Institute of Hydrology

Natural Environment Research Council

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NOTTINGHAMSHIRE EAST-WEST LINK.
BOUGHTON PUMPING STATION.

Preliminary Drawdown Predictions

1. GENERAL

The existing well/adit system at Boughton is to be replaced by three new boreholes, which, together with the existing production borehole (site 4), will form an uprated supply. Provisional locations for the new boreholes have been identified in each corner of the site to provide the maximum distance between each borehole and thereby reduce interference effects.

Other locations for the new boreholes are possible, but the final locations may depend on the likely interference drawdowns with prolonged pumping and other considerations. The aquifer conditions and properties need to be identified to establish the likely long term drawdowns. Such information would also be useful for the following:

- to plan the pumping test programme for the new boreholes

- to ensure that the site is capable of supporting the required abstraction using only boreholes rather than the well/adit system (for example, the permeability of the upper part of the aquifer tapped by the adit and wells could be more productive)

- to assess whether the River Maun, which is located some 600m west of the site, could form a recharge boundary (if so, this could contribute to the nitrate levels in the groundwater).

Pumping tests were undertaken on the boreholes and adit system by STWA in October 1986 and May 1987 and are described in report RIR/AB/446.02.01 of 21/12/88.

The step test carried out on borehole 4 on 6 October 1986 consisted of 5 consecutive steps each of 100 minutes at rates of 50 to 86 l/s. The borehole was allowed to recover for 2 days prior to the test.

The constant rate test on borehole 4 was carried out in May 1987 at a rate of 8275 m3/d (96 l/s) for 7 days following 3 days recovery. Water levels were measured during the test in the pumped borehole, the other production boreholes (1, 2 and 3 of the well/adit system) and in two observation boreholes located at 27m west (PH1) and ?237m south-east (PH2) of borehole 4.

The main conclusions drawn from the tests regarding borehole 4 and the aquifer properties of the site were as follows:

- well losses are small

- the specific capacity of borehole 4 is high, about 500 m2d, but being a function of the aquifer the yield drawdown relationship is less sensitive to the duration of pumping than the well/adit system

- transmissivity (T) was estimated to be about 300 m2d, although the step test indicated that T may be 1500 m2d

- an estimate of the storage coefficient (S) and specific yield (Sy) could not be derived from the data, but Sy is likely to be high

- the high T and Sy suggest that interference effects should be small.

The analysis of the constant rate test was limited by residual recovery (the rise in water level during the constant rate test was +1.2m at PH2 and +1.7m at boreholes 1,2 and 3 due to recovery from the previous pumping), well storage effects and doubts regarding the pumping rates.

The test data have been re-examined with type curve and semi-log methods and by optimisation techniques to obtain some preliminary estimates of the aquifer properties of the site for subsequent planning purposes.

2. AQUIFER PROPERTIES

(a) T from Specific Capacity

An approximate value of T can be derived from the specific capacity (Q/s) based on Logans method, where T=1.22 Q/s, provided well losses are small. For borehole 4, which has a well efficiency of about 95%, this gives a T value of about 600 m2/d.

(b) Time Drawdown Data

The constant rate test data are plotted on a log-log scale in Figures 2 and 3. The apparently marked decrease in the rate of drawdown after 500 minutes at PH1 may be due to measurement errors (although a recharge boundary effect cannot be discounted) and the late data from each borehole are not amenable to analysis due to the recovery still taking place from the preceding abstraction. The depth of PH1 is believed to be only 43m but the data have not been corrected for partial penetration.

The data for PH1 appear to conform to a leaky type curve of r/B of 0.1 to 0.2, which would normally suggest drainage through fine materials. The following estimates of T and early S were derived from the data from PH1: T 955 to 1155 m2/d and S 0.4%. The data for PH2 appear to conform to an r/B curve of 1.5, which gave a T estimate of 900 m2d and early S of 0.00004. Delayed response was not taken into account in this estimate of S and the variation in T is largely a function of which part of the data set is used for the type curve match.

The value of S from the tests is considered to be unrepresentative of the true specific yield of the Sherwood Sandstone Group, which may reach 20 to 30%. As water table conditions are expected, S is likely to decrease with distance (r) from the pumped well and increase with the duration (t) of pumping. Short term tests will provide estimates of the apparent Sy only. A longer period of pumping, perhaps by monitoring during sustained, routine production, may be required to derive a representative value of Sy.

The time drawdown data have also been plotted on a semi-log scale in Figures 4 and 5. This method of analysis, however, does not usually provide reliable estimates of Sy with water table conditions exhibiting gravity drainage and also depends on which part of the data set are used for the analysis. However, an analysis of the data from PH1 for the period 10 to 500 minutes from PH1 indicates a T of 1515 m2d and an S of 0.3%, which are similar to the results from the log-log analysis.

(c) Distance Drawdown

The drawdown data can also be plotted against distance from the test well, as shown on a semi-log scale in Figure 6 for a pumping period (t) of 100 minutes. As water levels were measured at only two observation wells, the reliability of the results from this type of analysis are also questionable, although this approach can provide reasonably representative results with water table conditions.

The data do not conform to a straight line and consequently the estimates of T and S depend on which portion of the data are used for the analysis. The drawdown data for the observation wells give a T value of 1600 m2d and an S of 0.3%, which also agrees reasonably well with the time drawdown analysis and the step test analysis results.

However, the drawdown values used for this analysis are open to doubt since water levels were still recovering. There is also a large difference in the depth to water level of 2.73m between PH1 and borehole 4, which are only 27m apart, at the start of the constant rate test. This is unlikely to be due to the difference in elevation of the measuring point (elevation data were not provided).

Residual recovery may to some extent account for the non- linearity of the distance drawdown plot but this could also be due to a decrease in T or an increase in S in the vicinity of the test well. It is most unlikely that well losses would account for the non-linearity but the data have not been corrected for the decrease in aquifer thickness.

