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DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY

HYDROGEOLOGY SECTION

POLDA BASIN AQUIFER CHARACTERISTICS

by

C. BLEYS
Senior Geologist
Hydrogeology Section

61/73

17th September, 1965.

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POLDA BASIN AQUIFER CHARACTERISTICS

ABSTRACT

East of Polda pumping trench pump-tests have been made on several 43 inch diameter boreholes. They were drilled in Polda Basin a portion of an extensive shallow non-pressure or drain aquifer. This aquifer covers a large part of County Musgrave. Polda Basin contains water of less than 1,000 ppm and is surrounded by waters of higher salinity.

The individual boreholes are capable of yielding up to 1.5 cusecs. Because of the large cone of drawdown formed while pumping continuously, PT bores 4 and 7 should be pumped at a rate not higher than 1 cusec. Groundwater stored is sufficient for further development of town and country supplies.

1.1 INTRODUCTION

The presence of freshwater in Polda Basin has been known and discussed for a very long time, as early as 1911 the suggestion was made that significant supplies of groundwater could be drawn from that area. Pump-tests which gave encouraging results were carried out in 1929.

A shortage of water for stock and other purposes on Eyre Peninsula became almost acute in 1962. This resulted in the construction of a 200 yard long trench from which the groundwater was pumped to Loch. Also an intensive hydrological investigation was started combined with an extensive drilling programme.

It soon became clear that an open trench has its disadvantages. Windblown materials could pollute the groundwater and growths of algae could block the suction pipes of the pumps. Therefore the Department was approached to investigate the possibility of obtaining large quantities of groundwater from boreholes. Encouraging results were obtained from the pump-tests done in 1963 on 16 inch diameter boreholes hence drilling of four larger diameter boreholes was recommended.

Pump-tests of seven days duration, followed by multiple stage tests were carried out on two of the 43 inch diameter bores while the third was tested for 23 hours at a single rate followed by a multiple stage test. The fourth was abandoned after a short test.

Unpublished reports on the area have been prepared by various writers, including R. Lockhart Jack, and R.G. Shepherd, included such earlier work in his report Hyd. No. 1486, Report Bk. No. 57/26, in which he gave a comprehensive description of the geology and hydrogeology. Therefore only the relevant data are used in this report.

1.2 LOCATION

Polda Basin comprises an area of 50 square miles and is a portion of an extensive basin in County Musgrave. It is named after the Homestead which lies almost in the centre of the basin and is located about 25 miles west of Loch adjacent to the Elliston road.

The area is generally undulating with some sand dunes. These are roughly parallel and trend south-easterly and lie at approximately half mile intervals. A large oblong shaped salt water swamp lies north-west of Polda homestead almost parallel with and north of the main road to Elliston.

The Engineering & Water Supply Department's pumping trench lies 2.15 miles west of the homestead and the pump-test boreholes are located on a line trending south from the trench. Pump-test borehole No. 4 (P.T. No. 4) is the first borehole south of the trench, see map S 4435, and is located at a distance of 729 yards from it. The distance separating the adjacent bores P.T. No. 4, P.T. No. 5, P.T. No. 6 and P.T. No. 7 are respectively 968 yards, 903 yards and 834 yards.

1.3 GEOLOGY

A thin clay bed of Pleistocene to Recent age, usually not more than 8 feet thick forms the base of the freshwater basin. The sequence below this clay bed is of Tertiary age, the upper beds of which are sandy. These Tertiary beds will not be further discussed. Aeolianites in which occasional lenses and thin bands of sandy silts occur, and cemented aeolianites overlie clay beds. About 30 feet of windblown sand was penetrated in a number of observation boreholes although this thickness is not consistent and as little as 10 feet of aeolianites were observed in one observation borehole.

These aeolianites are capped by a 4 feet thick crust of sheet kunkar. The older sand dunes directly overlie the aeolianites and a kunkar horizon was formed on them. The Recent sand dunes are deposited on this type of limestone.

1.4 HYDROGEOLOGY

Good quality groundwater of 770 parts per million of dissolved salts occurs in the Recent aeolianites. The salinity varies somewhat and in places rises to 1,000 parts per million. The average thickness of the aquifer is 14 to 18 feet and it is believed that the water is not only stored in the voids between the grains but also in cavities in the cemented aeolianite.

It appears that wherever sands or sandy silts occur the groundwater quality is in the order of 1,300 to 2,000 parts per million or even more. It is considered that the permeability in these sands is less and therefore the movement of the groundwater is restricted. Owing to the slower movement, the groundwater tends to become more saline as the time is increased to dissolve soluble salts. Since the groundwater movement through the sandy silts is restricted it is considered that these beds form a semi-boundary. Hence the Polda Basin of 50 square miles is an area of very good quality water surrounded by poorer quality water.

In the preceding section on Geology an 8 feet thick clay bed was mentioned as forming the impermeable base of the freshwater basin. It constitutes the seal between the overlying freshwater and saline water in the Tertiary sands below and is therefore an aquiclude. Its thickness is, under static conditions, sufficient to prevent downward movement of the freshwaters and also it is thick enough to form a barrier against upward movement of the saline waters which occur in the Tertiary sands directly underlying the aquiclude. If the pressure on the aquiclude is reduced considerably then there is a probability that the underlying waters may leak through the aquiclude and contaminate the overlying aquifer. This possibility must be kept in mind in the ultimate development of the aeolianite aquifer.

1.5 HYDROLOGIC CYCLE

There are no rain gauges in the area and thus the average annual rainfall must be deduced from rainfall recordings at sites outside the area. Actual recordings at Lock, Yeelanna and Elliston are respectively 16.00, 16.02 and 16.67. It is therefore considered that the rainfall at Polda Basin is approximately 16 inches per annum. From May to September is the wet season in which the average rainfall is 9 inches. A small portion of this is available for recharge of the aquifer. Effective rains do not fall in summer time.

Run-off occurs over short distances only and water may accumulate in small interdune flats. The remainder is either evaporated or evapotranspired and a small portion percolates downwards to the aquifer. Elsewhere in the State measurements have been made on the penetration rate of rain and it was concluded that in sandy soils the wetting front reached to 13 or 14 feet below the surface. In this area the groundwater level is at an average depth of 10 feet so that the annual recharge by downward percolating rainwater is not only possible but is the only source of intake.

To date no data are available on the evaporation, evapotranspiration and downward percolation. The quantity of groundwater which is discharged through springs farther to the west is also unknown. For assessment of the ultimate development potential of Polda Basin estimates of these factors should be obtained by means of rain gauges or pluviographs, soil moisture meters and possibly evaporation measurements. This however, will require a prolonged study of the area.

1.6 PIEZOMETRIC SURFACE

Monthly records of the water levels have been taken of some of the observation boreholes while three monthly records are measured on all bores. The accompanying four maps, S 4436 c, d, b and a, show the isopotentials just before pumping started from the Engineering & Water Supply Department trench, 1st. September, 1964; in the middle of the pumping period 15th January, 1965; at the end of the pumping period 1st. April, 1964 and the recovery after pumping was stopped 3rd. July, 1964.

In general the groundwater flows in a westerly direction and the gradient of the piezometric surface varies between 17 ft. per mile and .3.1 ft. per mile, the lower gradient occurring in the centre of the Basin. The yearly variation in the piezometric surface is not very great and in general the isopotential lines are displaced less than 0.2 of a mile, as shown on the maps mentioned above.

A rise in water level, as shown on the isopotential map of the 15th. January 1965, S 4436 d, was not expected during the period that the trench was pumped and appears to be anomalous.

The rapid change in gradient indicated by the closely spaced isopotentials is due to the change in permeability of the aquifer. Just east of the line of bores P.T. 4 to P.T. 7 the gradient is lowest. However, in this area the aquifer is not sufficiently thick to warrant the drilling of water supply bores.

There is a relatively very steep gradient just south of P.T.7 which suggests an aquifer boundary. However, the occurrence of such a boundary so close to the borehole i.e. within 250 ft. had certainly not been indicated by the drawdown data, during the 7 day single rate test on this bore. It could be argued that the period it had been pumped was insufficiently long for the cone of drawdown to reach this boundary. It will be explained later that this could not have been the case, as the drawdown in the bore P.T. 7 and the observation bores should have been influenced.

1.7 TYPE OF AQUIFER

Although small rises in the water level were recorded after penetrating the aquifer while drilling, it is considered that Polda Basin contains a free water table aquifer. The recorded rises in water level were probably due to the fact that the top of the water level was passed unnoticed.

Since the sediments forming the aquifer consist of aeolianites and cemented aeolianites it is unlikely that it is a homogeneous aquifer. Voids in the fine sands are not comparable in size with solution caverns which occur in the cemented aeolianites. However, the aquifer as a whole is continuous. This is of utmost importance in evaluation of the aquifer, as all present equations are based upon homogeneous aquifers extending to infinity.

The aquiclude is not a horizontal plane and therefore small variations were found in the thickness of the aquifer. The average is probably 18 feet but for calculations of the transmissibility and storage capacities the actual thicknesses are used in the equations.

1.8 POROSITY OF THE AQUIFER

Undisturbed samples of the beds forming the aquifer have not been available for porosity test. The sediments are probably comparable with fine sands. However, the cavernous cemented aeolianites could have a much higher porosity. An average porosity of 30% is estimated for this type of aquifer.

1.9 FACTORS AFFECTING THE FREE WATER TABLE AQUIFER

Workers on the aquifer evaluation such as G. Thiem, C. V. Theis, C. F. Tolman, L. K. Wenzel and others have developed equations for the calculations of transmissibilities and storage capacities of infinite artesian and homogenous aquifers. This is the ideal case, but the formulas can be used and give a good approximation. However, this is not the case for a 'drain' or 'free water table' aquifer. Different procedures have been suggested but in general the approximations are fairly poor. However, the best approximation may be obtained by the use of the equation developed by Jacob (1944) $'s = s - \frac{s^2}{2m}$ in which 's is the adjusted drawdown, 's' is the drawdown measured and 'm' is the aquifer thickness.

All water level readings have been adjusted in this manner, and used in the equations of the artesian aquifers. Drawdowns read from the graphs accompanying this report are the adjusted drawdowns and must be corrected for drawdowns which would actually occur in the field, see tables 1 to 14.

1.10 REQUIRED INFORMATION

Since the Polda Basin contains a drain aquifer which is recharged only by local rainfall, and as the withdrawal of an excessive quantity of water may result in collapse of the aquifer, it is of utmost importance to calculate a safe yield. It was therefore desired to arrive at a good approximation of the transmissibility and the storage capacity which are used to assess the cone of drawdown and calculate the extent of the area which will be affected by heavy pumping.

There is one other factor which must be considered. As discussed before, the aquiclude is a thin one only and overlies Tertiary sands containing saline waters. If the pressure of the fresh waters is reduced too much, then the saline waters may force their way upwards and contaminate the fresh water above.

It must be borne in mind that the aquifer is not uniform in character and certainly not of infinite extent. However, the effect of the pumping probably will not reach the boundary of the basin hence boundary effects will not be felt.

Short term water level fluctuations were not expected since the trench was not pumped while the boreholes were being tested. However, a rise of the water level resulted after some 2 inches of heavy rain during the recovery after the testing of P.T. No. 4. This rise, however, does not affect the calculations.

1.11 SALINITY

Analyses of samples taken at the end of the pumping test are given in the facsimiles of the analyst's reports.

Nitrates occur in these waters. Their total content level was high before pumping was started and probably above the accepted limit for adult human consumption. The analyses are relatively uniform with the exception of those of P.T. 4 which were anomalously high, in total salinity due mainly to sodium chloride.

The high salinity after pumping in bore No. 4 may be due to the saline swamp close to this bore and the fact that the trench was pumped the year before, which may have drawn some of the saline waters into this portion of the aquifer.

If this type of water is mixed with the water of P.T. No. 7 borehole waters suitable for drinking will be obtained except that the nitrate content may be above the accepted limit when the bores are pumped for the first time in the spring.

The high salinity in P.T. No. 4 is discouraging. If the trench is not pumped in the future an increase in salinity may not occur. Recommendations will be made later on the safe pumping rate for P.T. 4. It is in the order of one cusec and this yield may be low enough to avoid further increases in salinity.

1.12 DRILLING

Drilling of the 43 inch diameter test borehole and the observation borehole commenced on 29th July, 1964 and with some interuption these were ready for preliminary tests on 9th October, 1964. Five observation boreholes were drilled near bore P.T. 4 and three near each of bores P.T. 5 and 6. At bore P.T. 7 four observation bores were drilled. The pumping test bore and observation boreholes were discontinued in the clay underlying the aquifer. The bore logs of the P.T. bores are given in the appendix.

All observation boreholes were lined with 2 inch pipe while the pump-test boreholes were cased with 36 inch cement linings. These linings, however, were not completely satisfactory and were later replaced by 36 inch slotted steel pipe and in each case the annulus filled with well rounded gravel. P.T. No. 6 borehole gave a very small supply and was abandoned.

1.13 PUMPING EQUIPMENT

A five inch single stage Pomona turbine pump was installed, in each case, at about eight inches above the bottom of the borehole. In this manner the available drawdown was maximum. This pump was coupled to an A.U.D. 264 International driving and H. & E. head with a one and half to one ratio. This equipment was capable of pumping some 45,000 gallons per hour. Since the area is almost flat there was no difficulty in disposing of the quantity of water from P.T. No. 4 into the surface tanks at the trench. However, there is a small rise between P.T. Nos. 5, 6, and 7 and the trench therefore, a booster pump, a single stage Kelly and Lewis centrifugal pump coupled to a 3-cylinder Deutz was used to force the water over the little rise.

The single stage Pomona pump was considered the most suitable borehole pump as with this unit a high pumping rate could be obtained with minimum power consumption.

Although some minor repairs had to be made to the engines used, in general the equipment worked satisfactorily. A close watch was kept on the revolutions of the pump to ensure a continuous discharge.

1.14 DISCHARGE OF THE GROUNDWATER

Since the beds overlying the aquifer are very permeable any groundwater pumped from a bore and discharged at a short distance away could be expected to return almost immediately to the aquifer. Under these conditions pumping would result, after a short period of time, in recirculation of the groundwater. Therefore the Engineering & Water Supply Department was approached with a request to supply and lay a 6 inch diameter pipe line through which the pumped water could be delivered to tanks installed near the trench. From there it was pumped into the reticulation system and removed from the area, therefore no water was returned to the aquifer during the pumping testing.

The delivery pipe to the tanks entered these at the base. When these tanks were full there must have been a greater pumping head which decreased the discharge rate. This can be clearly seen in the drawdown log time graphs on which the plots do not lie on the curves or on a straight line.

1.15 DISCHARGE MEASUREMENT

The discharge line from the pump was directly coupled to the temporarily laid 6 inch surface pipe. A Helix water meter was installed in this short coupling line. The water pumped was delivered to the surface tanks at the trench, which hold only some 50,000 gallons. From there it was pumped into the reticulation mains. All water pumped into these mains passed a flowmetre and the quantities measured agreed closely with those measured near the pumping equipment.

Although a close watch was kept on the pump revolutions, there still were some slight differences in the discharge which slightly affected the drawdown levels as indicated previously.

1.16 WATER LEVEL MEASUREMENTS

Water levels of some observation bores on Polda Basin are measured every month while the remainder are included in the survey every three months. The yearly difference of the piezometric surface obtained from these surveys have already been discussed.

Good results from pump-tests are obtained if an aquifer is in static condition. Therefore the Engineering & Water Supply Department was requested not to pump from the trench in order not to disturb the water levels prior to the testing.

In the last years an electrical probe consisting of a twin core electrical lead, battery and an ampmeter was used to measure the levels in the pumping borehole and the observation boreholes.

It soon became apparent that marking of the leads and reading off the different water levels immediately was impracticable. Since chalk marks can easily be erased and ink markings are not easily readable on the black TV leads used, a new system was adopted. Each T.V. aerial wire was covered with marking tape and whenever a water level was measured a mark was made and a number placed against it. As soon as sufficient time was available between readings, the leads were measured and the water levels noted on the appropriate sheets. The marking tapes were removed after the completion of the tests and are still available as a permanent record.

All water level measurements were taken from a reference point either on the casing or 2 inch pipes of the observation boreholes and the height of this reference point also marked on the appropriate recording sheets.

Slight variations in water levels occurred after the equilibrium was reached. However, these fluctuations are probably due to variations in revolutions of the pumping equipment which could not be avoided and to an increase in head due to the filling of the surface tanks at the trench.

While P.T. 7 was being pump tested a water level recorder was placed on a borehole midway between P.T. 7 and P.T. 6. The recorder however, was not working satisfactorily so that the graph made cannot be used for calculations.

1.17 TESTING PROCEDURES

Supply from the Engineering & Water Supply trench had to be reduced in February 1964 as quantities of water up to 2 cusecs had been pumped from the trench and the water level decreased by as much as 4 feet over a period of three months. With this in mind the Engineering & Water Supply Department requested a seven day test on all P.T. bores.

A preliminary test run of short duration had to be made to develop the boreholes and to assess the total quantities of groundwater which could be removed before any long period of testing on any one borehole could be commenced.

It was decided that a 7 days pump-test was to be done at a single high rate followed by a recovery test on each P.T. hole after which a multiple stage test was to be made to calculate the aquifer loss and well loss.

P.T. No. 4 was the first tested and the pump was started on 9th October, 1964 at 09.00 hours, the recovery commenced on 16th October, 1964. Pumping was done on an average rate of 1.7 cusecs. After completion of the single stage test the multiple stage test was made. It commenced on 19th October, at 16.00 hours and was completed on the 20th October at 03.40 hours.

The pumping equipment was moved to P.T. No. 7 and a similar test procedure repeated. The pump was started on the 6th November, 1964 at 16.00 hours and the whole testing was completed on 16th at 22.00 hours.

Since the lining was not considered to be suitable, further testing was deferred until 36 inch slotted pipes were installed and the annuli filled with gravel.

To assess the possible improvement obtained by relining the borehole pump-tests were restarted on P.T. No. 7 on 13th February, 1965 and completed on 14th February, P.T. No. 5 was pump tested for 23 hours only, which started on the 22nd February, and recovery started on 23rd.

On P.T. No. 4 a second multiple test was made which started on the 3rd March, and was completed that day.

During the pump-test water levels were measured in at least three, and near P.T. No. 4 in five, observation boreholes. The water levels in these observation holes were used to check whether equilibrium had been reached. In general it was reached after a 24 hour pumping period although in many water table aquifers two days pumping are required.

Multiple stage tests can be made on free water table aquifers under certain conditions. No further explanation has been found in the literature as to what those conditions are. Therefore the time intervals between each stage were varied for each test on the different boreholes. It appears that only the last one made on P.T. 4 serial 030365 gave reliable data for the first three of the four stages.

1.18 RECOVERY

After the pump was stopped in each borehole the recovery of the water levels were taken at very rapid intervals. An example is P.T. NO. 4 where the total drawdown was about 14 feet. Six readings were taken in the first minute in which the water level recovered some 6 feet. Half minute readings were taken for a further 9 minutes and thereafter minute readings were taken until 40 minutes after the pump stopped. Then readings were taken at five minute intervals until 100 minutes after the pump had stopped. Ten minute readings were taken until 200 minutes thereafter 50 minute readings were made until 1,000 minutes. Then 100 minute readings were taken until 2,000 minutes. Thereafter 500 minute interval readings were made. The last reading was made 4,500 minutes after the pump was stopped and the water level was then still 0.40 feet below the static water level. This type of slow recovery is typical of the aeolianite and cemented aeolianite aquifers.

Similar readings were made after the pump testing of P.T. bores Nos. 7 and 5, and the results were comparable.

2.1 CALCULATIONS OF TRANSMISSIBILITY AND STORAGE CO-EFFICIENTS

The co-efficients of transmissibility indicate the capacity of an aquifer to transmit water and is equal to the co-efficient of permeability multiplied by the thickness of the aquifer. Storage properties of an aquifer are expressed by its co-efficient of storage which is defined as the volume of water the aquifer releases per unit change and the complement of head normal to that surface.

The co-efficient of transmissibility can be obtained from drawdown measurements from a pump-tested bore. For the calculations of the storage co-efficient however at least one observation borehole is required. These two co-efficients can be calculated with the Dupuit Thiem equations but in general the mathematical solutions are not as reliable as graphical ones. In the graphical approach small variations in pumping rates can be adjusted visually which is not possible when mathematical solutions are used.

Under the heading "Factors affecting a Free Water Table Aquifer" it was pointed out that all drawdown measurements must be adjusted before they can be used for the artesian aquifer equation. For convenience the formula is repeated here:

$$'s = s - \frac{s^2}{2m}$$

in which $'s$ is the adjusted drawdown, s the drawdown measured in the field and m the aquifer thickness.

The drawdown data used in the graphs for the calculations are the adjusted drawdowns. The conversion graph to the drawdown as would occur is shown on the left hand side of the Time and Distance Drawdown Curves 65-335/6, 65-414/5. Whenever the term field data is used in the following paragraphs it should be borne in mind that the adjusted field data are referred to and not the actual measured drawdown levels.

Theis (1935 developed a non leaky artesian aquifer type curve for computing either mathematically or graphically the transmissibility and storage capacity co-efficients. J.S. Colville (1965) (believed to be the first) further developed these equations for the basic units F, P, S and other units. A copy of the summary of the formulae in well hydraulics is given in the Appendix. The functions for the co-efficients of transmissibility 'T' and the storage capacity 'S' are

$$T = \frac{Q}{4 \Pi s} W(u)$$

and

$$S = \frac{4Tut}{r^2}$$

in which

Q is the pumping rate in cusecs,

's' is the drawdown in feet,

'r' is the distance in feet to the observation well,

't' is the time in seconds and,

W(u) is the well function of u.

A graphical solution of the equations is obtained by preparing a plot of the log of drawdown against the log of time. A curve drawn through the plot should be matched with the type curve of log W(u) against the log of $\frac{1}{u}$. Both plots are to be made on the same scale log log paper. After the type curve is matched against the drawdown time plot a convenient match point is selected. This match point does not necessarily have to lie on the type curve but can be chosen so that integers are obtained for the values W(u) and u on the type curve. The corresponding values of 's' and 't' are read from the drawdown time plot and the values so obtained should be substituted in the equations for 'T' and 'S'. It will be noted that in the graphs accompanying this report the type curve has been drawn on the drawdown time graph and that no separate type curve is supplied.

2.2 CALCULATIONS USING DATA OF THE PUMPING-TEST ON PT. 7

Graph 65-44 gives the plot of the log of the adjusted drawdown against the log of time of observation bore 7a. The variables obtained from this graph are:

$$s = 3.5 \text{ ft.}$$
$$t = 1.29 \times 10^4 \text{ sec.}$$
$$u = 10^{-3}$$
$$W(u) = 6.2$$

The constants are

$$Q = 1.9 \text{ cusec.}$$
$$r = 20 \text{ ft. from Pt. 7.}$$

These values substitued in the equation for T and S result in

$$T = \frac{1.9}{4 \pi 3.5} \times 6.2 = 2.8 \times 10^{-1} \text{ ft.}^2/\text{sec.}$$

$$S = \frac{4 \times 2.8 \times 10^{-1} \times 10^{-3} \times 1.29 \times 10^{4}}{4 \times 10^2} = 3.6 \times 10^{-2}$$

Calculations for T and S using Observation Bore 7b

The variables obtained from graph 65-45

$s = 3.7$ ft. $t = 5.16 \times 10^4$

$u = 10^{-3}$ and $W(u) = 6.24$

The constants are

$Q = 1.9$ cusecs and,

$r = 40$ ft.

These values substituted in equation for T and S give

$$T = \frac{1.9}{4 \pi 3.7} \times 6.2 = 2.5 \times 10^{-1} \text{ ft.}^2/\text{sec.}$$

$$S = \frac{4 \times 2.5 \times 10^{-1} \times 10^{-3} \times 5.16 \times 10^{4}}{1.6 \times 10^3} = 3.2 \times 10^{-2}$$

Calculations using Observation Bore 7c

The values of the variables obtained from graph 6-46 are

$s = 4.25$ ft.

$t = 1.98 \times 10^5$ sec.

$u = 10^{-3}$

$W(u) = 6.4$

The constants are

$Q = 1.9$

$r = 80$ ft.

These values substituted in the equation for T and S result in

$$T = \frac{1.9}{4 \Pi 4.25} \times 6.4 = 2.27 \times 10^{-} \text{ ft.}^2/\text{sec.}$$

$$S = \frac{4 \times 2.27 \times 10^{-1} \times 10^{-3} \times 1.98 \times 10^{-5}}{6.4 \times 10^{3}} = 2.8 \times 10^{-2}$$

It is evident that there is a close relationship between the values of T and S obtained in the three calculations. Those from the observation borehole 7c are lowest. Probably they are more reliable values as the pumping in bore PT 7 should not have influenced the drawdown in this observation hole. In further calculations for the distance time drawdown graphs the lower values of T and S will be used.

It should be noted that on all time drawdown graphs discussed the drawdown of the first 100 minutes do not lie on the type curves. This is a normal feature as in this short period of time equilibrium has not been reached which is a requirement for the graphical solution.

2.3 STRAIGHT LINE METHOD

Cooper and Jacob (1946) developed a modified non-leaky artesian aquifer equation which also can be used to arrive at the co-efficients of transmissibility and storage capacity. To solve these factors graphically, a plot is made of the drawdown against the log of time. The equations to be used in the FPS units are

$$T = \frac{0.183Q}{\text{delta s}} \quad \text{and}$$

$$S = \frac{2.25\ Tt}{r^2} \quad \text{in which}$$

Q = the pumping rate in cusecs

delta s = the drawdown per log cycle

t_o = the zero drawdown time, intercept of the drawdown curve of an observation borehole, in seconds

r = the distance of the observation borehole to the pumped borehole in feet.

On Graph 65-345 are plotted against log t the drawdown obtained in the pump well and those of the observation bore 7c. Straight lines are drawn through the plots representing the best mathematical fit. It should be noted that for a mathematical fit calculations have to be made, for time saving purposes only a visual cast fit is drawn. It should also be noted that the early drawdown data are usually erractic. They therefore are not used in the drawing of the curve. The constants and the variables obtained from the graph 65-345 are

Delta s = 1.15

t_o = 3 min = 180 sec.

Q = 1.9 cusecs.

r = 80 ft.

These values substituted in the equations give

$$T = \frac{0.183 \times 1.9}{1.15} = 3.04 \times 10^{-1} \text{ ft.}^2 \text{ per sec.}$$

$$S = \frac{2.25 \times 3.09 \times 10^{-1} \times 1.8 \times 10^2}{6.4 \times 10^3} = 1.96 \times 10^{-2}$$

The values obtained by this method for T and S are in good accordance with those obtained with the type curve method of Theis. There is an advantage in the straight line method. With the curves obtained the drawdown in the pump borehole can be predicted at any time e.g. the drawdown after 70 days of pumping, being equal to 10^5 minutes, is equal to the drawdown obtained after seven days pumping plus the delta **s** of 1.15 feet. In this case the drawdown after 70 days would be

7.09 feet + 1.15 feet = 8.29 feet.

A drawdown at any time can also be calculated with the Theis equations, however, but it is more complicated.

2.4 DUPUIT-THEIM EQUATION

For comparison the coefficient of transmissibility is also calculated with the use of this equation. However an expression of the coefficient of permeability which is equal to the coefficient of transmissibility divided by the aquifer thickness m. The aquifer's thickness varies slightly as it is 16.5 ft., 17 ft. and 19 ft. in the observation holes a, b and c of PT 7.

The equation developed for the coefficient of permeability kp or P is

$$kp = \frac{2.3Q \log {}^{r}1/r_2}{\pi(h_1^2 - h_2^2)}$$ in which

$Q = 1.9$ the pumping rate in cusecs.

$r_1 = r_c$ is 80 ft. the distance to the pumped borehole.

$r_2 = r_c$ is 40 ft. distance to the pumped borehole.

$h_1 = h_c = 19 - 5.54$ ft., the saturated thickness of the aquifer after 10 minutes pumping.

$h_2 = h_c = 17 - 6.24$ ft., the saturated thickness of the aquifer after 10^4 minutes pumping.

These values substituted in the equation gives

$$kp = \frac{2.3 \times 1.9 \log 2}{\pi\,(13.46^2 - 10.76^2)} = 6.34 \times 10^{-3} \text{ ft. per sec.}$$

as $T = k_p\, m$

and the average thickness of the aquifer is 17 ft.

the value for the coefficient of transmissibility becomes

$$T = 6.34 \times 10^{-3} \times 17 = 1.07 \times 10^{-1} \text{ ft.}^2 \text{ per sec.}$$

This value of T obtained is lower than those arrived at by using the other methods which is probably due to the visual adjustment made in the graphical approach. It is considered that the higher values of T are more relaible and therefore the Dupuit-Theim equation has not been used for the determinations of the values of S and T of the boreholes PT 4 and PT 5.

2.5 VALUES OF T AND S OBTAINED FROM PUMTING TEST ON BORES PT. 4 AND PT. 5

In the previous paragraphs 2,4, the values of these coefficients were calculated for PT. 7 by means of different methods. They appear also on the graphs and it is considered that further completed calculations are not warranted in this report. For completeness, however, the values of T and S obtained from the single stage pumping test on PT. 4, PT.5 and PT. 7 are given in the table below. In these tables TC stands for the graphical method in which the type curve is used and M.E. indicates that the results are obtained by means of the modified straight line equation.

Borehole No.	Method	Distance to P.T. bore in ft.	Q in cusecs	T in ft^2 per sec	S	Graph No.
4a	TC	10	1.7	2890 3.6×10^{-1}	2.9×10^{-2}	65-341
4b	TC	20	1.7	2170 2.7×10^{-1}	5.6×10^{-2}	65-341
4e	TC	40	1.7	2010 2.5×10^{-1}	8.3×10^{-5}	65-343
4a	ME	40	1.7	2330 2.9×10^{-1}	1.83×10^{-2}	65-872
PT. 4	ME		1.7	2890 3.6×10^{-1}	2.28×10^{-2}	65-872
5c	TC	40	0.64	1850 2.3×10^{-1}	2.8×10^{-3}	65-875
5b	TC	20	0.64	1370 1.7×10^{-1}	4.08×10^{-4}	65-873
PT. 5+	ME		0.64	1280 1.6×10^{-1}	1.9×10^{-2}	65-874
5c	ME	40	0.64	1850 2.3×10^{-1}	2.7×10^{-2}	65-874
7c	TC	80	1.9	1820 2.27×10^{-1}	2.8×10^{-2}	65-46
7b	TC	40	1.9	2010 2.5×10^{-1}	3.2×10^{-2}	65-45
7a	TC	20	1.9	2250 2.8×10^{-1}	3.6×10^{-2}	65-44
7c 1st test	ME	80	1.9	2440 3.04×10^{-1}	1.96×10^{-2}	65-345
PT.7 1st test	ME		1.9	2440 3.04×10^{-1}		65-345
7c 2nd test	ME	80	1.9	2440 3.04×10^{-1}	1.22×10^{-2}	65-346
PT.7 2nd test	ME		1.9	2440 3.04×10^{-1}		65-346

The drawdown data, used to prepare the graphs and to calculate the values for T and S, are given in the tables 1 to 14 as they are difficult to read from the graphs. It should be noted the adjusted drawdowns are given also. The raw field data cannot be used in the non leaky artesian aquifer equations.

There is a very close realtionship between the values of the coefficients obtained. The low value for S calculated from observation borehole 4e may be due to the fact that this is the only observation hole which was drilled down gradient of bore PT. 4. It is considered that some of the observation bores were drilled in more cavernous cemented aeolianites.

Bore PT. 5 must have been drilled in an area where there are probably no caverns as its total yield is very low. However the coefficient of transmissibility and storage capacities calculated from the observation holes are similar to those of the good yielding boreholes. It must be borne in mind that the aquifer is only 11 ft. thick in PT. 5.

It appears therefore that the aquifer is almost homogeneous.

The well loss is an important factor which influences the drawdown close to a well pumped hence it is unfortunate that smaller drawdowns were expected and therefore the observation boreholes drilled too close to the main boreholes.

Data given in Tables 1 to 14 is the field drawdown. It should be noted that the adjusted drawdown are given also. The raw field data cannot be used in the non leaky artesian aquifer equations.

2.6 HYDRAULIC CONDUCTIVITY P AND FLOW VELOCITY 'V'

Values for T obtained in the previous paragraphs are to be used to calculate the coefficient of Permeability also called Hydraulic Conductivity. It is the quotient of the coefficient of transmissibility divided by the aquifer thickness. The hydraulic conductivity is used to arrive at a velocity flow in Darcy's law.

