Geological Survey of Victoria

GROUNDWATER FOR GEELONG. REPORT ON THE HYDROGEOLOGICAL POTENTIAL OF THE GELLIBRAND SUB-BASIN

By ROGER BLAKE

UNPUBLISHED REPORT 1980/59

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DEPARTMENT OF MINERALS AND ENERGY

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SUMMARY

Analysis of the observation bore results from the SR & WSC pumping test in the G5 Storage basin indicate a Transmissivity in the range 290 - 360 $m^2\ day^{-1}$. This indicates an average permeability for the Wangerrip Group sands of between 6.9 to 8.6 m day^{-1}. On the basis of the Transmissivity derived from this pumping test a wellfield such as that proposed by Rose and Ife (1980) for the G5 Storage basin could yield up to 13 000 Ml in a normal six month pumping period or 20 000 Ml over a twelve month drought period.

Extrapolation of the results from the G5 wellfield to the Lardners Creek - Gellibrand River and Charleys Creek - Gellibrand River area indicate that the Gellibrand Sub-basin could yield up to 37 000 Ml over a six month pumping period and up to 57 500 Ml over a twelve month drought period. The volume which could be extracted in a normal year represents 32 per cent of the average yearly flow in the Gellibrand River at the Bunker Hill gauging station. The wellfield calculations presented here are subject to several important assumptions including the fact that only induced recharge from the Gellibrand River is considered and other potential sources of recharge are ignored.

A suitable bore design which could yield up to 10 Ml day^{-1} is presented together with a cost estimate for the G5 wellfield (excluding pipelines).

1 INTRODUCTION

A joint desk study comprising representatives of the State Rivers and Water Supply Commission, the Geelong Waterworks and Sewerage Trust and the Department of Minerals and Energy was initiated to study the groundwater resources of the Gellibrand Sub-basin. One of the reasons for initiating the study is that SR&WSC, as part of their submission to the State Parliamentary Public Works Committee Enquiry into the Gellibrand River, require estimates of the cost and likely yield of groundwater from the Gellibrand Sub-basin for the purpose of comparison with a surface water storage.

Two initial meetings of the study group were held and this report is the outcome of these initial meetings. SR&WSC presented reports to the group which included data from a pumping test in the G5 storage basin site and a discussion paper on a possible well field design in the G5 storage basin site (Ife, 1980; Rose and Ife, 1980). The GWW&ST presented data on their anticipated growth in demand and on the distribution of demand throughout the year. The Department of Minerals and Energy prepared a discussion paper primarily on infiltration capacities of the bed of the Gellibrand River (Williamson, 1980). Notes on the first meeting are included as an Appendix in this report. Much of the subject matter of this report was discussed at both meetings.

The initial analysis of the results of the SR&WSC pumping test suggested that the permeability of the aquifer sands in the G5 storage basin were only half that of the same aquifer sands in the Barwon Downs Sub-basin (Ife, 1980) and the resulting wellfield calculation (Rose and Ife, 1980) suggested much lower yields from the G5 storage basin site than would otherwise appear reasonable. Inspection of the lithologic and wireline logs from the test bores in the G5 storage basin suggested there was no geological reason why the permeability of the sands should differ from that in the Barwon Downs Sub-basin as they appeared to be from the same depositional environment. This report presents a re-analysis of the SR&WSC pumping test based on the observation bore results and concludes that the permeability of the Wangerrip Group sands is in fact the same as in the Barwon Downs Sub-basin.

In order to arrive at the possible cost of groundwater from the Gellibrand Sub-basin some estimate of the likely scale of development and total yield from the sub-basin should be made. The basic development option which the Gellibrand Sub-basin offers is the existance of a relatively permeable and porous aquifer which is in hydraulic connection with several permanent bodies of water (the Gellibrand River and Lardners, Charleys and possibly Loves Creeks). Staged developments of wellfields near or adjacent to the river and creeks could be designed to induce recharge into the aquifer. Induced recharge from the rivers whilst it is the most obvious and possibly the largest single source of additional water available, is by no means the only source of available water. The existence of an extended cone of depression into the natural intake areas will induce further recharge from these areas. The total base flow runoff from these areas which at present is derived from spring fed creeks could be diverted into a wellfield (by the extended cone of depression) and as such appear as induced recharge. The existence of an extended cone of depression beneath the presently regarded confining beds will similarly induce leakage from these beds. Most of the natural infiltration to the aquifer in the intake areas which at present discharges to the Gellibrand Sub-basin, could also be diverted into wellfields. Potentially a very large volume of water is available for development.

One way of estimating the volume of water which may be developed is to simplify the analysis into just that of a hydraulic connection between an aquifer and a permanent source of water (the river). The hydraulics of the aquifer and the feasible rates of extraction then become the limiting factors on the amount of water which can be economically developed. A computer program is available (Blake, 1978) in which recharge from a river can be modelled using 'Image Well' theory. The effects of altering various conditions such as aquifer properties, pumping rates and times for possible wellfield layouts can be examined. This was done for the possible wellfield layout in the G5 storage basin proposed by Rose and Ife (1980) and the results are discussed and tabulated.

On the basis of the results of the wellfield calculations a suitable Production bore design is presented which could yield between 8-10 Ml day^{-1} at the allowable drawdown. A cost estimate for the bore is presented for the purpose of costing groundwater from the Gellibrand Sub-basin.

2 GEOLOGY

Fig 1 is a geological map of the southern portion of the Gellibrand Sub-basin (the Gellibrand Sub-basin is defined in the notes in the Appendix). The main aquifers are sands within the Wangerrip Group. The Nirranda Group, Heytesbury Group and Quaternary alluvium form a barrier to direct infiltration to the Wangerrip Group where present. Fig 2 shows a breakdown of the Wangerrip Group into Formations in bore X in the G5 Storage basin.

Also shown on Fig 1 are structure contours on the top Otway Group prepared from all available bores which reach bedrock. The structure contours are necessarily tentative at this stage because of the paucity of data and are constructed in part using bores just off the area of the map. The structure contours show that the deepest part of the basin is at Gellibrand township itself which is consistent with the fact that the youngest Tertiary Formations in the area (the Clifton Formation of the Heytesbury Group) are preserved here. The structure contours also demonstrate that there is a fairly steep northerly dip in the basin which gives it the form of a half-graben. This is similar to the Barwon Downs Sub-basin to the northeast which is also a half-graben. Most of the mapping for Fig 1 was done during the Barwon Downs investigation at about the time the DM&E bore Yaugher 19 was drilled.

3 ANALYSIS OF PUMPING TEST IN THE G5 STORAGE BASIN

3.1 General Comments on the design of an aquifer test

Results from the observation bores X_1 and X_2 are analyzed here to determine the aquifer properties in the G5 storage basin site. Ife (1980) analyzed only the pumping bore results and as observation bore results are more reliable than those of a pumping bore these are analyzed here.

The SR&WSC test in the G5 storage basin was an unconventional test both from the point of view of design of bores, conducting of the test and analysis of the results. The following general observations can be made on the purpose of aquifer testing.

3.1.1 Observation Bores

Pumping tests can be performed to determine the Transmissivity, permeability and Storage Coefficient of an aquifer. Observation bores are drilled primarily because flow in the region of the pumping bore is non-laminar and turbulent. For this reacon the Storage Coefficient cannot be determined from pumping bore results alone.

3.1.2 Constant Rate Tests

Long-term constant rate tests are used to determine the type of aquifer, the presence of permeability boundaries or factors such as leakage. The presence of boundaries or leakage are determined by departures of the actual drawdown curve from the ideal curve generated by a long-term constant rate test.

3.1.3 Aquifers Tested

Aquifers with a different response (e.g. confined and unconfined) should not be tested in the same pumping bore. If the aquifer type is unknown observation bores should be constructed and tested prior to the pumping bore in order that decisions can be made on which aquifer to test in the pumping bore.

3.1.4 Distance-Drawdown Analysis

At least one Observation bore should test all of the sands which are tested in the pumping bore. This is because individual sands may have different permeabilities and the Pumping bore draws water from each sand tested. The drawdown results therefore give only an average Transmissivity for the entire sequence of sands tested. Piezometer bores testing individual sands should at least test the same sand as tested in the pumping bore. Piezometer bores are useful in determining head differences which exist within the aquifer but should not be used to the exclusion of observation bores testing the entire sequence of sands. If two or more fully penetrating observation bores exist at different distances from the pumping bore the Transmissivity and Storage Coefficient for an aquifer can be determined independently from Distance-Drawdown plots.

3.2 Analysis of Observation Bore Results

3.2.1 Plotting the Data

Time-drawdown results for the pumping bore X and observation bores X_1 and X_2 were stored on magnetic tape on an HP 9815A desktop computer. The data can be replotted for analysis in two different ways either as Log-log time-drawdown curves for analysis by the Theis curve matching technique or as semi-log plots for analysis by the Jacob straight tine method.

3.2.2 Results

Figures 3 and 4 are Log-Log plots of Time vs. Drawdown for bores X_1 and X_2 and figures 5, 6 and 7 are Semi-Log plots for bores X, X_1 and X_2. Also shown on figure 8 is a Distance-Drawdown plot for bores X_1 and X_2.

The plots were analyzed using both the Theis curve matching technique and the straight line method and the results are summarised in Table 1.

Table 1. Summary of Pumping Test Results

	Theis method		Jacob method	
	T (m^2 day^{-1})	S	T (m^2 day^{-1})	S
X	N.C.	N.A.	148	N.A.
X_1	N.C.	N.C.	290	0.04
X_2	324	2.7×10^{-3}	360	1.8×10^{-3}

N.A. Not applicable

N.C. Not calculated

The Theis curve match was not possible on bore X_1 because there was insufficient early data available to obtain a match before leakage occurred.

One of the initial problems in analyzing the test was in deciding whether the three short step drawdown tests performed during the first 40 minutes of the test significantly affected the results. Inspection of the drawdown results showed that drawdown did not occur in the observation bores until at least one hour after pumping

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LLOG-LOG PLOT OF DRAWDOWN
VS TIME

PROJECT GWW + ST
LOCATION Gellibrand Sub-basin
AQUIFER TESTED Dilwyn Formation
FROM: 30 m TO 33 m
REMARKS