(d) Optimisation

An estimate of T value was also derived using a modified form of programs developed by Rathod and Rushton (1984) and Rushton and Redshaw (1979) given in Walton (1988). The range of values of T and S derived from the graphical analyses were used to optimise a combination of T and S that reproduced the drawdowns observed during the constant rate test in borehole 4 and the observation wells PH1 and PH2. The method assumes an isotropic, infinite aquifer with water table conditions with the following values:

- effective well radius= actual well radius of 0.45m

- initial water level 19.5m

- pumping rate 8275 m3/d

- aquifer thickness 103m (base BPB minus rest water level)

The following drawdowns were predicted using an S of 0.00004 and an Sy of 0.4% with various T values:

	T 600 m2d	T 900 m2d Drawdown (m)	T 1500 m2d	Observed (m)
4	14.9	9.9	5.9	14.7
PH1	5.6	3.8	2.4	2.05
PH2	0.87	0.67	0.47	0.27

With these S and Sy values the same T value cannot simulate the drawdown at the test well (after allowing for well losses) and the observation wells. The decrease in the saturated thickness at the test well of 15m is not sufficient to account for the lower T, unless there is a marked difference in the permeabilty with depth.

Further optimisation provided a reasonable match with the early data from the test well data with T values of between 500 and 600 m2/d, as shown in Figure 2. Since the values of S or Sy have relatively little effect on drawdowns for the short duration of pumping, subsequent runs were undertaken with S=Sy=0.4%. These produced the following drawdowns after 100 minutes of pumping:

	T 515 m2d	Drawdown (m)	T 1500 m2d	Observed (m)
4	14.9		5.3	14.7
PH1	4.2		2.02	2.05
PH2	0.1		0.14	0.27

Whilst there is still an inconsistency between the drawdowns at the test well and the observation wells, these values were adopted for the predictions of the interference effects. The drawdowns for T values of 500-600 and 1500 are included with Figure 6.

The optimisation results must be considered as indicative only since the control water level data are themselves in doubt and the application program cannot take variations in T and S or boundary effects into account. The general indication is that T is about 515 m2d and early S is about 0.4%.

It is still not possible to derive an estimate of Sy from the data and therefore predictions of the drawdown after longer pumping periods can only be tentative.

4 Predicted Interference Effects

Normal production from the Boughton site will involve pumping three boreholes with the fourth as standby. The interference effects are given, however, for simultaneous abstraction from all four boreholes for three alternative configurations, as shown in Figure 1:

A. Sites at each corner

B. Sites along the northern boundary

C. Wider spaced sites along the northern boundary with one borehole in the centre of the site.

The distances between each well for these configurations are shown in Table 1. Except for the existing borehole 4, the well numbering is arbitrary and is not the same for each group.

The distance drawdown data can be used to estimate the drawdowns at different rates, times and distances. Drawdowns were predicted with the optimisation technique for 1 day, 7 days and 70 days pumping at the required rate of 7000 m3/d per borehole with an S=Sy of 0.4% and for T values of 515 and 1500 m2d. The results are plotted in Figures 7 and 8, which were used to obtain the drawdowns for the alternative borehole configurations.

The additional drawdowns at each production borehole due to interference effects for each configuration are given in Tables 2 to 7. These can be summarised as follows:

	T 515 m2d			T 1500 m2d		
			Pumping Duration (days)			
			70			70
			Additional Drawdown (m)			
Configuration A	3-5	9-11	16-18	2-3	4-5	6.5-7.5
Configuration B	6-8	12-14	19-22	3-4	5-6	7.5-8.5
Configuration C	5-7	11-13	18-21	2-4	5	7.5-8

For a T value of 515 m2d the maximum drawdown including interference effects would be about 43m after 70 days at each borehole. This would be equivalent to a pumping water level of about 63m at each production well.

The drawdown in the production well at the higher T value of 1500 m2d is less certain as the predicted drawdown is much less than that observed. If, however, the two sets of results are combined then the maximum drawdown in each production well with interference effects would be about 30m after 70 days, equivalent to a pumping water level of about 50m.

These predictions also suggest that between 10 to 20% of the aquifer will be dewatered over the site and the cone of depression extends from one to several kilometres. These conditions could intercept recharge from the R. Maun; increase the specific yield, such that the cone of depression will not expand so rapidly; and decrease the transmissivity at each production well due to a loss in saturated thickness of about 30 to 45%. Any variation in permeability with depth may then become an important control on the long term drawdowns.
The predicted drawdowns do not take into account any increase in Sy with prolonged pumping nor the possibility of recharge from the R. Maun. These would reduce the predicted drawdowns.

To illustrate the effects of an increase in S on drawdowns, two further predictive runs were made with same T values but increasing Sy from 0.4% to 14% for a pumping duration of 70 days. The results are also shown in Figures 7 and 8.

The effect in both cases is to reduce drawdowns to values similar to those after pumping for 7 days with the lower S of 0.4% and to reduce the radius of the cone of depression to about 1.5 to 2 km. The interference effects range from about 8.5 to 13.5m for a T value of 515 m2d and from 4.5 to 5.5m for a T value of 1500 m2d, similar to those given in Tables 3 and 6. The total drawdown at each production borehole from the combined results would be about 22 to 23m, or a pumping water level of about 42 to 43m.

CONCLUSIONS

The pumping test data available for the Boughton Pumping Station site are not amenable to a reliable analysis of the aquifer properties due to the effects of recovery during the constant rate test.

Nonetheless, predictions of the interference drawdowns with periods of pumping up to about 2 months have been attempted with the available data, although these must be regarded as very tentative due to the limitations of the test data and the uncertainty of extrapolation using aquifer properties based only on the early data.

