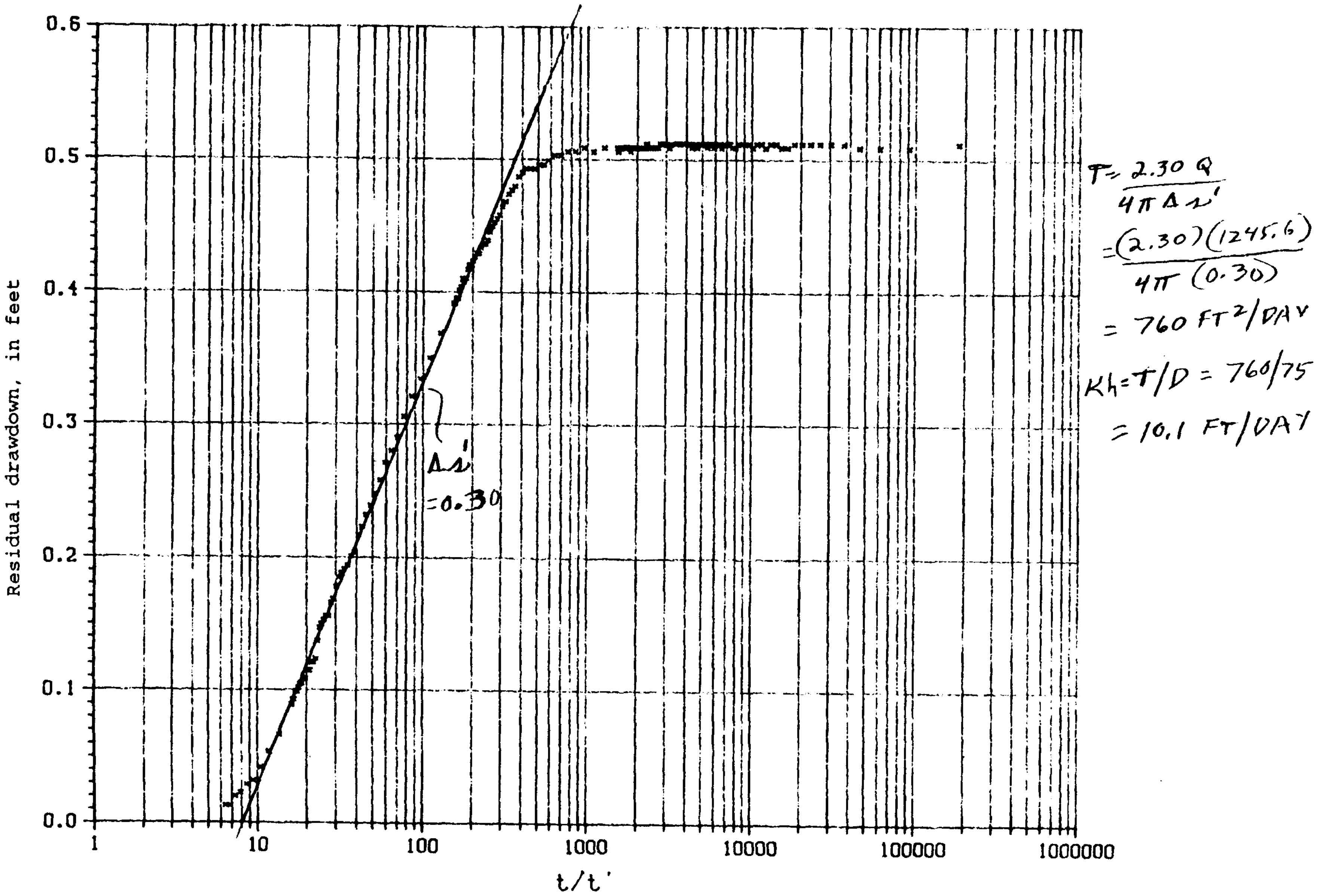


Figure 14. Time-recovery relation at well PS3, Theis (1935) method of analysis.