PAARISH Yaugher
SHEET 7620 OTWAY 1:100 000
CO-ORDS 724 500 5 733 200
OBSERVATION BORE/~~PUMPING BORE~~

GEOLOGICAL SURVEY OF VICTORIA
GROUNDWATER SECTION:
ANALYZED BY: R. Blake
TAPE: 9 FILE: - 44

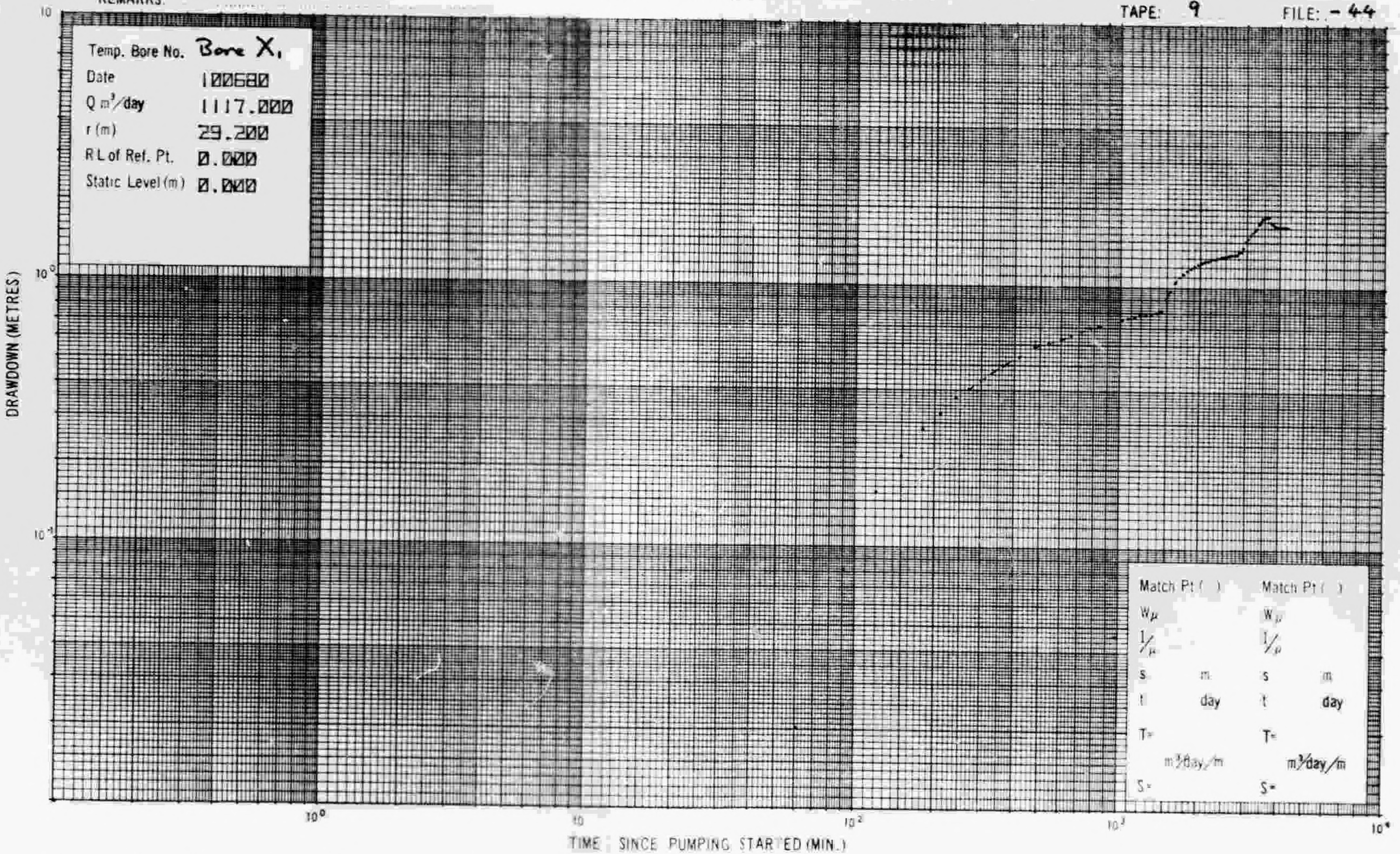

Fig. 3 Log-Log Plot of Time vs Drawdown for bore X_1

LLOG-LOG PLOT OF DRAWDOWN
VS TIME

PROJECT GWW + ST
LOCATION Gellibrand Sub-basin
AQUIFER TESTED Pebble Point Formation
FROM 52 m TO 58 m
REMARKS

PAARISH Yaugher
SHEET 7620 OTWAY 1:100 000
COO-ORDS: 724 500 5733 200
OBSERVATION BORE/~~PUMPING BORE~~

GEOLOGICAL SURVEY OF VICTORIA
GROUNDWATER SECTION:
ANALYZED BY: R. Blake
TAPE: 9 FILE: -45

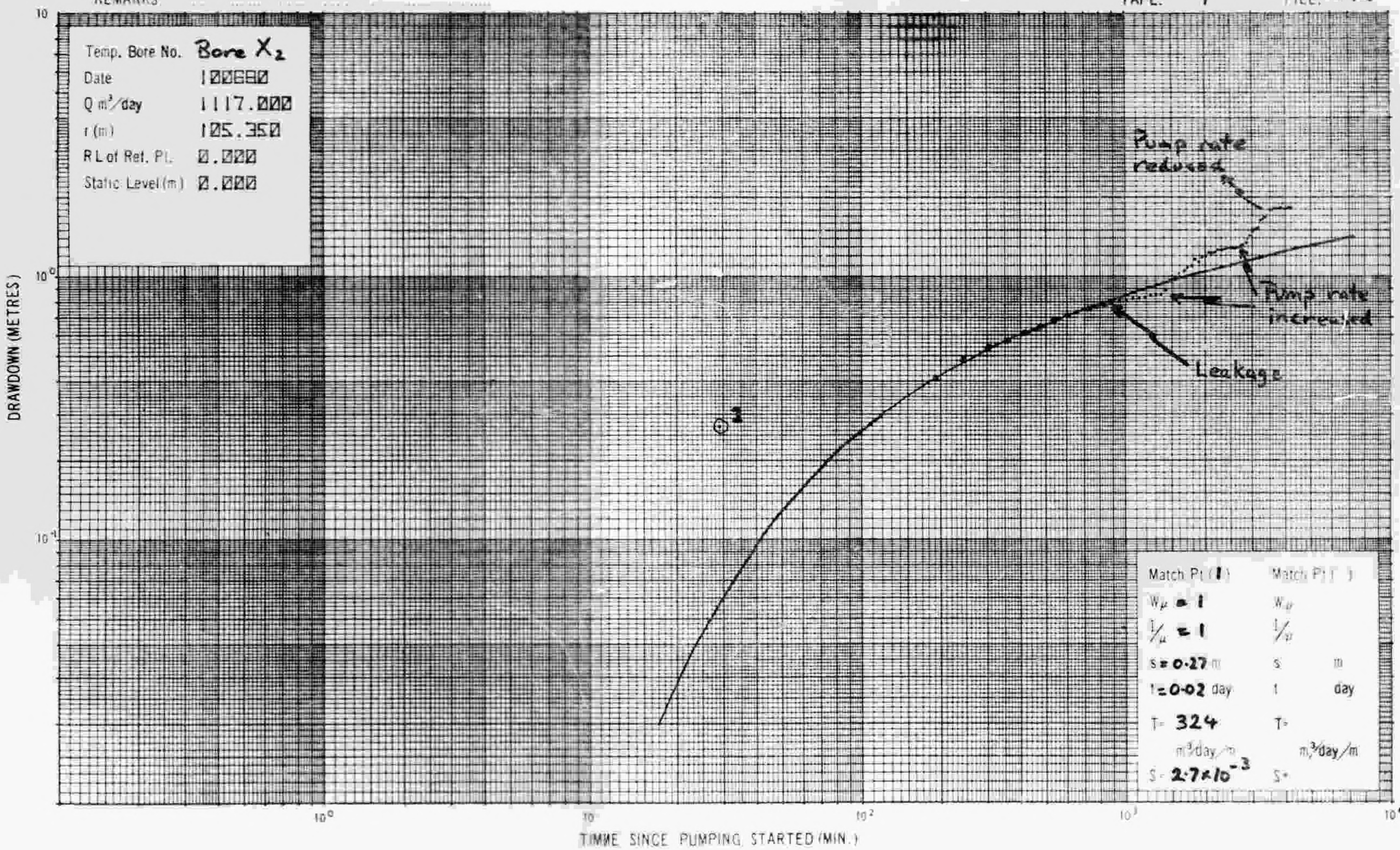

Fig. 4 Log-Log Plot of Time vs Drawdown for bore X_1

began so it was decided that the first 40 minutes may not significantly have affected the test. The test was therefore analyzed as a constant rate test pumping for 23 hours (the time of the next pumping rate change) at a rate of 1117 m^3 day^{-1}.

To further test the assumption that the first three step drawdown tests did not significantly affect the results the following assumption was made. If we apply the principle of superposition to a step drawdown pumping test each increase in pumping rate is equivalent to another bore at the pumping bore site beginning pumping at a rate equivalent to the increment by which the pumping rate was stepped up at the time at which the rate was increased. It is possible therefore to calculate the drawdown curve at each observation bore using the appropriate T and S in the Theis equation to drawdown and the principle of superposition. This was done for both observation bores and the results plotted with due allowance made for the first three step-drawdown tests. As can be seen the calculated curves (crosses) on Figs 6 and 7 agree closely with the actual drawdown curves (points) so it can be safely concluded that the T and S calculated are those for the aquifer and that the three short step drawdown tests did not affect the results.

Fig 5 is a semi-log plot for the pumping bore. Application of the Jacob method to the first ten minutes yielded a T = 148 m^2 day^{-1} (note the bore began pumping at 645 m^3 day^{-1}). However ten minutes is far too short a time for the pumping bore to settle down and produce reliable results on a constant rate test and the result must be considered unrepresentative.

3.2.3 Leakage

In Fig 5 the drawdown curve in the pumping bore departs from the straight line in a leaky fashion after about 330 minutes. The departure is observed at about 500 minutes in X_1 and 800 minutes in X_2. Calculation of the drawdown at the river shows there is insufficient drawdown at this distance

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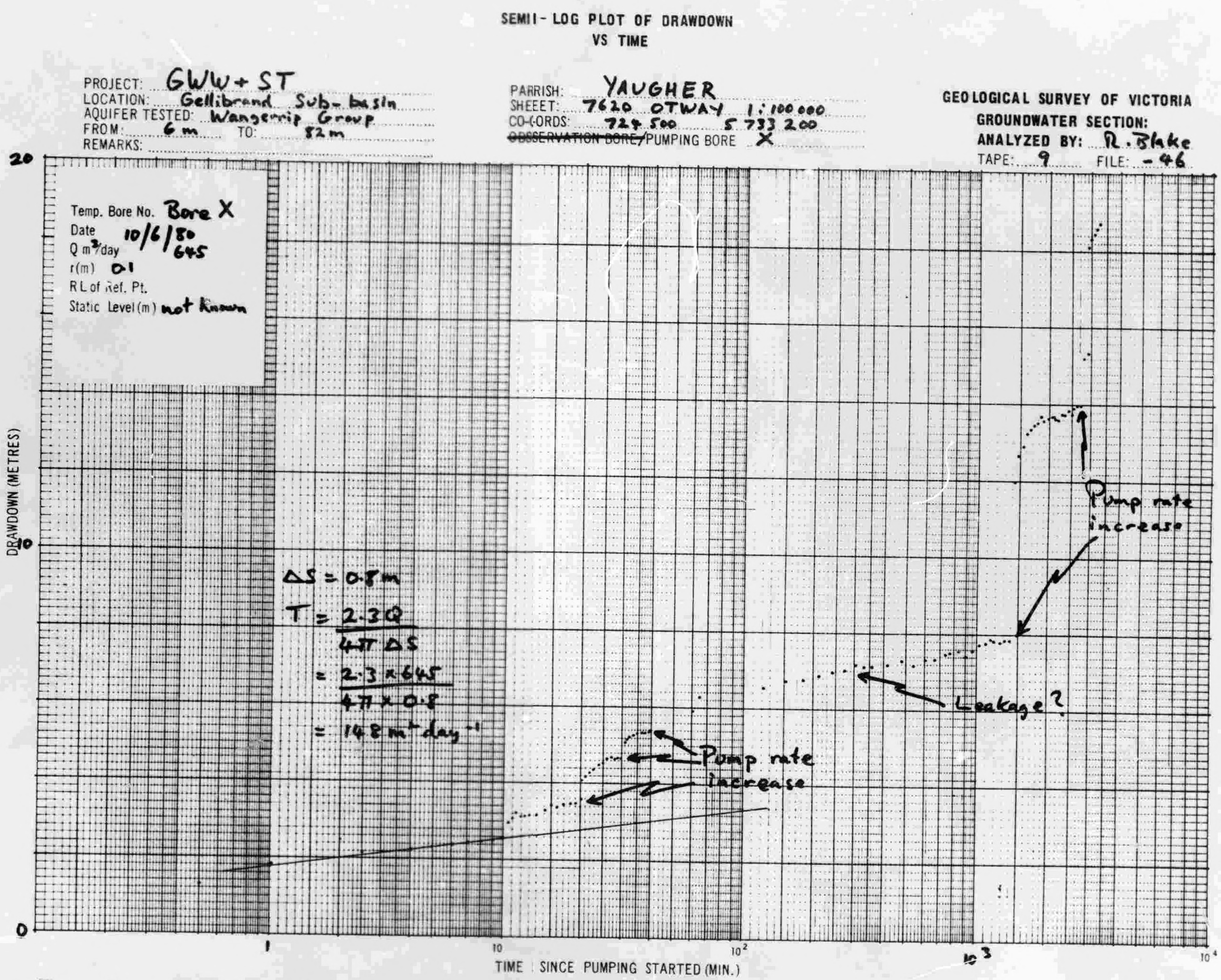

Fig 5 Semilog Plot of Time vs Drawdown for bore X

after 330 minutes of pumping for the departure to be due to a recharge boundary. The most probable explanation is that the pumping test encountered leakage either from overlying or underlying sediments. An alternative explanation is that the pumping rate dropped off but as this is not recorded on the data sheets this is assumed not to be the case.