The drawdown data from the pilot holes 1 and 2 suggest T values ranging from 900 to 1600 m2d, whereas the specific capacity data and optimisation techniques suggest that the effective T at borehole number 4 is about 500 to 600 m2d. The lower values may be more representative of the aquifer if the observation well data are being affected by recharge from the R. Maun and recovery.

Early S derived from the various methods applied is about 0.4%, but this is expected to increase with the duration of pumping. A representative value of Sy might only be obtained by monitoring during normal production or from cores.

It is considered likely that the additional drawdown due to interference effects will be similar to the predictions based on a T of 1500 m2d, which would produce pumping water levels of about 40 to 45m for the three configurations examined.

The R. Maun, which is situated only a few hundred metres from the site and at a similar elevation to the water level at Boughton, may form a recharge boundary and be influencing the time drawdown data. However, whilst no firm conclusions can be drawn from the data regarding the influence of the R. Maun, this aspect should be examined in more detail as the river may be contributing to the nitrate concentrations.

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TABLE 1. Well spacing for Configurations A to C in metres

	Borehole Number			
A. Corners				
	1	2	3	4
	0	125	250	200
2		0	235	300
3			0	275
4				0
B. Northern Boundary				
	0	90	180	270
2		0	90	180
3			0	90
4				0
C. North and Central areas				
1	0	190	135	190
2		0	135	270
3			0	135
4				0

Table 2 Drawdown Interference after 1 day in metres

	Borehole Number				Total
A. Corners					
	1	2	3	4	
	0	2.5	1.1	1.5	5.1
2	2.5	0	1.2	0.8	4.5
3	1.1	1.2	0	0.95	3.25
4	1.5	0.8	0.95	0	3.25
B. Northern Boundary					
1	0	3.2	1.7	1	5.9
2	3.2	0	3.2	1.7	8.1
3	1.7	3.2	0	3.2	8.1
4	1	1.7	3.2	0	5.9
C. North and Central areas					
1	0	1.6	2.3	1.6	5.5
2	1.6	0	2.3	1	4.9
3	2.3	2.3	0	2.3	6.9
4	1.6	1	2.3	0	4.9

Drawdown in each production borehole without interference = 15.3

Rate m3/d	7000
T m2d	515
S=Sy	0.004

Table 3 Drawdown Interference after 7 days in metres

	Borehole				Total
A. Corners					
	1	2	3	4	
	0	4.4	2.9	3.4	10.7
2	4.4	0	3.1	2.6	10.1
3	2.9	3.1	0	2.8	8.8
4	3.4	2.6	2.8	0	8.8
B. Northern Boundary					
1	0	5.2	3.6	2.8	11.6
2	5.2	0	5.2	3.6	14
3	3.6	5.2	0	5.2	14
4	2.8	3.6	5.2	0	11.6
C. North and Central areas					
1	0	3.5	4.3	3.5	11.3
2	3.5	0	4.3	2.8	10.6
3	4.3	4.3	0	4.3	12.9
4	3.5	2.8	4.3	0	10.6

Drawdown in each production borehole without interference = 17.8

Rate m3/d 7000

T m2d 515

S=Sy 0.004

Table 4 **Drawdown Interference after 70 day in metres**

	Borehole Number				Total
A. Corners					
	1		3	4	
	0		5.4	5.9	18.3
2	7	0	5.6	5	17.6
3	5.4	5.6	0	5.3	16.3
4	5.9	5	5.3	0	16.2
B. Northern Boundary					
1	0	7.8	6.2	5.3	19.3
2	7.8	0	7.8	6.2	21.8
3	6.2	7.8	0	7.8	21.8
4	5.3	6.2	7.8	0	19.3
C. North and Central areas					
1	0	6.1	6.9	6.1	19.1
2	6.1	0	6.9	5.3	18.3
3	6.9	6.9	0	6.9	20.7
4	6.1	5.3	6.9	0	18.3

Drawdown in each production borehole without interference = 20.8

Rate m3/d 7000

T m2d 515

S=Sy 0.004

Table 5 . Drawdown Interference after 1 day in metres

	Borehole Number				Total
A. Corners					
	1	2	3	4	
	0	1.25	0.7	0.9	2.85
	1.25	0	0.75	0.6	2.6
3	0.7	0.75	0	0.65	2.1
4	0.9	0.6	0.65	0	2.15
B. Northern Boundary					
1	0	1.45	0.95	0.7	3.1
2	1.45	0	1.45	0.95	3.85
3	0.95	1.45	0	1.45	3.85
4	0.7	0.95	1.45	0	3.1
C. North and Central areas					
1	0	0.9	1.2	0.9	3
2	0.9	0	1.2	0.7	2.8
3	1.2	1.2	0	1.2	3.6
4	0.9	0.7	1.2	0	2.8

Rate m3/d 7000
T m2d 1500
S=Sy 0.004

Table 6. Drawdown Interference after 7 days in metres

	Borehole Number				Total
A. Corners					
	1	2	3	4	
	0	1.9	1.4	1.55	4.85
2	1.9	0	1.45	1.25	4.6
3	1.4	1.45	0	1.35	4.2
4	1.55	1.25	1.35	0	4.15
B. Northern Boundary					
1	0	2.15	1.65	1.4	5.2
2	2.15	0	2.15	1.65	5.95
3	1.65	2.15	0	2.15	5.95
4	1.4	1.65	2.15	0	5.2
C. North and Central areas					
1	0	1.6	1.85	1.6	5.05
2	1.6	0	1.85	1.4	4.85
3	1.85	1.85	0	1.85	5.55
4	1.6	1.4	1.85	0	4.85