$v = P \times i$ in which

v is the velocity in feet per time unit

P is the hydraulic conductivity

i is the hydraulic gradient

Maps S4436 show that the fall in piezometric surface is 50 feet over a 5 mile interval. Hence the gradient 'i' in round figures is

$$50/5{,}000_{\wedge}^{\times 500} = 1/500 \approx 2. \times 10^{-3}$$

With the use of the values for T obtained earlier, calculations are made for the field permeability coefficient and the velocity of flow and they are tabulated below

P.T. No.	T in ft^2/sec.	Aquifer Thickness m in ft.	P in ft/sec	V in ft/sec
4	0.36	22.	1.6×10^{-2}	3.2×10^{-5}
4_a	0.36	23.5	1.6×10^{-2}	3.2×10^{-5}
4_b	0.27	25.5	1.08×10^{-2}	2.2×10^{-5}
4_e	0.25	21.0	1.2×10^{-2}	2.4×10^{-5}
5	0.16	11.0	1.5×10^{-2}	3.0×10^{-5}
5_c	0.23	18.	1.3×10^{-2}	2.6×10^{-5}
7	0.30	15.5	1.9×10^{-2}	3.8×10^{-5}
7_a	0.28	16.5	1.7×10^{-2}	3.4×10^{-5}
7b	0.25	17.0	1.5×10^{-2}	3×10^{-5}
7_c	0.23	19.	1.6 c 10^{-2}	3.2×10^{-5}

Flow velocity values and the coefficients of permeability are well suited to compare the pump-test results.

Although the agreement is good in columns for P and 'v' the velocity values are considered very high. This is best shown if the quantity of rain required to supply this flow is calculated. To do this the average value of flow velocity which is in the order of 3×10^{-5} ft/sec. should be converted to feet per day which is

$$3 \times 10^{-5} \times 8.64 \times 10^{4} = 2.6 \text{ ft. per day.}$$

The average thickness is thought to be 18 ft. so that the quantity of water flowing through an area of the aquifer of 1 foot wide would be

$$2.6 \times 18 \times 1 = 47 \text{ ft}^3/\text{day}$$

This volume of water flowing through this area should be equal to the rain falling on a surface area of one foot wide and 5 miles long as the rainfall is the only means of recharge of the aquifer. The surface area is in round figures.

$$5 \times 5{,}000 = 25 \times 10^3 \text{ ft.}^2$$

Hence the volume of flow of 47 ft^3/ day equals

$$47/25 \times 10^{-3} = 1.9 \times 10^{-3} \text{ ft. of rain per day.}$$

This converted to inches per year results in

$$1.9 \times 12 \times 365 \times 10^{-3} = 8.8 \text{ inches}$$

It was pointed out under the heading 'Hydrologic Cycle', 1.5, that the effective rainfall is in the order of 9 inches per year. The above calculations suggest that all this rain should reach the aquifer and that no water is lost be evaporation or evapotranspiration and this is considered to be unreasonable. It is therefore believed that the values of P and its dependent 'v' are about a factor 10 too high. Pump-tests done in 1929 and 1963 gave similar results and they were obtained by means of the Dupuit-Thiem equation. There is only one good explanation for this anomaly. Due to the pumping the gradient of the piezometric surface is increased considerably and hence the large value of P and V. However the rainfall is too low to supplement the quantity withdrawn hence the area will be overpumped if large quantities of water are withdrawn over a long period of time.

3.1 TIME AND DISTANCE DRAWDOWN GRAPHS

This type of graph is used to predict at any time the anticipated drawdown at any distance from a borehole being pumped at a rate Q. For each pumping rate a separate graph is to be constructed. Therefore graphs were prepared, No. 65-335, 65-336, 65-415 and 65-414 for the P.T. No. 4 and No. 7 for the rates 1 cusec and ½ cusec. To construct Time and Distance Drawdown Curves, the values of T and S obtained from pump-tests must be substituted in the Theis equations which in FPS units are

$$u = \frac{r^2 S}{4Tt}$$

and

$$s = \frac{Q}{4\pi T} W(u)$$

The relation between u and W(u), the well function of u, are obtained from the tables prepared by Wenzel (1942). Time 't' and the distance 'r' are variables which together with the constant pumping rate Q and the known values of T and S are substituted in these equations. Thence a value results for the drawdown s. An example will show clearly the procedure of the construction of a Time and Distance Drawdown graph. The adopted values for T and S, obtained from P.T. No. 7 are

$$T = 2.25 \times 10^{-1} \text{ ft}^2 \text{ per second}$$

$$S = 2.8 \times 10^{-2}$$

if

$$Q = 1 \text{ cusec}$$

$$r = 10 \text{ ft. distance from P.T. No. 7}$$

$$t = 0.1 \text{ day or } 8.64 \times 10^3 \text{ sec. since pumping started}$$

and these values substituted in the equation for u results in

$$u = \frac{10^2 \times 2.8 \times 10^{-2}}{4 \times 2.25 \times 10^{-1} \times 8.64 \times 10^3} = 3.6 \times 10^4$$

For this value of u a value of W(u) = 7.35 is found in Wenzels table hence

$$s = \frac{1}{4 \times 2.25 \times 10^{-1}} \times 7.35 = 2.3 \text{ ft.}$$

If the distance and pumping rate are kept constant but the time is changed to 1 day = 8.64×10^4 sec. s becomes

$s = 3.42$ ft. and

for a time $t = 10$ days or 8.64×10^5 sec.

$s = 4.28$ ft.

For convenience the values of s obtained are tabulated below.

Pumping rate Q in cusecs	Distance r in ft.	Time t in days	Drawdown s in feet
1	10	0.1	2.3
1	10	1	3.42
1	10	10	4.28

Values of s are plotted against log t and a straight line is obtained as shown on graph 65-335 by the line YX and marked $r = 10$ ft. Note that the values of log t are shown on the base of the graph. This line is extrapolated beyond the time of 10 days and the drawdown at 10 ft. from the pumping well can be read off this curve for as much as 1,000 days.

In order to construct the distance drawdown graph the value for the distance r is varied while the time is kept constant.

For a value of $r = 10$ and $t = 0.1$ day the solution of s is as above.

If r is taken 50 ft. the calculated value of

$s = 1.47$ ft. and for $r = 100$ ft.

s becomes 0.98 feet.

These values of s are again given in the table below.

Pumping rate Q in cusecs	Distance r in feet	Time t in days	Drawdown s in ft.
1	10	0.1	2.3
1	50	0.1	1.47
1	100	0.1	0.98

These values of s are plotted against the log of r as shown on graph 65-335 by line YZ and marked $t = 0.1$ day. Note that log r is shown on the top of the graph. The drawdown at any distance from the pumped well can be read off this curve for as much as 3,000 feet.

H.G. May 1963 developed a method by which time drawdowns and distance drawdowns can be obtained for any time and any distance with the aid of an index curve that is related to the initial curves.

The relation between the distance from the well and time since pumping started can be expressed as

$$r = 10^n t$$

in which n is an integer.

The vertical distance between the time drawdown curve and the index curve should be n times the distance measured along the same vertical line, between the distance drawdown curve and this index curve. Consequently the index line Y O is drawn through points that divide the vertical lines bounded by the two curves Y Z and Y X into segments whose length are in the ratio 2 to 1.

An example will assist the reader in the use of the graph. All lines parallel to the time drawdown graph Y X would indicate the drawdown at any time at different distances from the borehole.

A broken line as shown on graph 65-335 parallel to this line Y X intersects the index line on the vertical line $r = 10^2$. It is therefore the time drawdown curve for 100 ft. from the well. At this distance after one days pumping the anticipated drawdown is o.2 ft. after 10 days it is 1.1 ft. and after 100 days it is 1.85 ft. The conversion graph at the left of the Time and Distance Drawdown curves indicates that the anticipated drawdown in the field would be 1.95 ft. instead of 1.85 ft. Similarly a dashed line is drawn parallel to the distance drawdown curve Y Z. It intersects the index line and on the vertical line to 12.5 days. It is therefore the distance drawdown curve after twelve and one half days of pumping. The anticipated drawdown at 10 ft. from the borehole is 4.2 ft. and 100 ft. away from the bore hole it is 2.78 ft. the conversion graph to the left indicates that the anticipated drawdown in the field would be 3.1 instead of 2.78 ft.

Graph 65-336 is the P.T. 7 Time and Distance Drawdown graph for a pumping rate of Q = 0.5 cusecs. On this the anticipated drawdowns for as little as 1/100 of a day can be obtained. For convenience the time drawdown and distance drawdown curves are marked with the same capital letters as was done on graph 65-335.

The basic data from which this graph was prepared are tabled below:

Pumping Rate Q in cusecs	Distance r in ft.	Time t in days	Drawdown 's in ft.
$\frac{1}{2}$	10	0.01	0.92
$\frac{1}{2}$	10	0.1	1.32
$\frac{1}{2}$	10	1	1.74
$\frac{1}{2}$	50	0.1	0.78
$\frac{1}{2}$	100	0.1	0.62

The same type of graphs were prepared for P.T. 4, they are graph No. 65-415 for the pumping rate of 1 cusec and 65-414 for a pumping rate of $\frac{1}{2}$ cusec.

Basic data from which they are prepared are

$$T = 3.6 \times 10^{-1} \text{ ft}^2/\text{sec.}$$

$$S = 2.9 \times 10^{-2}$$

The values calculated with the coefficients are tabled below:

Pumping rate Q in cusec	Distance r in ft.	Time t in days	Drawdown 's in ft.
1	10	10	2.74
1	10	1	2.24
1	10	0.1	1.25
1	50	0.2	1.05
1	100	0.1	0.76
$\frac{1}{2}$	10	10	1.46
$\frac{1}{2}$	10	1	1.15
$\frac{1}{2}$	10	C.1	0.84
$\frac{1}{2}$	50	0.1	0.47
$\frac{1}{2}$	100	0.1	0.30

It will be noticed on the graphs that the anticipated drawdowns for P.T. 4 are less than those of P.T. 7. The explanation is found in the different values for coefficients of transmissibility and storage capacity used in both cases. It should be borne in mind that the anticipated drawdown which can be produced from these graphs are estimations. They are dependent on the validity of the equations used for the calculations of T and S.

Since the distance between these boreholes P.T. 4 and P.T. 7 is 8,310 feet, the distance drawdown curves of the graphs indicates that if P.T. 7 is pumped at a rate of 1 cusec the cone of drawdown will reach a point midway between P.T. 7 and P.T. 4 12.5 days after pumping starts. The dashed line on graph 65-335 indicates this situation. Similarly if P.T. 4 is pumped at a rate of 1 cusec the cone of drawdown will reach the same point midway between P.T. 7 and P.T. 4 after 5 days. Obviously if the pumping rates were increased to1.5 cusecs or to those used while testing the boreholes this point 4,650 ft. away from both bores will be reached after a shorter time of pumping. To elucidate this matter the Time Drawdown curve for P.T. 7 graph 65-337, was prepared. The anticipated drawdown increasing with time are shown for pumping rates o.5 cusec, 1 cusec and 1.9 cusecs. The curve for 1.9 cusecs shows clearly that the P.T. 7 would be depleted in a short period of time if it was pumped at the high rate of 1.9 cusecs. The specific capacity curves prepared for P.T. 7, graph 65-338, discloses the same characteristics as the quantity of water obtainable per foot of drawdown ,specific yield, decreases rapidly with the increase in pumping rate.

It was mentioned under the heading Piezometric Surface 1.6, that boundary conditions were not observed during the pump-test on P.T. 7. The Time and Distance Drawdown graph for 1 cusec, 65-335, indicates that after less than 0.1 day pumping the cone of drawdown would reach a point 250 feet away from

P.T. 7. If there is a boundary then the rate of drawdown should have doubled in the first hour of pumping as pumping rate was not one but 1.9 cusecs. This is also indicated on the Time Drawdown curve, 65-337. A rapid increase in the rate of drawdown is not recorded during the test.

The occurrence of boundary conditions are not supported by the coefficients of permeability calculated, 2.6. It should not have been reached by the cone of drawdown during the single rate test on P.T. 4. Hence a large difference between the P's calculated for the two P.T. bores 4 and 7 should have resulted if it occurs.

3.2 SAFE PUMPING RATES FOR P.T. 4 and P.T. 7

It was shown in the previous paragraphs that the point midway between P.T. 4 and P.T. 7 would be reached after some 12 days if P.T. 7 is pumped at a rate of 1 cusec. If both bores are being pumped at the same time at this rate mutual interference will occur after approximately 4 days. In that time a large area above the cone of drawdown will have been depleted. An even larger volume of aquifer will be drained by pumping continuously. To date it is not known whether an area depleted during the pumping season would be capable of restoring, by means of recharge, to its full capacity after pumping has ceased. Aquifer collapse may occur when all water is drained from it. Since the groundwater is stored mainly in cemented aeolianites the danger of collapse is probably not very great. Return to the static water level after pumping season, as measured in the past on the observation boreholes, does not necessarily mean that no aquifer collapse has occurred.

Groundwater used in the financial years 1963-64 and 1964-65 are respectively 3.2×10^7 cubic feet (200 mill galls.) and 2.7×10^7 cubic feet (164 mill galls.) It is considered likely that in the future the demand will increase. It is therefore assumed that both bores will be pumped at a rate of 1 cusec for 200 days continuously. The groundwater withdrawn in a pumping season would then be.

$$2 \times 200 \times 8.64 \times 10^4 = 3.44 \times 10^7 \text{ cubic feet.}$$

Since the average thickness of the aquifer is 18 feet and the Polda Basin covers about 50 square miles, the volume of the aquifer is estimated to be $50 \times 18 \times (5.28 \times 10^3)^2 = 2.51 \times 10^{10}$ cubic feet. Assuming that the porosity of 30% is a reliable approximation the volume of the water stored would then be

$$2.51 \times 10^{10} \times 0.3 = 7.5 \times 10^9 \text{ cubic feet.}$$

Average rainfall between May and September is about 10 inches. If it is assumed that 1/20 of the rainfall is available for recharge while the remainder is taken up by evaporation and evapotranspiration, the total quantity of water recharging the aquifer would be

$$1/20 \times \frac{10}{12} \times 50 \times 2.8 \times 10^7 = 5.8 \times 10^7$$

If this assumption is correct then there appears to be an excess of yearly recharge over demand equal to

$$5.8 \times 10^7 - 3.44 \times 10^7 = 2.4 \times 10^7 \text{ cubic feet.}$$

This quantity of water would reach the natural outlets to the westward. It appears therefore that the volume of annual recharge is large enough to supply the demand without drawing on the much larger volume of stored water.

The volume of groundwater which can be withdrawn from P.T. 4 and P.T. 7, if they are used only, is restricted by the flow of water towards these. If the demand increases above the estimated quantity new bores should be drilled well away from the present sites.

It will be noted that the yield of P.T. 5 has not been mentioned. This bore lies well within the area which will be affected by the cone of drawdown of the two P.T. bores 4 and 7. As the mutual interference will increase considerably whenever this bore is pumped and since the yield of P.T. 5 is not very great it is considered that it should be used as a standby only. It should be pumped only in case mechanical difficulties arise on one of the other two P.T. boreholes.

It is interesting to calculate the entry velocity under heavy pumping conditions. After 100 days pumping at a rate of 1 cusec the specific capacity of P.T. 7, see graph 65-338, is

0.165 cusecs per foot

the surface area of P.T. 7 is

$3.58 \times 1/\pi = 11.2$ ft. per foot height.

Groundwater enters through 30% of the area being

$3/10 \times 11.2$ ft. $= 34$ ft.^{2} in view of the porosity adopted.

Hence the entry velocity of the groundwater is

$0.165/3.4 = 0.05$ ft. per sec.

This low entry velocity is due to the large diameter of the borehole. It avoids the breakdown of the aquifer.

There is however another factor which needs careful consideration. Seepage or leakage of saline water may occur from the swamp which lies about 1 mile west of P.T. 4. De Wiest (1965) decribes an equation with which the cone of drawdown can be calculated for a two or more well system in an unconfined aquifer. In this equation an arbitrary distance is chosen away from the supply borehole and this will be reached by the cone of drawdown whenever steady state is obtained. This is an ideal condition as it is considered that in the Polda Basin steady state will not be reached as long as groundwaters are withdrawn from it. It is assumed however that steady state will be obtained when the cone of drawdown reaches the saline swamp so that the arbitrary radius of the cone of drawdown is 5,280 feet.

The equation to be used for the calculation is

$$h^2 = \frac{1}{2\,\Pi P} \left(Q_1 \times 2.31 \log (r_1 + r_2) + Q_2 \times 2.3 \log (r_1 - r_2)\right) + D.$$

in which

h = the saturated thickness of the aquifer in feet.

P = the hydraulic conductivity in ft/sec.

Q_1 and Q_2 = pumping rate of each borehole in cusecs.

r_1 = any distance from the point midway between the bore holes in feet.

r_2 = distance from the boreholes to the point midway between them in feet.

D = a constant.

An average value of 1.6×10^{-2} ft/sec. is adopted for the hydraulic conductivity, see 2.6. The point midway between the two P.T. bores 4 and 7 is 4,650 feet, and the average thickness, m, of the aquifer is 18 feet.

Where the cone of drawdown reaches its limit, steady static conditions, there is no drawdown so that $h = m = 18$ feet. In this supposition the cone of drawdown would reach 5,280 feet away from P.T. No. 4 being the distance to the saline swamps so that $r_1 = 5{,}280$ feet.

It is assumed that a simultaneous discharge of one cusec is sustained in both boreholes and these and other known values substituted in the equation results in

$$18^2 = \frac{1}{2\,\Pi \times 1.6^{-2}} \times 2.3\,(\log\,(5280 + 4650)^2 + \log\,(5280 - 4650)^2 + D \text{ or}$$

$$D = 324 - 23(\log 98 \times 10^6 + \log 3.96 \times 10^5)$$

$$D = 324 - 23 \times 13.6$$

$$D = 324 - 312 = 12 \text{ ft.}^2$$

With the value of D known the saturated thickness oan be calculated at the point midway between the two P.T. boreholes.

In that case r_1 becomes 0 and r_2 remains 4,650 feet. The value of P and Q are not changed so that the known values substituted in the equation results in

$$h^2 = 23\,(\log 4650^2 + \log - 4650^2) + 12$$

$$= 23\,(\log 21.6 \times 10^6 + \log 21.6 \times 10^6) + 12$$

$$= 23 \times 2 \times 7.3 - 12 \text{ ft.}^2$$

$$= 336 + 12 = 348 \text{ ft.}^2$$

so that h = 18.6 feet.

Therefore there would not be any drawdown at this point. The Time and Distance Drawdown graphs for 1 cusec.,65-335, and 65-414, for P.T. No. 7 and No. 4 indicate that if each one is pumped separately this point midway between the boreholes will be reached after 12.5 days and 5 days respectively. Therefore the assumption is incorrect that the cone of drawdown will not reach the boundary of the saline swamp but reach beyond it. Hence seepage of saline water into the aquifer may occur. A slight increase may be noticed in the groundwater salinity during the pumping season.

4.1 MULTIPLE STAGE OR STEP DRAWDOWN TEST

A complete analysis of this type of test made on P.T. 4 Serial No. 030365 will be discussed hereunder.

Multiple stage tests are done to calculate the aquifer loss and the well loss by either mathematical or graphical means. Jacob (1947) considers that in a pumped borehole, the total drawdown 'sw' is equal to $BQ + CQ^2$ in which BQ is the aquifer loss and CQ^2 the well loss. B and C are both constant and Q is the pumping rate in cusecs. Rorabaugh (1953) developed a slightly different equation and points out that the power of Q in CQ is not 2 but a slightly higher or lower figure. He suggested therefore the use of the equation $sw = BQ + CQ^n$. In addition he points out that part of the losses occurring in the pumped well are due to turbulent flow, which would decrease with an increase in hole size.

To assess separately the well loss and the aquifer loss a borehole could be pumped at different rates and the drawdown sw taken after a fixed time interval provided that the well was in a static condition prior to each step, i.e. the water level had fully recovered. However, to save time in the field, the well is not allowed to recover between stages.

Jacobs method requires that the incremental drawdown due to the increase in pumping rates be calculated and therefore the drawdown data must be adjusted except for those of the first stage.

In a multiple stage test the procedure is that the well is first pumped at a low rate Q_1 cusecs. After some reasonable time the rate is increased to Q_2 cusecs. The pumping rate is increased to Q_3 cusecs after a further time interval preferably equal to that used for the first stage. Further stages may be performed.

The table below gives the relevant values for the multiple test on P.T. 4, Serial No. 030365

Stage	Average Q in gall/hr.	Q in cusecs.	t time after start in minutes from	to
1	10.388	0.46	0	150
2	19.300	0.86	150	300
3	32.196	1.43	300	450
4	44.100	1.96	450	600

4.2 MATHEMATICAL APPROACH

First Stage

Drawdowns measured in the pumping well, and obtained during this stage, plotted against log t (time in minutes) should give points through which a straight line should be drawn. If the pumping rate is not constant then the points on the graph may be slightly scattered and the line to be drawn should represent the best mathematical fit. A best visual fit is used here.

The two causes of drawdown are assumed to be additive and for a moderately large time can be approximated by the function

$$s_1(t) = Q_1\ (a + b \log t) + CQ^2 \text{ or}$$
$$= Q_1\ (a + b \log t) + CQ^n \text{ in which}$$

$s_1(t)$ = the drawdown at time t.

Q_1 = the first pumping rate in cusecs.

'a' is a constant.

'b' is also a constant which can be calculated from the drawdown per log cycle.

'C' is a constant.

CQ^2 or CQ^n is the well loss.

Q_1 the pumping rate of the first stage in P.T. 4 was 0.46 cusecs and therefore T the transmissibility could be calculated. To do so Jacob's modified non steady state formula is used. However the unknowns 'a' and 'C' cannot be obtained from one step only. It should be noted that for all different times t the drawdown s_1 can be read directly from the curve (straight line) of the graph 65-864 indicated by $F_1(t)$. This notation is used as it will be convenient later.

The drawdown data for the first steps are given in Table I 1.

The equation of the straight line of $s_1(t)$ against log t is

$$F_1(t) = Q\ (a + b \log t) + CQ_1{}^2 \text{ or}$$
$$= aQ + bQ \log t + CQ^2{}_1 \text{ or } \dots\ \dots\ CQ_1{}^n$$

It can be seen on graph 65-761 that at $t = 10$ minutes the drawdown s is 1.25 feet. This is composed of the drawdown at log 1 minute = 1.00 ft. plus

delta s per log cycle of = 0.25 ft.

Therefore at 10 minutes

$$F_1(t) = 1.25 + 0.25 \log t - 0.25$$

Equating constant and time dependent terms in the two equations for $F_1(t)$ results in

$bQ_1 \log t = 0.25 \log t$ and

$aQ_1 + CQ_1^2 = 1.25 - 0.25 = 1$

as $\log 10 = 1$ and $Q_1 = 0.46$

$bQ_1 \log t = bQ_1 = 0.25$ and

$b = 0.25/0.46 = 0.49$

It gives also an expression for a and C

$aQ_1 + CQ_1^2 = 0.46 + 0.46^2 C = 1$ or

$2.18 = a + 0.46C.$

<u>Second Stage</u>

At a time t_1, in this case after 150 minutes, the pumping rate is increased to 0.86 cusecs. It is considered that at this time a second pump joins the original and is working at a rate of $0.86 - 0.46 = 0.40$ cusecs.

Immediately after the increment of pumping rate the drawdown will increase rapidly but at a sufficiently large time $t_2 > t_1$ the drawdown is again changing slowly. The well loss becomes immediately CQ_2^2 or CQ_2^n. The new expression for the drawdown is

$$s_2(t) = (Q_2 - Q_1 (a + b \log (t-t_1)) + CQ_2^2$$
$$+ Q_1 (a + b \log t)$$

In the Rorabaugh method the expression for the drawdown is the same except for the well loss which is CQ_2^n.

The incremental drawdown (s_2-s_1) is obtained by subtracting from the drawdown measured in the second stage the drawdown which would have occurred if the first pump had continued working.

Equations to be used to plot the drawdown versus the log of time are

$$s_2(t) = (Q_2 - Q_1)(a + b \log (t-t_1)) + CQ_2^{\,2}$$
$$+ Q_1 (a + b \log t) \quad \text{and}$$
$$s_1(t) = Q_1 (a + b \log t) + CQ_1^{\,2}$$

Subtraction results in

$$s_2(t) - s_1(t) = Q_2 - Q_1)(a + b \log (t-t_1)) + C(Q_2^{\,2} - Q_1^{\,2})$$

The plot of the incremental drawdown $F_2(t-t_1)$ is given as a function of $\log (t-t_1)$.

Table I 2 gives the incremental drawdowns. It should be noted that the values of $F_1(t)$ are read from the extrapolated curve.

Substituting the values obtained from $F_2(t-t_1)$ graph 65-864, at a time $(t-t_1) = 10$ minutes obtained is $F_2(t-t_1) = 1.55$ ft. $- 0.31 \log (t-t_1)$ which must be identical with

$$F_2(t-t_1) = a(Q_2 - Q_1) + b(Q_2 - Q_1) \log (t-t_1)$$
$$+ C(Q_2^{\,2} - Q_1^{\,2})$$

$(Q_2 - Q_1)\, b \log (t-t_1)$ is the term dependent on t hence

$$(Q_2 - Q_1)\, b \log (t-t_1) = 0.31 \log (t-t_1)$$

As $Q_2 - Q_1$ equals 0.40

$$0.40\, b \log (t-t_1) = 0.31 \log (t-t_1) \qquad \text{or}$$
$$0.40\, b = 0.31$$
$$b = 0.77$$

There is no good agreement between the calculations of 'b' from the first and second stages.

Obtained also from the function of $F_2(t-t_1)$

$$1.55 - 0.31 = a\,(Q_2 - Q_1) + C(Q_2^{\,2} - Q_1^{\,2}) \qquad \text{or}$$
$$1.24 = 0.40\, a + (0.739 - 0.271)C$$
$$3.01 = a + 1.30C$$

$2.18 = a + 0.46C$ was obtained from the First Stage, and subtraction gives

$$0.83 = 0.84\, C \qquad \text{or}$$
$$C = 1.00\ \text{ft}^2/\text{sec}^5$$

Third stage

300 minutes after the start of the pumping the rate Q was increased to 1.43 cusecs. It is assumed that a third pump joins the other two and is working at a rate Q_3-Q_2 or 1.43 - 0.86 = 0.57 cusecs. The drawdown will increase rapidly at first but at a sufficiently large time t, the drawdown will change slowly again. The well loss becomes immediately CQ_3^2 or CQ_3^n.

The new expression for the drawdown is now

$$\begin{aligned} s_3(t) &= (Q_3 - Q_2)(a + b \log (t-t_2)) + CQ_3^2, \text{ or } CQ_3^n \\ &+ (Q_2 - Q_1)(a + b \log (t-t_1)) \\ &+ Q_1 (a + b \log t) \end{aligned}$$

The plot of incremental drawdown indicated by the function

$s_3(t) - (s_2(t-t_2) + s_1(t) = F_3(t-t_2)$ is a function of t.

The incremental drawdown is obtained by subtracting from the field drawdowns of the third stage the sum of the drawdowns at the times t which would have occurred if the first pump had continued working, and the drawdowns at the times $(t-t_2)$ which would have occurred if the second pump had continued working. The equations to be used to plot the drawdown versus log time are

$$\begin{aligned} s_3(t) &= (Q_3 - Q_2)(a + b \log (t-t_2)) + CQ_3^2 \\ &+ (Q_2 - Q_1)(a + b \log (t-t_1)) \\ &+ Q_1 (a + b \log t) \qquad \text{and} \end{aligned}$$

$$\begin{aligned} s_2(t) &= (Q_2 - Q_1)(a + b \log (t-t_1)) + CQ_2^2 \\ &+ Q_1(a + b \log t) \end{aligned}$$

Subtraction gives

$$\begin{aligned} s_3(t) = s_2(t) = F_3(t-t_2) &= (Q_3 - Q_2)(a + b \log (t-t_2)) \\ &+ CQ_3^2 - CQ_2^2 \end{aligned}$$

The value for $F_3(t-t_2)$ are given in Table 1 3.

The best visual fit of the straight line of $F_3(t-t_2)$, as shown on graph 65-864, is given as a function of $\log (t-t_2)$. Substituting the value obtained from the graph into the equation at time $(t-t_2)$ = 10 minutes results in

$$\begin{aligned} F_3 (t-t_2) &= 2.58 + 0.40 \text{ lot } (t-t_2) - 0.40 \\ &= 2.18 + 0.40 \log (t-t_2) \text{ being identical with} \end{aligned}$$

$$(Q_2 - Q_2)(a + b \log (t-t_2)) + C(Q_3^2 - Q_2^2)$$

$(Q_3 - Q_2)(b \log (t-t_2))$ is the only term dependent on log time therefore

$$2.18 = (Q_3 - Q_2)\ a + (Q_3^{\ 2} - Q_2^{\ 2})C$$

$$2.18 = 0.57\ a + (2.04 - 0.739)C$$

$$2.18 = 0.57\ a + 1.30\ C \qquad \text{gives}$$

$$3.82 = a + 2.28\ C$$

$3.01\ a + 1.30\ C$ was obtained from stage 1.

Subtraction gives

$$0.81 = 0.98\ C$$

so that $C = 0.81/_{0.98} = 0.81\ ft^2/sec^5$

The value of 'b' from the first stage is considered lower than those of the second and third stages. This low value cannot be readily explained. It is however just possible that the aquifer was less severely drained in this stage. The values of C obtained from the two calculations agree well. $C = 0.90\ ft^2/sec^5$ is considered a good approximation. These two values for 'C' and 'b' will be used later to resolve an equation for any pumping rate.

<u>Fourth Stage</u>

The pumping rate was increased to 1.96 cusecs 450 minutes after the start of the pump. Once again it is assumed that a new pump is added to those already working and the new expression for the drawdown is now

$$\begin{aligned} s_4(t) = {} & (Q_4 - Q_3)(a + b \log (t-t_3))\ CQ_4^{\ 2} \\ & (Q_3 - Q_2)(a + b \log (t-t_2)) \\ & (Q_2 - Q_1)(a + b \log (t-t_1)) \\ & Q_1\ (a + b \log t) \end{aligned}$$

For calculating the incremental drawdown the same procedure, as used previously is followed. The values of the incremental drawdown are given in Table I 4 and the function as plotted on graph 65-864 is marked $F_4(t-t_3)$

Using this fourth step for a check on the calculations made above results in a low value of 'b' and a very low value of 'C'. It is considered that therefore this stage can not be used for further calculations. Walton (1962) suggested that a low value for C indicates development of the borehole. This can not be the case at it was tested at this high rate at an earlier date and development should have occurred then.

4.3 CALCULATION OF 'a' and THE EQUATION FOR sw

Since the constants 'C' and 'b' are know, 'a' can also be calculated. In stage two a function for 'a' and 'C' was obtained being

$$2.18 = a + 0.46\ C \qquad \text{or}$$

$$2.18 = a + 0.77 \times 0.74 \qquad \text{so that}$$

$$2.18 = a + 0.46$$

$$a = 2.18 - 1.46 = 0.72$$

As the values of 'a', 'b' and C are known the drawdown at any time for any pumping rate can be calculated as

$sw = Q(a + b \log t) + CQ^2$ substituting the known values gives $sw = Q(0.72 + 0.74 \log t) + 0.90\ Q^2$

If the drawdown is calculated for a fixed pumping rate Q_x at three different times the functions of $F_x(t)$ against log t will give a straight line from which the delta s can be read. The drawdown can the be calculated for any time.

4.4 METHOD TO CALCULATE ANTICIPATED DRAWDOWN FOR A DRAWDWON LOG t CURVE FOR ANY PUMPING RATE

If between pumping at different rates the borehole is left idle and the water returned to the static condition then a true drawdown log t curve can be drawn from water levels obtained during the pumping periods. However the sytem as generally used is time saving in the field.

J.S. Colville (1965) believed to be the first to give a full account, developed a method by which the true drawdown log t curve can be obtained by using the incremental drawdown curves.

The mathematic procedure is more complicated. It is convenient to recast the observed data so that an anticipated drawdown is obtained which would have occurred if the pumping had been done on a single rate from the static level of the aquifer. Suppose that such data were available then for some convenient and constant time t_e the equations would be

$$\bar{s}_1\ t_e = Q_1(a + b \log t) + CQ_1{}^n$$
$$\bar{s}_2\ t_e = Q_2(a + b \log t) + CQ_2{}^n$$
$$\bar{s}_3\ t_e = Q_3(a + b \log t) + CQ_3{}^n$$
$$\bar{s}_4\ t_e = Q_4(a + b \log t) + CQ_4{}^n$$

in which $\bar{s}_1$, $\bar{s}_2$, $\bar{s}_3$ and $\bar{s}_4$ are the anticipated drawdowns which would occur if the bore was pumped at single rates Q_1, Q_2, Q_3 and Q_4.

