

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

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AN ARTIFICIAL RECHARGE EXPERI-
MENT IN THE ANGAS-BREMER
IRRIGATION AREA, SOUTH
AUSTRALIA

GEOLOGICAL SURVEY

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IRRIGATION AREA, SOUTH AUSTRALIA

ABSTRACT

A confined aquifer system in the Angas-Bremer area north of Lake Alexandrina is exploited for the irrigation of a range of crops. Water budget and salt balance studies indicate an inevitable deterioration in water quality with time since there is now no natural outflow for the confined groundwater and its salt load.

Artificial recharge of the confined aquifer using Lake Alexandrina water and/or excess flows in the Angas and Bremer Rivers has been suggested as a method of minimising salinity increase. A controlled well recharge experiment was performed using water from Lake Alexandrina with two injection and three pump-out cycles being performed. The tests showed that injection is practical and that a significant proportion of the injected water is recovered on pumping. The results suggest however, that there was an irreversible decrease in well efficiency.

INTRODUCTION

The Angas-Bremer irrigation area is centred on the Angas and Bremer Rivers on the north shore of L. Alexandrina 60 km southeast of Adelaide (Fig. 1). Approximately 25,000. Megalitres are pumped annually from a confined aquifer to irrigate a variety of crops, dominantly lucerne, pasture and potatoes (Waterhouse et al., 1978). This pumping has led to a significant cone of depression in the potentiometric surface which does not completely disappear over the winter. (Fig. 2).

The maintenance of the cone of depression means that no flushing of the confined aquifer occurs and hence all salts are ultimately recycled (apart from the small amount removed in

plants exported from the area). Combined with the lateral inward movement of more saline groundwaters, this means that water quality will inevitably deteriorate. Management control was effected over the area on July 1st, 1981 when the area became a Proclaimed Region under the Water Resources Act, 1976. All irrigation wells will ultimately be equipped with meters and withdrawal quotas issued.

A possible management tool suggested by the Angas-Bremer Water Resources Advisory Committee (established under the Water Resources Act 1976) is the artificial recharge of the confined aquifer using excess River Murray water or flows in the Angas and Bremer Rivers. Much earlier, Carasone (1973) had described a proposed artificial recharge experiment in the area using water pumped from Lake Alexandrina.

J. Beal of the Groundwater and Engineering Section subsequently designed and undertook such an experiment and on his secondment to the Engineering and Water Supply Department the joint author completed analysis of the results.

HYDROGEOLOGY

The hydrogeology of the Angas-Bremer irrigation area has been comprehensively described in Waterhouse et al. (1978) and is briefly described here. A summary is given in Table 1.

The unconfined aquifer is contained within a sequence of Quaternary clays, silts and sands with occasional gravels, 10 to 35 m thick. Hydraulic conductivities are low but variable and salinities are extremely variable, from 1 000 to 30 000 + milligrams per litre (mg/L). The unconfined aquifer is recharged by the Angas and Bremer Rivers, especially in the northern part of the area. In this area the unconfined aquifers are hydraulically separated from the confined aquifer but this is not

TABLE 1

STRATIGRAPHIC AND HYDROGEOLOGICAL SUMMARY

FormationAquifer CharacteristicsQUATERNARY
SEQUENCE

Variable fluvial and lacustrine clays, silts and sands with occasional gravels. Equivalent in part to Blanchetown Clay and Chowilla Sand. Modern aeolian sands and floodplain silts with dated wood fragments overlie the sequence. 10-35m thick, typically red-brown and mottled.

Forms unconfined (sometimes slightly confined) aquifer in most of area. Generally low, but variable transmissivities and extremely variable salinities (1,000-30,000+ mg/l) characteristic. Good hydraulic separation from underlying aquifer system only in northern part of area. Little development has occurred because of generally high salinities and low well yields.

TERTIARY
SEQUENCE

EOCENE-MIOCENE PLIOCENE

Sands and clays of Parilla Sand, with occasional interfingering of shelly Norwest Bend Formation occur in most of area. 0-5 m thick; pale yellow brown.