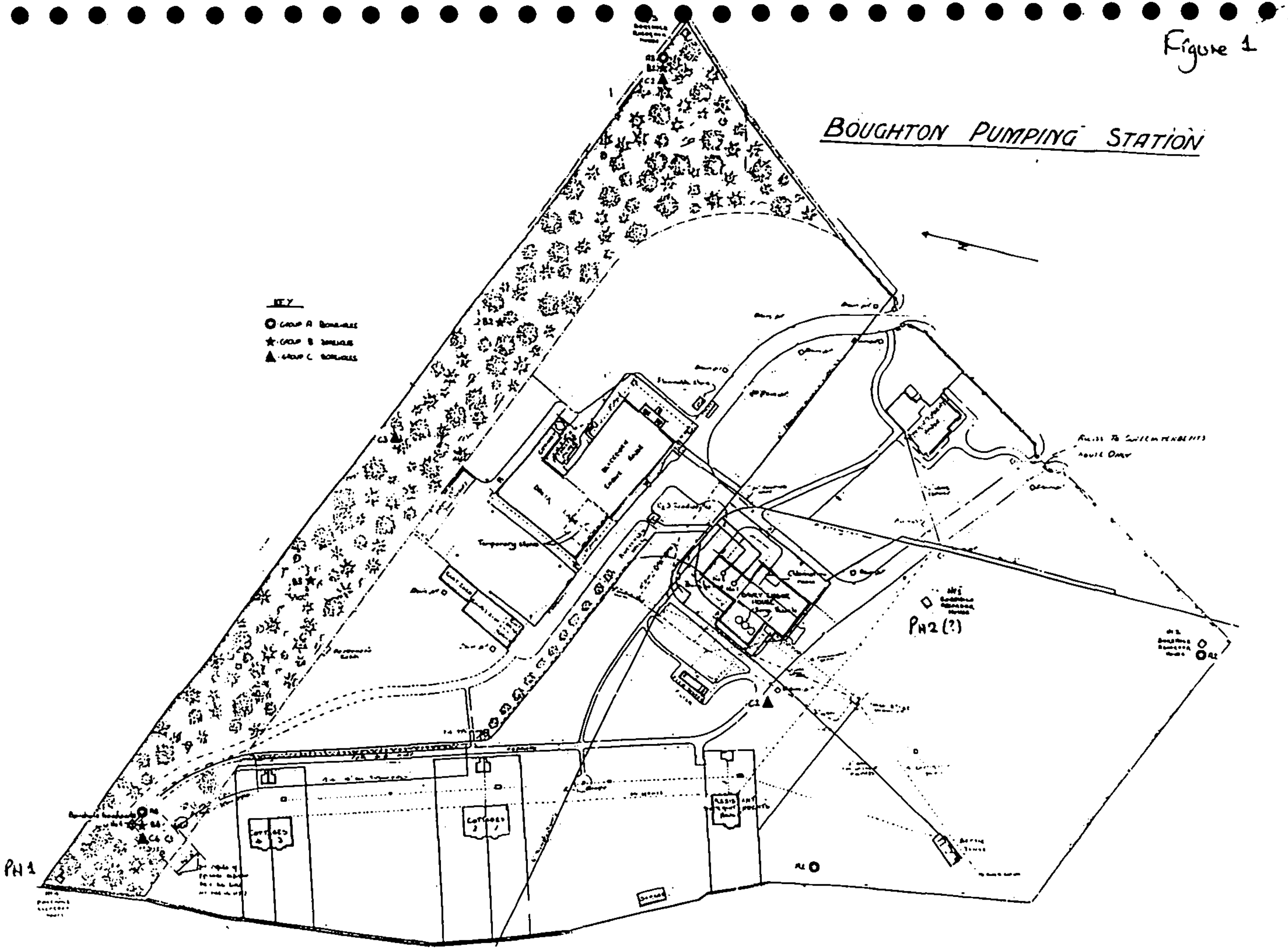
Rate m3/d 7000
T m2d 1500
S=Sy 0.004

Table 7 Drawdown Interference after 70 days in metres

	Borehole Number				Total
A. Corners					
	1	2	3	4	
	0	2.75	2.25	2.4	7.4
	2.75	0	2.3	2.1	7.15
	2.25	2.3	0	2.15	6.7
4	2.4	2.1	2.15	0	6.65
B. Northern Boundary					
	0	3.05	2.5	2.2	7.75
2	3.05	0	3.05	2.5	8.6
3	2.5	3.05	0	3.05	8.6
4	2.2	2.5	3.05	0	7.75
C. North and Central areas					
1	0	2.45	2.7	2.45	7.6
2	2.45	0	2.7	2.2	7.35
3	2.7	2.7	0	2.7	8.1
4	2.45	2.2	2.7	0	7.35