This set of equations must be solved by repeated trial for $(a + b \log t_e)$, 'C' and 'n'. It should be noted that '**a**', 'b' and 'C' are already known.

The problem is to find a method of calculating the artificial drawdown $\bar{s}_1(t)$, $\bar{s}_2(t)$ etc. The first value presents no difficulty as the borehole was pumped at a rate of Q_1 from static level.

Field drawdown data, Table I 1 of this stage without further adjustment, can be plotted against log t as was done previously for the calculations of the incremental drawdown graphs. It is therefore identical to the $F_1(t)$ curve. Itc is shown on graph 65-866 and indicated as Q_1. The delta s per log cycle which can be read from the graph can be used to predict the drawdown in the pumped well at any time. The method to be used is the same as explained under 2.3 Cooper and Jacob Method.

For the second stage the equation for the incremental drawdown is

$$s_2(t) - s_1(t) = (Q_2 - Q_1)(a + b \log (t-t_1)) + CQ_2^n - CQ_1^n$$

To calculate the expression for Q_2 all terms involving Q_1 must be removed. These terms are identical to those in

$$s_1(t-t_1) = Q_1(a + b \log (t-t_1)) + CQ_1^2$$

addition of these two equations results in

$$s_2(t) - s_1(t) + s_1(t-t_1) = Q_2(a + b \log (t-t_1)) + CQ_2^n$$

which is of the right form but is given in terms of $(t-t_1)$ instead of t. Changing the argument gives

$$s_2(t-t_1) - s_1(t-t_1) + s_1(t) = Q_2(a + b \log t) + CQ_2^n \equiv \bar{s}_2(t)$$

Hence the required equation is obtained $\bar{s}_2(t)$ can be calculated from the incremental graphs $F_1(t) + F_2(t)$ as

$$\bar{s}_2(t) = F_1(t) + F_2(t) = Q_2(a + b \log t) + CQ_2^n$$

i.e. the anticipated drawdown which would have occurred if the borehole had been pumped at a single rate Q_2 from static level. It is shown as the line Q_2 on graph 65-866.

The expression for a third stage can also be developed from the equation of the incremental drawdown of the third stage by systematic elimination of the terms of Q_2 and thereafter of Q_1.

This results in

$$s_3(t) - s_2(t) + s_2(t+t-t_2) - s_1(t-t-t_2) + s_1(t-t_2) =$$
$$Q_3(a + b \log t-t_3) + CQ_3^n$$

This again is an equation of the right form but involves the terms $(t-t_2)$ instead of (t). The argument can be changed again resulting in

$$\bar{s}_3(t) = s_3(t-t_2) + s_2(t-t_2) + s_2(t+t_1) - s_1(t+t_1) + s_1(t)$$
$$= Q_3(a + b \log t) + CQ_3^n$$
$$\equiv F_3(t) + F_2(t) + F_1(t) \text{ or } F_3(t) + \bar{s}_2 t$$

This is the equation required to obtain the anticipated drawdown if the borehole had been pumped at a single rate Q_3 from the static water level. It is shown as the line Q_3 on graph 65-866.

For a fourth stage the equation is

$$\bar{s}_4(t) = F_4(t) + F_3(t) + F_2(t) + F_1(t) \text{ or } F_4(t) + \bar{s}_3(t).$$

It is now possible to read from the straight line incremental drawdown plots, graph 65-864 immediately, what the drawdown should be at a time t_e. For example if the borehole was pumped at a rate Q_3 = 1.43 cusecs at atime t_e = 100 minutes the drawdown should be (see graph 65-864 and Table G 1.)

$$\bar{s}_3(100) = 1.50 + 1.85 + 3.00 = 6.35 \text{ ft.}$$

Two values for the rate Q_3 are sufficient to draw the anticipation drawdown curve, a third one is required for a check. In Table G 1 drawdowns at 10 minute intervals are given for the four stages of P.T. 4 and they are plotted on graph 65-866. Each drawdown curve is marked with its relevant pumping rate.

4.5 CALCULATION OF ANTICIPATED DRAWDOWNS FOR A DRAWDOWN LOG t CURVE WITHOUT USING THE INCREMENTAL DRAWDOWN CURVES

In this method the first stage again presents no difficulty.

For the second, third and fourth stages a little more tabulation of drawdowns or expected drawdown is required than in the method discussed above.

The equation

$$\bar{s}\ (t-t_1) = s_2(t) - s_1(t) + s_1(t-t_1)$$
$$= Q_2\ )a + b \log t-t_1) + CQ_2{}^n$$

was developed for the previous method, 4.3. With this equation it is possible to compute the drawdown expected had the borehole been pumped only at a rate Q_2.

The drawdown $\bar{s}_2$ is obtained by subtracting from the drawdown of the field data of the second stage the sum of the drawdown at times (t) and $(t-t_1)$ which would have occurred if the first pump had continued working. This sum is always negative.

Calculations for $\bar{s}_2$ are given in Table G 2. In column 1 are tabulated time t after $t_1 = 150$ minutes. In the second column are tabulated the drawdown of the first stage which is anticipated at times t. In the third column are tabulated the drawdowns of the first stage which occur at times $(t-t_1)$, (t-150 min.) Subtractions of the values of column 3 from those of column 2 are given in column 4. These values are adjustments to be made to the values of the field data of stage 2 given in column 5. The values of the anticipated drawdowns are tabulated in column 6 which would occur if the borehole is pumped only at a rate of Q_2 from static water level. Times $(t-t_1)$ values plotted against those of $\bar{s}_2$ should lie on a straight line. Small deviationsof this straight line occur as shown on graph 65-865, due to slight differences in pumping rates and possibly inaccurcy of reading the tapes. It should be kept in mind that the differences occurring are generally less than 0.05 of a foot. The delta s per log cycle can be used again to predict the water level at any time. An example will show the method clearly. At

100 minutes the drawdown level is 1.42 ft. as read from the line Q_2 graph 65-865.

At 10^4 minutes being equal to 7 days the drawdowns would be

$$s = 1.42 \text{ ft.} + 2 \times \text{delta } s \text{ or}$$
$$= 1.42 \text{ ft.} + 2 \times 0.73 \text{ ft.} = 2.88 \text{ ft.}$$

Having constructed the curve for the second stage which would occur if the borehole was pumped from the static water level it should be used to construct a similar one for the pumping rate of Q_3. The equation to be used is almost identical to that of the second stage being

$$\bar{s}_3(t-t_2) = Q_3(a + b \log (t-t_2)) + CQ_3^{\,2}$$
$$= \bar{s}_3(t) - \bar{s}_2(t-t_1) + \bar{s}_2(t-t_2)$$

The calculation for $\bar{s}_3$ is made in Table G 3. The columns used are similar to those of the second stage in Table G 2, and hence need no further explanation.

$\bar{s}_3$ plotted against the log $(t-t_2)$ again gives points through which the straight line should be drawn shown as Q_3 on graph 65-865. Delta s per log cycle can be used again for the prediction of drawdowns which would occur at any time.

For the last stage the procedure is the same again and therefore will not be further discussed. The anticipated drawdowns are tabulated in Table G 4.

Comments on the Calculations of the Anticipated Drawdown Curves

An equation was developed for the drawdown at any time for any pumping rate with the mathematical method discussed earlier. It was pointed out that the calculations for the fourth stage was not in agreement with those of the first three stages, therefore it is considered that the anticipated drawdown curve for the fourth stage as developed in the preceding paragraphs should be used with caution.

4.6 GRAPHICAL METHODS OF COMPUTING B AND C

Hundred minutes drawdown levels for the different pumping rate Q_1, Q_2, and Q_3 are read from graph 65-866 and divided by their successive pumping rates as shown in the table below. The fourth stage is not used as it is suspect and it may effect the results.

Stage	Q	sw_{100}	sw_{100}/Q
1	0.46	1.50	3.26
2	0.86	3.35	3.90
3	1.43	6.36	4.40

In Jacob's method the specific drawdown sw/Q is plotted against the pumping rates Q on arithmetic paper. A line is drawn through the points so obtained representing the best visual fit as shown on graph S4390. The intercept of this line with the abscissa is the value of B in this case B = 2.8. The slope of the line is the value of C being 1.16 $ft.^2/sec^5$.

In the final form $sw_{100} = BQ + CQ^2$ becomes therefore

$$sw_{100} = 2.8\ Q + 1.16\ Q^2$$

The 100 minute drawdown which would occur at any pumping rate can be computed with this equation.

As mentioned before Rorabaugh brings a third unknown 'n' into his equation.

$sw = BQ + CQ^n$ In order to solve it the log of the specific drawdown sw/Q minus B is plotted against the log of the pumping rates. Values of B must be assumed and the solution of equation is obtained when a value of B is found that produces a straight line. C is obtained from the intercept with the vertical line through Q = 1 as $C = \frac{sw}{Q} - B$. The slope of the line equals (n - 1) which produces a solution for n. Graph 65-42 illustrates the methods.

The values for B, C and n are respectively 0.9, 3.12 and 1.7 as illustrated on graph 65-42.

In the final form the equation becomes

$$sw_{100} = 0.9Q + 3.12\ Q^{1.7}$$

In the table hereunder the solution obtained with the Jacob method is set out against that of the Rorabaugh method.

Stage	Jacob			Rorabaugh for B = 0.9			
	BQ	CQ^2	sw_{100}	BQ	CQ^n	sw_{100}	sw_{100} anticipated
1	1.29	0.25	1.54	0.44	0.84	1.26	1.50
2	2.40	0.86	3.26	0.77	2.39	3.16	3.35
3	4.00	2.36	6.36	1.29	5.71	7.00	6.36

This table is shown also graphically on the graphs S4391 and 65-41.

Illustrated in the table is that both methods give almost similar results. However with the Jacob method better results are obtained than that of Rorabaugh's.

The drawdown anticipated after 100 minutes pumping can be read from graph S4391 for any given pumping rate and in addition the expected well loss evaluated.

Previously it was indicated that the two causes of drawdown can be approximated by the function $s_1(t) = Q_1(a + b \log t) + CQ^2$, it could also be written as

$$sw = Q(a + b \log t) + CQ^2$$

this is identical with $sw = B\,Q + CQ^2$.

It is therefore evident that the factor B is time dependent as $Q(a + b \log t) \doteq BQ$.

Substituting the value for B = 2.8 of the Jacob method and bear in mind that this value is obtained for a time t = 100 results in

$$2.8\ Q = (a + b \log 100)\ Q$$

b log t is the only term dependent on time therefore,

$$Q\ b \log 100 = \text{delta s per log cycle.}$$

delta s per log cycle for the second stage = 0.98

and $Q = 0.84$ cusecs hence

$$0.84 \times b \times 2 = 0.98 \qquad \text{or}$$

$$b = \frac{0.98}{1.68} = 0.58$$

This value of b substituted in the equation for BQ results in

$$2.8\ Q = (a + 0.58 \times 2)\ Q \qquad \text{or}$$

$$2.8 = 2 + 1.6 \qquad \text{so that}$$

$$a = 1.64$$

The values of a ,b and C are now known therefore in this final form the equation for

$$sw = BQ + CQ^2 = Q(a + b \log t) + CQ^2 \qquad \text{becomes}$$

$$= Q\ (1.64 + 0.58 \log t) + 1.16\ Q^2$$

With this equation can be calculated any drawdown for any given pumping rate.

4.7 MULTIPLE STAGE TEST ON P.T. 7 and P.T. 5

This type of test was made on both of these bores. Results obtained however are not encouraging. Calculations made on the first two stages of P.T. 7 appear to be in good agreement with the theory.

The incremental drawdown log time curves of this test are shown on graph 65-761 and the relevant drawdown data are given in Tables I 5 to I 8.

Calculations made to arrive at values of the aquifer loss and well loss are given below (see curve $F_1(t)$ graph 65-761).

At 10 minutes s = 1.02 ft.

delta s/log cycle = 0.37 ft. therefore

$$s_1(t) = 1.02 + 0.37 \log t - 0.37$$

$$\equiv (a + b \log t)\, Q + CQ^2$$

Equating the constant and time dependent terms in the two equations we have

$bQ_1 \log t = 0.37 \log t$ and

$aQ + CQ^2 = 1.02 - 0.37$ or

as t = 10 minutes log t = 1

and Q = 0.77 cusecs. These values substituted results in

$$0.77 \times b = 0.37$$

$$b = 0.37/_{0.77} = 0.48$$

and also

$a \times 0.77 + 0.77^2 C = 0.65$ or

$$a + 0.77C = 0.65/_{0.77} = 0.84$$

The 10 minute incremental drawdown of curve $F_2(t-t_1)$ graph 65-761 = 0.92 ft.

Delta s per log cycle = 0.20 ft.

so that $F_2(t-t_1) = 0.93 + 0.20 \log (t-t_1) - 0.20$

$$= (Q_2 - Q_1)(a + b \log (t-t_1)) - C(Q_2{}^2 - Q_1{}^2)$$

$$Q_2 = 1.23$$

$$Q_1 = 0.77$$

These values substituted and equating the time dependent and constant terms results in

(Q_2-Q_1) b log $(t-t_1)$ = 0.20 log $(t-t_1)$

(Q_2-Q_1) a + C$(Q_2^2-Q_1^2)$ = 0.96 - 0.20 = 0.73 and

further development results in

$$(1.23 - 0.77)\ b = 0.20$$

$$b = 0.20/_{0.46} = 0.40 \quad \text{and}$$

$$(1.23 - 0.77)\ a + C(1.52 - 0.59) = 0.73 \quad \text{or}$$

$$0.46\ a + 0.93\ C = 0.73 \quad \text{or}$$

$$a + 2.02C = 1.6$$

from stage one is obtained

$$\frac{a + 0.77C = 0.84}{1.25C = 0.76} \text{ - subtraction gives}$$

$$C = 0.76/1.25 = 0.61\ \text{ft.}^2/\text{sec } 5.$$

Since 'C' and 'b' are known 'a' can be calculated from second stage

$$a + 2.02C = 1.6 \quad \text{or}$$

$$a + 2.02 \times 0.61 = 1.6$$

$$a = 1.6 - 2.02 \times 0.61 = 4.35$$

In the final form the equation for drawdown becomes now

$$sw = (0.35 + 0.4 \log t)\ Q + 0.61\ Q^2$$

Calculations made by using curve $F_3(t-t_3)$ results in a value of b = 1 which is much too high and a value of C = 0.03 ft^2/sec 5 which is much too low. This third stage therefore cannot be used for further calculation.

On graph 65-43 are drawn a curve of drawdown versus log t for the pumping rates Q_1 indicated as Q_1 and the anticipated curve for Q_2, indicated as Q_2,as would have resulted if the bore P.T. 7 was pumped at a rate of Q_2 from the static level. This curve was drawn with the values for $\bar{s}_2$ obtained from Table G 5. The drawdown curve for a rate Q = 1.9 cusecs obtained from the single rate test made on 22nd February 1965, is also drawn on this graph and indicated by Q_s.

An attempt was made to solve the equation for well loss and aquifer loss by means of the modified Jacob method as shown on graph S4518.

The values for B and C from this graph are B = 0.96 and $C = 0.52\ ft^2/sec^5$.

These values substituted in the equation results in

$$sw_{100} = 0.96Q + 0.52\ Q^2$$

The values of C and B are consideravly different from those obtained from the mathematical method. It is considered that the results obtained with the mathematical procedure are more reliable.

The drawdown data obtained from the first of the multiple stage on P.T. 5 are very erratic and it appears impossible to draw a reliable drawdown curve. It is therefore considered that an attempt to obtain any value for the well loss and aquifer loss would be fruitless.

There can be only one conclusion to be drawn from the results of the multiple stage tests. This aquifer's characteristics are such that calculations of well and aquifer loss are very difficult to obtain. It is questionable whether further attempts should be made to arrive at values for these factors.

Walton's suggestion that lower or higher values for C from the multiple stage test indicate development or collapse of the aquifer would not apply. Single stage test of 7 day duration were conducted prior to the multiple stage test and full development of the aquifer should have occurred then.

5.1 CONCLUSIONS

A drain of free water table aquifer is not altogether suited for the calculations of the aquifer characteristics. The values of T and S are approximations only largely due to the fact that the equations used are based upon infinite and homogeneous artesian aquifers. Good agreement is obtained however for the hydraulic conductivities 'P' calculated from the test results of the three P.T. bores Nos. 4, 5, and 7.

Discouraging is the anomalous high flow velocity of 3×10^{-5} ft/sec. which suggest depletion of the aquifer under heavy pumping conditions.

Annual effective rainfall is considered low compared with the rain required to sustain the calculated flow velocity.

It is estimated that 7.5×10^{9} cubic feet or 172,000 acre feet of water is stored in Polda Basin.

The boundary suggested by the steep gradient of the piezometric surface south of P.T. No. 7 have not been recorded during the 7 day single rate pumping test. No good reason for this is apparent.

It is considered that cemented aeolianite forming the Polda Basin aquifer is not suited for multiple stage test.

The single rate pump-tests done so far indicate that a large but shallow cone of drawdown will be established under heavy pumping conditions. Individual bores should be spaced at least at one and one half mile intervals but where practical the distance between boreholes should be greater, preferably 2 miles.

Large supplies of 1.9 - 2 cusecs are obtainable from the 43 inch diameter boreholes for a short period of time. An average pumping rate of one cusec is recommended for a prolonged pumping period.

The low entry velocity of 0.05 ft. per sec. of the groundwater into the 43 inch diameter boreholes is an advantage as it avoids the breakdown of the aquifer.

5.2 ACKNOWLEDGMENTS

Mr. J.S. Colville of the C.S.I.R.O. Division of Soils has been very helpful in explaining some aspects of well hydraulics. He wrote special notes on the Theory of Multiple Stage Test which will also be of great value to other officers of the Hydrogeology Section. His patience with the writer is appreciated very much. The suggestions and assistance from Mr. J.W. Holmes, also of the Division of Soils, C.S.I.R.O., is acknowledged. The writer is grateful for willing help from many of his colleagues and friends on the staff of the Engineering and Water Supply and the Mines Department, and also for the patience of the departmental typistes.

C. BLEYS
Senior Geologist
Hydrogeology Section

17th September, 1965

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Time t in minutes after start	R.W.L.	Drawdown in feet	Adjusted draw-down in feet
16.0	219.48	3.41	2.88
15.0	219.51	3.38	2.86
14.0	219.53	3.36	2.85
13.0	219.56	3.33	2.83
12.0	219.60	3.29	2.80
11.0	219.63	3.26	2.78
10.0	219.67	3.22	2.75
9.5	219.69	3.20	2.74
9.0	219.72	3.17	2.71
8.5	219.75	3.14	2.69
8.0	219.77	3.12	2.68
7.5	219.81	3.08	2.65
7.0	219.84	3.05	2.63
6.5	219.87	3.02	2.61
6.0	219.92	2.97	2.57
5.5	219.96	2.93	2.54
5.0	220.02	2.87	2.50
4.5	220.09	2.80	2.44
4.0	220.17	2.72	2.38
3.5	220.29	2.60	2.22
3.0	220.42	2.47	2.19
2.5	220.63	2.26	2.03
2.0	220.84	2.05	1.86
1.5	221.21	1.68	1.55
1.0	221.66	1.23	1.16
0.5	222.30	0.59	.57
	222.89		

Pump started on 22.2.65 at 13.00 hr.

SURVEY: Polda Basin

LOCATION: Polda

SECTION: 19 HUNDRED: Squire

WELL OWNER: Department of Mines

PUMP SETTING: R.L.

AQUIFER THICKNESS: m 11ft.

TABLE 10

Pump stopped on 23.2.65 at 12.0

ELEVATION: 244.35 ft.

MILITARY SHEET: Kappawanta

AERIAL PHOTO: Run 1, No. 12

PUMPING RATE, Q, 0.64 cusecs

SERIAL NO. 220265

WELL NO. PT 5

Ttime t in minutes after start	R.W.L.	Drawdown in feet	Adjusted draw-down in feet
160.0	217.47	4.42	3.53
150.0	217.54	4.35	3.49
140.0	217.59	4.30	3.46
130.0	217.69	4.20	3.40
120.0	2.7.87	4.02	3.29
110.0	218.92	3.97	3.25
100.0	218.94	3.95	3.24
95.0	218.96	3.93	3.23
90.0	218.96	3.93	3.23
85.0	218.98	3.91	3.22
80.0	218.98	3.91	3.22
75.0	218.98	3.91	3.22
70.0	218.99	3.90	3.21
65.0	219.00	3.89	3.20
60.0	219.03	3.86	3.18
55.0	219.06	3.83	3.16
50.0	219.07	3.82	3.16
45.0	219.08	3.81	3.15
40.0	219.13	3.76	3.12
35.0	219.18	3.71	3.08
30.0	219.20	3169	3.07
29.0	219.20	3.69	3.07
28.0	219.21	3.68	3.06
27.0	219.21	3.68	3.06
26.0	219.22	3.67	3.06
25.0	219.24	3.65	3.04
24.0	219.26	3.63	3.03
23.0	219.28	3.61	3.02
22.0	219.31	3.58	3.00
21.0	219.33	3.56	2.98
20.0	219.36	3.53	2.96
19.0	219.39	3.50	2.94
18.0	219.42	3.47	2.92
17.0	219.45	3.44	2.90

P.T.5

TABLE 10

Serial No. 220265

Continuation Sheet No. 1

Time t in minutes after start	R.W.L.	Drawdown in feet	Adjusted drawdown in feet
4380	215.52	7.37	4.90
4000	215.11	7.78	5.02
3500	215.63	7.26	4.86
3000	215.17	7.72	5.01
2500	215.51	7.38	4.90
2000	215.89	7.00	4.77
1900	215.63	7.26	4.86
1800	215.71	7.18	4.84
1700	215.93	6.96	4.76
1600	215.52	7.37	4.90
1500	215.59	7.30	4.88
1400	215.59	7.30	4.88
1300	215.96	6.93	4.75
1200	216.37	6.52	4.59
1100	216.33	6.56	4.60
1000	216.49	6.40	4.54
950	216.58	6.31	4.50
900	216.50	6.39	4.53
850.0	216.53	6.36	4.52
800.0	216.57	6.32	4.50
750.0	216.61	6.28	4.49
700.0	216.68	6.21	4.46
650.0	216.83	6.06	4.39
600.0	216.83	6.06	4.39
550.0	216.98	4.91	3.81
500.0	217.02	4.87	3.79
450.0	216.93	4.96	3.84
400.0	217.03	4.86	3.79
350.0	217.08	4.81	3.76
300.0	217.07	4.82	3.76
250.0	217.18	4.71	3.70
200.0	217.28	4.61	3.64
190.0			
180.0	217.34	4.55	3.61
170.0	217.43	4.46	3.56

PT5

Serial No. 220265

TABLE 10

Continuation Sheet No. 2

S460

TABLE I 1

P.T. 4 Serial 030365

Time t in minutes	Drawdown s in ft.
1	0.75
5	1.15
10	1.23
15	1.29
20	1.33
25	1.35
30	1.37
40	1.38
50	1.43
60	1.45
70	1.48
80	1.50
90	1.50
100	1.52
120	1.53
140	1.54
150	1.56

TABLE I 2

Calculation of the incremental drawdown $s_2 - s_1$

t	$s_2(t)$	$F_1(t)$	(s_2-s_1)	$(t-t_1)$
151	2.82	1.55	1.27	1
155	2.93	1.55	1.38	5
160	3.07	1.56	1.51	10
165	3.14	1.56	1.58	15
170	3.19	1.57	1.62	20
175	3.23	1.57	1.66	25
180	3.26	1.57	1.69	30
185	3.29	1.57	1.72	35
190	3.31	1.58	1.73	40
195	3.32	1.58	1.74	45
200	3.35	1.58	1.77	50
210	3.38	1.59	1.79	60
220	3.41	1.59	1.82	70
230	3.49	1.60	1.89	80
240	3.46	1.60	1.86	90
250	3.49	1.61	1.88	100
280	3.53	1.62	1.91	130
300	3.54	1.63	1.91	150
1	2	3	4	5

Values of column 3 subtracted from those of column 2 give the values of s_2-s_1 in column 4.

The values of column 4 are plotted against log $(t-t_1)$ of column 5 and result in $F_2(t-t_1)$

TABLE I 3

Calculation for the incremental drawdown s_3-s_2

t	$F_1(t)$	$(t-t_1)$	$F_2(t-t_1)$	Adjustment	$s_3(t)$	s_3-s_2	$t-t_2$
301	1.63	151	1.91	3.54	4.80	1.26	1
305	1.63	155	1.91	3.54	5.93	1.47	5
310	1.63	160	1.92	3.54	6.12	2.58	10
315	1.63	165	1.92	3.56	6.22	2.66	15
320	1.64	170	1.93	3.57	6.29	2.72	20
325	1.64	175	1.93	3.57	6.34	2.77	25
330	1.64	180	1.93	3.57	6.38	2.81	30
335	1.64	185	1.94	3.58	6.41	2.83	35
340	1.64	190	1.94	3.58	6.43	2.85	40
345	1.65	195	1.95	3.60	6.46	2.86	45
350	1.65	200	1.95	3.60	6.48	2.88	50
360	1.65	210	1.95	3.60	6.53	2.93	60
370	1.65	220	1.96	3.61	6.42	2.81	70
380	1.65	230	1.96	3.61	6.41	2.80	80
390	1.65	240	1.97	3.62	6.44	2.82	90
400	1.66	250	1.97	3.63	6.46	2.83	100
410	1.66	260	1.98	3.64	6.47	2.83	110
420	1.66	270	1.98	3.64	6.49	2.85	120
430	1.66	280	1.98	3.64	6.54	2.90	130
440	1.67	290	1.99	3.66	6.57	2.91	140
450	1.67	300	2.00	3.67	6.62	2.95	150
1	2	3	4	5	6	7	8

Addition of the value of columns 2 + 4 gives those of column 5.

Values of column 6 minus those of column 5 gives value for s_3-s_2 in column 7.

The values of column 7 are plotted against the log of $(t-t_2)$ of column 8 and result in $F_3(t-t_2)$.

P.T.4 Serial 030365

TABLE I 4

t	$F_1(t)$	$(t-t_1)$	$F_2(t-t_1)$	$(t-t_2)$	$F_3(t-t_2)$	Adjustment	$s_4(t)$	s_4-s_3	$t-t_3$
451	1.67	301	2.04	151	3.08	6.79	7.74	0.95	1
455	1.67	305	2.04	155	3.09	6.80	8.60	1.80	5
460	1.67	310	2.05	160	3.09	6.81	8.85	2.04	10
465	1.67	315	2.05	165	3.10	6.82	8.95	2.13	15
470	1.67	320	2.05	170	3.10	6.82	9.00	2.18	20
475	1.67	325	2.05	175	3.11	6.83	9.04	2.21	25
480	1.68	330	2.05	180	3.12	6.85	9.08	2.23	30
485	1.68	335	2.06	185	3.12	6.86	9.11	2.25	35
490	1.68	340	2.06	190	3.12	6.86	9.15	2.29	40
495	1.68	345	2.06	195	3.13	6.87	9.18	2.31	45
500	1.68	350	2.07	200	3.13	6.88	9.19	2.31	50
510	1.68	360	2.07	210	3.14	6.89	9.22	2.33	60
520	1.69	370	2.07	220	3.15	6.91	9.27	2.36	70
530	1.69	380	2.08	230	3.16	6.93	9.31	2.38	80
540	1.69	390	2.08	240	3.17	6.94	9.35	2.41	90
550	1.70	400	2.09	250	3.18	6.97	9.38	2.41	100
560	1.70	410	2.09	260	3.18	6.97	9.40	2.43	110
570	1.70	420	2.10	270	3.19	6.99	9.43	2.44	120
580	1.70	430	2.10	280	3.20	7.00	9.47	2.47	130
590	1.70	440	2.10	290	3.20	7.00	9.49	2.49	140
600	1.70	450	2.11	300	3.21	7.02	9.50	2.48	150
1	2	3	4	5	6	7	8	9	10

Addition of the value of columns 2 + 4 + 6 gives the value of column 7.

Value of column 8 minus that of column 7 gives values for s_4-s_3 in column 9.

The values of column 9 are plotted against log of $(t-t_3)$ of column 10 and result in $F_4(t-t_3)$.

TABLE I 5

First stage of 60 minutes

$Q = 0.77$

Time	s in ft.
1	0.18
5	0.96
10	1.03
20	1.12
25	1.14
30	1.17
40	1.21
50	1.25
60	1.26

TABLE I 6

CALCULATIONS FOR INCREMENT IN DRAWDOWN DUE TO THE INCREASE IN PUMPING RATE FROM 0.77 to 1.23 CUSECS

The first step was of 60 minute duration, the second step is of 300 minutes duration and continued to 360 minutes after the start of the pump.

t	s_2 observed	F_1	incremental $s_2 - s_1$	t in mimutes after inc. in pumping rate.
65	2.10m	1.29	0.81	5
70	2.25	1.30	0.95	10
74	2.27	1.32	0.95	14
80	2.30	1.33	0.97	20
85	2.34	1.33	1.01	25
90	2.37	1.34	1.03	30
100	2.42	1.35	1.07	40
110	2.45	1.37	1.08	50
120	2.46	1.38	1.08	60
140	2.51	1.40	1.11	80
160	2.55	1.43	1.12	100
180	2.59	1.45	1.15	120
200	2.62	1.46	1.16	140
210	2.63	1.47	1.16	150
260	2.69	1.50	1.19	200
310	2.73	1.52	1.21	250
360	2.77	1.55	1.22	300
1	2	3	4	5

Values of column 3 subtracted from those of column 2 are given in column 4. Those plotted against log t of column 5 are shown as curve $F_2(t-t_1)$ on Graph 65-761

TABLE I 7

Step 1. 60 minutes   Step 2. 360 minutes at Q 1.23 cusecs

Step 3. continued for t 720 minutes at a rate of Q 1.56

Time	F_1 Anticipated	F_2 anticipated	Adjust-ment	s_3 observed	incre-mental s_3-s_2	step 3 t - 360
370	1.55	1.23	2.78	3.47	0.69	10
380	1.55	1.24	2.79	3.55	0.76	20
390	1.56	1.24	2.80	3.52	0.72	30
400	1.56	1.24	2.80	3.51	0.71	40
410	1.57	1.25	2.82	3.51	0.69	50
420	1.57	1.25	2.82	3.54	0.72	60
430	1.57	1.25	2.82	3.59	0.77	70
440	1.58	1.25	2.83	3.59	0.76	80
450	1.58	1.25	2.83	3.62	0.79	90
460	1.58	1.26	2.84	3.65	0.81	100
480	1.59	1.26	2.85	3.67	0.82	120
510	1.60	1.26	2.86	3.73	0.87	150
560	1.62	1.27	2.89	3.80	0.91	200
610	1.63	1.28	2.91	3.88	0.97	250
660	1.64	1.30	2.94	3.89	0.95	300
710	1.65	1.30	2.95	3.93	0.98	350
1	2	3	4	5	6	7

The values of column 2 and those of column 3 are added and given in column 4. These values subtracted from those of column 5 are given in column 6. Values of column 6 plotted against log t of column 7 are shown as the curve $F_3(t-t_2)$ on Graph 65-761

TABLE G 1

For calaulations of $\bar{s}_2(t)$, $\bar{s}_3(t)$ and $\bar{s}_4(t)$

using equation

$$\bar{s}_2(t) = F_1(t) + F_2(t)$$
$$\bar{s}_3(t) = \bar{s}_2(t) + F_3(t)$$
$$\bar{s}_4(t) = \bar{s}_3(t) + F_3(t)$$

t	$F_1(t)$	$F_2(t)$	$\bar{s}_2(t)$	$F_3(t)$	$\bar{s}_3(t)$	$F_4(t)$	$\bar{s}_4(t)$
1	1.00	1.23	2.23	2.22	4.45	1.70	6.15
5	1.17	1.38	2.55	2.47	5.02	1.93	6.95
10	1.24	1.54	2.78	2.59	5.37	2.07	7.44
20	1.33	1.64	2.97	2.72	5.69	2.17	7.86
30	1.37	1.69	3.06	2.73	5.80	2.24	8.04
40	1.40	1.73	3.13	2.84	5.97	2.28	8.25
50	1.43	1.75	3.18	2.87	6.05	2.31	8.36
60	1.45	1.78	3.23	2.92	6.15	2.33	8.48
70	1.47	1.81	3.28	2.95	6.23	2.36	8.59
80	1.48	1.83	3.31	2.97	6.28	2.38	8.66
90	1.49	1.84	3.33	2.99	6.32	2.40	8.72
100	1.50	1.85	3.35	3.00	6.35	2.42	8.77
150	1.55	1.91	3.46	3.08	6.54	2.48	9.02
1	2	3	4	5	6	7	8

The addition of values of column 2 and those of column 3 result in the anticipated drawdown $\bar{s}_2(t)$ of column 4. Their values added to those of column 5 result in the anticipated drawdown $\bar{s}_3(t)$ given in column 6.