Form aquifer which may be connected with either overlying unconfined or underlying confined aquifers, or both. Reputed to be more saline than underlying aquifer.

Sequence dominated by richly fossiliferous Limestones with sandy and marly interbeds of variable thickness. Mannum and Ettrick Formations distinguishable on palaeontological grounds only. Carbonaceous clays and greensands towards base help identify Buccleuch beds.

Confined aquifer from which virtually all groundwater used locally is extracted. Salinities range from 1500 mg/l near recharge zone to more than 10,000 mg/l in the east and west, controlling the location of the irrigation area. Large well yields, up to 500 m³ day⁻¹, are common.

CAMBRIAN
BASEMENT

Schists, phyllites and greywackes of the Kanmantoo Group.

Poor aquifer with generally low permeabilities and high salinities in the adjacent Mount Lofty Ranges.

necessarily true in the south. The unconfined aquifers are little used.

Beneath the Quaternary aquifers a thin (0-5 m) unconfined or confined aquifer is found in the Pliocene sands and clays of the Parilla Sand/Norwest Bend Formation.

The main aquifer in use in the area is the confined Morgan-Mannum Limestone and Ettrick Formation (Eocene-Miocene). Hydraulic conductivities are generally high and well yields up to 2000 m³/day are common. Salinities range from 1500 mg/L near recharge zones, especially parallel to the rivers, to more than 10,000 mg/L to the east and west (Fig. 2). Salinity places limits on the area of irrigation.

The main aquifer is underlain by carbonaceous clays and green sands of the Buccleuch Beds above Cambrian basement. These are low grade aquifers though little data are available on them.

Waterhouse et al. (1978) state that of the estimated 25,000 Ml withdrawn from the confined aquifer each year, 52% is balanced by downward vertical leakage from the unconfined aquifer, 22% by natural recharge from the rivers in the north and northwest, 12% by induced recharge from Lake Alexandrina and 14% by lateral flow of more saline groundwaters. Thus deterioration of water quality is inevitable and this is the most important management problem.

DESIGN OF THE EXPERIMENT

The wells for the experiment were drilled on sections 3370 and 3374 Hd. of Freeling on the property of Langhorne Pastoral Co. (Figs. 2 & 3). The site was chosen to take advantage of an existing irrigation reticulation system utilizing Lake Alexandrina water.

One injection well and six observation wells were drilled for the experiment (Fig. 3,4, Table 2). No control well in the

TABLE 2

INJECTION AND OBSERVATION WELL DETAILS

WELL CODE	UNIT NO.	FINAL DEPTH (M)	OPEN INTERVAL (M)	UNIT MONITORED	DISTANCE TO INJECTION WELL (M)	WELL STATUS
IBI	6727-400-02101	64	29-64	MORGAN-MANNUM CONFINED AQUIFER	-	PUMPING/INJECTION
OBI	6727-400-02102	29	26.8-29	PARILLA SANDS/UPPER MORGAN-MANNUM CONFINED AQUIFER.	96.4	OBSERVATION
OB2	6727-400-02103	30.5	27.5-30.5	AS ABOVE	25.2	OBSERVATION
OB3	6727-400-02104	24	23-24	BASE OF QUATERNARY WATER TABLE AQUIFER	23.6	OBSERVATION
OB4	6727-400-02105	16	15-16	WATER TABLE AQUIFER	21.6	OBSERVATION
OB5	6727-400-02107	36.5	35-36.5	UPPER MORGAN-MANNUM CONFINED AQUIFER	31.3	OBSERVATION
OB6	6727-400-02108	49	48-49	AS ABOVE	28.7	OBSERVATION

confined aquifer was drilled outside the expected area of influence of the testing and therefore no data are available to correct for any regional fluctuations. An attempt was made to place an automatic recorder on one of the observation wells between tests but this proved ineffective.

Water from Lake Alexandrina was supplied through the reticulation system with no pretreatment. Regular testing of salinity of the lake water was done during the first injection and a few isolated checks during the second. The salinity was stable during both tests. Variations in suspended solids, dissolved gases, organic material and water chemistry are unknown.