Rate m3/d 7000
T m2d 1500
S-Sy= 0.004

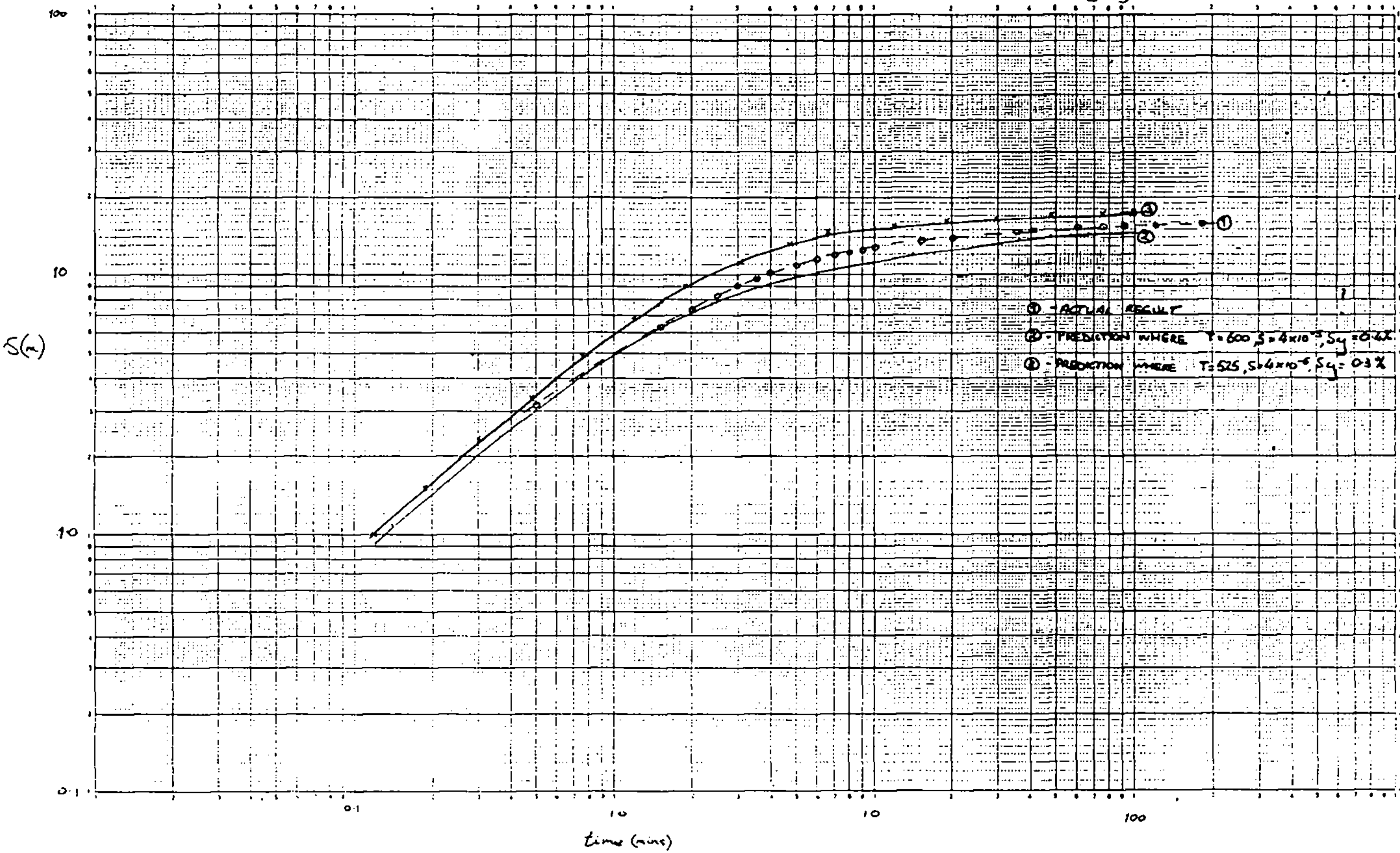
Figure 1


BOUGHTON PUMPING STATION
KEY
GROUP A BOREHOLES
GROUP B BOREHOLES
GROUP C BOREHOLES
PH1
PH2 (?)
Cottages 1 2
Cottages 3 4
Temporary store
C1
C3
R1
R2
B3