These again added to those of column 7 result in the anticipated drawdown of $\bar{s}_4(t)$ as given in the column 8.

Values of columns 4, 6 and 8 plotted against the log of t of column 1 give the anticipated drawdown log time graph.

TABLE C 2

Calculation of Drawdown $\bar{s}_2$ of the second stage using the equations

$\bar{s}_2(t-t_1) = Q_2(a + b \log (t-t_1) + CQ^2 = s_2(t) + (s_1(t-t_1) - s_1(t))$

Time	$s_1(t)$ anticipated	$s_1(t-t_1)$ or $s_1(t-150)$	Adjust-ment	$s_2(t)$	$\bar{s}_2(t-t_1)$	$(t-t_1)$
151	1.55	1.00	0.55	2.82	2.27	1
155	1.55	1.17	0.38	2.93	2.55	5
160	1.56	1.25	0.31	3.07	2.76	10
165	1.56	1.29	0.27	3.14	2.87	15
170	1.57	1.33	0.24	3.19	2.95	20
175	1.57	1.35	0.22	3.23	3.01	25
180	1.57	1.37	0.20	3.26	3.06	30
185	1.58	1.37	0.20	3.29	3.09	35
190	1.58	1.40	0.18	3.31	3.13	40
200	1.58	1.43	0.15	3.35	3.20	50
210	1.59	1.45	0.14	3.38	3.24	60
220	1.59	1.47	0.12	3.41	3.29	70
230	1.60	1.48	0.12	3.49	3.37	80
240	1.60	1.49	0.11	3.46	3.35	90
250	1.61	1.50	0.11	3.49	3.38	100
280	1.62	1.54	0.08	3.53	3.55	130
300	1.63	1.55	0.08	3.54	3.56	150
1	2	3	4	5	6	7

The values of folumn 2 minus those of column 3 are given in column 4. Values of column 5 minus those of column4 results in the $\bar{s}_2$ which plotted against log t of column 7 gives the anticipated slope of the drawdown for a pumping rate Q_2.

TABLE G3

Calculation of Drawdown $\bar{s}_3$ of the third stage using the equation

$$\bar{s}_3(t-t_2) = Q_3\ (a + b \log (t-t_2)) + CQ_3^{\ 2} = s_3(t) - (\bar{s}_2(t-t_2)) - \bar{s}_2(t-t_1))$$

Time	$\bar{s}_2(t-t_1)$ anticipated or $s_2(t-150)$	$\bar{s}_2(t-t_2)$ Or $\bar{s}_2(t-300)$	Adjustment	$s_3(t)$	$\bar{s}_3(t-t_2)$ or $\bar{s}_3(t-150)$	$(t-t_2)$ or $(t-300)$
301	3.54	1.94	1.60	4.80	3.20	1
305	3.55	2.46	1.09	5.93	4.84	5
310	3.57	2.78	0.79	6.12	5.33	10
315	3.58	2.81	0.77	6.22	5.45	15
320	3.59	2.90	0.69	6.29	5.60	20
325	3.60	2.97	0.63	6.34	5.71	25
330	3.60	3.03	0.57	6.38	5.81	30
335	3.61	3.08	0.53	6.41	5.88	35
340	3.62	3.13	0.49	6.43	5.94	40
350	3.63	3.20	0.43	6.46	6.03	50
360	3.66	3.27	0.39	6.48	6.09	60
370	3.68	3.31	0.37	6.53	6.16	70
380	3.69	3.36	0.33	6.42	6.19	80
390	3.70	3.40	0.30	6.41	6.11	90
400	3.71	3.43	0.28	6.44	6.16	100
430	3.75	3.50	0.25	6.54	6.29	130
450	3.78	3.54	0.24	6.62	6.38	150
1	2	3	4	5	6	7

The values of column 2 minus those of column 3 are given in column 4. Values of column 5 minus those of column 4 results in the $\bar{s}_3$ which plotted against the log t of column 7 gives the anticipated slope of the drawdown for a pumping rate Q_3.

TABLE G 4

Calculation of Drawdown $\bar{s}_4$ from the fourth stage using the equation

$$\bar{s}_4(t-t_3) = Q_4(a + b \log (t-t_4)) = s_4(t) - (\bar{s}_3(t-t_3) - \bar{s}_3(t-t_2))$$

Time t	$\bar{s}_3(t-t_2)$ or $\bar{s}_3(t-390)$	$\bar{s}_3(t-t_3)$ or $\bar{s}_3(t-450)$	Adjustment	$s_4(t)$	$\bar{s}_4(t-t_3)$	$t-t_3$ or $(t-450)$
451	6.44	4.46	1.98	7.74	5.76	1
455	6.45	5.10	1.35	8.60	7.25	5
460	6.46	5.38	1.08	8.85	7.78	10
465	6.47	5.52	0.95	8.95	8.00	15
470	6.48	5.66	0.82	9.00	8.18	20
475	6.49	5.74	0.75	9.04	8.29	25
480	6.50	5.81	0.69	9.08	8.39	30
485	6.62	5.87	0.65	9.11	8.46	35
490	6.53	5.92	0.59	9.15	8.56	40
500	6.56	5.99	0.57	9.19	8.62	50
510	6.57	6.08	0.49	9.22	8.73	60
520	6.59	6.13	0.46	9.27	8.81	70
530	6.61	6.19	0.42	9.31	8.89	80
540	6.63	6.24	0.39	9.35	8.96	90
550	6.65	6.28	0.37	9.38	9.01	100
580	6.69	6.38	0.29	9.47	9.18	130
600	6.72	6.44	0.28	9.50	9.22	150
1	2	3	4	5	6	7

The values of column 2 minus those of column 3 are given in column 4. Values of column 5 minus column 4 results in the $\bar{s}_4$ which plotted against the log t of column 7 gives the anticipated slope of the drawdown for a pumping rate Q_4.

P.T. 7 Serial 161164

TABLE G 5

Calculation of Drawdown $\bar{s}_2$ of the Second Stage using the equation

$Q_2 [a + b \log (t-t_1)] + CQ_2^2 = s_2(t) - s_1(t) + s_1(t-t_1) = \bar{s}_2$

Time t	s_1 anticipated	s_1 observed and anticipated at $(t-t_1)$	Adjustment	$s_2(t)$ observed	$\bar{s}_2$	$(t-t_1)$
61	1.28	0.64	0.64	1.86	1.22	1
61.5	1.28	0.71	0.57	1.96	1.39	1.5
62	1.28	0.75	0.53	2.02	1.49	2
62.5	1.28	0.78	0.53	2.05	1.52	2.5
63	1.29	0.82	0.47	2.09	1.62	3
63.5	1.29	0.84	0.45	2.10	1.65	3.5
64	1.29	0.86	0.43	2.12	1.64	4
64.5	1.29	0.87	0.42	2.14	1.72	4.5
65	1.29	0.89	0.40	2.15	1.75	5
66	1.30	0.92	0.38	2.18	1.80	6
67	1.30	0.94	0.36	2.19	1.83	7
68	1.30	0.96	0.34	2.20	1.86	8
69	1.31	0.98	0.33	2.22	1.89	9
70	1.31	1.00	0.31	2.25	1.94	10
72	1.32	1.03	0.29	2.27	1.98	12
74	1.32	1.05	0.27	2.27	2.00	14
76	1.33	1.07	0.26	2.28	2.02	16
78	1.33	1.08	0.25	2.29	2.04	18
80	1.33	1.11	0.22	2.30	2.08	20
85	1.34	1.14	0.20	2.34	2.14	25
90	1.35	1.17	0.18	2.37	2.19	30
95	1.35	1.19	0.16	2.39	2.23	35
100	1.36	1.21	0.15	2.42	2.27	40
105	1.37	1.23	0.14	2.44	2.30	45
110	1.38	1.25	0.13	2.45	2.32	50
115	1.38	1.27	0.11	2.45	2.34	55
120	1.39	1.28	0.11	2.46	2.35	60
130	1.40	1.31	0.09	2.47	2.38	70
140	1.42	1.34	0.08	2.51	2.43	80
150	1.43	1.35	0.08	2.54	2.46	90
160	1.44	1.36	0.08	2.55	2.47	100
210	1.48	1.42	0.06	2.63	2.57	150
260	1.50	1.47	0.03	2.69	2.66	200
310	1.53	1.50	0.03	2.73	2.70	250
360	1.55	1.53	0.02	2.77	2.75	300
1	2	3	4	5	6	7

Values of column 3 subtracted from those of column 2 are given in column 4. Values of column 4 subtracted from those of column 5 are given in column 6. These plotted against the values of column 7 are represented as curve Q_2 on Graph 65-43.

AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

W2429/64 WATER ANALYSIS

	Parts per Million	Assumed Composition of Salts	Parts per Million
Chloride, Cl	282	Calcium carbonate	172
Sulphate, SO_4	44	Calcium sulphate	-
Carbonate, CO_3	126	Calcium chloride	-
Nitrate, NO_3	36	Magnesium carbonate	32
Sodium, Na	158	Magnesium sulphate	55
Potassium, K	-	Magnesium chloride	82
Calcium, Ca	69	Sodium carbonate	-
Magnesium, Mg	41	Sodium sulphate	-
Silica, SiO_2	-	Sodium chloride	365
		Sodium nitrate	50
Total saline matter	·756	Potassium chloride	-

Hardness (as Calcium Carbonate)	
Total	341
Temporary	209
Permanent	132
Due to calcium	172
Due to magnesium	169

Name Polda Basin
Hundred Squire
Section 19
Bore No. PT. 5
Supply 15-18,000
Date collected 19/11/64

L. Wallace Coffer
Director

AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

W2430/64 WATER ANALYSIS

	Parts per Million	Assumed composition of Salts	Parts per Million
Chloride, Cl	183	Calcium carbonate	150
Sulphate, SO_4	40	Calcium sulphate	-
Carbonate, CO_3	137	Calcium chloride	-
Nitrate, NO_3	36	Magnesium carbonate	66
Sodium, Na	133	Magnesium sulphate	50
Potassium, K	-	Magnesium chloride	-
Calcium, Ca	60	Sodium carbonate	-
Magnesium, Mg	29	Sodium sulphate	-
Silica, SiO_3	-	Sodium chloride	302
Total saline matter	618	Sodium nitrate	50
		Potassium chloride	-

Name	Polda Basin
Hundred	Squire
Section	19
Bore No.	PT. 6
Supply	6-8,000
Date Collected	19/11/64

Hardness (as Calcium Carbonate)	
Total	269
Temporary	228
Permanent	41
Due to calcium	150
Due to magnesium	119

L. Wallace Coffer
Director

AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

W2431/64 WATER ANALYSIS

	Parts per Million	Assumed Compositin of Salts	Parts per Million
Chloride, Cl	260	Calcium carbonate	177
Sulphate, SO_4	30	Calcium sulphate	-
Carbonate, CO_3	123	Calcium chloride	-
Nitrate, NO_3	73	Magnesium carbonate	24
Sodium, Na	160	Magnesium sulphate	38
Potassium, K	-	Magnesium chloride	74
Calcium, Ca	71	Sodium carbonate	-
Magnesium, Mg	34	Sodium sulphate	-
Silica, SiO_3	-	Sodium chloride	338
		Sodium nitrate	100
Total saline matter	751	Potassium chloride	-

Name	Polda Basin	Hardness (as Calcium Carbonate)	
Hundred	Squire	Total	317
Section	19	Temporary	206
Bore No.	PT. 7	Permanent	111
Water Level	26	Due to calcium	177
Supply	43,300 g/h	Due to magnesium	140
Depth Bore	30'		
Date Collected	13/11/64	L. Wallace Coffer Director	

B

AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

W2441/64 WATER ANALYSIS

	Parts per Million	Assumed Composition of Salts	Parts per Million
Chloride, Cl	607	Calcium carbonate	222
Sulphate, SO_4	105	Calcium sulphate	-
Carbonate, CO_3	199	Calcium chloride	-
Nitrate, No_3	7	Magnesium carbonate	93
Sodium, Na	355	Magnesium sulphate	132
Potassium, K	-	Magnesium chloride	86
Calcium, Ca	89	Sodium carbonate	-
Magnesium, Mg	76	Sodium sulphate	-
Silica, SiO_3	-	Sodium chloride	895
		Sodium nitrate	10
Total saline matter	1438	Potassium chloride	-

Address	Polda Basin
Hundred	Squire
Section	19
Bore No.	P.T. 4
Water Cut	8'
Water Level	6'
Supply	38,000
Depth Bore	30'
Date Collected	16/10/64

Hardness (as Calcium Carbonate	
Total	535
Temporary	333
Permanent	202
Due to calcium	222
Due to magnesium	313

L. Wallice Coffer
Director

AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

W1392/65 WATER ANALYSIS

	Parts per Million	Assumed Composition of Salts	Parts per Million
Chloride, Cl	662	Calcium carbonate	92
Sulphate, SO_4	119	Calcium sulphate	-
Carbonate, CO_3	115	Calcium chloride	-
Nitrate, NO_3	29	Magnesium carbonate	84
Sodium, Na	389	Magnesium sulphate	149
Potassium, K	-	Magnesium chloride	106
Calcium, Ca	37	Sodium carbonate	-
Magnesium, Mg	81	Sodium sulphate	-
Silica, SiO_3	-	Sodium chloride	960
		Sodium nitrate	40
Total saline matter	1432	Potassium chloride	-

		Hardness (as Calcium Carbonate)	
Address	Polda		
Hundred	-		
Section	-		
Sample collected by	Paech	Total	426
Bore No.	PT. 5	Temporary	191
Water Level	6'8"	Permanent	235
Supply	14,000	Due to calcium	92
Depth Bore	29-6	Due to magnesium	334
Date Collected	3/3/65		

P. Dixon
Acting Director

AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

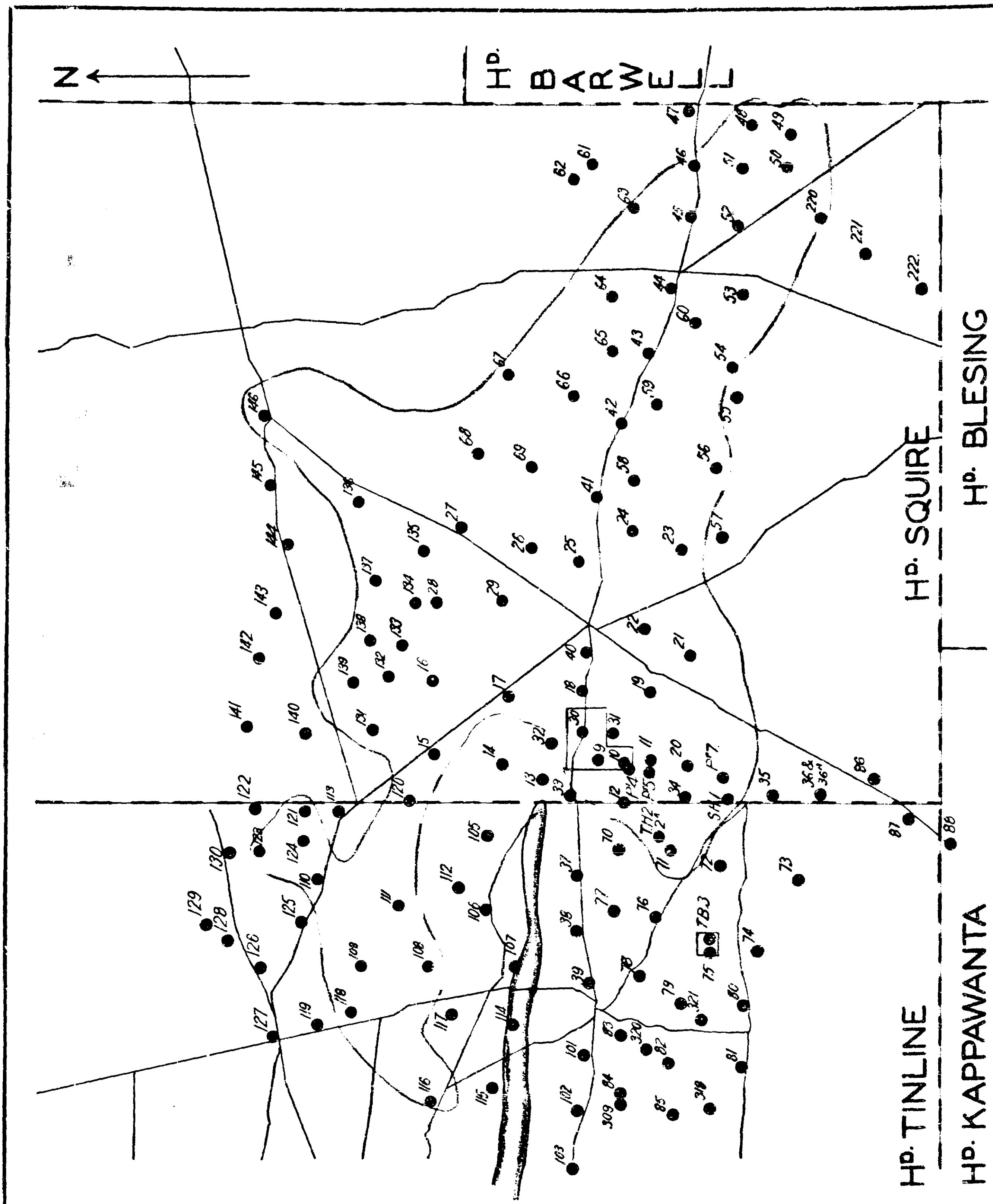
W1393/65 WATER ANALYSIS

	Parts per Million	Assumed Composition of Salts	Parts per Million
Chloride, Cl	262	Calcium carbonate	180
Sulphate, SO_4	36	Calcium sulphate	-
Carbonate, CO_3	155	Calcium chloride	-
Nitrate, NO_3	15	Magnesium carbonate	66
Sodium, Na	163	Magnesium sulphate	45
Potassium, K	-	Magnesium chloride	27
Calcium, Ca	72	Sodium carbonate	-
Magnesium, Mg	35	Sodium sulphate	-
Silica, SiO_3	-	Sodium chloride	399
		Sodium nitrate	21
Total saline matter	738	Potassium chloride	-

Name	Polda Basin
Hundred	-
Section	-
Sample Collected by	E. Wojeck
Bore No.	P.T. 7
Water Cut	-
Water Level	-
Supply	42,400
Depth Bore	29'6"
Date collected	14/2/65

Hardness (as Calcium Carbonate)	
Total	324
Temporary	258
Permanent	66
Due to calcium	180
Due to magnesium	144

P. Dixon
Asting Director



Observation bores with number •63

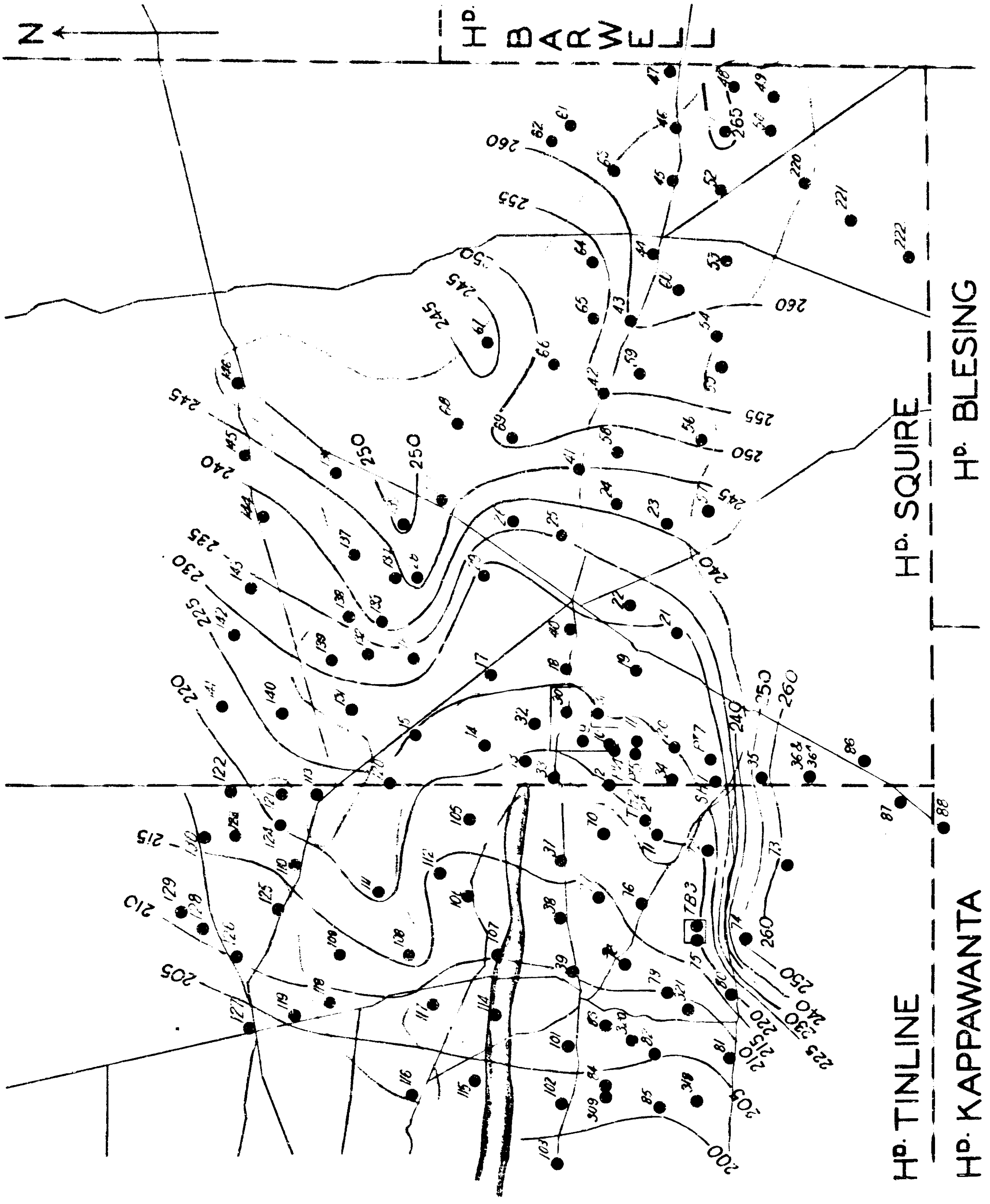
Water table contours at

Poelpena Swamp Area ....

MILE 1 ½ 0 1 2 3 MILES

S.A. DEPARTMENT OF MINES

Approved	Passed	Drn.	POLDA BASIN	D.M.	Scale 1inch:2 miles
		Tcd. E.J.W. M.R.L.	Showing	Req.	S-4436
		Ckd.	S.W.L. Contours.		DI 2/4
Director		Exd.			Date 9-7-65



Observation bores with number •63

Water table contours at 1-4-64

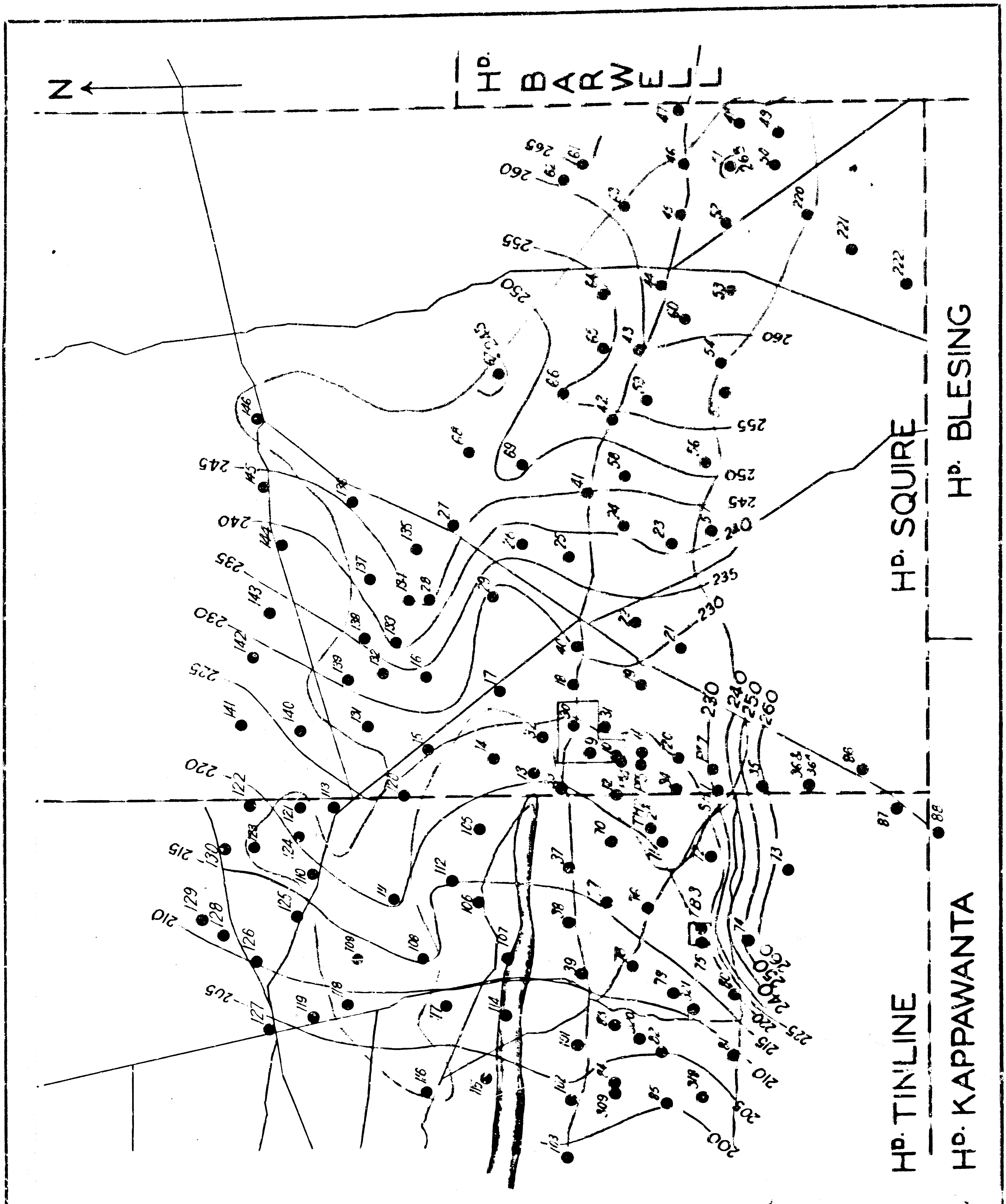
Poelpena Swamp Area ....

MILE 1 ½ 0 1 2 3 MILES

S.A. DEPARTMENT OF MINES

Approved	Passed	Drn.	POLDA BASIN	D.M.	Scale 1inch:2 miles
		Tcd. EJW MRL	Showing	Req.	S—4436a
		Ckd.	S.W.L. Contours.		DI 2/4
Director		Exd.			Date 9-7-65

400— 8.63 1423



Observation bores with number •63

Water table contours at..............3-7-64

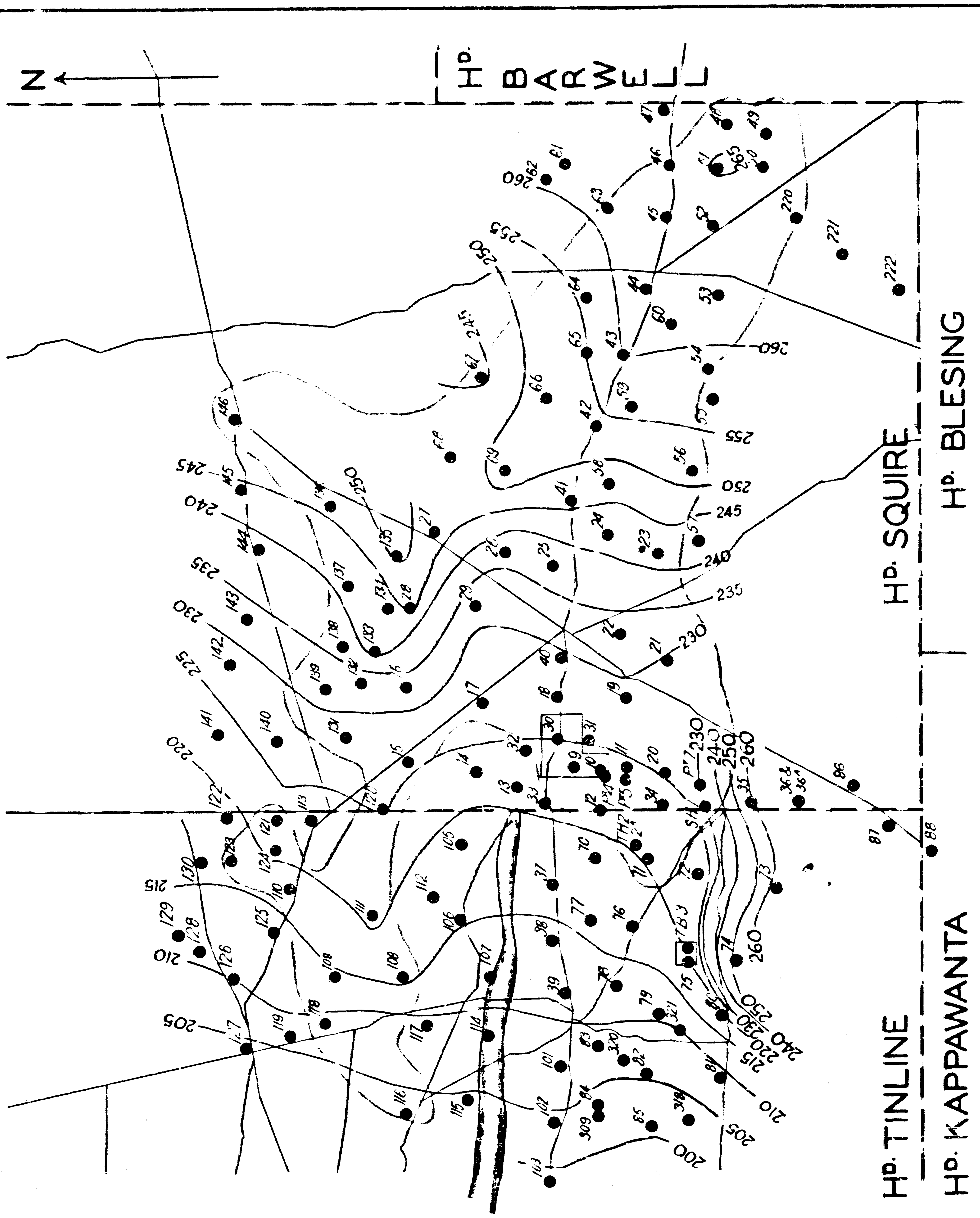
Poelpena Swamp Area ....