PRELIMINARY TESTS

Before any water was injected into the aquifer the injection well was pumped for 72 hours to obtain aquifer characteristics. Short term approximations of step-drawdown tests performed prior to this to obtain well parameters yielded marginally useful results.

Plots of drawdown against time for the pumped well and the various observation wells are given on Figures. 5 to 8 and calculated results in Table 3. Unfortunately no recovery measurements were made after the cessation of pumping. The variation of the Specific Capacity (S.C.) of the pumped well with time i.e. its yield in m^3/day per metre of drawdown is given on Figure. 9.

During the test salinity of the pumped water increased from 2580 mg/L to 2690 mg/L (Appendix A).

The test showed that the aquifer pumped is of the leaky confined type with drawdown stabilizing with time. The cone of depression is stabilized by leakage of water from the overlying

TABLE 3
AQUIFER PROPERTIES AND WELL RESPONSES, FIRST PUMP-OUT TEST

OBSERVED AT	METHOD OF ANALYSIS	AQUIFER TRANSMISSIVITY T m ³ /day/m	STORAGE CO-EFFICIENT S	AQUITARD PERMEABILITY P m ³ /day/m ²	COMMENTS
PUMP WELL IB1	JACOB	590	-	-	NO DISCHARGE DATA AFTER 400 MINS. LEAKAGE EFFECTS AFTER 25 MINS. MAXIMUM DRAWDOWN 9.3 m.
OB1	-	-	-	-	RESPONSE AFTER ABOUT 300 MINS BUT RESULTS NOT ANALYSABLE MAXIMUM DRAWDOWN 0.52 m
OB2	-	-	-	-	RESPONSE AFTER ABOUT 500 MINS BUT RESULTS NOT ANALYSABLE MAXIMUM DRAWDOWN 0.17m
OB3	-	-	-	-	THIS WELL DID NOT APPEAR TO RESPOND TO PUMPING. COLLAPSE OF THE OPEN INTERVAL IS POSSIBLE.
OB4	-	-	-	-	OBSERVATION WELL IN WATER TABLE AQUIFER RESPONDED WELL TO PUMPING IN CONFINED AQUIFER MAXIMUM DRAWDOWN 2.63 m.

OB5

JACOB
WALTON

670
700

1.9×10^{-4}
 2×10^{-4}

3×10^{-3}

RESPONDED IMMEDIATELY TO
PUMPING. REASONABLE FIT ON
LEAKY TYPE-CURVES. NEUMAN &
WITHERSPOON (1972) CONSIDER
THIS METHOD MAY OVERESTIMATE
T AND UNDERESTIMATE P'
MAXIMUM DRAWDOWN 3.05 m

OB6

-

-

-

-

DESPITE SIMILAR RESPONSE
TO OB5 THE DATA COULD NOT BE
ANALYSED BY JACOB'S
OR WALTONS METHODS.

unconfined aquifer with the response shown by observation well OB4* (Fig. 6) in which the water table started to decline after about 45 minutes pumping. By the end of the test the drawdown was similar to that shown by the confined aquifer observation wells (OBS5, 6, Fig. 7). Observation well OB3 showed no response during this or subsequent tests and bottom hole collapse is probable. Observation well OB2 responded to pumping but differently from later tests (Fig. 6 and 17).

The values obtained for Transmissivity, Storage Coefficient and the aquitard permeability are consistent with results obtained from earlier testing in the area (Waterhouse, et al 1978).

The "sinusoidal" pressure surface fluctuations toward the end of the test (Fig. 5) could be a reflection of barometric pressure fluctuations although they appear to have a period close to 24 hours.