BOUGHTON PUMPING STATION. CONSTANT RATE TEST, MAY 1987

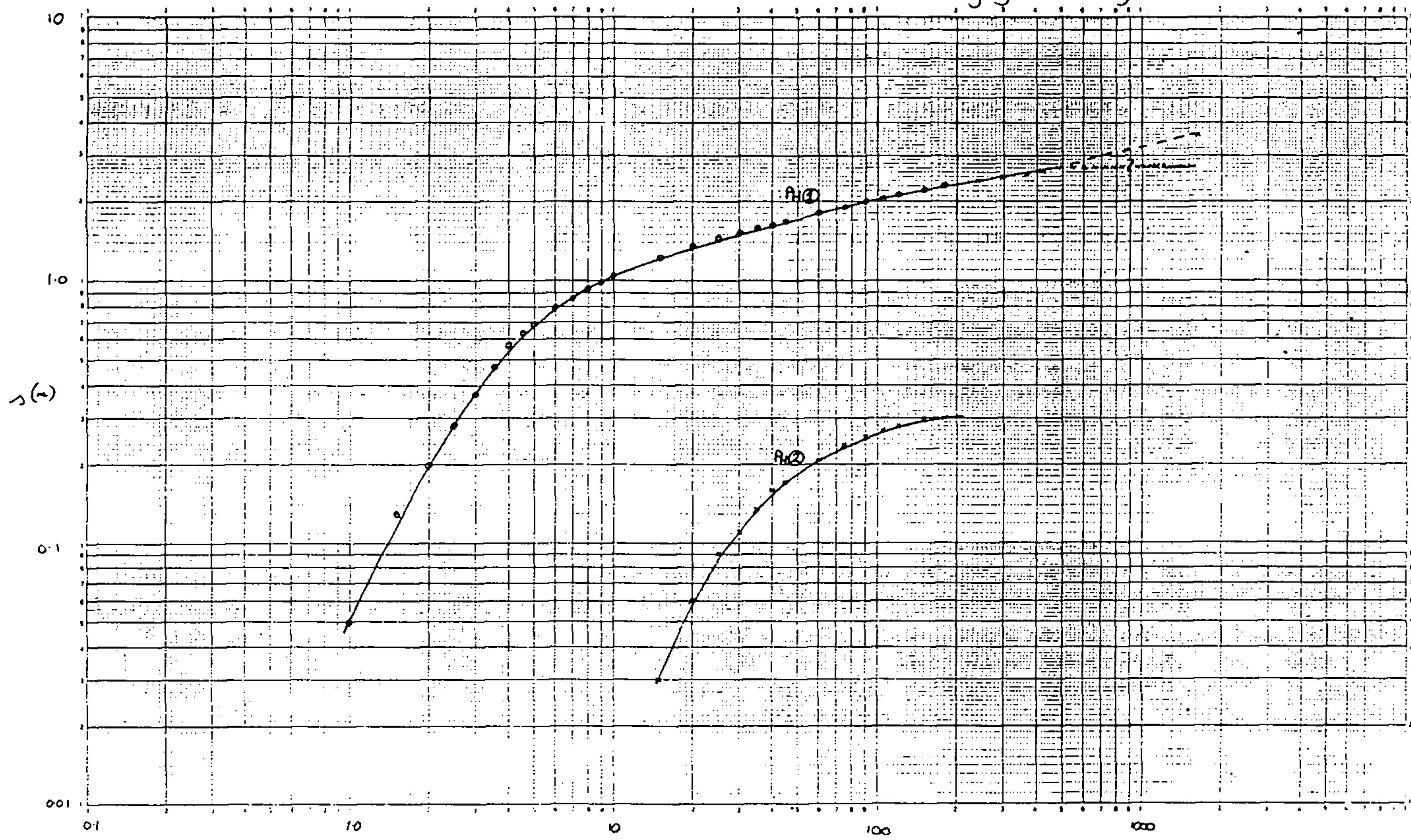
FIGURE 2

DRAWDOWN AT BOREHOLE 4. Log Log plot

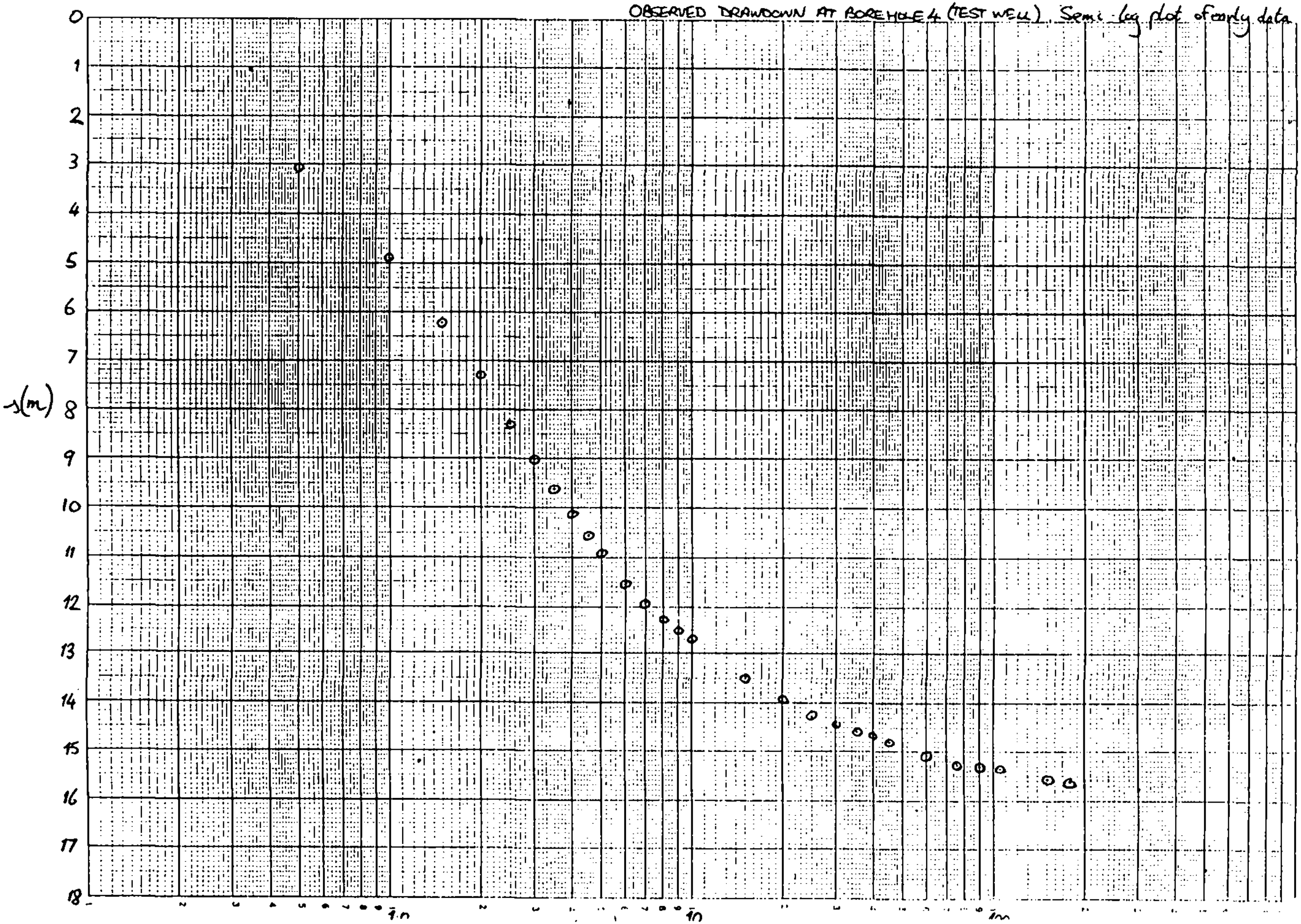


BOUGHTON PUMPING STATION . CONSTANT RATE TEST, MAY 1987. FIGURE 3