MILE 1 ½ 0 1 2 3 MILES

S.A. DEPARTMENT OF MINES

Approved	Passed	Drn.	POLDA BASIN	D.M.	Scale 1inch:2 miles
		Tcd. EJW / MRL	Showing	Req.	S-4436b
		Ckd.	S.W.L. Contours		DI 2/4
Director		Exd.			Date 9-7-65

400—8.63 1423



Observation bores with number •63

Water table contours at............. 1-9-64

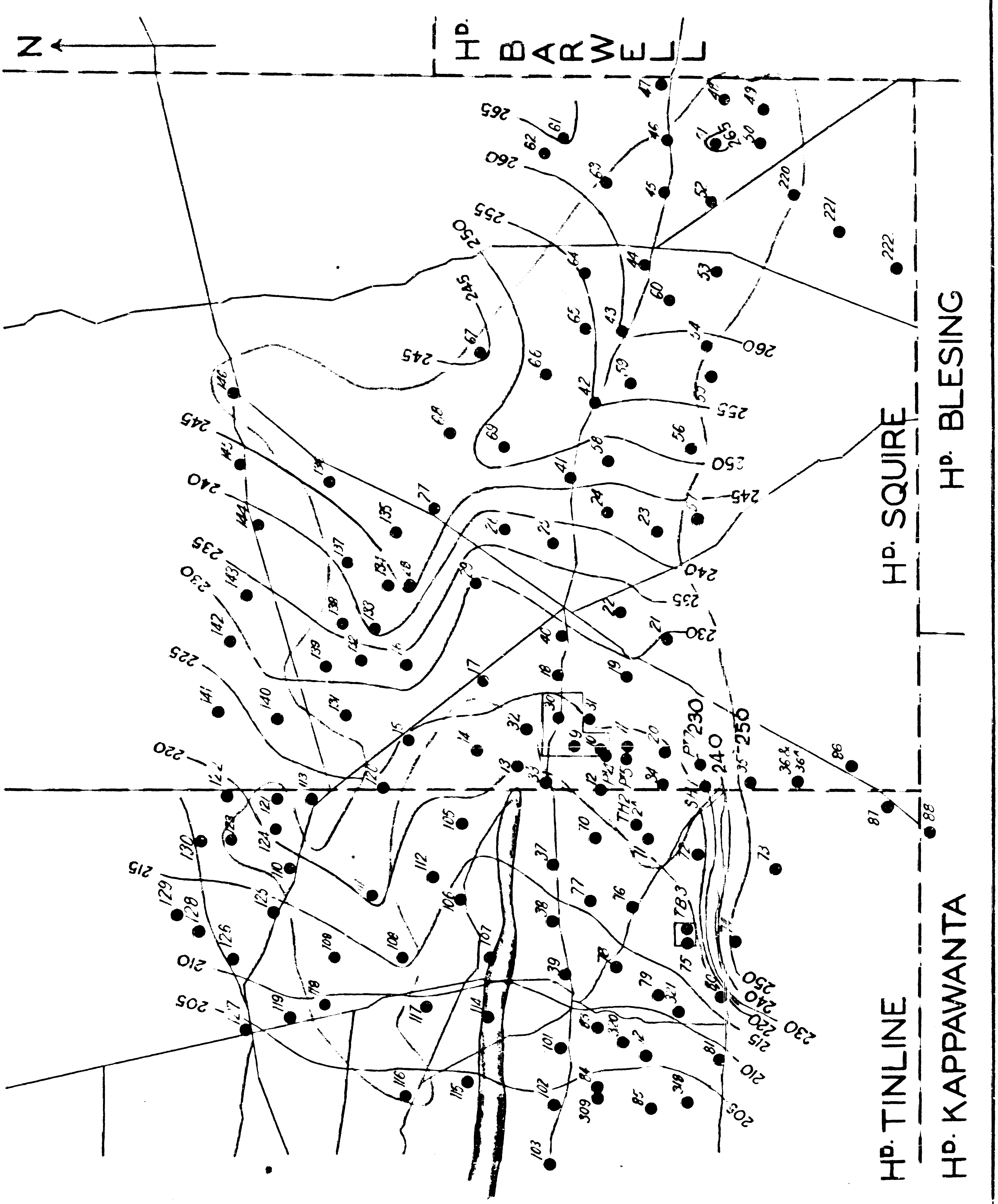
Poelpena Swamp Area ....

MILE 1 ½ 0 1 2 3 MILES

S.A. DEPARTMENT OF MINES

Approved	Passed	Drn.	POLDA BASIN	D.M.	Scale 1inch:2 miles
		Tcd. EJW MRL	Showing	Req.	S-4436c
		Ckd.	S.W.L. Contours.		DI 2/4
Director		Exd.			Date 9-7-65

400— 8.63 1423



Observation bores with number •63

Water table contours at.............15-1-65

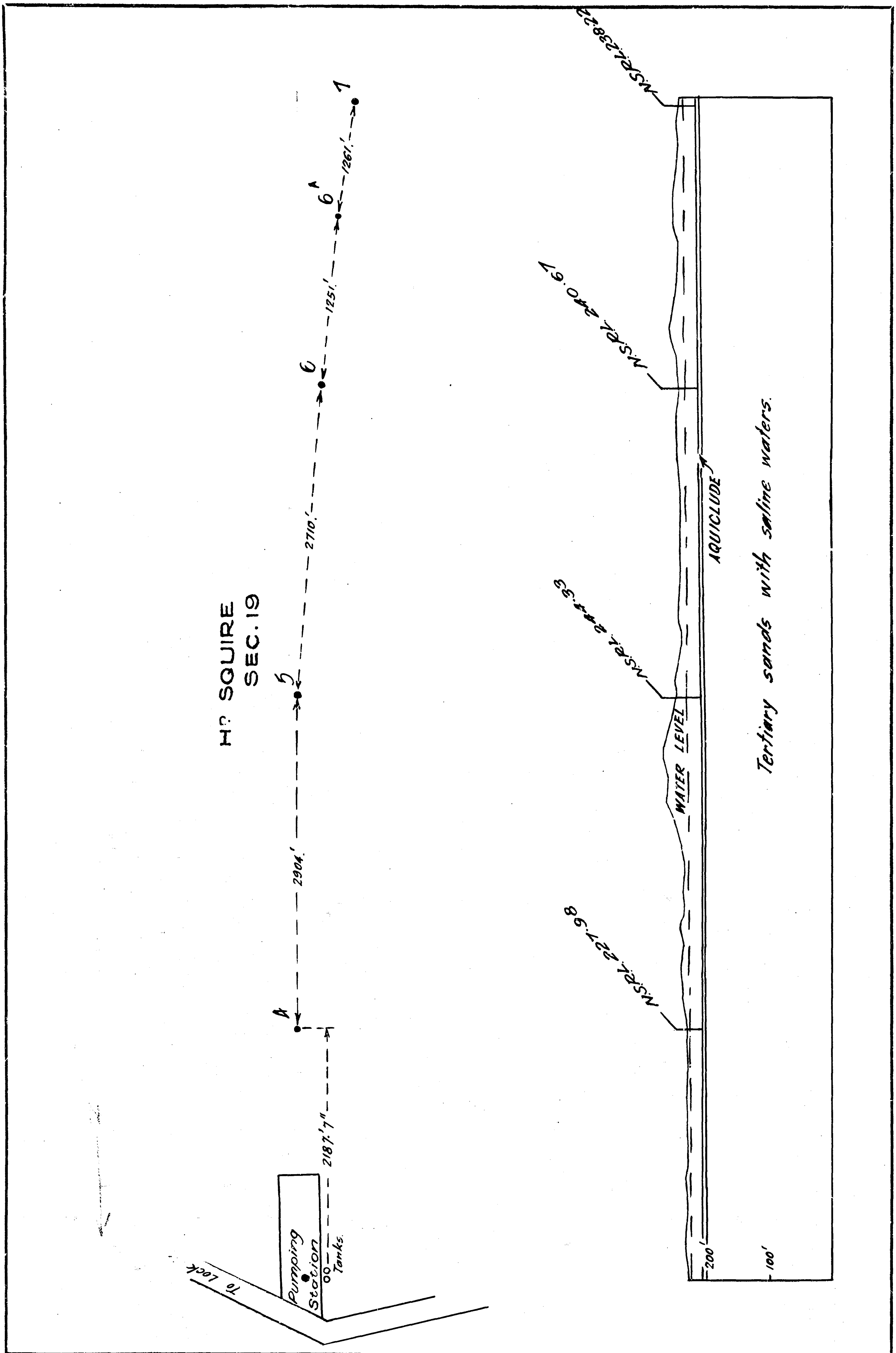
Poelpena Swamp Area ....

MILE 1 ½ 0 1 2 3 MILES

S.A. DEPARTMENT OF MINES

Approved	Passed	Drn.	POLDA BASIN	D.M.	Scale linch:2 miles
		Tcd. EJW MRL	Showing	Req.	S–4436d
		Ckd.	S.W.L. Contours.		DI 2/4
Director		Exd.			Date 9-7-65

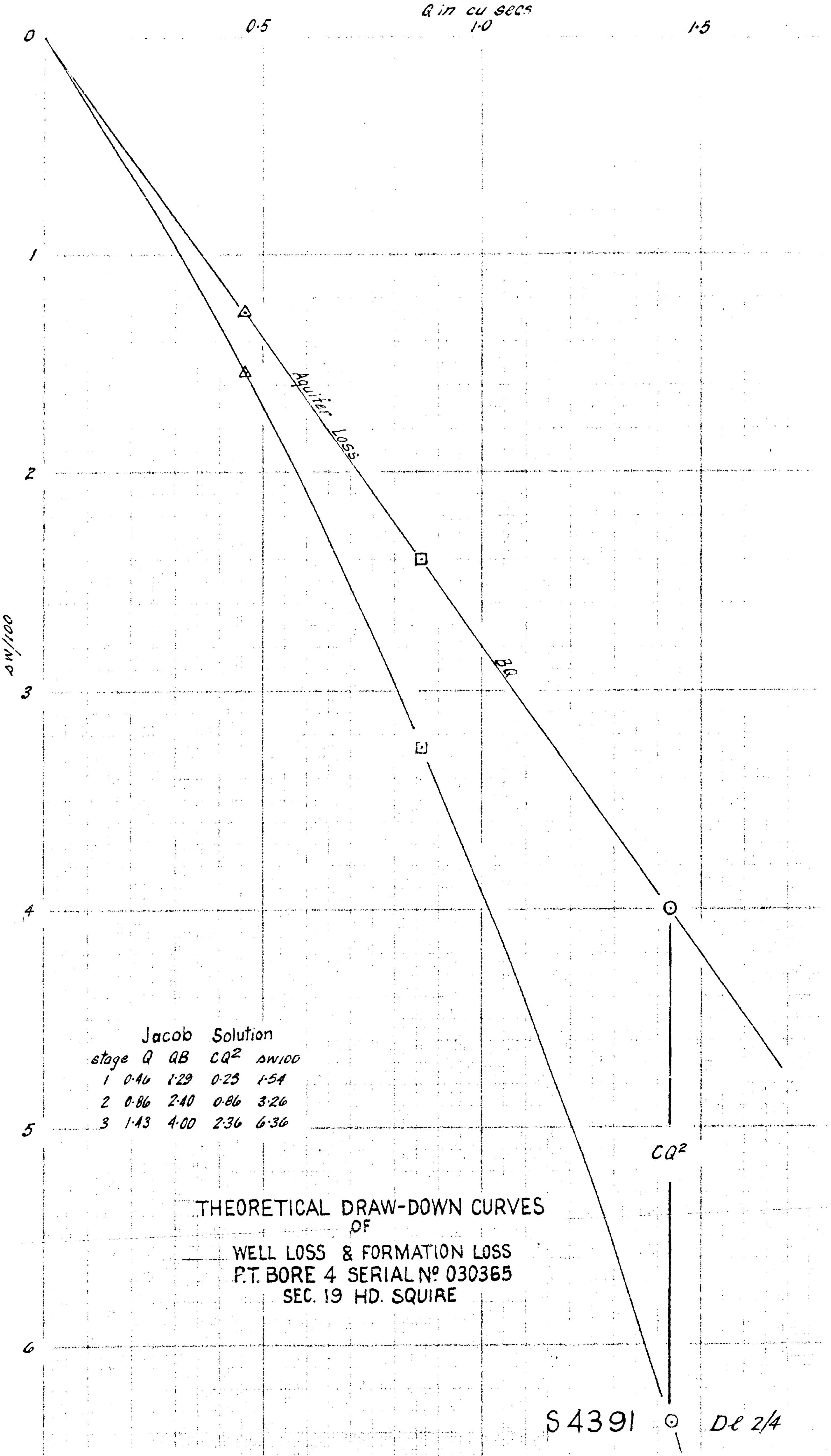
400— 6.63 1423



S.A. DEPARTMENT OF MINES

Approved	Passed	Drn.	POLDA BASIN INVESTIGATION	D.M.	Scale
		Tcd. G.M.	MAIN PUMPING BORES	Req.	S4435
		Ckd.	LOCATION & SURFACE		Di 2/4
Director		Exd.	PROFILE		Date 9.7.65

400— 6.63 1423



Jacob Solution

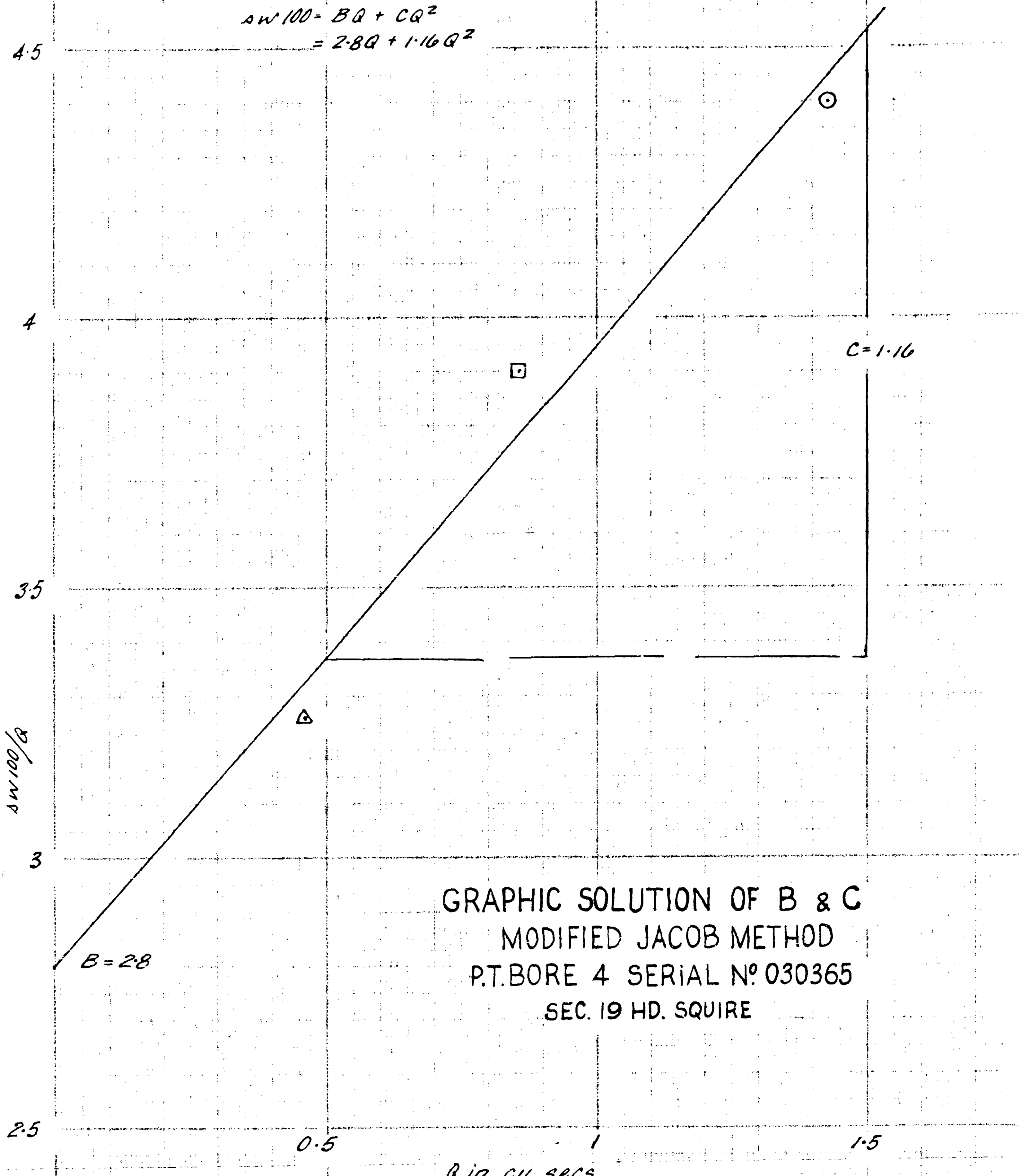
stage	Q	QB	CQ^2	sw/100
1	0·46	1·29	0·25	1·54
2	0·86	2·40	0·86	3·26
3	1·43	4·00	2·36	6·36

THEORETICAL DRAW-DOWN CURVES
OF
WELL LOSS & FORMATION LOSS
P.T. BORE 4 SERIAL Nº 030365
SEC. 19 HD. SQUIRE

S 4391 Dℓ 2/4

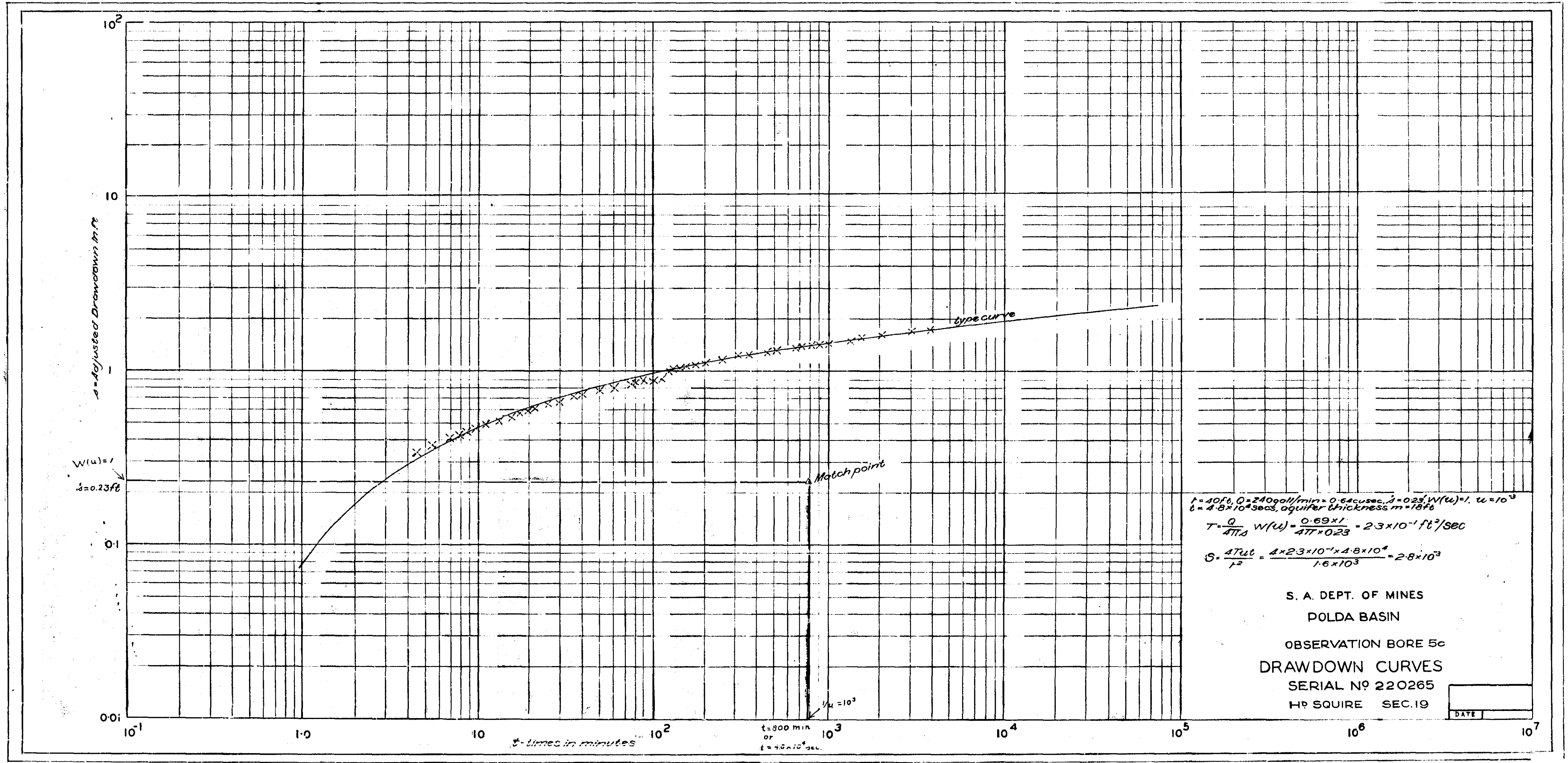
Stage	Q in cu secs	sw 100	sw 100/Q
1	0·46	1·50	3·26
2	0·86	3·35	3·90
3	1·43	6·36	4·40

$$sw100 = BQ + CQ^2$$
$$= 2{\cdot}8Q + 1{\cdot}16Q^2$$



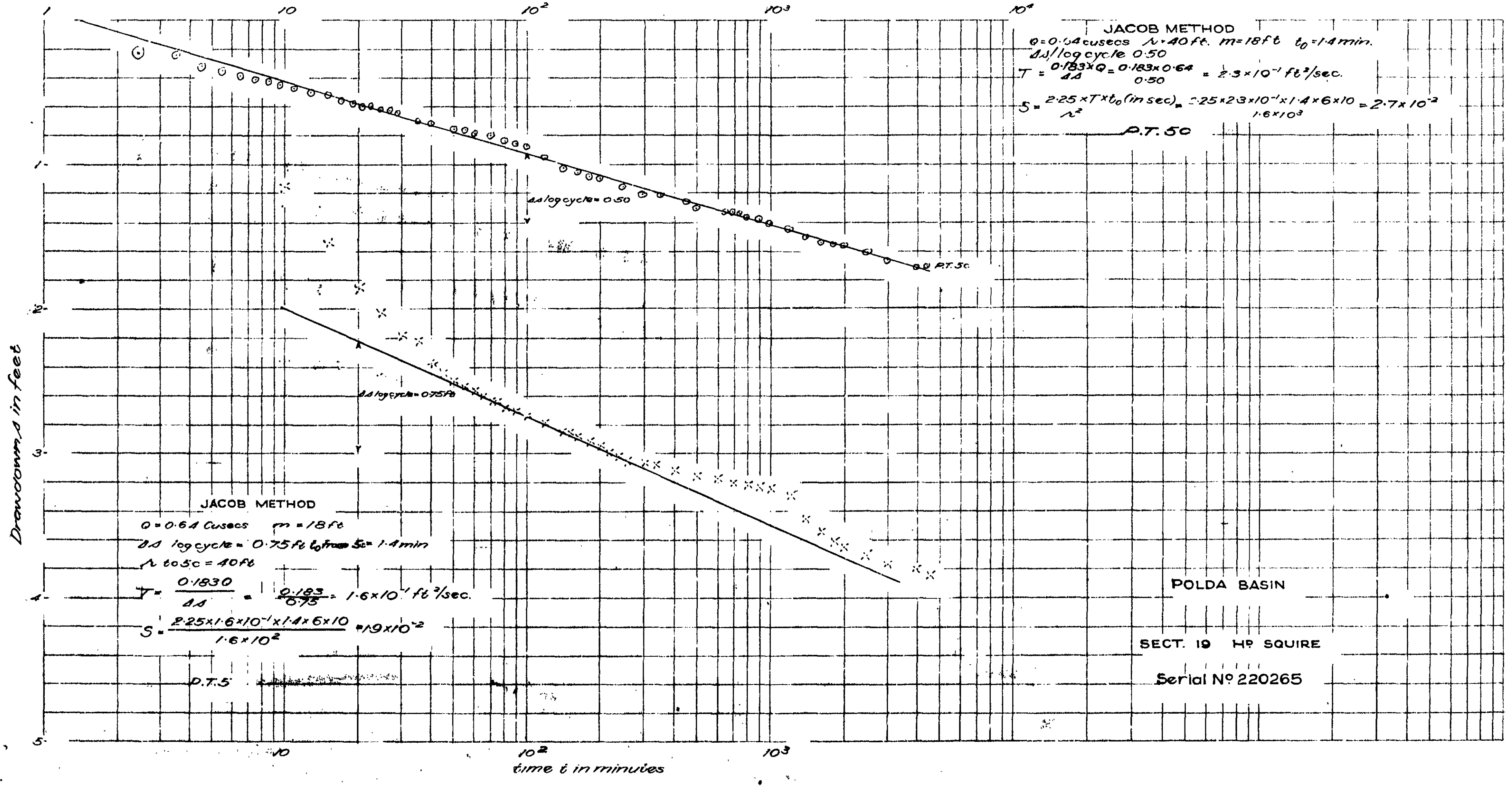
GRAPHIC SOLUTION OF B & C
MODIFIED JACOB METHOD
P.T. BORE 4 SERIAL Nº 030365
SEC. 19 HD. SQUIRE

S 4390 Dl 2/4



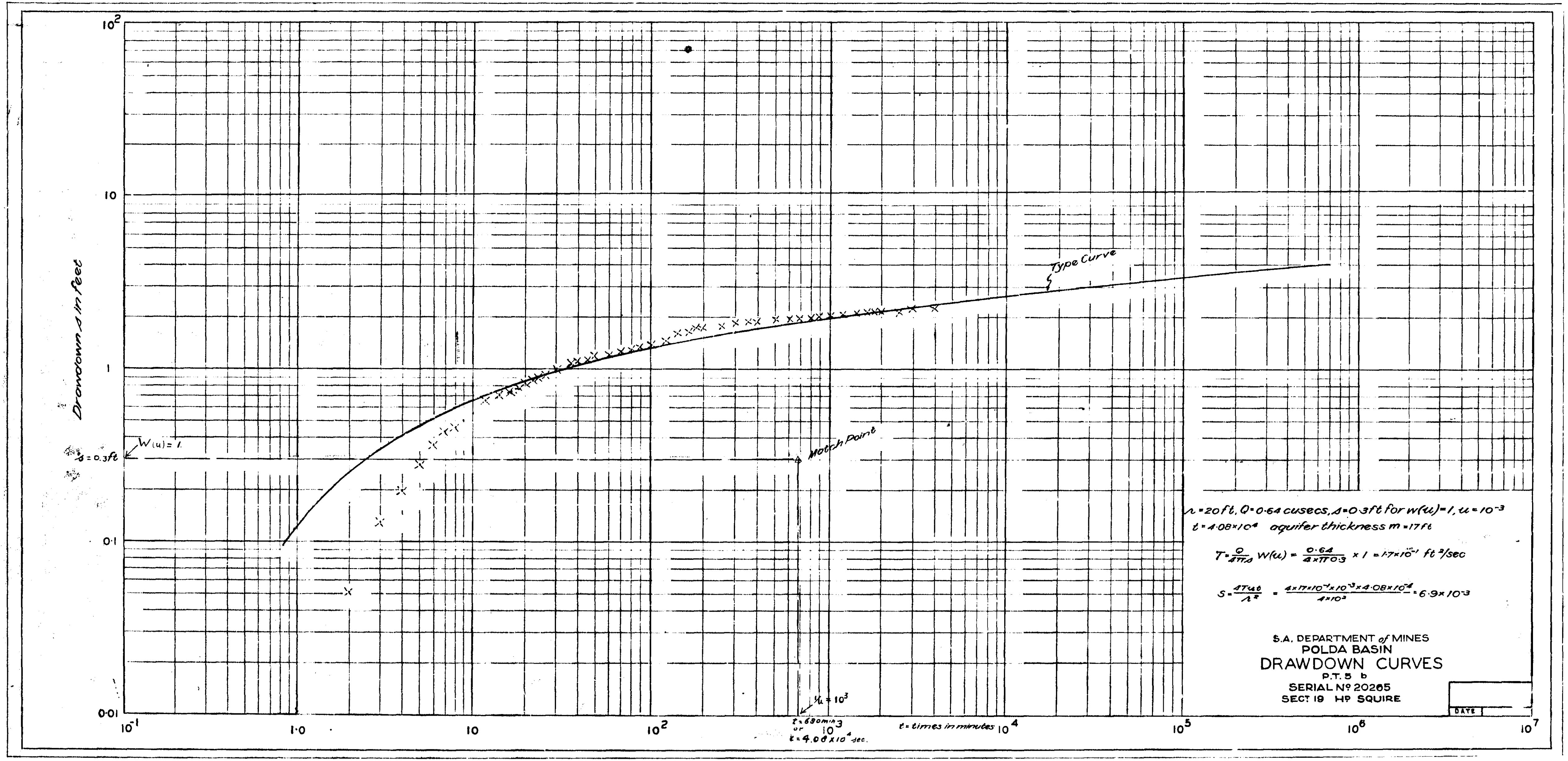
10^2
10
1
0·1
0·01
10^{-1}
1·0
10
10^2
10^3
10^4
10^5
10^6
10^7
s = Adjusted Drawdown in ft
t - times in minutes
type curve
Match point
W(u) = 1
s = 0.23 ft
t = 800 min or t = 4.8 × 10⁴ sec.
1/u = 10³
r = 40 ft, Q = 240 gall/min = 0·64 cusec, s = 0·23', W(u) = 1, u = 10⁻³
t = 4·8 × 10⁴ secs, aquifer thickness m = 18 ft
$T = \frac{Q}{4\pi s} W(u) = \frac{0{\cdot}69 \times 1}{4\pi \times 0{\cdot}23} = 2{\cdot}3 \times 10^{-1}\ ft^2/sec$
$S = \frac{4Tut}{r^2} = \frac{4 \times 2{\cdot}3 \times 10^{-1} \times 4{\cdot}8 \times 10^4}{1{\cdot}6 \times 10^3} = 2{\cdot}8 \times 10^{-3}$
S. A. DEPT. OF MINES
POLDA BASIN
OBSERVATION BORE 5c
DRAWDOWN CURVES
SERIAL Nº 220265
Hº SQUIRE SEC. 19
DATE

65-875
DL 2/4



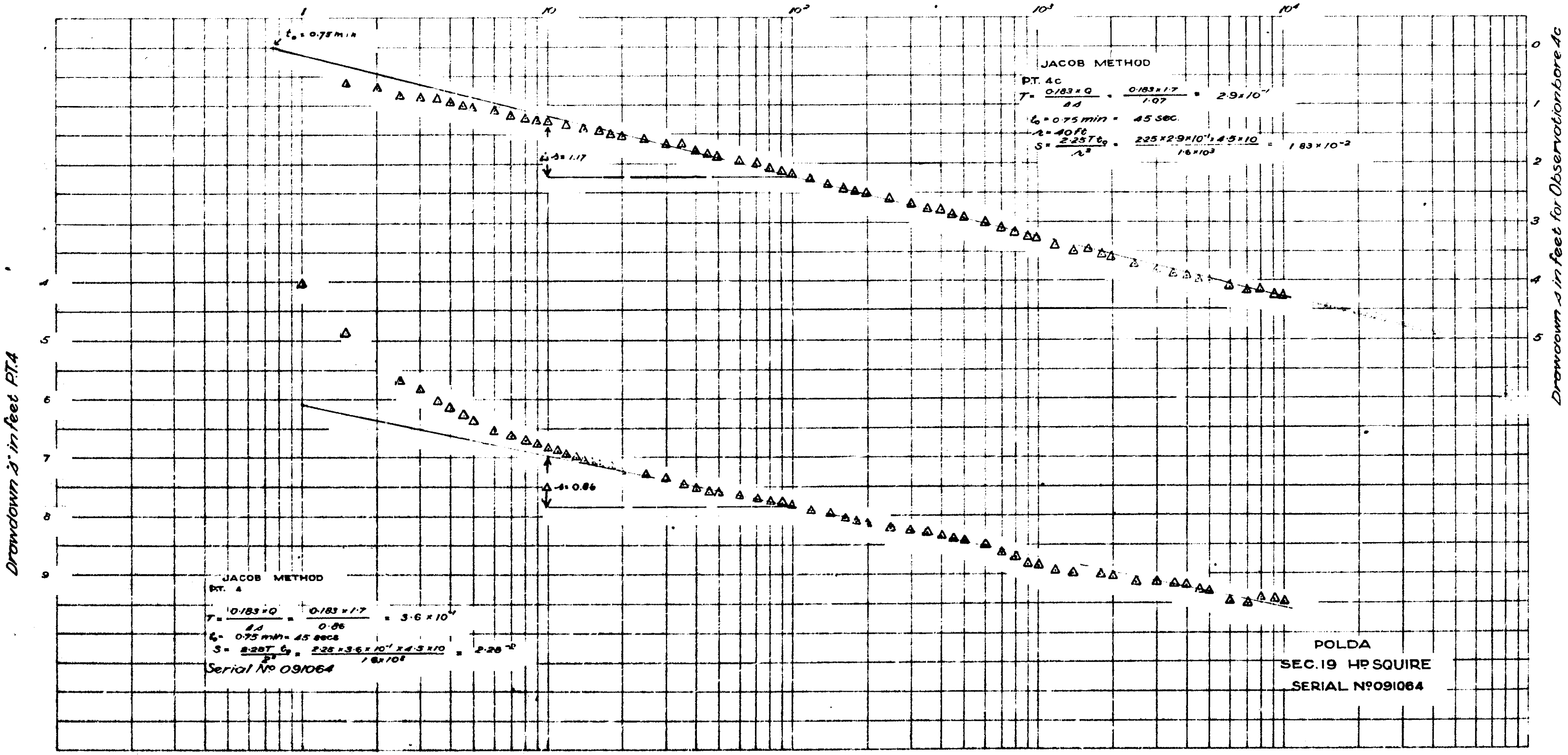
JACOB METHOD
Q=0.64 cusecs r=40 ft. m=18 ft t₀=1.4 min.
Δs/log cycle 0.50
T = 0.183×Q/Δs = 0.183×0.64/0.50 = 2.3×10⁻¹ ft²/sec.
S = 2.25×T×t₀(in sec)/r² = 2.25×2.3×10⁻¹×1.4×6×10/1.6×10³ = 2.7×10⁻²
P.T. 50
Δs log cycle = 0.50
P.T. 50
Δs log cycle = 0.75 ft
JACOB METHOD
Q = 0.64 Cusecs m = 18 ft
Δs log cycle = 0.75 ft t₀ from 5c = 1.4 min
r to 5c = 40 ft
T = 0.183Q/Δs = 0.183/0.75 = 1.6×10⁻¹ ft²/sec.
S = 2.25×1.6×10⁻¹×1.4×6×10/1.6×10² = 1.9×10⁻²
P.T. 5
POLDA BASIN
SECT. 19 Hº SQUIRE
Serial Nº 220265
Drawdown s in feet
time t in minutes