FIRST INJECTION/PUMP OUT CYCLE

Hydraulic Effects

For the first test about 4850 m³ (1,066,000 gallons) of lake water was injected down the well under gravity. The water level in the well was held as close as possible to ground level. Water levels were measured routinely in the observation wells and plots of the rise in water levels (mound buildup) are given in Figures 10 & 11. Valve adjustments had to be made frequently to prevent rupture of the inlet pipe and to control the water level in the well. Complications arose when the lake pump stopped for about 45 minutes after 2600 minutes. Variations in the injection rate (Fig. 14) are reflected in the graphs of the rise in the pressure

* For the relationship between observation numbers and unit numbers refer to Table 2 and Fig. 3.

surface (Figs. 10,11). No meter readings are available for the first 250 minutes of the test thus the cause of a rapid increase in head after 80-100 minutes is not known.

Rises of up to 2 metres were recorded in observation wells OB2, 5 and 6 (Figs. 10,11) whilst a rise in the water table aquifer (OB4) of up to 1.6 m was noted (Fig. 10). No effect was noted in observation well OB1 (confined aquifer) at a distance of about 100 m.

For the confined aquifer, water level rises stabilized after 200-300 minutes and then slowly declined. This is probably due to a combination of falling injection rate, steady-state hydraulic conditions being approached, and possibly regional fluctuations in the potentiometric surface. The unconfined aquifer showed a similar, but delayed, response.

When injection stopped the mound decayed (Fig. 12,13). As shown the confined aquifer observation wells (OB5, OB6) and the injection well (IB1) showed a rapid decay whereas observation wells in overlying aquifers showed a delayed response, e.g. well OB3, open in the base of the unconfined aquifer, showed no decay.

Commencing on the 23rd October, 1980 a second pump-out test was performed for 72 hours at an average pumping rate of 2499 m³/day but the actual rate decreased 10% from the beginning to the end of the test (Fig. 15). Plots of drawdowns and residual drawdowns (recovery phase) recorded in each well are given on Figures. 16 to 21, and the hydraulic properties determined from these plots are given in Table 4. Observation wells OB1 and 3 did not respond whereas OB2 responded rapidly (cf test no. 1). Well OB4 again showed the rapid response of the unconfined aquifer to pumping of the confined aquifer with measurable drawdowns being recorded after about 30 minutes of pumping. The

TABLE 4
AQUIFER PROPERTIES AND WELL RESPONSES, SECOND PUMP-OUT TEST

OBSERVED AT	METHOD OF ANALYSIS	AQUIFER TRANSMISSIVITY T m ³ /day/m	STORAGE COEFFICIENT	AQUITARD PERMEABILITY P' m ³ /day/m ²	COMMENTS
PUMP WELL IB1	JACOB (RESIDUAL DRAWDOWN)	544	-	-	DRAWDOWN DATA NOT USEFUL SINCE STABILISED AFTER 30 MINUTES AND STARTED TO RISE AT END OF TEST. RESIDUAL DRAWDOWN ANALYSED.
OBSERVATION WELL OB1		-	-	-	NO RESULTS RECORDED
OB2	JACOB (RESIDUAL DRAWDOWN)	467	-	-	RESPONDED AFTER ABOUT 8 MINUTES WITH A MAXIMUM DRAWDOWN OF 3.05m c.f. FIRST PUMPOUT TEST. DRAWDOWN PLOT CURVED, RESIDUAL DRAWDOWN ANALYSED SOME DOUBT AS TO VALIDITY OF METHODS USED LOG-LOG PLOT NOT ANALYSABLE.
OB3	-	-	-	-	SEE RESULTS FIRST PUMP-OUT TEST (TABLE 3)
OB4	-	-	-	-	AS FOR THE FIRST TEST THIS WATER TABLE OBSERVATION WELL RESPONDED TO PUMPING OF THE CONFINED AQUIFER AFTER ABOUT 30 MINUTES. MAXIMUM DRAWDOWN ABOUT 2.78m. COMPARE WITH OB3 WHICH IS A DEEPER WELL THAT DID NOT RESPOND.
OB5	JACOB (DRAWDOWN)	683	1.7 x 10 ⁻²	-	IMMEDIATE RESPONSE TO PUMPING, MAXIMUM DRAWDOWN 2.4m cf. OB4. BOTH SEMI-LOG DRAWDOWN AND RESIDUAL DRAWDOWN PLOTS CAN BE ANALYSED, THE FORMER SHOWING THE EFFECTS OF LEAKAGE AFTER ABOUT 70 MINUTES. ON THE LOG-LOG PLOT (WALTON) LATER STAGE DATA ARE ERRATIC AND MAKE CURVE FITTING DIFFICULT THUS THE VALUE OBTAINED FOR P' MAY BE IN ERROR.
	JACOB (RESIDUAL)	698			
	WALTON	585	2.16 x 10 ⁻⁴	0.027	
OB6	-	-	-	-	EARLY TIME RESPONSE DIFFERENT TO OB5 THUS SEMI-LOG PLOT NOT ANALYSABLE. WHILST THE LOG-LOG PLOT FINALLY BECOMES IDENTICAL (MERGES) WITH THAT FOR OB5 UNIQUE TYPE-CURVE (WALTON) FITTING WAS NOT POSSIBLE.