3.2.4 Permeability of the Sands

SR&WSC estimated a total of 42 m of sands in the pumping bore (Ife, 1980) and if we accept a T in the range 290 to 360 m^2 day^{-1} this indicates a permeability of 6.9 to 8.6 m day^{-1}. This is in very good agreement with the permeabilities obtained for the same sequence of sands in the Barwon Downs Sub-basin of 6.8 to 9.8 m day^{-1} (Blake, 1978). It should be noted that the permeability calculated is directly dependent upon the estimate of the proportion of sands to shales.

3.2.5 Storage Coefficients

Table 1 shows quite different Storage Coefficients obtained for bores X_1 and X_2. This is probably explained by the fact that X_1 and X_2 test different sands (Fig 2).

The result for X_1 indicates a storage coefficient of 0.04, i.e. in the range of a semi-unconfined aquifer. Inspection of the γ ray log for bore X (Fig 2) shows this to be a reasonable result as there are minor confining beds above the sand tested by X_1 within the Dilwyn Formation. However care should be exercised in interpreting S for X_1 because the sand tested by X_1 was not actually tested in the pumping bore. In this case flow lines will not be horizontal in the sand tested by X_1 but will diverge both upwards and downwards towards the actual sands tested. Whilst this may not affect the rate of drawdown in X_1 (and therefore Δ s and the calculation for T) the absolute value of the drawdowns (and hence S) will be reduced. This could also be an explanation for the unusual Distance-Drawdown result (see below).

The Storage Coefficient calculated for X_2 of $\approx 2 \times 10^{-3}$ is at the upper end of the range for confined aquifers. This is consistent with the stratigraphic position of the test interval of X_2 which is in the Pebble Point Formation. In Fig 2 the test interval is horizontally opposite the Pember Mudstone but, because of a northerly dip between X_2 and X, the test interval in X_2 is actually within the Pebble Point Formation below the Pember Mudstone. In the vicinity of the test location the Pebble Point Formation is confined by the Pember Mudstone.

3.2.6 The later data

From 23 hours onward the pumping rate was stepped up in four successive steps and then reduced in one final step. Because the test was not a constant rate test for the entire 72 hours it is not really possible to accurately estimate whether the leakage initiated after about five hours continued for the full test or if boundaries were encountered. However by treating the later step-drawdowns as if they were also produced by incremental pumping bores the drawdown curves for the later part of the tests could also be calculated and compared with the actual drawdown curves. As can be seen there is a fairly good match for both bores on Figs 6 and 7.

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SEMI - LLOG PLOT OF DRAWDOWN VS TIME

PROJECT: GWW + ST
LOCATION: Gellibrand Sub-basin
AQUIFER TESTED: Dilwyn Formation
FROM: 30 m TO: 33 m
REMARKS:

PARISH: Yaugher
SHEET: 7620 OTWAY 1:100 000
CO-ORDDS: 724 500 5733 200
OBSERVATION BORE/~~PUMPING BORE~~

GEOLOGICAL SURVEY OF VICTORIA
GROUNDWATER SECTION:
ANALYZED BY: R. Blake
TAPE: 9 FILE: -44

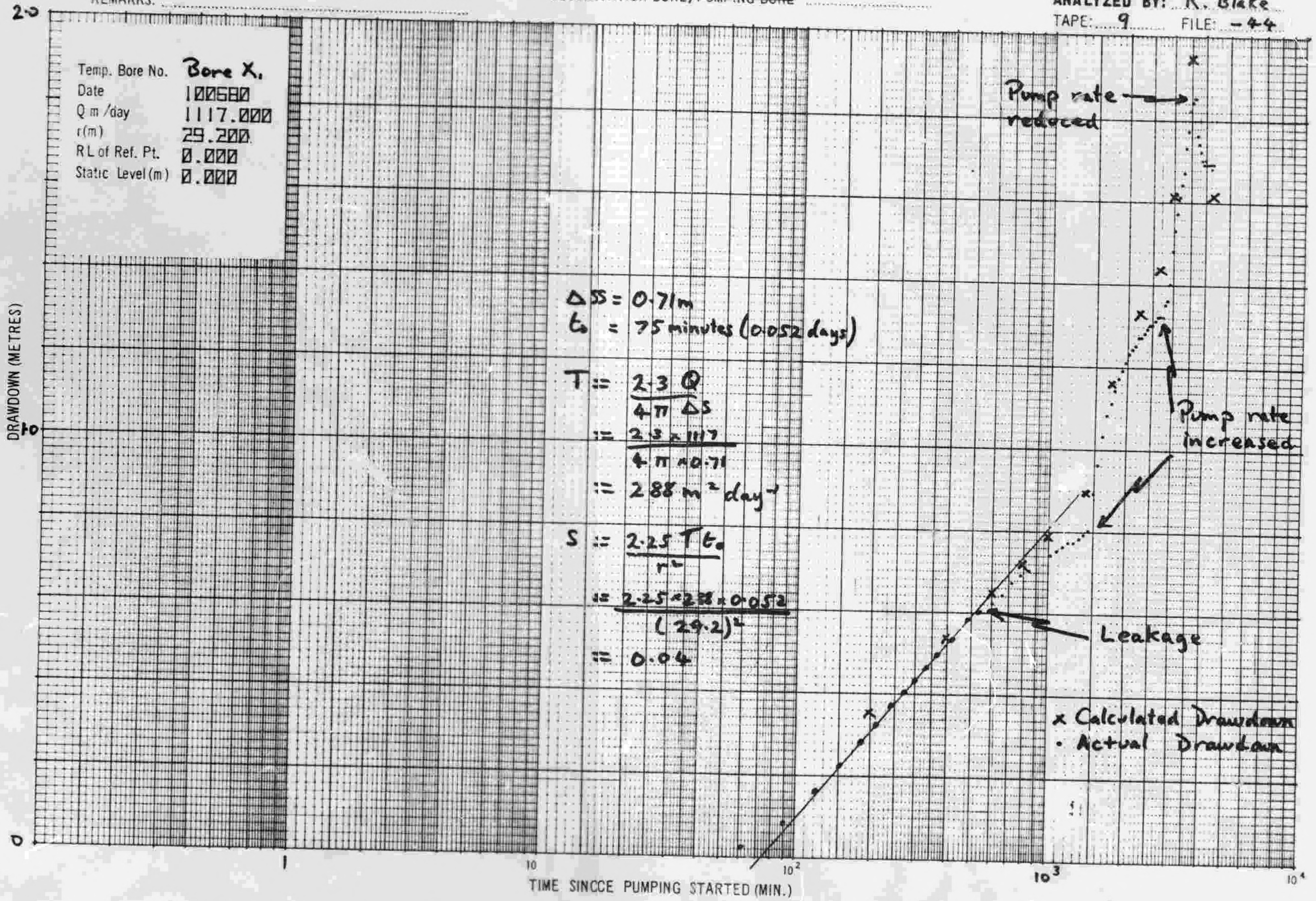

Fig. 6 Semilog Plot of Time vs Drawdown for bore X1

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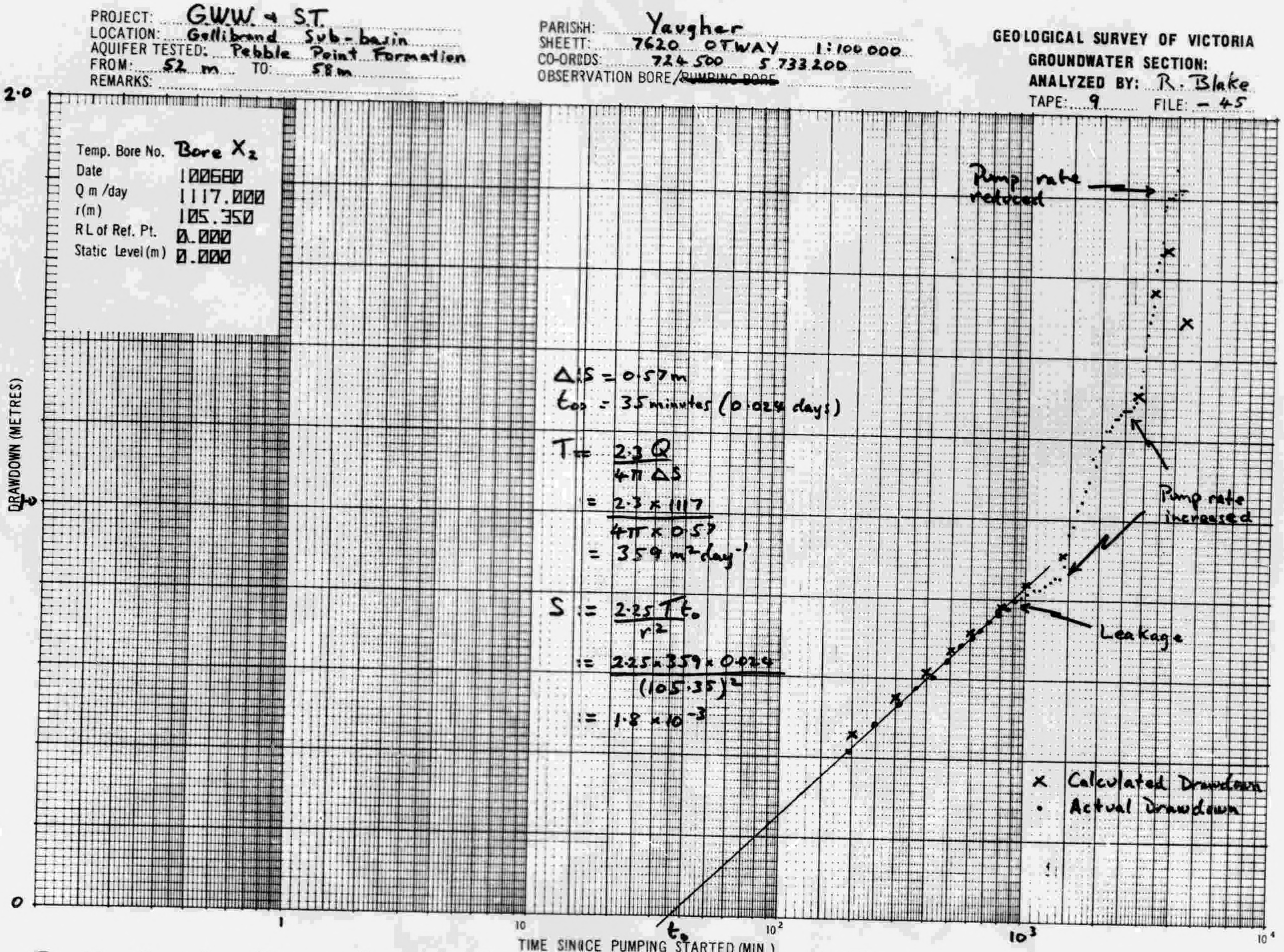