65-874
D12/4



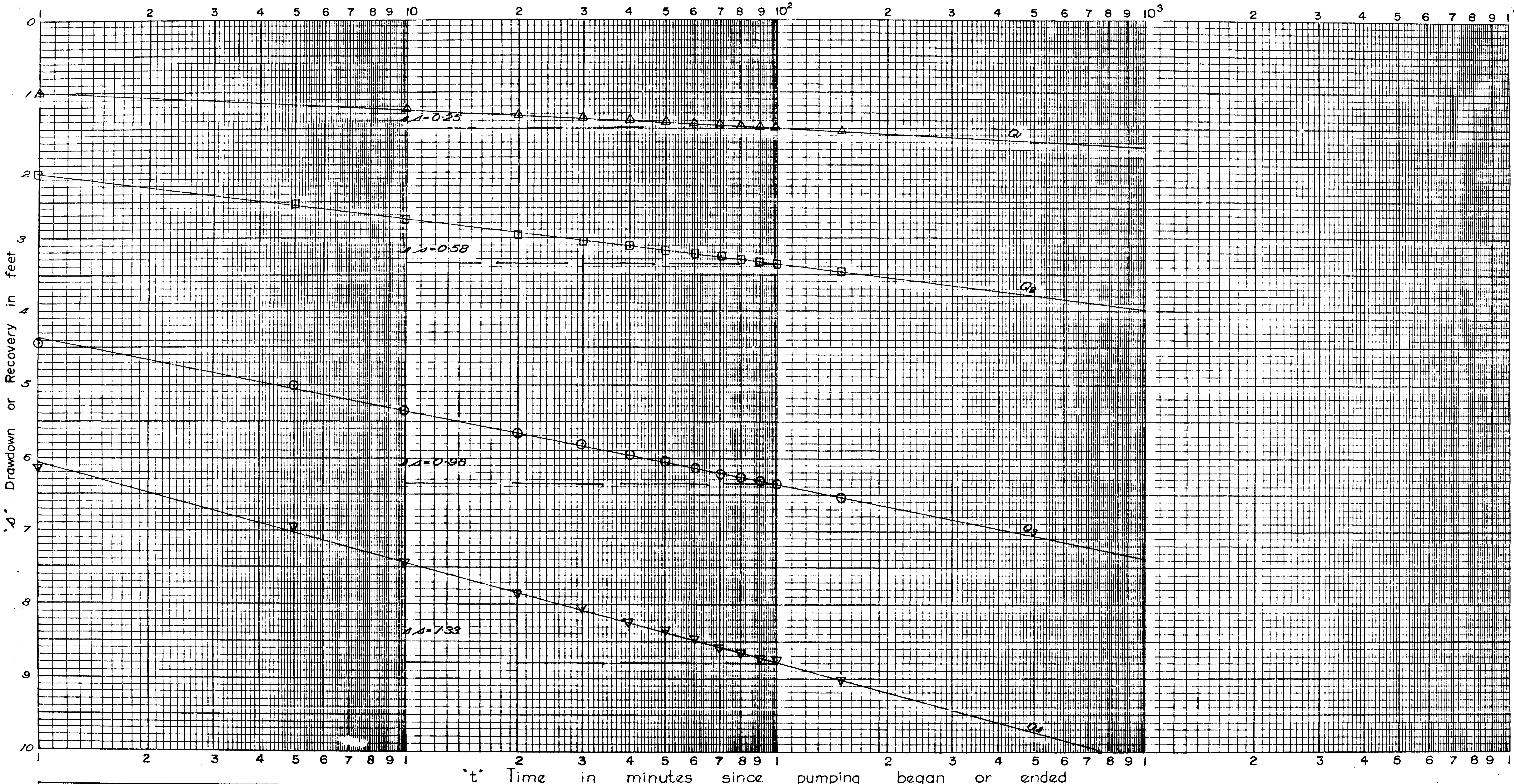
10^2
10
1
0·1
0·01
Drawdown s in feet
$W(u) = 1$
$s = 0.3$ ft
Type Curve
Match Point
$1/u = 10^3$
10^{-1}
1·0
10
10^2
$t = 680$ min or $t = 4.08 \times 10^4$ sec.
10^3
t = times in minutes
10^4
10^5
10^6
10^7
$r = 20$ ft, $Q = 0.64$ cusecs, $s = 0.3$ ft for $W(u) = 1$, $u = 10^{-3}$
$t = 4.08 \times 10^4$ aquifer thickness $m = 17$ ft
$T = \frac{Q}{4\pi s} W(u) = \frac{0.64}{4 \times \pi \, 0.3} \times 1 = 1.7 \times 10^{-1}$ ft²/sec
$S = \frac{4Tut}{r^2} = \frac{4 \times 17 \times 10^{-1} \times 10^{-3} \times 4.08 \times 10^{-4}}{4 \times 10^2} = 6.9 \times 10^{-3}$
S.A. DEPARTMENT of MINES
POLDA BASIN
DRAWDOWN CURVES
P.T. 5 b
SERIAL Nº 20265
SECT 19 Hº SQUIRE
DATE

65-873
D22/4



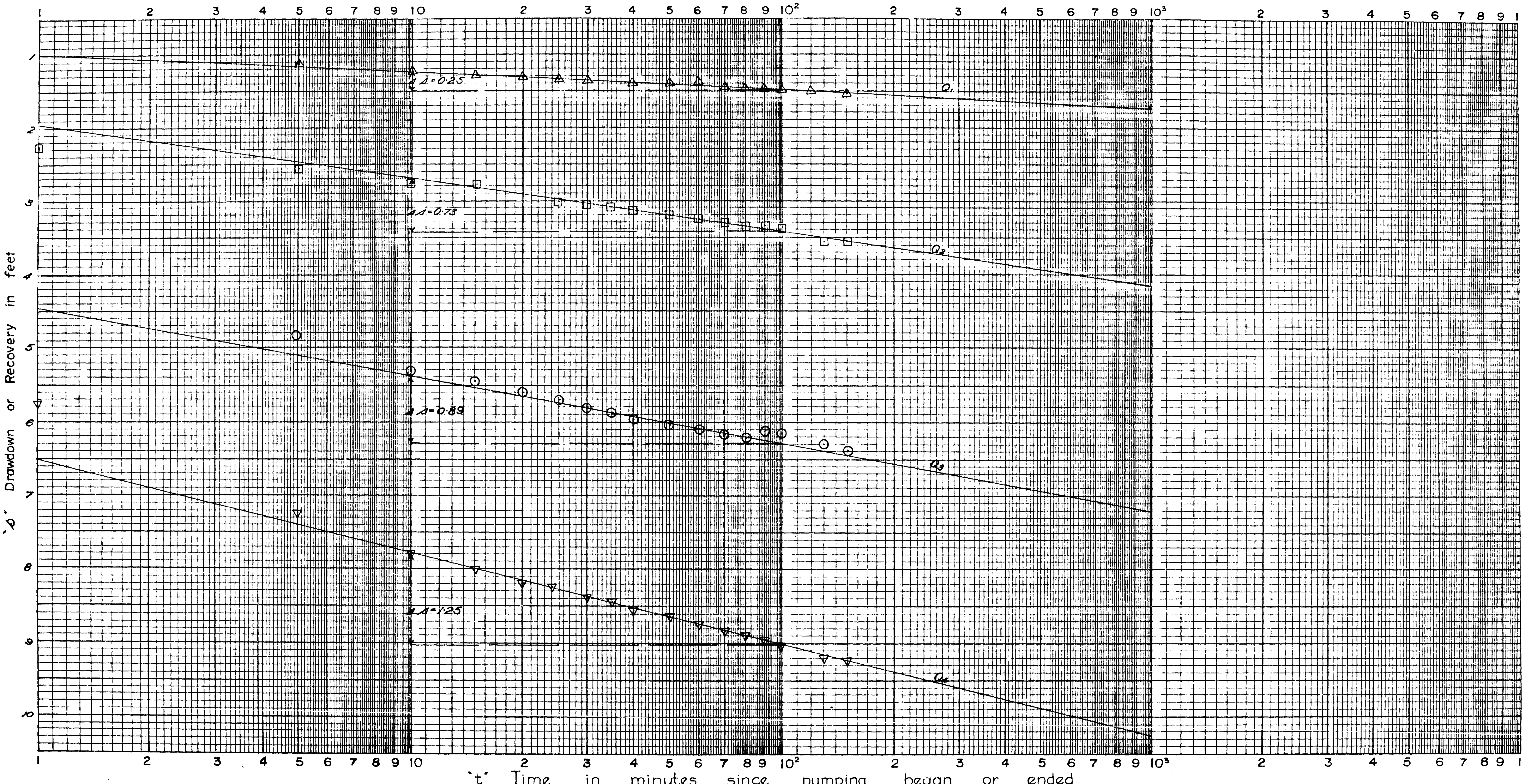
1
10
10^2
10^3
10^4
$t_o = 0.75$ min
$\Delta s = 1.17$
$\Delta s = 0.86$
JACOB METHOD
P.T. 4c
$T = \frac{0.183 \times Q}{\Delta s} = \frac{0.183 \times 1.7}{1.07} = 2.9 \times 10^{-1}$
$t_o = 0.75$ min = 45 sec.
$r = 40$ ft
$S = \frac{2.25 T t_o}{r^2} = \frac{2.25 \times 2.9 \times 10^{-1} \times 4.5 \times 10}{1.6 \times 10^3} = 1.83 \times 10^{-2}$
JACOB METHOD
P.T. 4
$T = \frac{0.183 \times Q}{\Delta s} = \frac{0.183 \times 1.7}{0.86} = 3.6 \times 10^{-1}$
$t_o = 0.75$ min = 45 secs
$S = \frac{2.25 T t_o}{r^2} = \frac{2.25 \times 3.6 \times 10^{-1} \times 4.5 \times 10}{1.6 \times 10^3} = 2.28^{-2}$
Serial No 091064
POLDA
SEC.19 Hp SQUIRE
SERIAL No 091064
Drawdown 's' in feet P.T.4
Drawdown s in feet for Observation bore 4c
0
1
2
3
4
5
6
7
8
9

65-872
D22/4



OWNER Dept. of Mines .... FILE No. DM 1580/64 DATE OF TEST .... 3 March 1965 TYPE OF PUMP .. Pomona Single Stage STATIC WATER LEVEL R.W.L. 221·26 PUMP INTAKE SETTING .. R.L. 198·73 AVAILABLE DRAWDOWNS .... 20·5 ft. ANALYSIS BY ...... C. Bleys	PUMPING RATE Q in Cu. Secs. Stage 1 0·46 .... Stage 2 0·86 ...... Stage 3 1·43 .... Stage 4 1·96 ADOPTED RATE OF DRAWDOWN 0·25, 0·58, 0·98, 1·33 FT/LOG CYCLE AT 0·46, 0·86, 1·43, 1·96 Cu. Secs. REMARKS .... Drawdown log t graphs for Q1, Q2, Q3 and Q4, incremental method	S.A. DEPT. OF MINES HYDROLOGY SECTION PUMP TEST ANALYSIS P.T. No 4 SERIAL No 030365 SECT. 19 Hd SQUIRE

65-866
Dc 2/4



OWNER Dept. of Mines FILE No. DM. 1580/64
DATE OF TEST 3 March 1965
TYPE OF PUMP Pomona Single Stage
STATIC WATER LEVEL R.W.L. 221.26
PUMP INTAKE SETTING R.L. 198.73
AVAILABLE DRAWDOWNS 20.5 ft.
ANALYSIS BY C. Bleys

PUMPING RATE Q in Cu. Secs. Stage 1 0·46 Stage 2 0·86 Stage 3 1·43 Stage 4 1·96

ADOPTED RATE OF DRAWDOWN 0.25, 0.73, 0.89, 1.25 FT/LOG CYCLE AT 0.46, 0.86, 1.43, 1.96 Cu. Secs.

REMARKS

Drawdown log "t" graph for Q_1, Q_2, Q_3 and Q_4 direct method

S.A. DEPT. OF MINES

HYDROLOGY SECTION

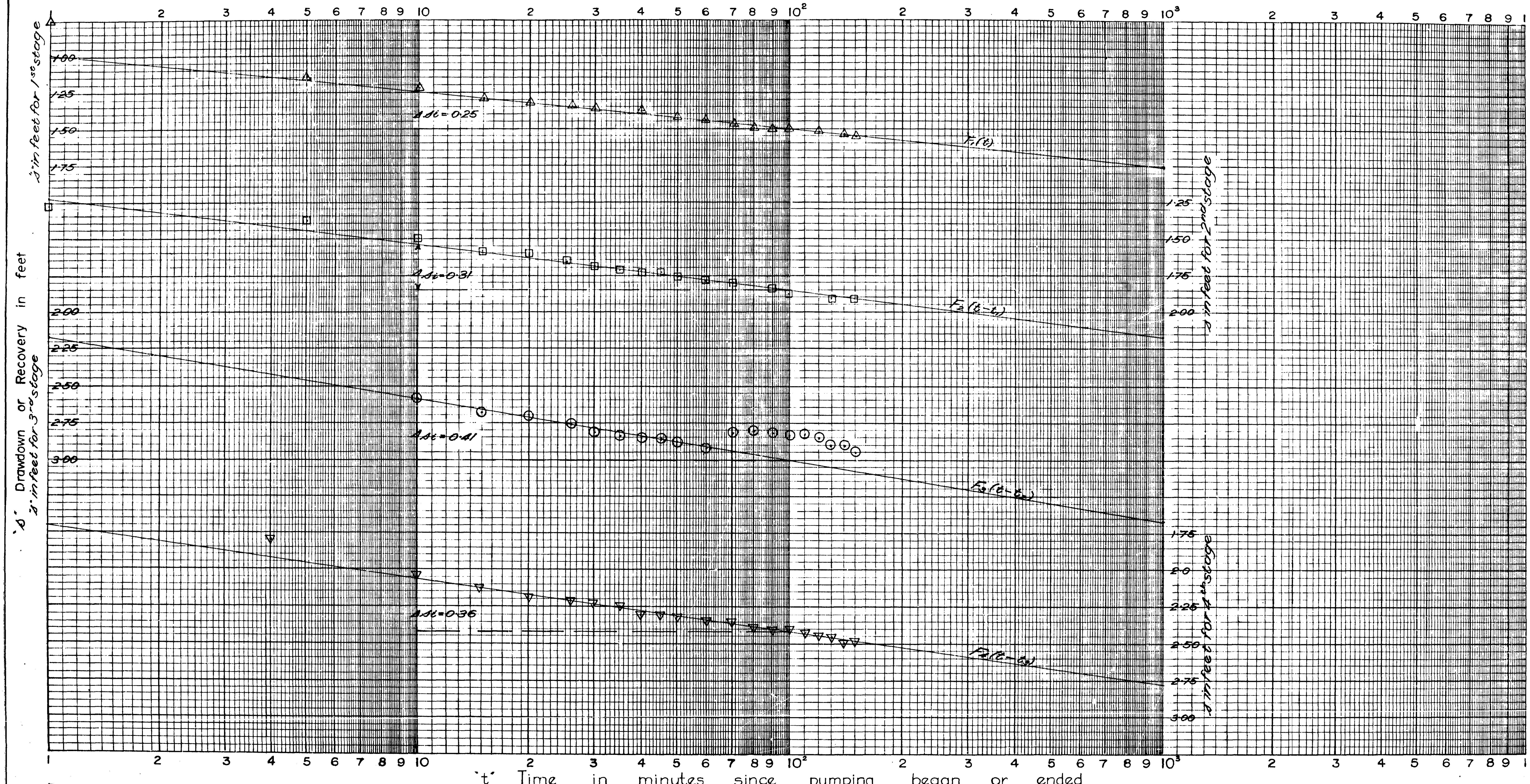
PUMP TEST ANALYSIS

P.T. No. 4

SERIAL No. 030365

SECT. 19 Hd. SQUIRE

65·865
Dl 2/4



OWNER Dept. of Mines FILE No. DM 1580/64
DATE OF TEST 8 March 1965
TYPE OF PUMP Pomona Single Stage
STATIC WATER LEVEL R.W.L. 221.26
PUMP INTAKE SETTING R.L. 198.73
AVAILABLE DRAWDOWNS 20.5 ft
ANALYSIS BY C. Bleys

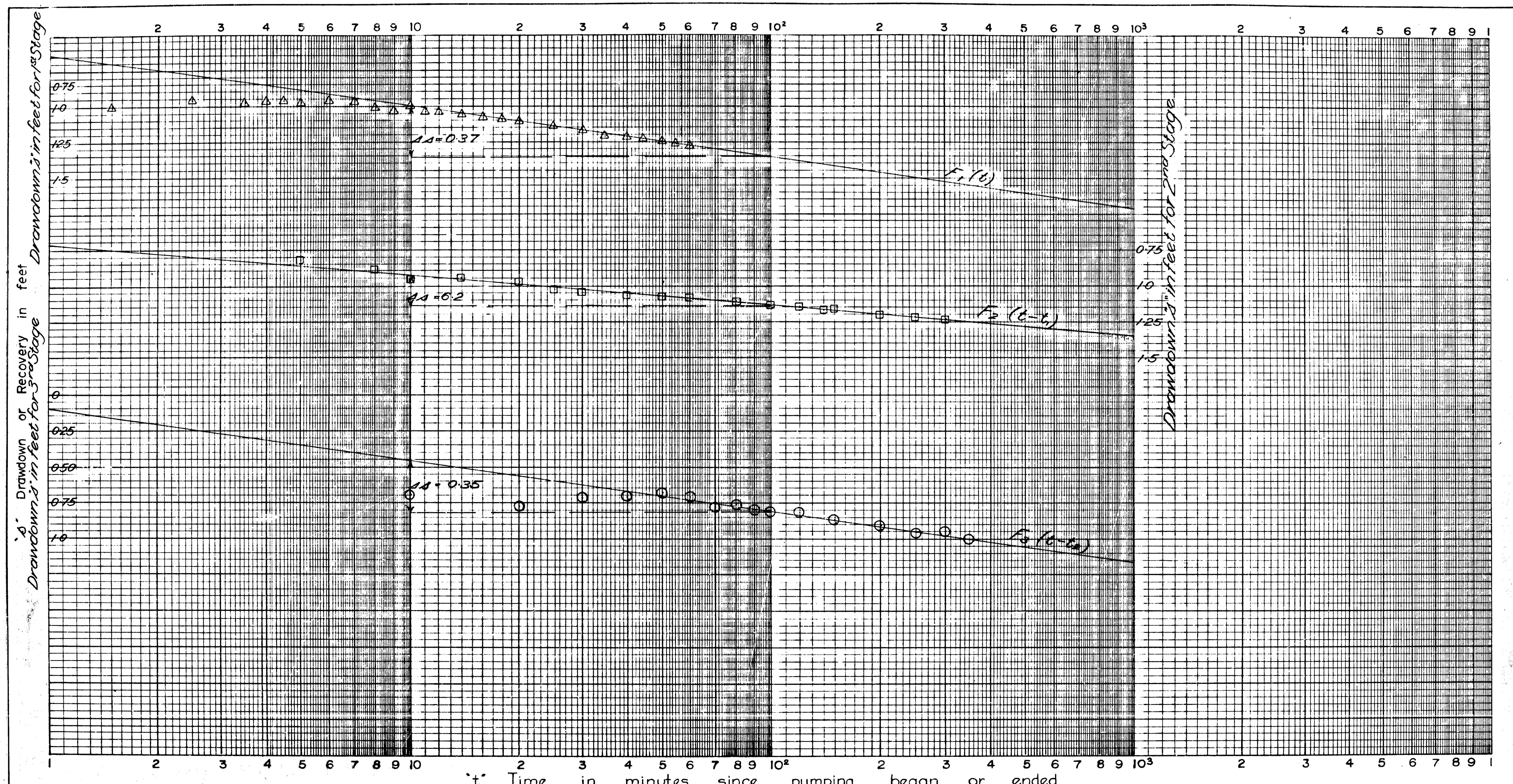
INCREMENTAL
PUMPING RATE Q in Cu. Secs. Stage 1 0.46 Stage 2 0.4 Stage 3 0.57 Stage 4 0.53

ADOPTED RATE OF DRAWDOWN .... FT/LOG CYCLE AT .... Cu. Secs.
REMARKS Incremental drawdown curves

S.A. DEPT. OF MINES
HYDROLOGY SECTION

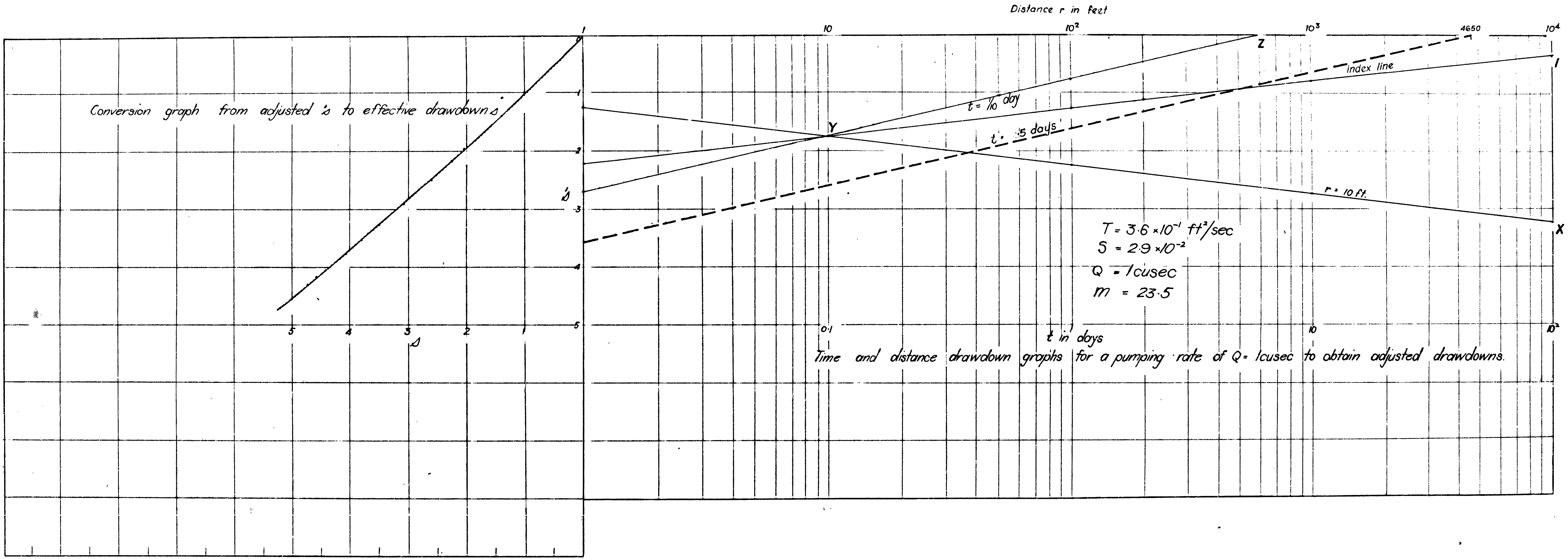
PUMP TEST ANALYSIS
P.T. No. 4
SERIAL No. 030365
SEC 19 Hd. SQUIRE

65-864
D22/4



OWNER Dept. of Mines FILE Nº 1580/64 DATE OF TEST 16 Nov. '64 TYPE OF PUMP Pomona Single Stage STATIC WATER LEVEL R.W.L. 224.16 PUMP INTAKE SETTING R.L. 211.50 AVAILABLE DRAWDOWNS 12 ft. ANALYSIS BY C. Bleys	INCREMENTAL PUMPING RATE Q in Cu. Secs. Stage 1 0.77 Stage 2 0.46 Stage 3 0.33 Stage 4 ADOPTED RATE OF DRAWDOWN FT/LOG CYCLE AT Cu. Secs REMARKS Incremental drawdown log t and curves $F_1(t)$, $F_2(t-t_1)$ and $F_3(t-t_2)$	S.A. DEPT. OF MINES HYDROLOGY SECTION PUMP TEST ANALYSIS P.T. 7 SERIAL Nº 161164 SEC. 19 Hº SQUIRE

65-761
D2 2/4



S.A. DEPARTMENT OF MINES

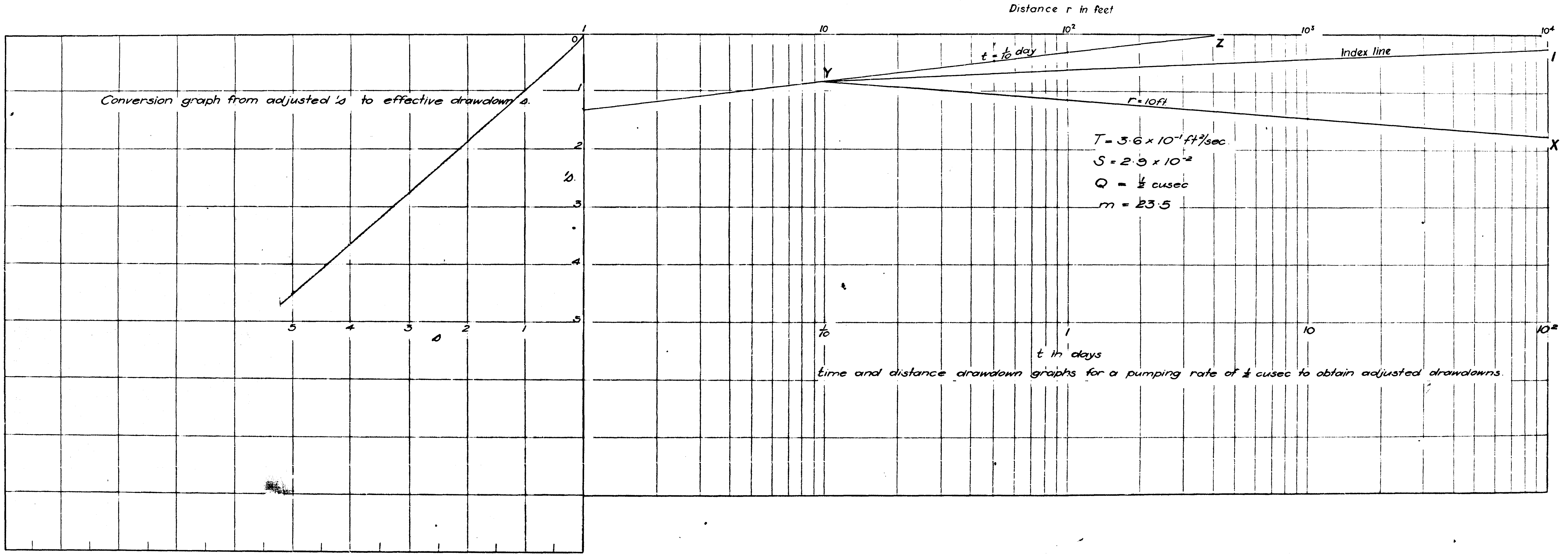
PUMP TEST SERIAL: 091064

PT. BORE 4.

SEC. 19 HD. SQUIRE

65-415

DI 2/4



S.A. DEPARTMENT OF MINES

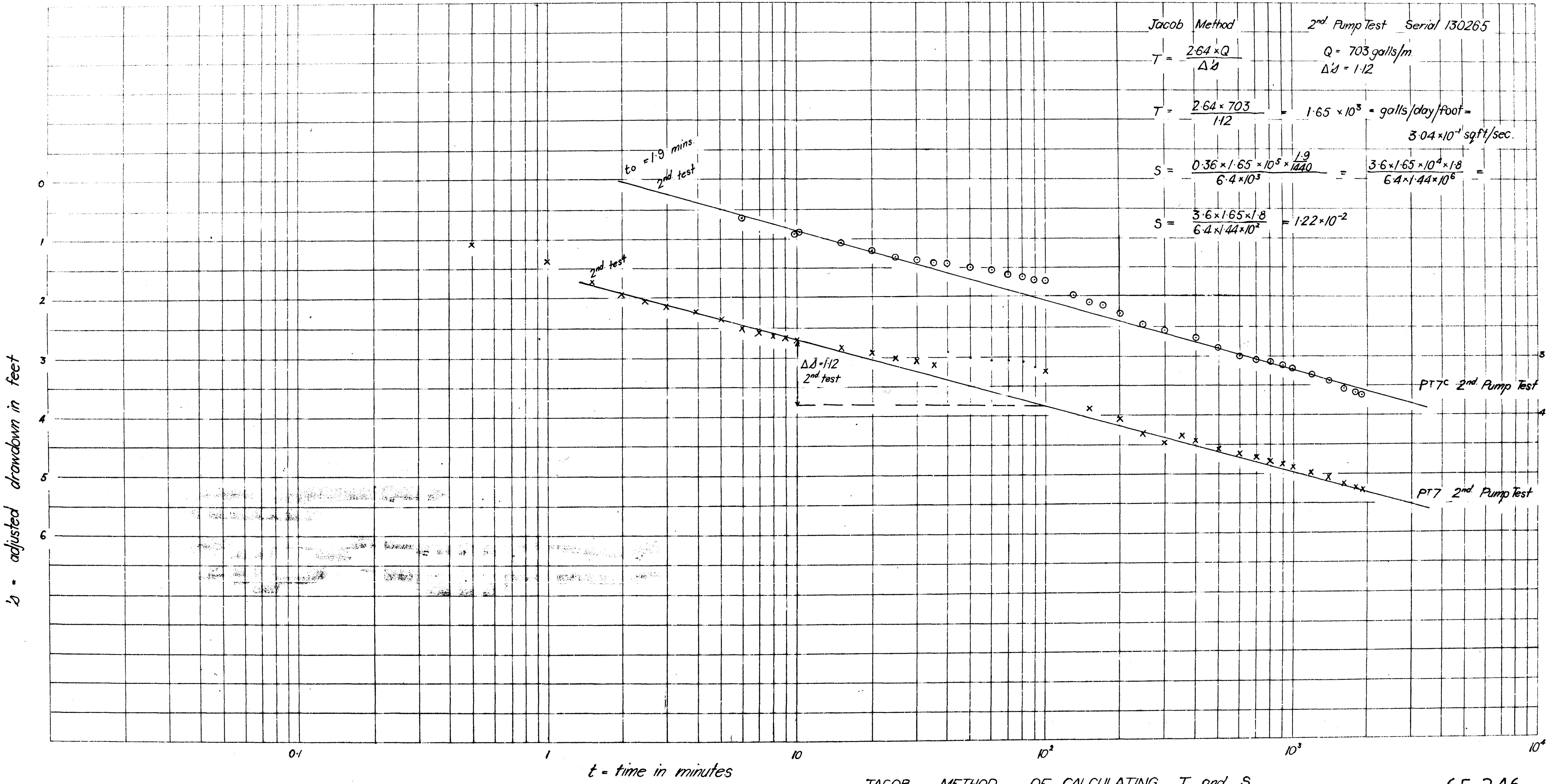
PUMP TEST SERIAL: 091064

PT. BORE 4.