rather erratic data from later stages of the test in OB5 made the type curve analysis (Walton) difficult (Fig. 21) and thus the values quoted in Table 4 should be treated with caution.

Water Quality Effects

Eleven samples of lake water were collected during the injection phase at the well head and analysed for total dissolved solids (TDS) and pH only (Appendix A). The TDS remained constant at 525 mg/L whilst the pH fluctuated between 8.0 and 8.2. No chemical analyses were performed on the lake water at this time but analysis of an earlier sample (collected on the 8th May 1980) is given in Appendix A. A suspended solids analysis was also done and gave before ignition, 48 mg/L and after, 45 mg/L, indicating most of the suspended solids were inorganic. Variations in these parameters were not monitored.

After injection the water remained in the aquifer for about 59½ hours and pumping of the well then commenced. Field salinity measurements using a portable conductivity meter were taken regularly on the pumped water (Fig. 22). Results showed that field tests were consistently higher than laboratory analyses (Appendix A).

Using laboratory salinity data the volume pumped over any one time interval was apportioned between recovered lake water and native groundwater (Appendix B). A straight line relationship between lake and groundwater salinities was assumed (Fig. 23), thus the recorded salinity at any one time represented a ratio between lake and groundwater. Calculations indicated that of the 4850 m³ of lake water injected over the three day period, about 4080 m³ (84%) was recovered by pumping for the same length of time (Fig. 24). At the end of pumping salinity of the pumped water was about 350 mg/L less than the original

groundwater, thus additional pumping would have recovered more of the injected water but at a decreasing rate.

Since no samples were collected for chemical analysis no comment can be made on any chemical changes which may have occurred.

SECOND INJECTION/PUMP-OUT CYCLE

From the 12th to 15th November 1980 about 4840 m³ or 1,065,000 gallons of lake water was again injected down well WW2101. The water level in this well was kept as close as possible to ground level and water levels were monitored in all observation wells. Injection continued for 61 hours 40 minutes but as in the first experiment, changes had to be made to the injection rate and the pump stopped twice. The variation in the injection rate including two stoppages is given on Figure 14 and from this it is obvious that the average injection rate for the second test was higher than the first (1884 m³/day compared with 1617 m³/day).

Hydraulic Effects

The effects of injection on the potentiometric surfaces of the confined and unconfined aquifers and decay of the pressure mound are shown by the responses of the various observation wells (Figs. 25 to 28). These were similar to those recorded in the earlier injection test. On cessation of pumping the mound in the pressure surface (as represented by wells WW2107 and 2108) had almost dissipated after about 6 hours, whilst the corresponding mound in the water table had receded by only 25% during this time.

The injected water was then left in the aquifer until the 9th December 1980, when a third 72 hour pump-out test commenced. The injected water therefore remained in the aquifer for 586½ hours after injection.

The responses of the various wells to this pumping are shown on Figures. 29 to 33 and the hydraulic parameters obtained from analysis of these graphs are given in Table 5.