Fig. 7 Semilog Plot of Time vs Drawdown for bore X_2

For X_1 the actual drawdowns are less than the calculated drawdowns which quite definitely suggests that no discharging boundaries were encountered and probably suggests leakage continued throughout the test. A better match was obtained for X_2 which indicates that X_2 behaved more ideally. However towards the end of the test the observed drawdowns in X_2 are greater than the calculated drawdowns which suggests either a discharging boundary or leakage from the aquifer. This is particularly apparent at the end of the test when the pumping rate was reduced. The water level in X_2 instead of recovering as it should (cf X_1) actually continued to fall. This is a most unusual result and the most probable explanation is that towards the end of the test the Pebble Point Formation was leaking upwards into the overlying Dilwyn Formation. For this to occur the drawdown in the sands immediately above the Pember Mudstone must be greater than the drawdown in the Pebble Point Formation. Upward leakage, through the Pember Mudstone, would continue until the original head difference was restored. It should be noted that even at equilibrium prior to the test leakage must occur from the Pebble Point Formation into the Dilwyn Formation because the initial head difference is higher in the lower aquifer. The rate of leakage is governed by the vertical permeability of the Pember Mudstone. The pumping test would simply accelerate the rate of leakage by drawing more water from the Dilwyn Formation than from the Pebble Point Formation.

3.2.7 Distance-Drawdown Plots

Fig 8 is a Distance-Drawdown plot for X_1 and X_2. The most obvious feature of the plot is that the slope of the lines are the reverse of that expected i.e. drawdown is greater closer to the pumping bore. If extrapolated to the pumping bore this leads to the quite unrealistic result of a zero drawdown after four hours pumping. The most probable explanation for this unusual result is that X_1 and X_2 test different sands. Such a result is possible if the sand tested by X_2 has a lower permeability than X_1. In this case for a given volume of extraction, Q, from each sand, drawdown is greater in the bore of lower permeability.

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SEMI-LOG PLOT OF ~~DRAWDOWN VS TIME~~ DISTANCE-DRAWDOWN.

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PROJECT: GWW + ST
LOCATION: Gellibrand Sub-basin
AQUIFER TESTED: Wangerip Group
FROM: 6m TO: 82 m
REMARKS:

PARRISH: Yaugher
SHEEET: 7620 OTWAY 1:100000
CO-OORDS: 724 500 5 733 200
OBSEERVATION BORE/~~PUMPING BORE~~ X_1 and X_2

GEOLOGICAL SURVEY OF VICTORIA
GROUNDWATER SECTION:
ANALYZED BY:
TAPE: FILE:

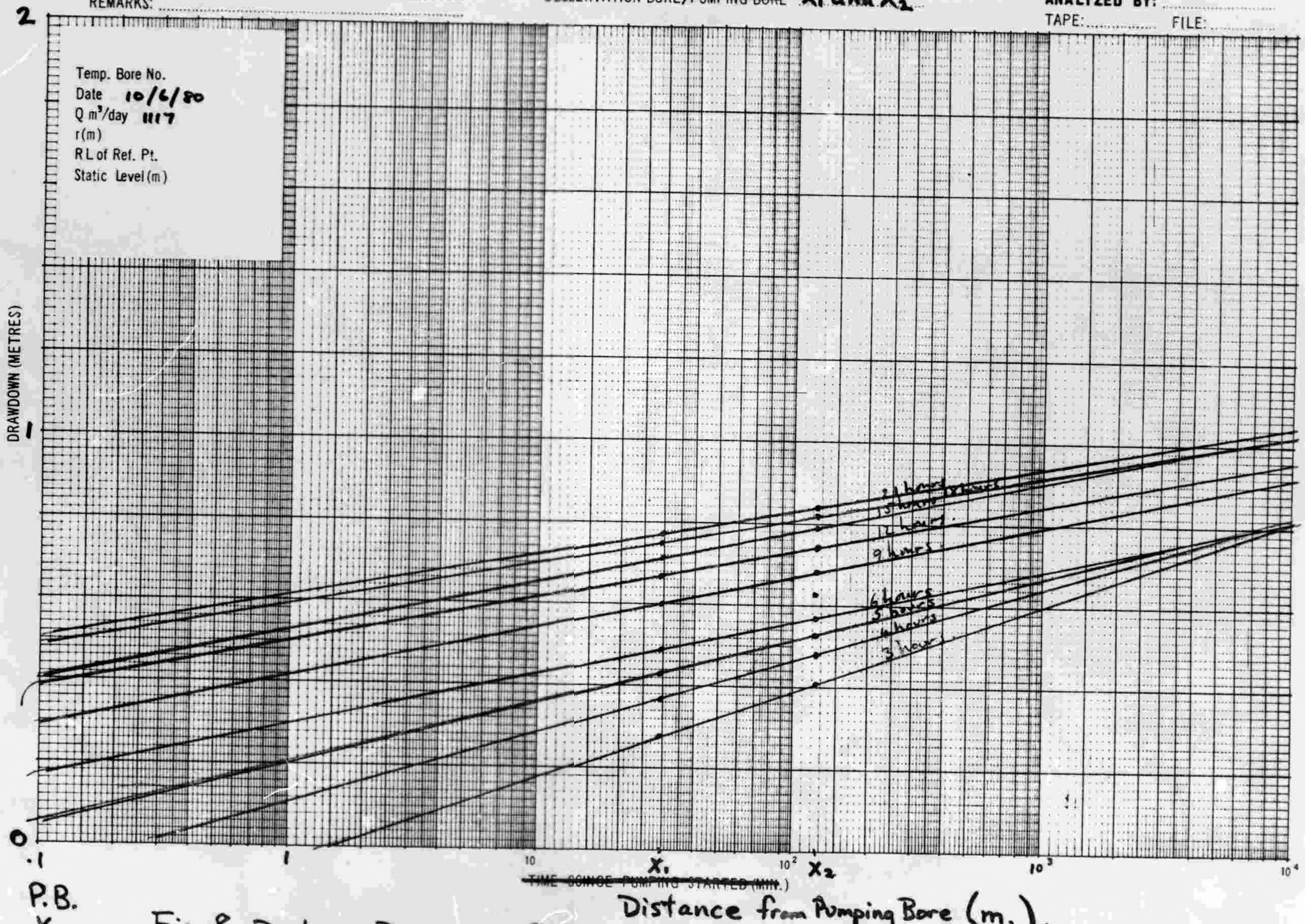

Fig. 8 Distance-Drawdown Plott for bores X_1 and X_2

Alternatively the fact that the pumping bore does not actually test the same sand as tested in X_1 (see above 3.2.5) could mean that the drawdown in X_1 is less than it should be.

Whatever the explanation the Distance-Drawdown result is a good demonstration of the need for observation bores testing all of the same sands as are tested in the pumping bore.

3.3 Conclusion

The Wangerrip Group sands in the Gellibrand Sub-basin, as tested by bore X, yielded a Transmissivity in the range 290-360 $m^2\ day^{-1}$. This yields permeabilities for the sands which are the same as those in the Barwon Downs Sub-basin.

At the test site the sands of the Dilwyn Formation indicate a Storage Coefficient of 0.04 i.e. a semi unconfined aquifer, and the sands of the Pebble Point Formation behaved as a confined aquifer with a Storage Coefficient of $\approx 2 \times 10^{-3}$.

Leakage was encountered during the test after 330 minutes in the pumping bore and observed at 500 minutes in X_1 and 800 minutes in X_2. From the behaviour of the water level in X_2 towards the end of the test it is concluded that upward leakage is initiated by pumping, from the Pebble Point Formation into the Dilwyn Formation, a result consistent with the expected behaviour of the system. This is significant from the point of view of a wellfield development at this locality because it suggests that the Pember Mudstone will act as a leaky confining bed to the Pebble Point Formation.

4 WELLFIELD DESIGN

4.1 General Comments on the Principle of Superposition in Unconfined Aquifers

Rose and Ife (1980) applied image well theorys and the principle of superposition to an initial wellfield design in the G5 Storage basin site. The following general comments relate to the applicability of superposition in unconfined aquifers such as the G5 Storage basin.

For superposition to apply the following conditions must be met.

4.1.1 Uniform Thickness

The aquifer must be of uniform thickness. If significant dewatering takes place in an unconfined aquifer (say $>10\%$) this requirement is not met. In addition to dewatering the aquifer dips up and wedges out in a southerly direction in the G5 Storage basin. Geologically therefore the basin does not meet the uniform thickness requirement.

4.1.2 Natural Infiltration

Natural infiltration (as distinct from induced recharge from the river) is spread over the entire intake area and therefore difficult to model using image wells.

4.1.3 Leakage

Leakage cannot be allowed for using image well theory. After leakage is encountered the rate of drawdown changes and the aquifer acts as if it had a higher T. In the G5 Storage basin sources of leakage include the alluvium overlying the aquifer, silts and clays within the aquifer, the Otway Group beneath the aquifer and the Nirranda Group fine sands and silts to the north of the river.

4.1.4 Parallel Boundaries

As mentioned above (4.1.1) the aquifer does not extend a large distance to the south. In a strict sense the problem should be treated as a parallel boundary problem i.e. a recharge boundary to the north and a discharge boundary to the south. In this case the use of image well theory is an iterative process i.e. each image well has an image well of its own and so on. In a wellfield with a large number of bores this leads to an unmanageable number of calculations.

4.2 Digital Aquifer Model

4.2.1 Variable and Minimum Streamflows

It should be appreciated that the use of image well theory in the G5 Storage basin is a very simplistic approach to the problem. The method is really only amenable to calculating the drawdown in bores pumping adjacent to a constant head recharge source such as a lake or river. The method is not amenable to solving problems such as variable infiltration capacities in the bed of a river, variable flows in a river (including maintenance of minimum flows) or variable natural infiltration. Such problems can only be tackled using a digital aquifer model.

4.2.2 Hydrogeological Investigation

To solve questions such as the above a detailed hydrogeological investigation should be undertaken to establish

i) The distribution and thickness of the Wangerrip Group and overlying sediments

ii) The variability in aquifer parameters

iii) The present groundwater flow configuration

iv) Streambed infiltration capacities

v) The variation in climatically influenced factors such as rainfall, streamflow and baseflow.

Data from such an investigation could be used as input to a digital aquifer model in which all of the factors which will affect the location and design of wellfields could be allowed for.

4.3 Practicality of Designing Wellfields at this stage

For the above reasons considerable reservations are held on the practicality of designing a wellfield at this stage on the basis of the presently available data and on the applicability of image well theory to this particular case. However, as mentioned in the introduction SR&WSC need data on the groundwater resources of the Gellibrand Sub-basin for the purposes of comparison with a large surface water storage. An attempt is therefore made here to estimate the likely yield from a wellfield such as that proposed by Rose and Ife (1980) but the reservations expressed here should be borne in mind.