SEC. 19 HD. SQUIRE

65-414

DI 2/4

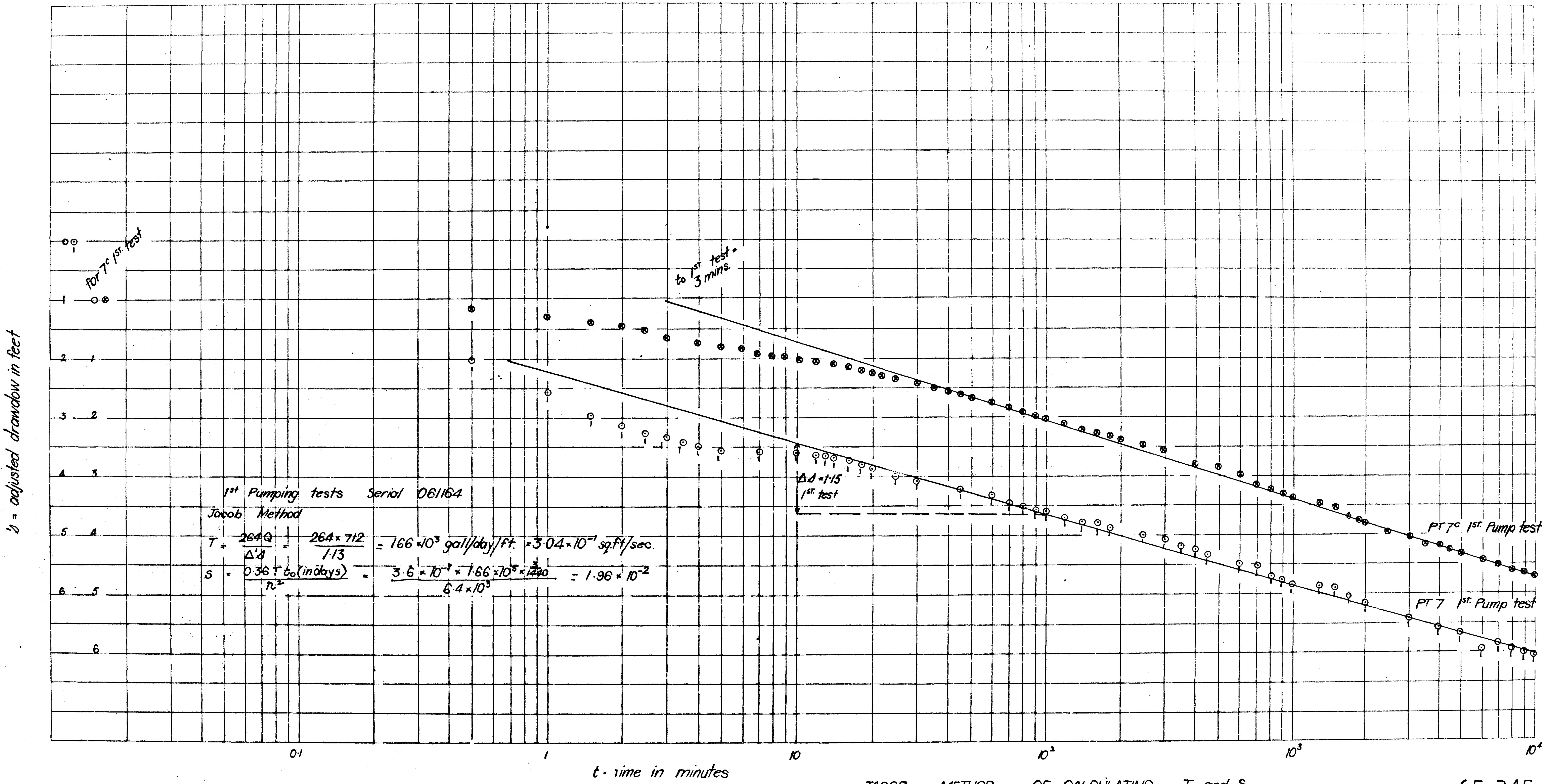


JACOB METHOD OF CALCULATING T and S

POLDA Pt 7

65-346

DL 2/4

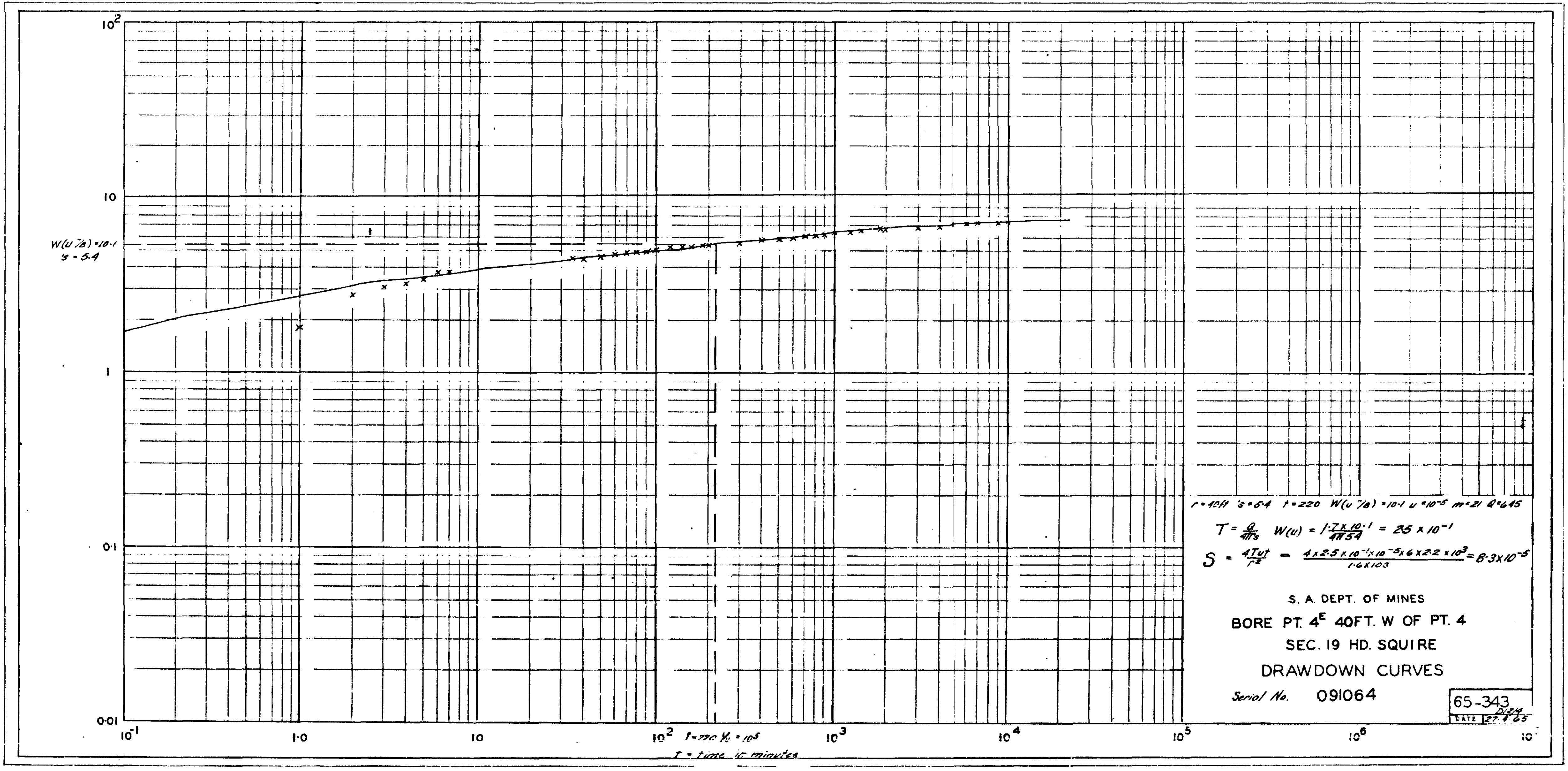


JACOB METHOD OF CALCULATING T and S

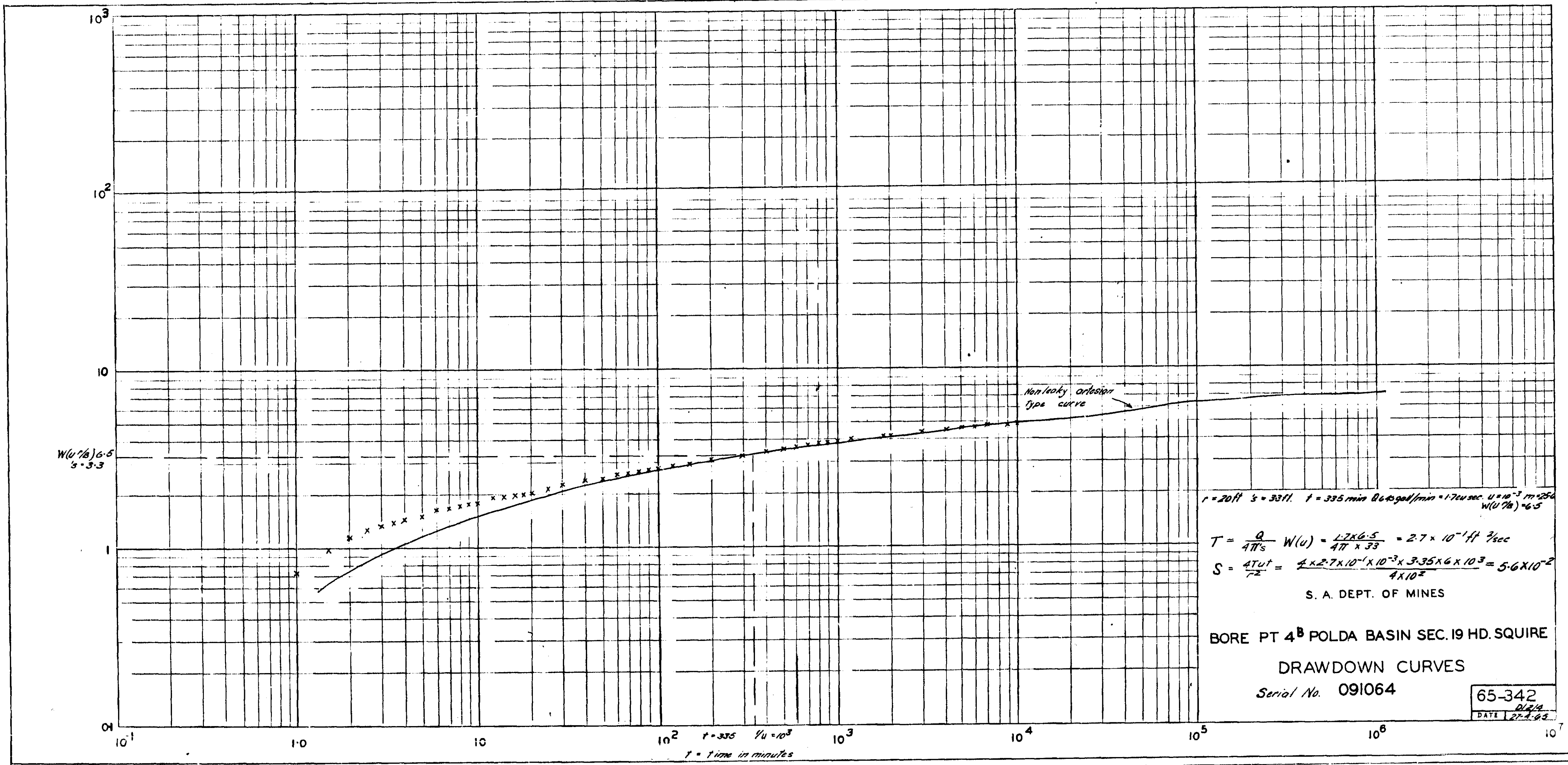
POLDA PT 7

65-345

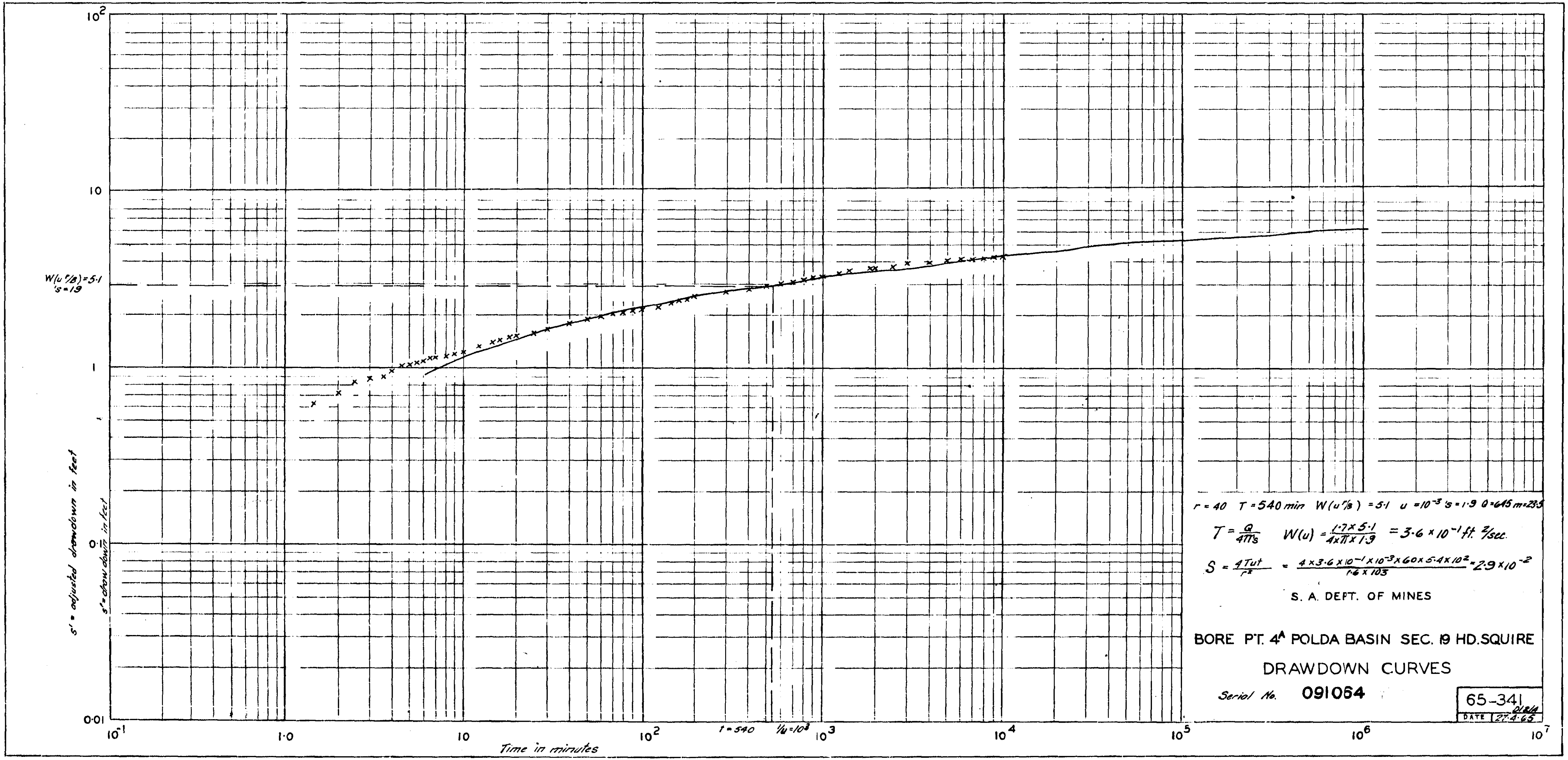
DL 2/4



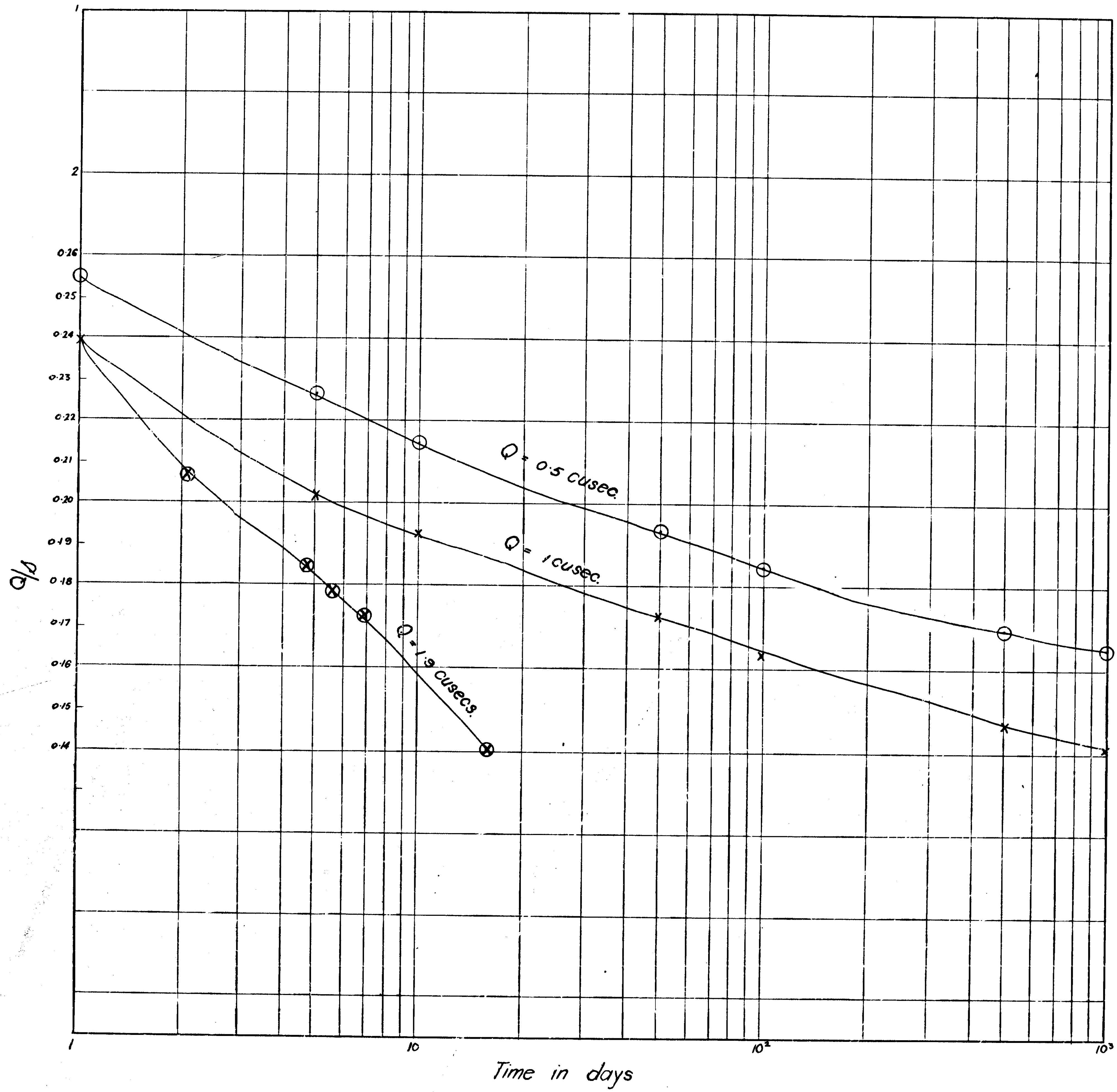
10²
10
1
0·1
0·01
W(u ⁻/B) = 10·1
's = 5.4
10⁻¹
1·0
10
10²
t = 220 ¹/u = 10⁵
10³
10⁴
10⁵
10⁶
10⁷
t = time in minutes
r = 40ft 's = 5·4 t = 220 W(u ⁻/B) = 10·1 u = 10⁻⁵ m = 21 Q = 645
T = Q/4πs W(u) = 1·7 x 10·1 / 4π 5·4 = 2·5 x 10⁻¹
S = 4Tut/r² = 4 x 2·5 x 10⁻¹ x 10⁻⁵ x 6 x 2·2 x 10³ / 1·6 x 103 = 8·3 x 10⁻⁵
S. A. DEPT. OF MINES
BORE PT. 4ᴱ 40FT. W OF PT. 4
SEC. 19 HD. SQUIRE
DRAWDOWN CURVES
Serial No. 091064
65-343
D1214
DATE 27.4.65



10³
10²
10
1
·01
W(u r/B) 6·5
's = 3·3
10⁻¹
1·0
10
10²
t = 335
1/u = 10³
10³
10⁴
10⁵
10⁶
10⁷
t = time in minutes
Non leaky artesian type curve
r = 20ft 's = 33ft. t = 335 min Q645gall/min = 1·7cu sec. u = 10⁻³ m = 25·6
W(u r/B) = 6·5
T = Q/4π's W(u) = 1·7×6·5 / 4π × 33 = 2·7 × 10⁻¹ ft ²/sec
S = 4Tut/r² = 4×2·7×10⁻¹×10⁻³×3·35×6×10³ / 4×10² = 5·6×10⁻²
S. A. DEPT. OF MINES
BORE PT 4B POLDA BASIN SEC. 19 HD. SQUIRE
DRAWDOWN CURVES
Serial No. 091064
65-342
D/2/4
DATE 27-4-65



r = 40 T = 540 min W(u'/B) = 5·1 u = 10^-3 's = 1·9 Q = 645 m = 23·5
T = Q/4π's W(u) = 1·7 × 5·1 / 4 × π × 1·9 = 3·6 × 10^-1 ft.²/sec.
S = 4Tut/r² = 4 × 3·6 × 10^-1 × 10^-3 × 60 × 5·4 × 10² / 1·6 × 103 = 2·9 × 10^-2
S. A. DEPT. OF MINES
BORE PT. 4A POLDA BASIN SEC. 19 HD. SQUIRE
DRAWDOWN CURVES
Serial No. 091064
65-341
DATE 27·4·65
W(u'/B) = 5·1
's = 1·9
s' = adjusted drawdown in feet
s' = drawdown in feet
Time in minutes
t = 540
1/u = 10³
10²
10
1
0·1
0·01
10^-1
1·0
10
10²
10³
10⁴
10⁵
10⁶
10⁷

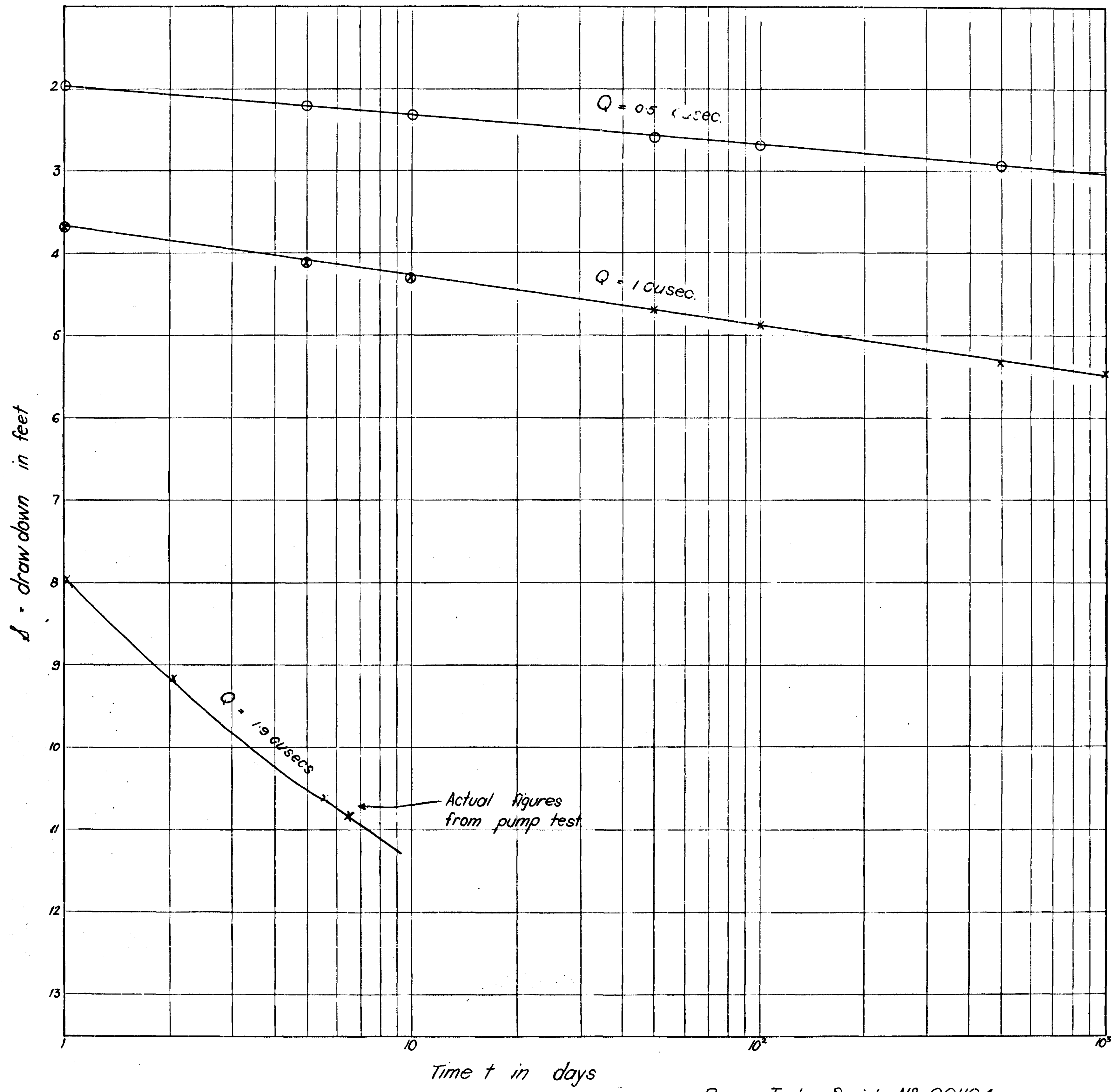


Pump Test Serial No. 061164

S.A. DEPARTMENT OF MINES

No.	Amendment	Exd.	Date		Approved	Passed		Scale :
				SPECIFIC CAPACITY TIME CURVE OF WELL Pt 7			Drn.	
							Tcd. R.H	65 - 338
				SECTION 19 Hd. SQUIRE			Ckd.	DL 2/4
					Director		Exd.	Date 31·3·65

200—8.63 1423



Pump Test Serial N° 061/64

S.A. DEPARTMENT OF MINES

TIME DRAWDOWN CURVE OF WELL Pt 7

SECTION 19 Hd. SQUIRE

No.	Amendment	Exd.	Date

Approved: Director

Passed

Drn.
Tcd. R.H.
Ckd.
Exd.

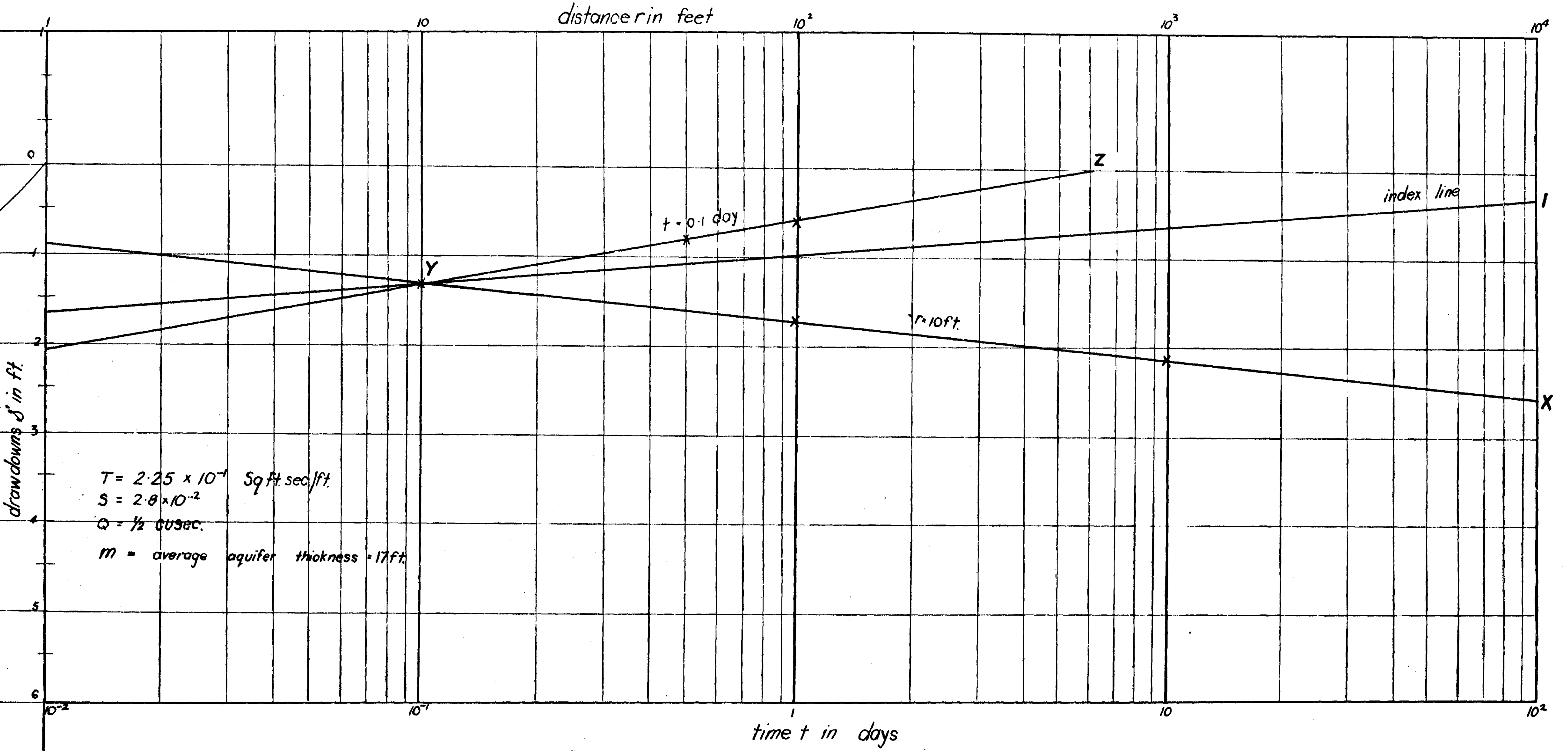
Scale:

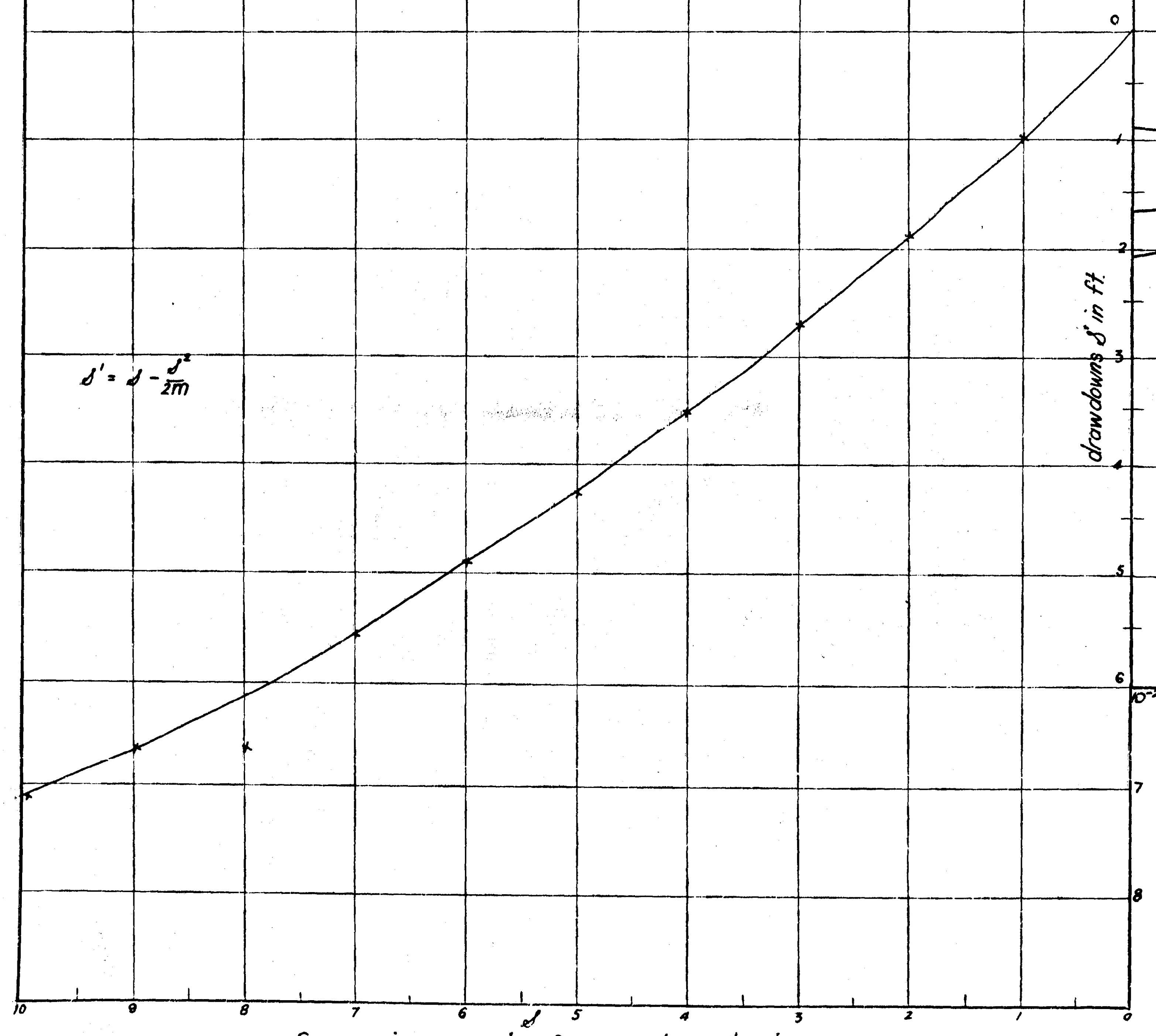
65 - 337

De 2/4

Date 31·3·65

200—8.63 1423





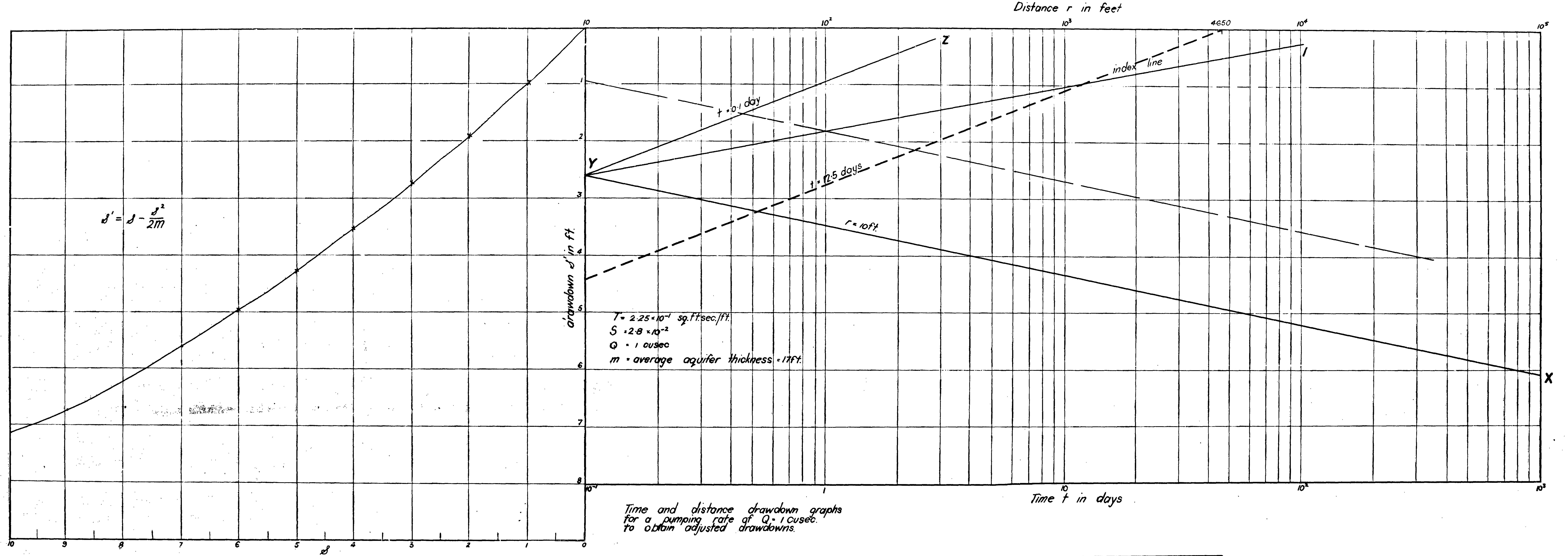
Conversion graph from adjusted δ' to measured drawdown δ

Time and distance drawdown graphs for a pumping rate of Q = ½ cusec. to obtain adjusted drawdowns

S.A. DEPARTMENT OF MINES

PUMPING TEST Nº 061164
WELL Pt 7
SECTION 19 Hd. SQUIRE

65-336
DE 2/4



Time and distance drawdown graphs for a pumping rate of Q = 1 cusec. to obtain adjusted drawdowns.