OBSERVED DRAWDOWN AT PH1 AND PH2 . Log Log plot of early data



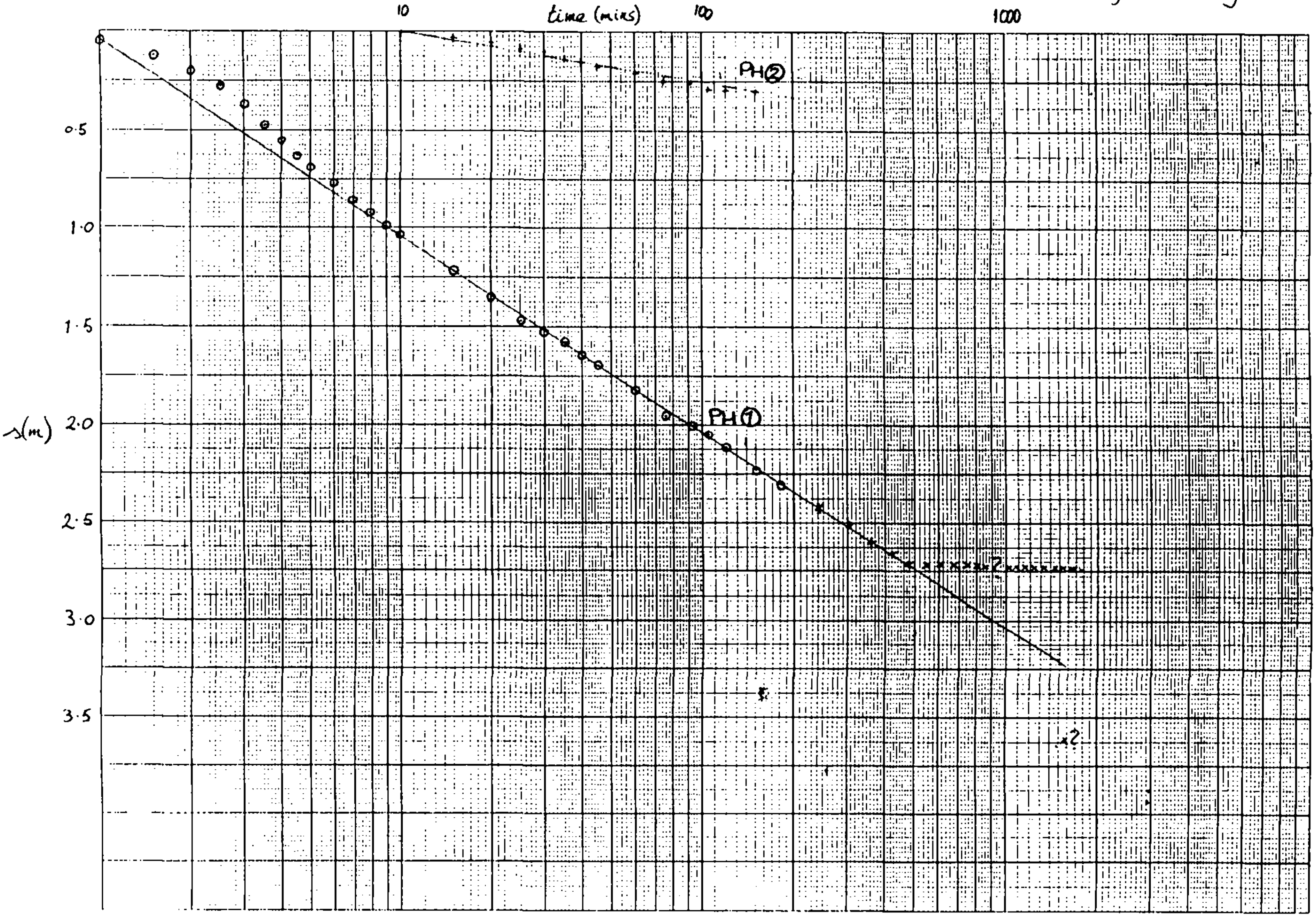
BOUGHTON PUMPING STATION. CONSTANT RATE TEST, MAY 1987. FIGURE 4



BOUGHTON PUMPING STATION. CONSTANT RATE TEST, MAY 1987

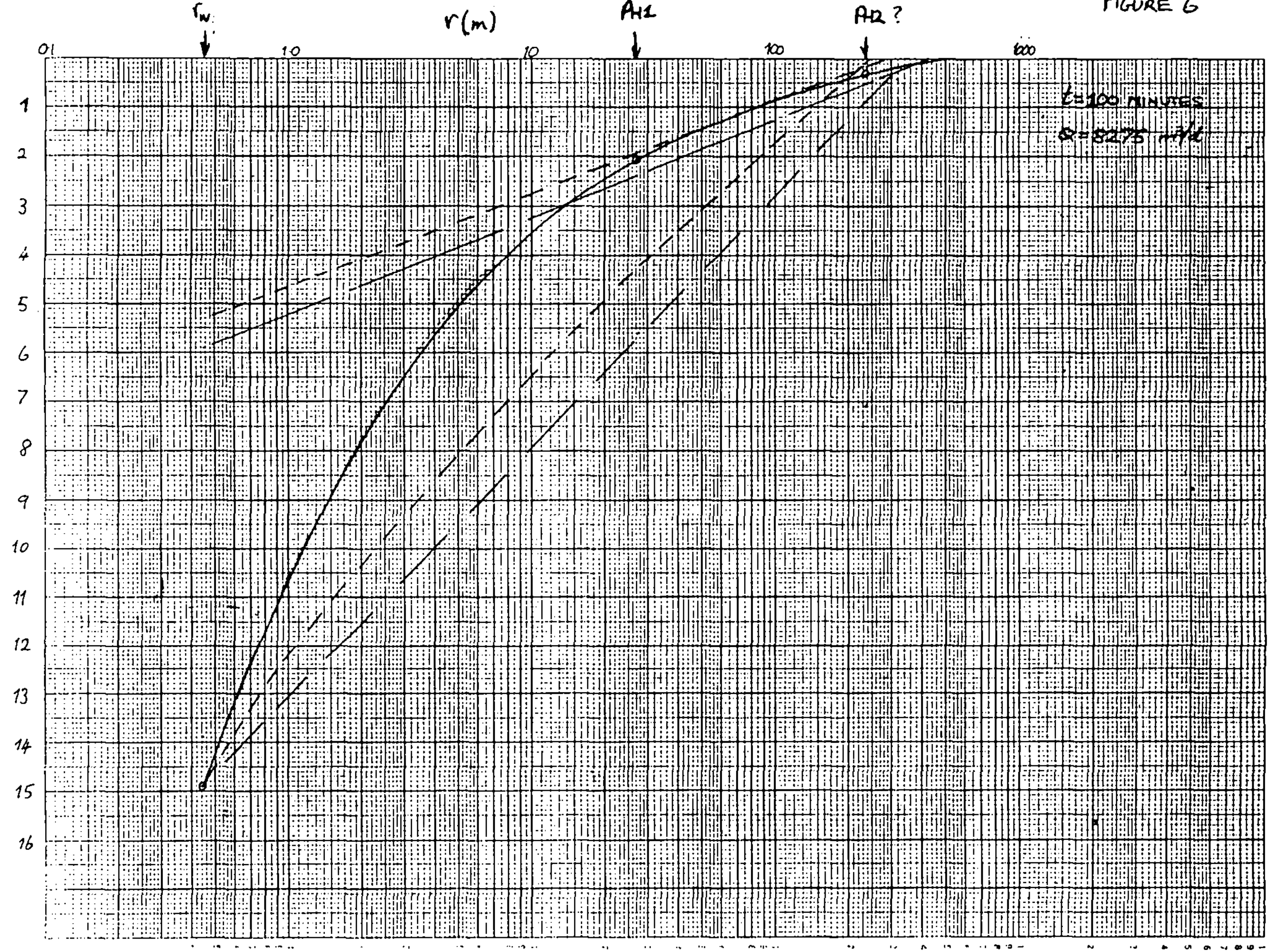
FIGURE 5