4.4 Wellfield Program

A computer program is available (Blake, 1978) in which a wellfield can be modelled using image well theory to allow for boundary effects, and which uses the principle of superposition. Input to the program includes the T and S of the aquifer, radius and well constant of the pumping bores (if required) and the pumping rate and metric coordinates of each bore. The program calculates the drawdown at each bore and the drawdown caused by interference of every other bore and plots the result adjacent to the position of the appropriate bores.

For a confined aquifer in which the aquifer is relatively large in extent the program probably gives quite reasonable results. For an unconfined aquifer however superposition does not strictly apply as mentioned above (4.1.1) if significant dewatering is achieved in practice.

4.4.1 Assumptions made in the Wellfield Calculations

The following assumptions were made in the wellfield calculations.

i) The aquifer is of uniform thickness (i.e. the same T in all directions) and infinite in extent. The probable discharge boundary to the south was not allowed for.

ii) Infiltration was ignored. There is probably somewhere between 2-4000 Ml $year^{-1}$ available from present direct infiltration not allowed for in the wellfield calculations. This figure would be higher when the cone of depression moves into the intake area. The only source of recharge considered was the induced recharge from the Gellibrand River and, when taken into account, the induced recharge was considered to be proportional to the pumping rate.

iii) No allowance for well loss was made and the drawdown calculated is only that due to the aquifer. To allow for well loss in an 80 percent efficient well (for example) the calculated drawdowns should be increased by about 15 percent in the present wellfield design.

iv) Potential sources of leakage could not be allowed for. After leakage is encountered the aquifer acts as if it had a higher T.

The effect of i) and iii) is to underestimate the drawdowns although iii) can be allowed for and the effect of ii) and iv) is to overestimate them. No estimate of errors are made but as each of the wellfield runs are subject to the same errors (or nearly so) at least the method offers a means of comparing possible layouts, varying pumping rates and times or varying aquifer parameters. The actual drawdowns should not be taken too implicitly but the differences between various wellfield conditions are probably quite valid.

4.4.2 Conditions Modelled

As discussed above the principal advantage of the program is that the effects of changing Transmissivity, pumping rate and time on a wellfield can be compared. For the purposes of comparison the position of the bores in the wellfield were taken as the most westerly of the seven bores proposed by Rose and Ife (1980) for the G5 Storage basin, i.e. the layout was each bore 200 m from the river and 500 m apart.

The effects on the wellfield of varying the following parameters were modelled.

i) Transmissivity

Runs were made with aquifer parameters of

a) $T = 150\ m^2 day^{-1}$, $S = 0.1$
b) $T = 300\ m^2 day^{-1}$, $S = 0.1$

ii) Presence of Image Wells

For each Transmissivity runs were made assuming

a) The presence of the river
b) The absence of the river

iii) Different Times

For each pumping rate selected the wells were allowed to pump continuously for different times (e.g. six months, one year and 18 months). The effect of pumping for only six months with six month recovery would be Geelong's normal requirement whereas 18 months pumping might be a drought year requirement.

4.4.3 General Form of the Drawdown

Fig 9 shows the position of each of the pumping bores and the Gellibrand River in the G5 Storage basin. The bores are numbered from one to seven as shown for the purpose of tabulating the results.

One of the advantages of the program is that the drawdown in observation bores can be calculated simply by entering the coordinates of the observation bore and a zero pumping rate. Observation wells can be entered on a grid pattern around the wellfield and the drawdown in the aquifer contoured. Fig 10 shows a contour map of drawdown in the aquifer for the wellfield with each bore pumping continuously for six months at a rate of 5 Ml day^{-1} with a T = 150 $m^2 day^{-1}$ and an S = 0.1. The contour interval is one metre to the south of the bores and two metres between the bores and the river (because space did not allow a closer contour interval). The immediate area around each pumping bore was also not contoured because this is the steepest part of the cone of depression. The actual drawdowns at each bore are shown adjacent to the bore. The main feature to note is the asymmetry of the drawdowns caused by the proximity of the river. Between the bores and the river the cone is very steep with zero drawdown at the river. To the south however the cone is flatter and extends much further into the natural intake area. The steepest part of the cone is within 100 m or so of each bore and as such is limited to the area underneath the alluvial flats.

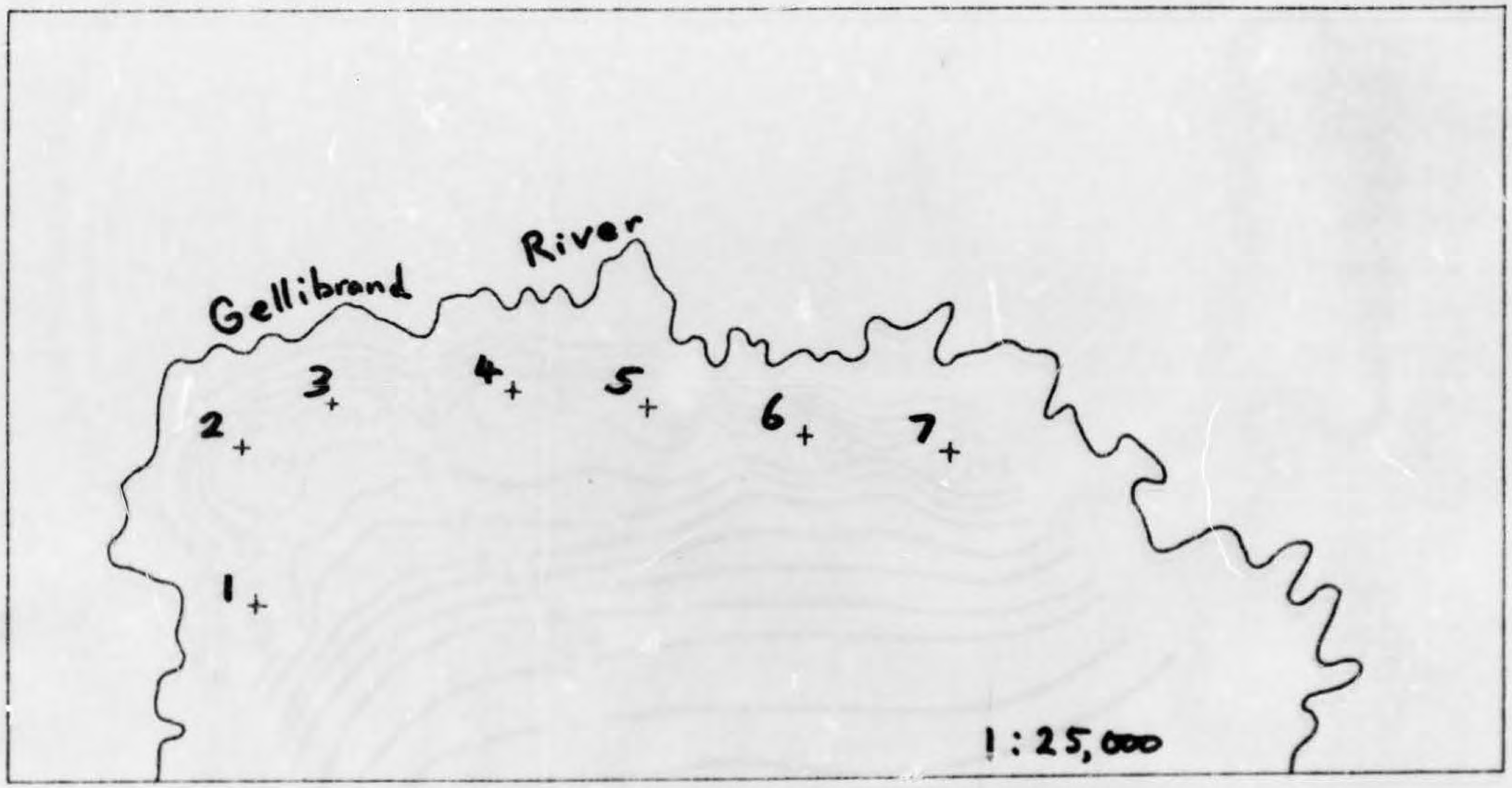

Fig. 9 Position of Pumping bores in the G5 Storage basin

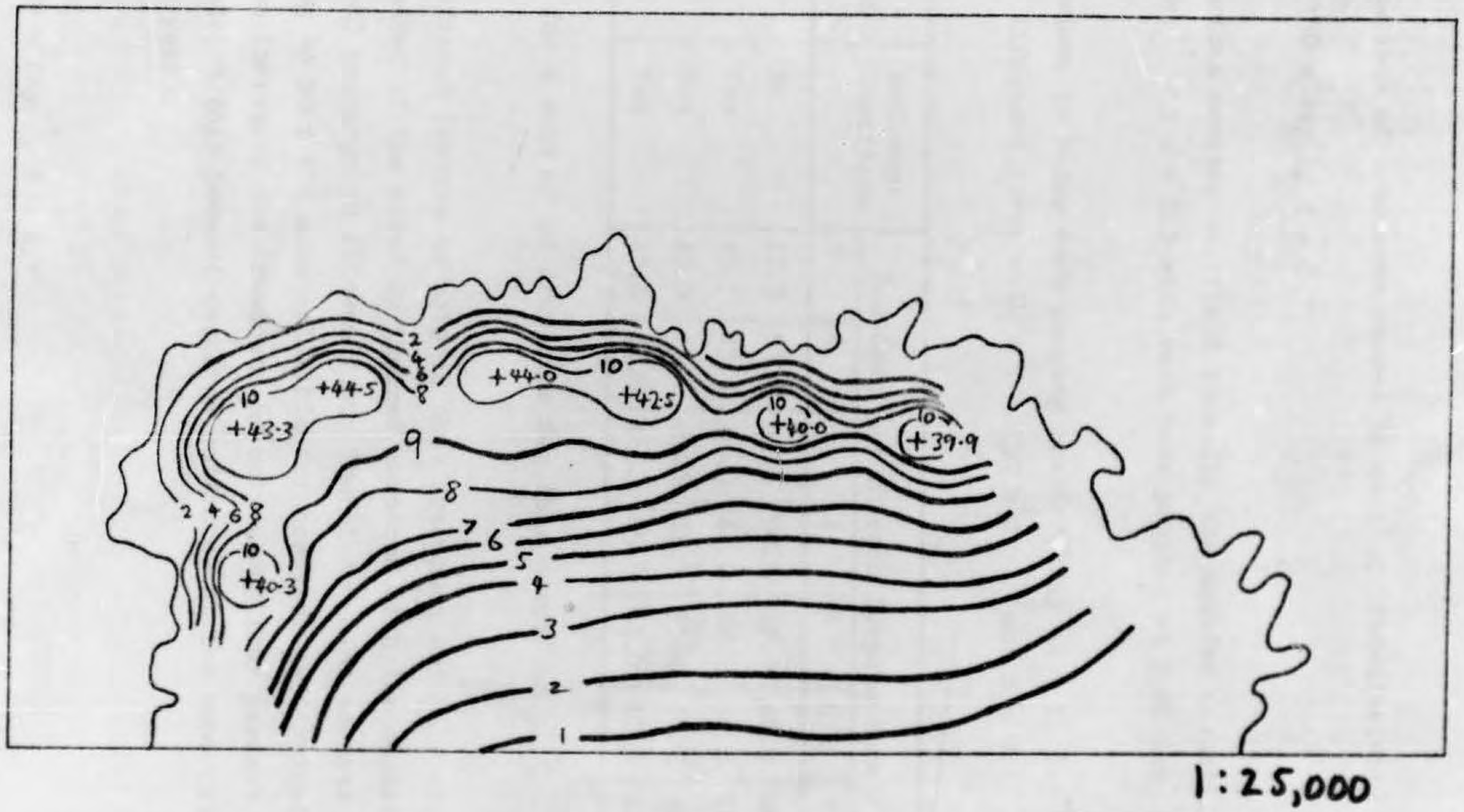

Fig .10 Contour map of drawdown in the aquifer for the wellfield with each bore pumping continuously for six months at 5 Mℓ day^{-1} with a $T = 150\ m^2 day^{-1}$ and $S = 0.1$

4.4.4 Comparison of Drawdowns caused by varying Transmissivity

i) $T = 150\ m^2 day^{-1}$, $S = 0.1$

Table 2 summarizes several wellfield runs for the aquifer assuming a $T = 150\ m^2 day^{-1}$ and $S = 0.1$ with each bore pumping at 5 Ml day^{-1}.