Conversion graph from adjusted s' to measured drawdowns s

S.A. DEPARTMENT OF MINES

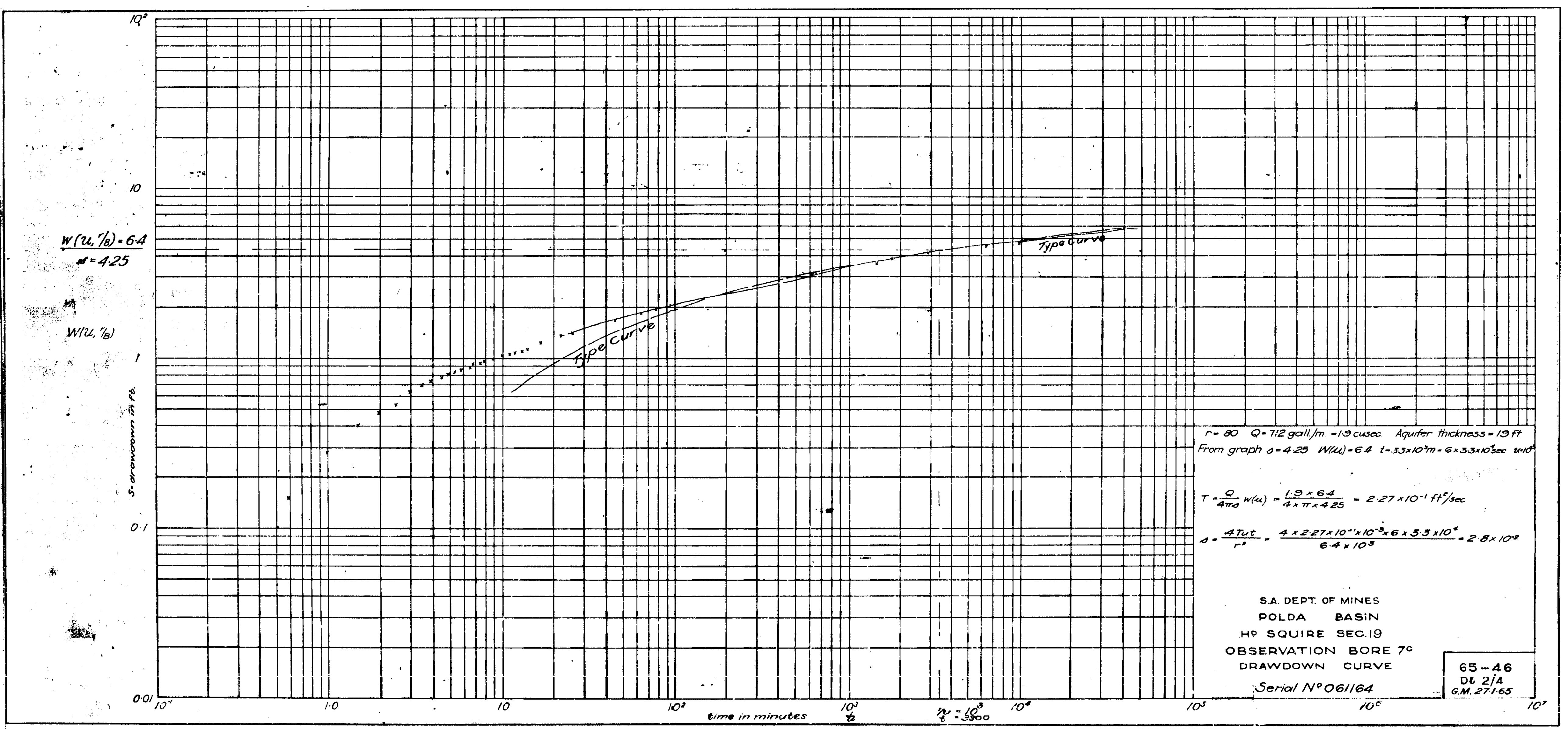
PUMPING TEST Nº 061164

WELL Pᵀ 7

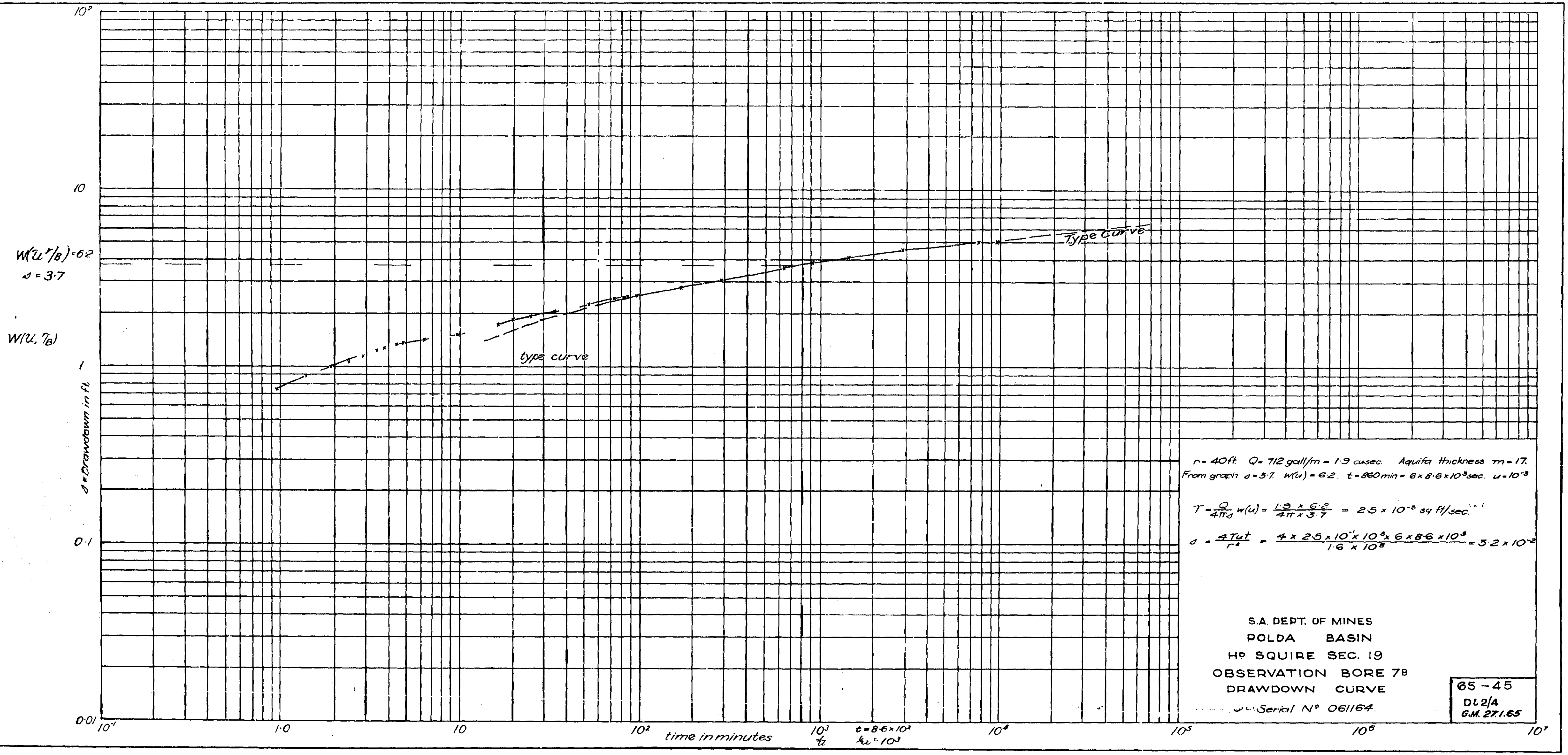
SECTION 19 Hd. SQUIRE

65-335

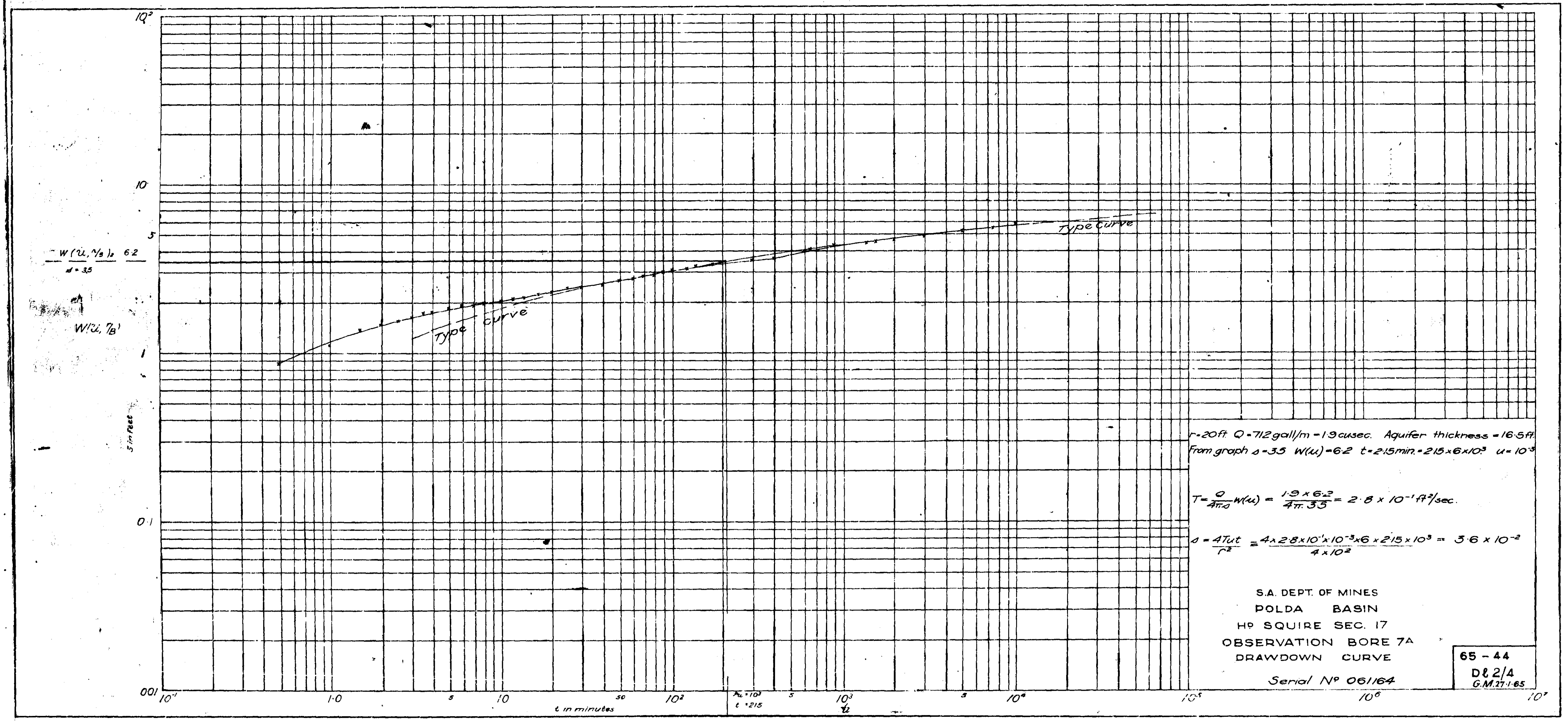
DC 2/4



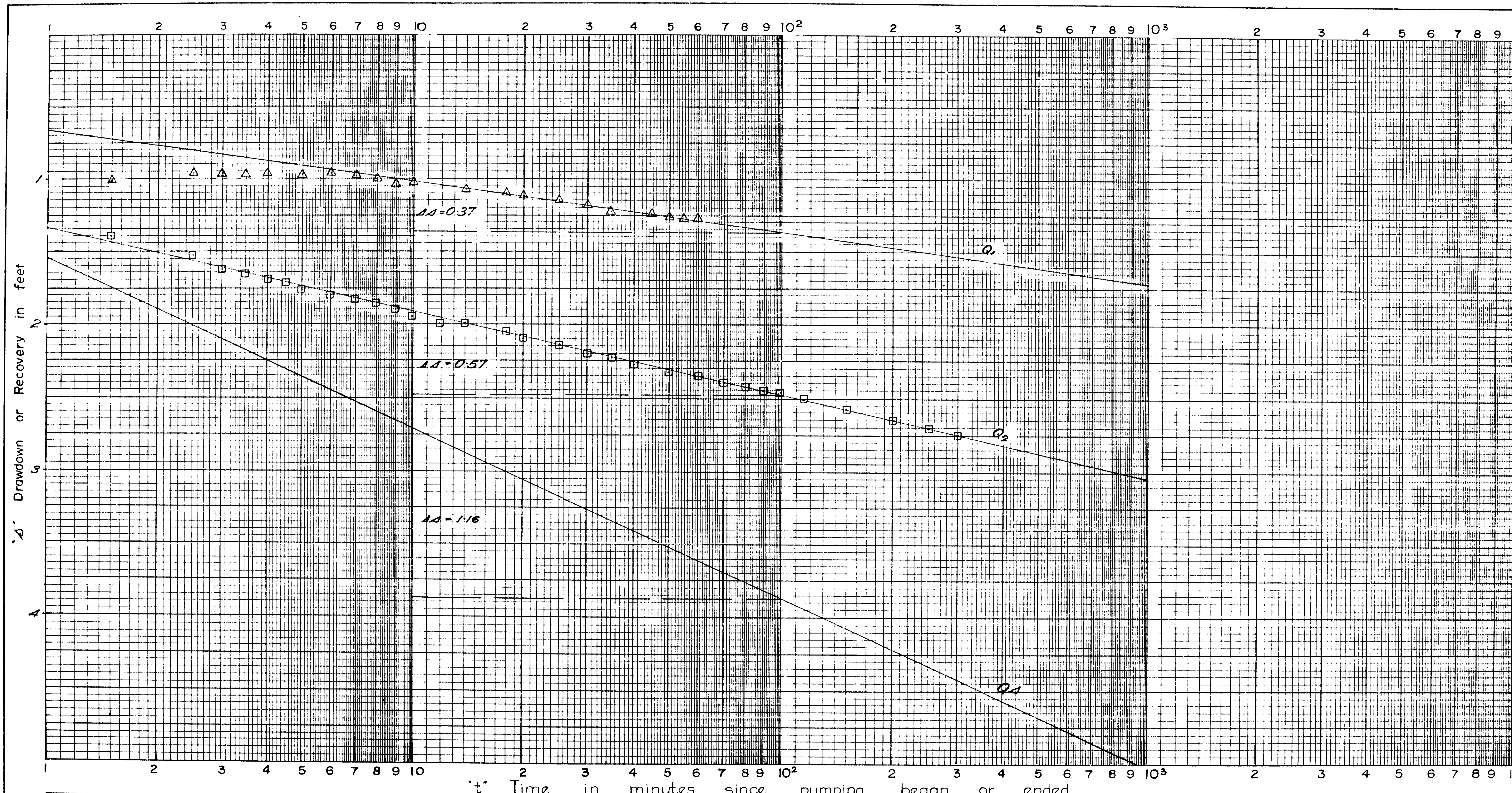
W(u, r/B) = 6·4
s = 4·25
W(u, r/B)
s = drawdown in ft.
10²
10
1
0·1
0·01
10⁻¹
1·0
10
10²
10³
10⁴
10⁵
10⁶
10⁷
time in minutes
t
1/u = 10³
t = 3300
Type Curve
Type Curve
r = 80 Q = 7.2 gall./m. = 1·9 cusec Aquifer thickness = 19 ft
From graph s = 4·25 W(u) = 6·4 t = 3·3×10³m = 6×3·3×10⁴sec u = 10⁻³
T = Q/4πs w(u) = 1·9 × 6·4 / 4 × π × 4·25 = 2·27 × 10⁻¹ ft²/sec
s = 4Tut/r² = 4 × 2·27 × 10⁻¹ × 10⁻³ × 6 × 3·3 × 10⁴ / 6·4 × 10³ = 2·8 × 10⁻²
S.A. DEPT. OF MINES
POLDA BASIN
Hd SQUIRE SEC.19
OBSERVATION BORE 7C
DRAWDOWN CURVE
Serial Nº 061164
65-46
Dd 2/4
G.M. 27.1.65



10^2
10
1
0·1
0·01
$W(u^r/B) = 6·2$
$s = 3·7$
$W(u, r/B)$
s = Drawdown in ft
10^{-1}
1·0
10
10^2
time in minutes
10^3
t = 8·6 × 10^2
$1/u = 10^3$
10^4
10^5
10^6
10^7
Type Curve
type curve
r = 40ft. Q = 712 gall/m = 1·9 cusec. Aquifa thickness m = 17.
From graph s = 3·7. W(u) = 6·2. t = 860 min = 6 × 8·6 × 10^3 sec. u = 10^{-3}
$T = \frac{Q}{4\pi s} W(u) = \frac{1·9 \times 6·2}{4\pi \times 3·7} = 2·5 \times 10^{-5}$ sq ft/sec.
$s = \frac{4Tut}{r^2} = \frac{4 \times 2·5 \times 10^{-1} \times 10^{-3} \times 6 \times 8·6 \times 10^3}{1·6 \times 10^3} = 3·2 \times 10^{-2}$
S.A. DEPT. OF MINES
POLDA BASIN
Hº SQUIRE SEC. 19
OBSERVATION BORE 7B
DRAWDOWN CURVE
Serial Nº 061/64.
65 - 45
DL 2/4
G.M. 27.1.65



Type curve
Type curve
W(u, r/B) = 6.2
s = 3.5
W(u, r/B)
s in feet
t in minutes
1/u = 10³
t = 215
1/u
r = 20ft. Q = 712 gall/m = 1.9 cusec. Aquifer thickness = 16.5 ft.
From graph s = 3.5 W(u) = 6.2 t = 2.15 min. = 2.15 × 6 × 10³ u = 10⁻³
T = Q/(4πs) W(u) = (1.9 × 6.2)/(4π.3.5) = 2.8 × 10⁻¹ ft²/sec.
s = 4Tut/r² = (4 × 2.8 × 10⁻¹ × 10⁻³ × 6 × 2.15 × 10³)/(4 × 10²) = 3.6 × 10⁻²
S.A. DEPT. OF MINES
POLDA BASIN
Hd SQUIRE SEC. 17
OBSERVATION BORE 7A
DRAWDOWN CURVE
Serial Nº 061164
65 - 44
Dl 2/4
G.M. 27.1.65



OWNER Dept. of Mines ... FILE No. 1580/64
DATE OF TEST 16 Nov. 1964
TYPE OF PUMP Pomona Single Stage
STATIC WATER LEVEL R.W.L. 224·16
PUMP INTAKE SETTING R.L. 211·50
AVAILABLE DRAWDOWNS 12 ft
ANALYSIS BY C. Bleys

PUMPING RATE Q in Cu. Secs. Stage 1. 0·77 Stage 2 1·23 Stage 3 1·56 Stage 4

ADOPTED RATE OF DRAWDOWN 0·37 and 0·57 FT/LOG CYCLE AT 0·77 and 1·23 Cu. Secs.

REMARKS Drawdown log t curves for pumping rates Q_1 and Q_2

Q_s curve is from the single rate pumping test made 13 Feb 1965

S.A. DEPT. OF MINES

HYDROLOGY SECTION

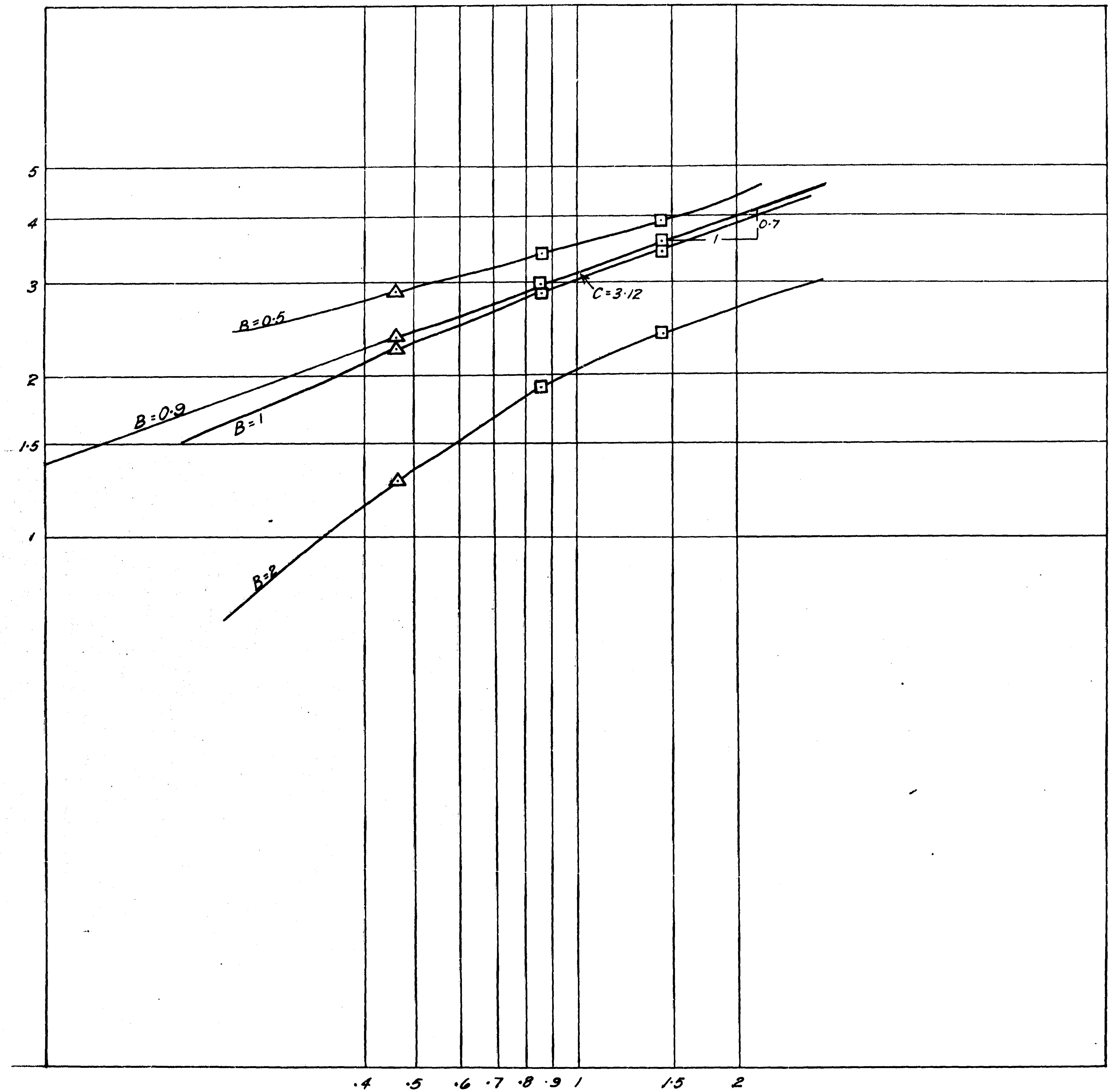
PUMP TEST ANALYSIS

P.T. 7

SERIAL No. 16116 4

SEC. 19 Hd. SQUIRE

65-43
D22/4



Rorabough Method

Stage	Q in cu sec	SW100	SW100/Q	SW100/Q − B: B=2	B=1	B=0·9	B=0·5
1	0·46	1·50	3·26	1·26	2·26	2·37	2·76
2	0·86	3·35	3·90	1·90	2·90	3·00	3·40
3	1·43	6·36	4·40	1·40	3·40	3·50	3·90

$SW100 = BQ + CQ^n$

$= 0{\cdot}9Q\ 3{\cdot}12Q^{1\cdot7}$

DEPARTMENT OF MINES — SOUTH AUSTRALIA

GRAPHIC SOLUTION OF B,C & n
RORABOUGH METHOD
P.T. BORE 4 SERIAL Nº 030365
Sec. 19 Hd. Squire

		Drn. C.B.	SCALE:
		Tcd. B.L.S.	65 - 42 D12/4
		Ckd.	
Director of Mines		Exd.	DATE: 11-8-65

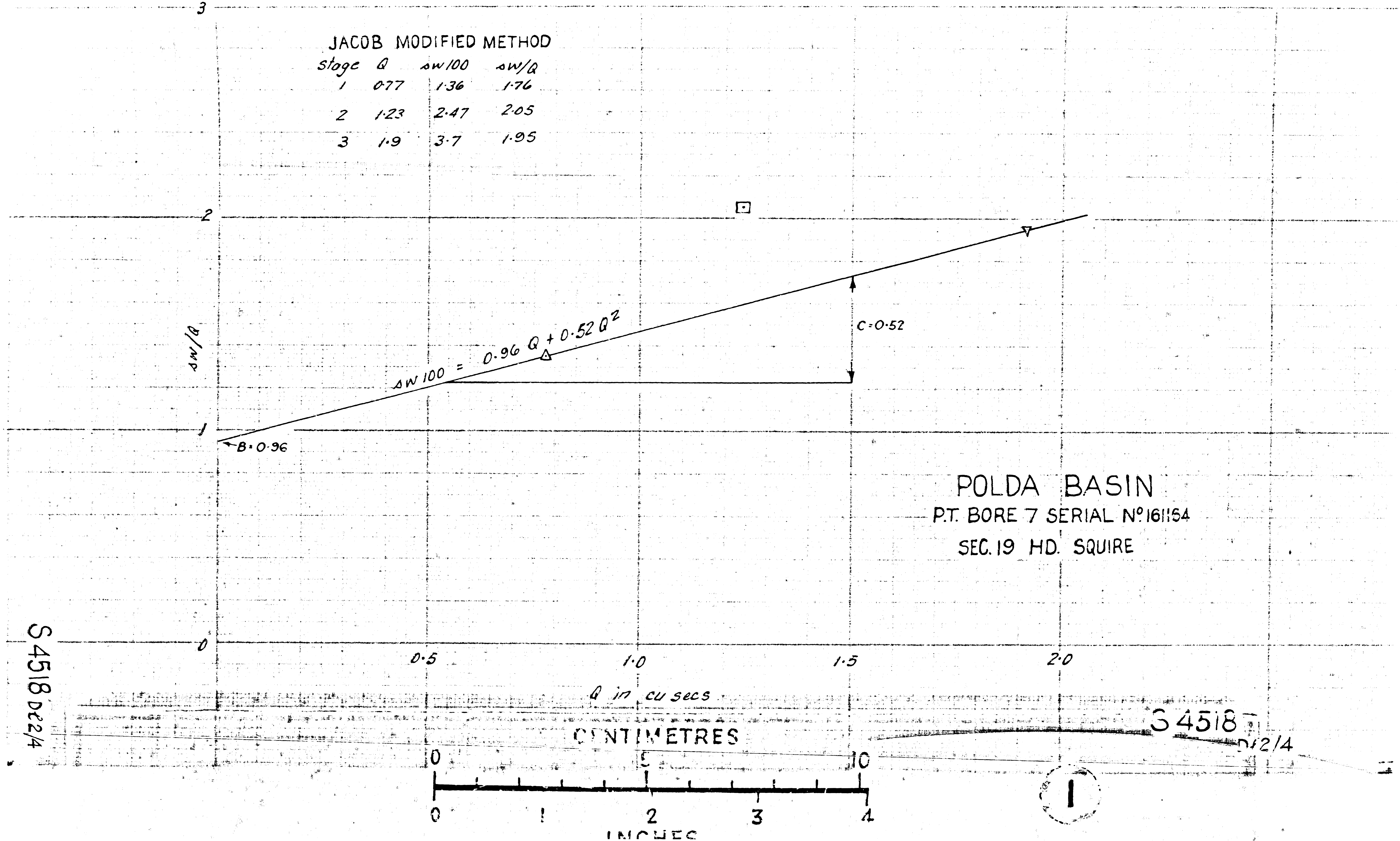
RORABOUGH SOLUTION

Stage	Q	BQ	CQ^2	ΔW 100
1	0.46	0.44	0.84	1.26
2	0.86	0.77	2.39	3.16
3	1.43	1.29	5.71	7.00

THEORETICAL DRAW-DOWN CURVES
OF
WELL LOSS & AQUIFER LOSS
P.T. BORE 4 SERIAL Nº 030365
SEC. 19 HD. SQUIRE

CENTIMETRES 5 10
INCHES 2 3 4

65-41 Pl 2/4


JACOB MODIFIED METHOD
stage Q sw/100 sw/Q
1 0.77 1.36 1.76
2 1.23 2.47 2.05
3 1.9 3.7 1.95
sw/Q
sw 100 = 0.96 Q + 0.52 Q²
C = 0.52
B = 0.96
Q in cu secs
0.5
1.0
1.5
2.0
POLDA BASIN
P.T. BORE 7 SERIAL Nº 161154
SEC. 19 HD. SQUIRE
S 4518
CENTIMETRES
INCHES