OBSERVED DRAWDOWN AT PH1 AND PH2 Semi-log plot of early data

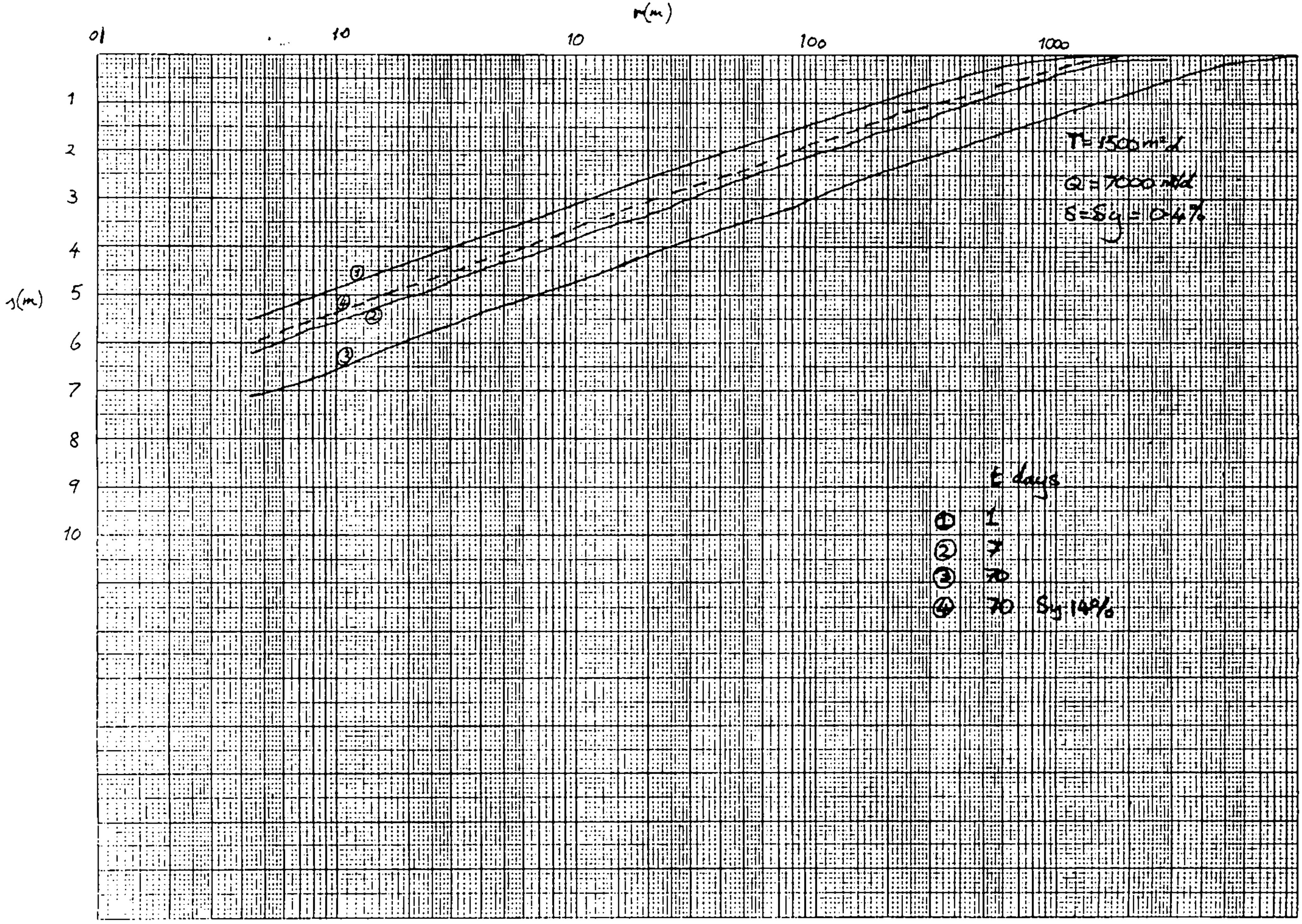


BOUGHTON PUMPING STATION CONSTANT RATE TEST, MAY 1987. DISTANCE DRAWDOWN PLOT

FIGURE 6



BOUGHTON PUMPING STATION. DRAWDOWN PREDICTIONS. FIGURE 7



BOUGHTON PUMPING STATION. DRAWDOWN PREDICTIONS.

FIGURE 8