Table 2. Drawdown in bores each pumping continuously at 5 Ml day^{-1} for different times with a $T = 150\ m^2 day^{-1}$ and $S = 0.1$

Q_T (ML)	Time Pumped (days)	Recharge Condition	Drawdown (m) in each Pumping Bore						
			1	2	3	4	5	6	7
6300	180	No	47.3	51.3	51.6	50.1	49.9	48.8	46.2
6300*	180	Yes	40.3	43.3	44.5	44.0	42.5	40.0	39.9
9450	270	Yes	41.0	44.1	45.5	45.1	43.4	40.5	40.2
12775	365	Yes	41.6	44.6	46.2	45.9	44.0	40.9	40.4

* See Fig 10 for a contour of drawdowns for this condition.

The most significant feature to note is that drawdowns are only about 16 percent greater if the river is ignored compared with the condition in which induced recharge is allowed for. The other point to note is that continuing to pump the same wellfield for one year as distinct from six months increases the drawdowns by only about four percent (with the provision that induced recharge continues at the same rate throughout the year).

ii) $T = 300\ m^2 day^{-1}$, $S = 0.1$

Table 3 summarizes several wellfield runs for the aquifer assuming a $T = 300\ m^2 day^{-1}$ and $S = 0.1$. The effect of doubling the pumping rate from 5 Ml day^{-1} to 10 Ml day^{-1} in each bore is compared. In each case induced recharge is considered proportional to the pumping rate for the period pumped.

Table 3. Drawdowns in bores pumping continuously at 5 Ml day^{-1} and 10 Ml day^{-1} with a T = 300 $m^2 day^{-1}$ and S = 0.1

Q_{Total} (Ml)	$Q_{Each\ Bore}$ (Ml day^{-1})	Time Pumped (days)	Drawdown (m) in each Pumping Bore						
			1	2	3	4	5	6	7
6 300	5	180	20.8	22.4	23.2	23.5	22.0	20.1	20.0
12 600	10	180	41.5	44.5	46.2	45.8	44.0	40.9	40.3
25 550	10	365	42.8	45.5	47.3	47.2	45.2	41.8	40.9

The most important point to note is that doubling the Transmissivity allows a doubling of the pumping rate for virtually the same drawdown after six months (cf Table 2).

In a year of normal rainfall in which pumping would continue for six months with six months recovery it would appear from Table 3 that this particular wellfield layout could sustain a pump rate in each bore of 10 Ml day^{-1} for a total yield of 12 600 Ml in six months.

It should be noted that the wellfield calculation above relied only on induced recharge from the river and ignores natural infiltration (2-4000 Ml $year^{-1}$), other sources of induced recharge or other sources of leakage.

4.4.5 Long Periods of Continuous Pumping

In a drought year much longer periods of continuous pumping might be required. For example with the failure of one winters rainfall the wellfield might be required to pump continuously for 18 months (i.e. through one summer, winter and the following summer) before being allowed to recover. Several wellfield runs were made assumming the same T and S (300 m^2 day^{-1} and 0.1) but pumping for longer times at a reduced rate (in this case each bore at 8 Ml day^{-1} instead of 10 Ml day^{-1}). Table 4 summarizes the results.

Table 4. Drawdown in bores pumping continuously at 8 Ml day^{-1} with and without recharge for up to 18 months with a T = 300 m^2 day^{-1} and S = 0.1

Q_T (ML)	Time Pumped (days)	Recharge Condition	Drawdown (m) in each pumping bore						
			1	2	3	4	5	6	7
10 080	180	NONE	42.4	46.5	47.3	46.4	45.9	44.2	40.8
20 440	365	NONE	48.7	53.5	54.9	54.5	53.7	51.0	46.3
30 520	545	NONE	52.9	58.1	59.7	59.6	58.7	55.5	50.1
10 080	180	WITH	33.2	35.8	36.9	36.7	35.2	32.7	32.3
20 440	365	WITH	34.2	36.4	37.8	37.7	36.2	33.5	32.7
30 520	545	WITH	34.7	36.7	38.2	38.1	36.6	33.9	33.0
10 080	180	HALF	37.9	41.1	42.1	41.6	40.6	38.5	36.6
20 440	365	HALF	41.5	45.0	46.4	46.1	45.0	42.2	39.5
30 520	545	HALF	43.8	47.4	49.0	48.9	47.7	44.7	41.6

It would appear that even with induced recharge reduced by half the wellfield could sustain continuous pumping for a period of 18 months with each bore pumping at 8 Ml day^{-1} equivalent to a total annual extraction of 20 440 Ml. At the end of 18 months the aquifer would be allowed six months to recover but there would be a deficit in the aquifer of 15 260 Ml (cf a normal year) which the aquifer would have to make up by induced recharge from the river and other sources in this time.

4.4.6 Conclusion

A wellfield could be designed for the G5 Storage basin to yield up to 13 000 Ml $year^{-1}$ over a six months period. This is dependent upon an average aquifer Transmissivity of 300 m^2 day^{-1} and Storage Coefficient of 0.1. The wellfield calculations above relied only on induced recharge from the river and ignored all other sources of recharge.

The wellfield layout tested here is fairly arbitrary and one which would simply supply the desired volume of water. Different layouts may result when other factors such as infiltration, leakage, artificial recharge or minimum stream flow requirements are taken into account. No allowance is made here for environmental factors such as maintenance of minimum river flows for two reasons:

i) There is insufficient data on factors such as streambed permeabilities available.

ii) The method is not really amenable to such calculations anyway.

For the purpose of costing a groundwater scheme in the G5 Storage basin it may be preferable to consider the conditions under which the wellfield would have to operate in a drought year as well as the case for a normal year. In a drought up to 30 000 Ml could be pumped over an 18 month period but the initial rate of 13 000 Ml in six months could not be sustained. In the case of a drought water is actually withdrawn from storage in the aquifer for the period of the drought.

Individual pumping bores could be equipped with pumps of either 8 Ml day^{-1} capacity or 10 Ml day^{-1} capacity. If 8 Ml day^{-1} capacity pumps were installed the volume of water pumped over a six month period would drop to 10 000 Ml (cf 10 Ml day^{-1} pumps) but the drought capacity would remain the same.

5 PUMPING BORE DESIGN AND COST

5.1.1 Yield

For the purpose of bore design a yield of 8-10 Ml day^{-1} per bore with a pump setting 55 m and total pumping head of 80 m is assumed (the total pumping head is dependent upon the location of a main pumping station on the pipeline).

5.1.2 Pump Size

The diameter of the bore is governed by the size of a pump required to pump up to 10 Ml day^{-1} against an 80 m head. For a submersible electric pump pumping at 8 Ml day^{-1} this would require a 130 Kw Motor with a nominal diameter of 305 mm. Pump manufacturers normally recommend a bore diameter of two sizes larger, i.e. a 350 mm diameter bore. For a yield of 10 Ml day^{-1} a motor of 185 Kw is required but the nominal diameter can remain the same if necessary (i.e. 305 mm).

In order that well losses be kept to a minimum it is probably advisable to increase the bore diameter to 400 mm (16 inches).

5.1.3 Screens Required

If 400 mm (16") diameter stainless steel screens are used then only about two metres of screen is required to pass 8 Ml day^{-1} at recommended entrance velocities. However with a gravel packed bore two metres of screen could not effectively gather all the water from a 70 m section of aquifer. A suitable length of screen might be 15 m placed at five separate depths opposite the best sands.

5.1.4 Gravel Pack

To drain all the sands including the top section which will be dewatered a gravel pack would be the most suitable design. This is particularly so as much of the Dilwyn Formation sand is in the medium sand size range.

5.1.5 Bore Construction

Long life and corrosion resistance with minimum maintenance would be desirable for a wellfield of this nature and construction materials should be the currently available most corrosion resistant possible commensurate with reasonable cost. Casing could therefore be Linelock AC casing butted to stainless steel screens.

The bore construction would be as follows:

Length of bore	-	80 m
Outside diameter	-	762 m
Length of surface casing	-	6 m (915 mm)
Length of casing	-	65 m (445 m ID)
Length of screen	-	15 m (406 mm API screens)
Gravel pack annulus	-	80 m

5.1.6 Cost per bore

On the basis of the above requirements a quote was obtained from a leading well drilling contractor for a bore of the above design. The quote received can be itemized as follows:

Rig Mobilization and Demobilization	-	\$ 8 750
Drilling and Consumables	-	\$16 040
Construction Materials	-	\$20 318
Total cost per single bore	-	\$45 108

Because the rig mobilization costs could be spread over a number of bores rather than one bore the cost per bore drops to \$39 275 (say \$40 000) if say three bores are drilled at a time.

5.1.7 Cost of Pump and Rising Main

The cost of the pump is dependent upon the capacity it is wished to install. The wellfield calculations showed that the bores could be pumped at from 8 Ml day^{-1} to 10 Ml day^{-1} depending upon the conditions under which the wellfield was operated.

On the basis of these requirements quotes were received from two leading pump manufacturers for submersible electric motors and pumps with a 8 Ml day^{-1} capacity and a 10 Ml day^{-1} capacity. The quotes can be summarized as follows:

i) 8 Ml day^{-1} capacity pumping against 80 m head

a) Four stage pump driven by 133 Kw motor - \$11 861

b) Three stage pump driven by 133 Kw motor - \$11 000

ii) 10 Ml day^{-1} capacity pumping against 80 m head

a) Three (or more) stage pump driven by 190 Kw motor - \$25 028

b) Five stage pump driven by 185 Kw motor - \$23 400

The quotes received included only the pump and motor assembly and excluded electric cables, rising main, valves etc.

A suitable corrosion resistant material for rising main might be resin bonded fibreglass tubing.

Total cost 50 m @ \$45 per m = \$2 250

5.1.8 Total Cost of Bores Equipped

The total cost per bore equipped with 8 Ml day^{-1} capacity pump, rising main and connected to a pipeline would be

Bore	$40 000
Pumpset	$11 000
Rising Main	$ 2 250
Surface Works*	$ 5 000
Total	$58 250

* Guesstimate only and includes valve, seals, electric cables etc.
The cost rises to $70 650 if a 10 Ml day^{-1} pump capacity is installed.

5.1.9 Total Cost of Bores in the Wellfield

The total number of bores required is seven. The possibility of a sudden bore failure is fairly remote. When a bore does fail it is generally observed as a gradual deterioration in performance and there is plenty of time to plan repairs or replacements. Pump failures, on the other hand, do occur suddenly even with regular maintenance so spare pumps (two say) should be available. It is unlikely that Geelong's water requirements would be so critical that a bore could not be out of production for a few days for pump replacement.

Under normal operation the field would only produce for six months of the year and any bore maintenance (e.g. redevelopment) could be carried out in the other six months.

For a wellfield with each bore equipped with 8 Ml day^{-1} capacity pumps the total cost (excluding pipelines) is:

Seven bores @ $58 250 per bore equipped		$407 750
Two pumps @ $11 000 per pump		$ 22 000
	Total	$429 750

The yield from such a field would be 10 000 Ml in a normal six month pumping period or 20 000 Ml with continuous pumping over a 12 month period in a drought year.

If each bore was equipped with 10 Ml day^{-1} capacity pumps the total cost (excluding pipelines) is:

Seven bores @ $70 650 per bore equipped		$494 550
Two pumps @ $23 400 per pump		$ 46 800
	Total	$541 350

The yield from such a field would be 13 000 Ml in a normal six month pumping period but the daily rate would drop over a 12 month drought period to yield a total of 20 000 Ml (in order that the maximum pumping depth was not exceeded if pumping continued for 18 months).

6 YIELD FROM THE GELLIBRAND SUB-BASIN

6.1 Main Pipeline from Gellibrand Catchment to Barwon Catchment

The GWWT representative on the study group is to prepare estimates on the cost of pipelines for the G5 wellfield. However in order that pipeline layout and designs can be prepared some idea of the eventual yield from the entire Gellibrand Sub-basin is required. It is assumed here that, for the purpose of comparison with a surface water storage, the cost of a pipeline out of the Gellibrand catchment into the Barwon catchment is the same for a wellfield as for an equivalent surface water storage, although the individual pipelines may start from different locations. It is also assumed that, for a wellfield in the G5 Storage basin, a pumping station would be required somewhere at the eastern end of the Storage basin site to lift water out of the Gellibrand catchment. It is the location of this pumping station which determines the total head against which the borehole pumps will have to pump.

6.2 Capacity of the pipeline in the G5 Storage basin wellfield

If only the yield from the G5 Storage basin wellfield is considered the pipeline linking the wellfield to the pumping station need only be designed to carry a maximum of 70 Ml day^{-1} (i.e. seven bores at 10 Ml day^{-1} per bore). The yield from such a field would be approximately 13 000 Ml in a normal six month pumping season rising to 20 000 Ml in a drought year.

However, as mentioned in the introduction, some estimate should be made of the yield from the entire Gellibrand Sub-basin, not just the G5 Storage basin site, for the purpose of costing possible groundwater schemes.

Because the yield from the Gellibrand Sub-basin would be much higher than just that of a G5 wellfield, the capacity of the pipeline in the G5 wellfield would need to be designed from the outset to take the total capacity of the Sub-basin.

6.3 Possible Yield from the Gellibrand Sub-basin downstream of the G5 wellfield

The possible yield of the Gellibrand Sub-basin can be calculated simply on the basis of extrapolating the results from the G5 wellfield to the rest of the Sub-basin.

6.3.1 Lardners Creek - Gellibrand River

At 500 m spacings a further six bores could be located along this stretch of the river. These bores would yield between 8640 Ml and 10 800 Ml in a normal six months pumping season with bores pumping at 8 Ml day^{-1} or 10 Ml day^{-1}. In a drought year the yield could rise to 17 520 Ml over a 12 month period with each bore pumping continuously at an average of 8 Ml day^{-1}.

6.3.2 Charleys Creek - Gellibrand River

This area of the Gellibrand Sub-basin has the highest potential of the entire Gellibrand Sub-basin for development. Here the aquifer is thickest (and hence a higher T) and the combined volume of water flowing in the Gellibrand River, Charleys Creek and Loves Creek (which adds its component to the Gellibrand) is highest. The wellfield layout would probably be different to the G5 Storage basin as it could be based between the two stretches of the Gellibrand River and Charleys Creek. For the purpose of this report a yield equivalent to the G5 wellfield can be assumed but in practice could probably be much higher.

6.3.3 Further Surface Water Supplies

The existence of a pipeline to Gellibrand would make further surface water supplies available. Run of the river pumping is envisaged for the Gellibrand River at the eastern end of the G5 Storage basin at a rate of approximately 3500 Ml $year^{-1}$ (see notes in Appendix). A further 10 000 Ml $year^{-1}$ might be available from run of the river pumping on Lardners Creek, Charleys Creek and Loves Creek on the basis of comparison with the intended run of the river pumping on the Gellibrand. This estimate is only very approximate and is made merely to illustrate the fact that the existence of wellfields and associated pipelines would make available an extra source of surface water for very little cost. The capacity of the pipeline initially installed in the G5 wellfield should take account of this extra volume.

6.4 Total Yield from Wellfields in the Gellibrand Sub-basin

On the basis of extrapolation of results of the G5 wellfield calculations, two estimates of the total yield from the Gellibrand Sub-basin can be made:

i) Normal year

This can be calculated on the basis of each bore pumping at 10 Ml day^{-1} for six months and can be summarized as follows.

a)	G5 Storage basin	-	13 000 Ml
b)	Lardners Creek - Gellibrand River	-	11 000 Ml
c)	Charleys Creek - Gellibrand River	-	13 000 Ml
			37 000 Ml

ii) Drought year

This can be calculated on the basis of each bore pumping at a rate equivalent to 8 Ml day^{-1} continuously for twelve months.

a)	G5 Storage basin	- 20 000 Ml
b)	Lardners Creek - Gellibrand River	- 17 500 Ml
c)	Charleys Creek - Gellibrand River	- 20 000 Ml
		57 500 Ml

The same reservations expressed for the wellfield calculations performed for the G5 Storage basin wellfield (Section 4.3) apply to the above calculations. The volume which could be extracted in a normal year (37 000 Ml) represents 32 percent of the average yearly flow in the Gellibrand river at the Bunkers Hill gauging station.

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Blake, R., 1978. Groundwater for Geelong. Completion Report on the hydrogeological investigation of the Barwon Downs basin. Geological Survey of Victoria Unpublished Report 1978/38.

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7 May 1980

THE FUTURE WATER SUPPLY FOR GEELONG

NOTES ON THE FIRST MEETING OF THE DESK STUDY TO INVESTIGATE THE GROUNDWATER RESOURCES OF THE GELLIBRAND SUB-BASIN

TIME: 10.00 am, Monday 5 May 1980

VENUE: Room 309, 107 Russell Street Melbourne

PRESENT: Les Barrow (GWW & ST), Howard Rose and David Ife (SR & WSC), Roger Blake and Robert Williamson (DM & E)

The following notes are a result of the first meeting of those participating in the Desk Study and the points outlined here are not necessarily in the order in which they were discussed. The notes are therefore not an accurate record of the minutes of the meeting but do contain most of the essential subjects raised.

HYDROLOGY AND HYDROGEOLOGY OF THE SUB-BASIN

1) Definition of the Sub-basin

The area of the Gellibrand Sub-basin (a convenient name to distinguish it from the Barwon Downs Sub-basin) was discussed and extended to include the Loves Creek to the north and Lardners Creek and Charleys Creek to the west. To the north and south it is bounded by Otway Group sediments which form impermeable boundaries whereas the eastern and western boundaries are permeable boundaries.

2) Basic Groundwater flow regime

The relationship of the inferred groundwater flow to the river and both the two dimensional and three dimensional flow within the aquifer were outlined. Arising from this it was realized that one of the components of flow into the Gellibrand Sub-basin (that from the Barangarook recharge area) assumed in the H Rose and D Ife report, cannot be considered to contribute to the Gellibrand Sub-basin because it is already committed to the Barwon Downs Sub-basin development. The eastern boundary then, although a permeable boundary, can be considered a "no flow" boundary which will be artificially created by pumping in the Barwon Downs Sub-basin. Outflow from the Sub-basin occurs through the permeable boundary to the west.

3) Potential recharge to the outcropping Wangerrip Group in the Sub-basin

It was agreed that the area of the basin should be defined and potential recharge from direct rainfall, using a range of recharge rates, should be calculated.

4) Streamflow into and out of the Sub-basin should be more closely defined

This would include analysis of the Bunker Hill gauging station results to more closely define surface outflow (particularly base flow) from the Sub-basin. It was pointed out that one of the major weaknesses was the lack of gauging information on Loves Creek. The sum of the flows of the Gellibrand River (upstream of Loves Creek), Lardners Creek and Charleys Creek exceeded flow through the Gellibrand River at Bunkers Hill. This infers that an amount at least equal to or in excess of Loves Creek flows recharges the aquifer from the river between Gellibrand and Bunker Hill (alternatively "water flows back up Loves Creek" - Les).

5) Groundwater outflow from the Sub-basin

Groundwater outflow from the basin takes place through the narrow gap in the Tertiaries just to the west of Charleys Creek (between Charleys Creek and Bunkers Hill). It was agreed that an estimate of this flow should be made using simple one dimensional Darcy flow assumptions.

6) The Aquifers

The recent drilling of bore X and the earlier Yaugher 19 indicate that the Wangerrip Group in the Sub-basin can be subdivided into three units:- The Dilwyn Formation, the Pember Mudstone and the Pebble Point Formation. The Pember Mudstone forms an aquitard between the Pebble Point and Dilwyn aquifers. It was considered that the two aquifers will behave differently in response to development: the Pebble Point being essentially confined and the Dilwyn Formation essentially unconfined. In order to more precisely define aquifer parameters, aquifer tests will eventually have to be performed on each aquifer separately. For the purpose of wellfield calculations (see below) it was considered that the aquifer should be treated as essentially unconfined with average aquifer parameters of $K = 5$ m day^{-1} and $S = 1 \times 10^{-1}$.

GROUNDWATER DEVELOPMENT

1) Bore Constructions

It was agreed that the bores should be designed for a maximum possible yield. Both aquifers should therefore be developed (in spite of the complication of pumping test analysis). The bores should be large diameter (say 500 mm) with maximum screens available. Bore X achieved a specific capacity of 0.09 Ml day^{-1} m^{-1} but bores testing the Wangerrip Group elsewhere indicate that specific capacities in the range 0.15 - 0.3 Ml day^{-1} m^{-1} should be possible. An arbitrary maximum drawdown of 60 m in each production well could be aimed at. This is opposite the Pember Mudstone in bore X. It was felt desirable that dewatering of the confined Pebble Point Formation should not be attempted (because of damage to the aquifer) and that it is desirable that some of the aquifer sands developed should be below the pumps to prevent cavitation above the pumps and maintain cooling (if submersible). A drawdown of 60 m would produce cascading in the bore (because of dewatering of the upper sands). This is undesirable from the point of view of corrossion and aeration of the water (with consequent precipitation of iron within the bore) but is unavoidable if a reasonable drawdown is to be achieved.

For the purpose of initial wellfield calculations a yield of 10 Ml day^{-1} could be used (i.e. Specific Capacity x Drawdown = 0.17 x 60 m = 10 Ml day^{-1}). The distance apart, the number of Production wells and distance to the river will all affect the ultimate yield of the individual bores.

2) Wellfield Design

The major purpose of the desk study is to come up with order of magnitude estimates of numbers of bores, lengths of pipelines etc upon which costs may be prepared for comparison with alternative surface water storages. This aim led to much discussion on the nature of the various management practices which might be employed (i.e. the alternative ways in which the conjunctive development of groundwater and river water could be considered). It was agreed that the amount of manual calculation required to investigate suitable wellfield designs and alternative management practices was prohibitive without the use of at least some type of mathematical model. The use of several finite difference (or a finite element) mathematical models which could handle the type of problem (i.e. stream flowing over an unconfined aquifer) were discussed. The use of one particular model was discussed which, in addition to being three dimensional, could handle the problem of reduced river recharge caused by the lower vertical permeability alluvium over which the river flows. If the model could be modified to run in a reasonably short time it was considered that the following parameters might be entered initially as a starting wellfield design:

Yield per bore	=	10 Ml day^{-1}
Distance between bores	=	1 km
Distance of bores from Gellibrand river	=	1 km
K	=	5 m day^{-1}
S	=	1×10^{-1}

The available bore information would be used to estimate aquifer thicknesses over the area of the grid. Output from the model would consist of drawdowns in the pumping bores and the nearness of the calculated values to the desired 60 m drawdown available would allow pumping rates and bore spacings to be varied in subsequent runs.

3) Management alternatives

The discussion on wellfield design led to discussion of the alternative ways in which groundwater could be extracted. Basically the problem reduces to the extent to which the normal groundwater flow to the river can be reversed i.e. the amount of recharge which will be induced from the river to the aquifer by the operation of a pumping wellfield. Two extreme possibilities emerged:-

a) No river recharge

This alternative involves the design of a wellfield in which the existence of the river is ignored. This of course is a physically impossible situation if the induced pumping cone extends beneath the river but would give a conservative estimate of the yields and lead to maximum spacings of the bores required. The absolute amount of development in this case is only that which infiltrates directly from rain water to the aquifer. In the case of the area occupied by the G5 storage basin only this was calculated at 3000 Ml/annum (assuming a 20% infiltration rate).

b) Entire river recharge

In this case assume that the cone of depression produced by pumping is such that the entire flow of the Gellibrand River (upstream of the G5 gauging station say) can be induced to recharge (either by naturally induced recharge or artificially induced recharge). This case is also physically impossible because of constraints due to natural vertical conductivities or periods of very high river flows (such as floods). The absolute amount of water available for this alternative is 46 000 Ml/annum (flow at G5 gauging station) plus 3000 Ml/annum (infiltration) i.e. 49 000 Ml/annum.

Clearly a solution will lie somewhere inbetween the two extreme possibilities and hopefully a wellfield can be designed which achieves an optimum mix between groundwater and induced river recharge and takes account of minimum required downstream baseflows and meets Geelong's future water requirements. Again it was generally felt that reasonable answers to this type of problem could only be achieved by use of mathematical modelling.

4) Geelong's water requirements

It was decided that the amount of water required by Geelong at various times in the future, and for which periods of the year it was required, would form the major input to the wellfield design i.e. would decide the number of bores required (Geelong's requirement/10 Ml day^{-1} = No. of bores).

It was also considered that the groundwater contribution should be only that required after "run of the river" pumping from the Gellibrand had been allowed for in Geelong's requirements.

TASKS FOR NEXT MEETING

Following on from the above points it was agreed that the following data should be available for the next meeting (if possible).

1) Define the area of the Gellibrand Sub-Basin - Roger.

2) Calculate the area of potential infiltration using a range of rates (say 5-20%) - David.

3) Calculate groundwater outflow from the Sub-basin to the west using simple Darcy assumptions - Roger.

4) Look at range of stream flows out of the Sub-basin using the Bunkers Hill gauging station for comparison with streamflows within the basin - Howard.

5) Geelong's water requirements - seasonal, long term and drought for various times in future - Les.

6) Mathematical models available - both in house and outside consultants. Estimate time to modify models for our purposes and possible estimate of computing costs - Rob.

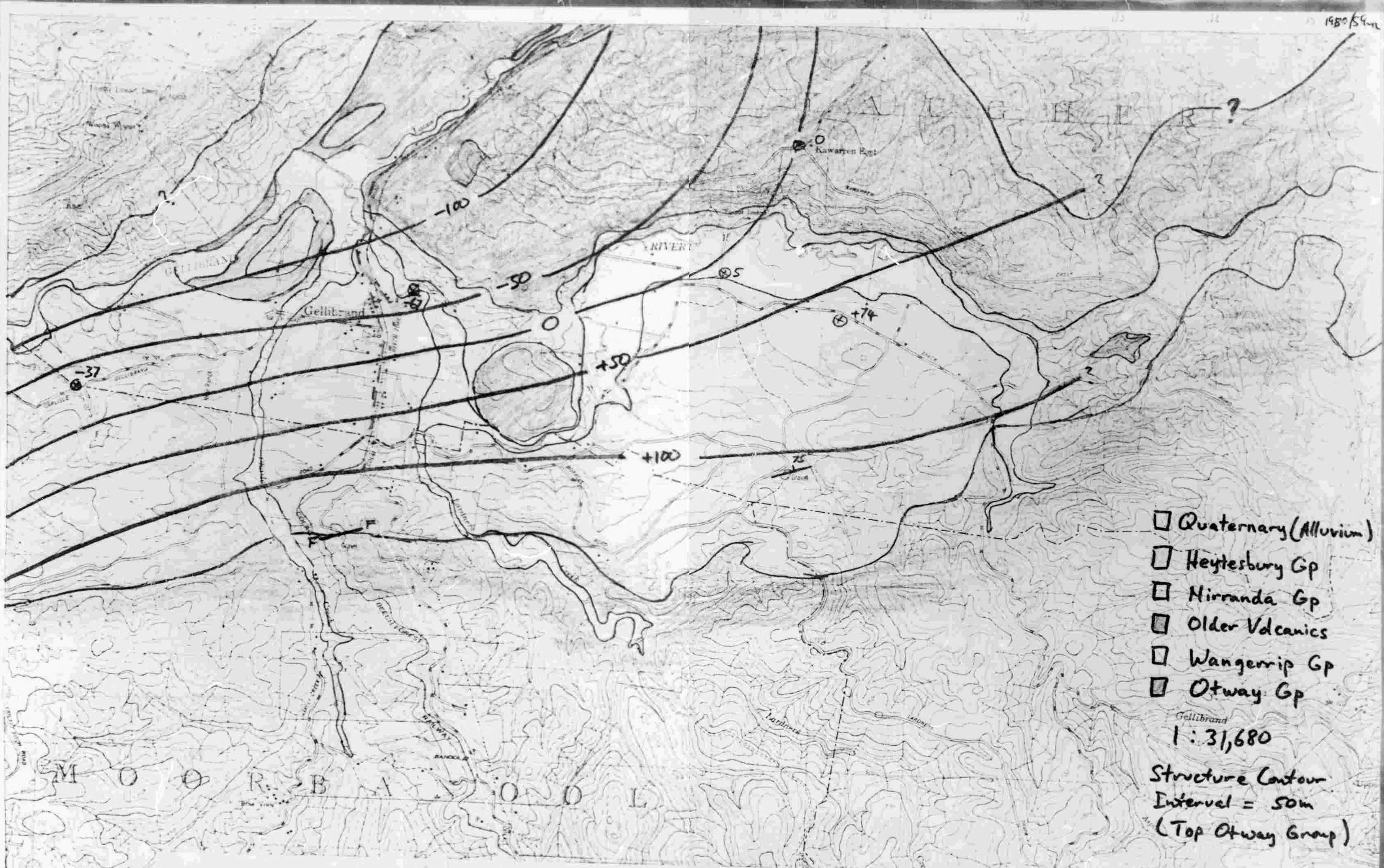

Fig. 1 Geological map of the southern portion of the Gellibrand Sub-basin

1980/59 ua.

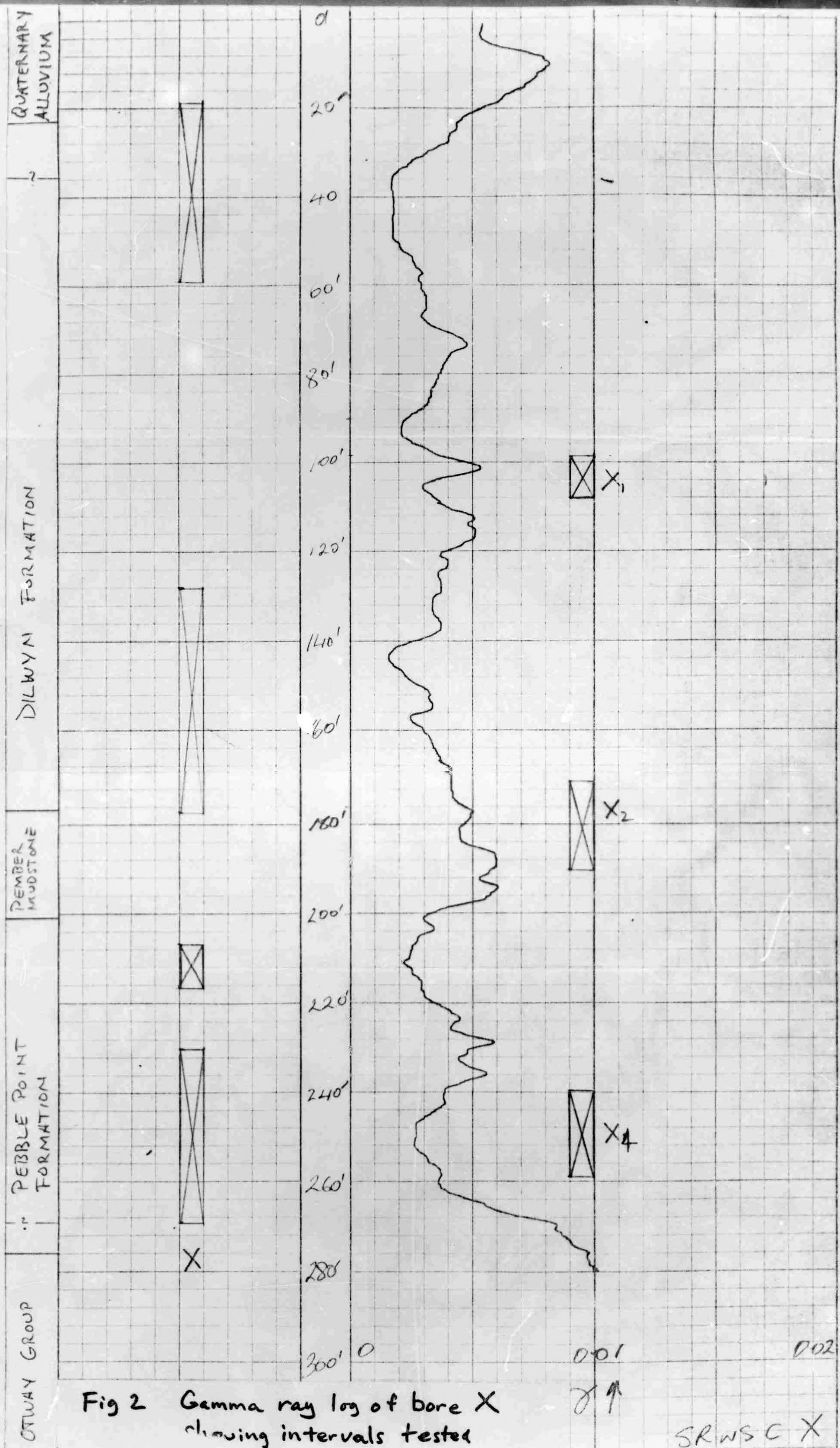

Fig 2 Gamma ray log of bore X showing intervals tested

SRWSC X

25/10/79