Water Quality Effects

During injection of lake water three samples were collected and analysed for TDS and pH only and showed consistent results of 545 mg/L and 8.2 respectively (Appendix A). No other analyses were performed.

Field salinity measurements using a portable conductivity meter were recorded systematically throughout the pump-out test and 30 samples were collected for laboratory determination of TDS or full chemical analysis (Appendix A). Compared with the previous pump-out test there was generally good agreement between field and laboratory measurements (Fig. 22). The more variable field measurements probably reflect complex mixing conditions due to the non-isotropic nature of the limestone aquifer, although the accuracy of the meter could explain some fluctuations.

If the same graph of salinity vs percentage of lake water is used as for the first injection/second pump-out test then about 17% of the lake water was not recovered within 72 hours (Fig. 34 and Appendix B). If a modified graph (Fig. 23) is used, based on lake water salinity measured at the start, and salinity of the groundwater at the end of the second pump-out test, then about 26% of the lake water was not recovered within 72 hours pumping (Fig. 34). During that period 6350 m^3 was extracted, and extrapolating the salinity vs. time graph to the pre-existing groundwater salinity then an estimate of the extra volume to be pumped to completely recover the injected water can be made. If the salinity of the native groundwater is taken as that existing prior to any injection then an additional 3998 m^3 would have to

TABLE 5
AQUIFER PROPERTIES AND WELL RESPONSES, THIRD PUMP-OUT TEST

OBSERVED AT	METHOD OF ANALYSIS	AQUIFER TRANSMISSIVITY T m ³ /day/m	STORAGE COEFFICIENT	AQUITARD PERMEABILITY P' m ³ /day/m ²	REMARKS
PUMP WELL IB1	JACOB (Residual Drawdown)	517	-	-	RESIDUAL DRAWDOWN DATA ANALYSED DRAWDOWN STARTED TO STEADY STATE AFTER ABOUT 500 MINS. MAXIMUM DRAWDOWN ABOUT 7.5 m.
OBSERVATION WELL OB1		-	-	-	NO RESULTS RECORDED
OB2					RESPONDED AFTER ABOUT 7 MINUTES BUT BOTH SEMI-LOG AND LOG-LOG PLOTS NOT ANALYSABLE. MAXIMUM DRAWDOWN 2.65m.
OB3					SEE RESULTS FIRST PUMP-OUT TEST.
OB4					RESPONDED TO PUMPING AFTER 20 MINUTES WITH AN OPEN S-SHAPED SEMI-LOG DRAWDOWN PLOT. ON CESSATION OF PUMPING WATER LEVEL DID NOT START TO RECOVER UNTIL 40 MINUTES HAD ELAPSED. MAXIMUM DRAWDOWN 2.55 m
OB5	JACOB (Drawdown)	657	1.67 x 10 ⁻⁴		IMMEDIATE RESPONSE TO PUMPING. MAXIMUM DRAWDOWN 2.35m "SINUSOIDAL" FLUCTUATIONS AT END OF TEST WITH A PERIODICITY OF AROUND 24 HOURS.
	JACOB (Residual Drawdown)	646			
	WALTON	674	1.9 x 10 ⁻⁴	2.79 x 10 ⁻³	
OB6	WALTON	100	1.12 x 10 ⁻³	-	EARLY-TIME DATA FITS THE CURVED PART OF THE TYPE-CURVE REASONABLY WELL BUT THE FLATTER LATER-TIME PORTION COULD NOT BE MATCHED WITH A TYPE-CURVE.

be pumped. If we use the salinity of the groundwater as being that recorded at the end of the second pump-out test (i.e. contains some lake water from the first injection) then an extra 2498 m³ would have to be pumped to remove the total volume injected during the second injection phase. Thus significant mixing of injected water and native groundwater had occurred.

During the pump-out test three samples were collected for full chemical analysis (Fig. 35 and Appendix A). Analyses of lake water collected in May, 1980 and native groundwater from a well close to the experimental site are included. The percentage ionic proportions (Fig. 35) shows the gradual approach of the pumped water to the native groundwater as pumping progresses. It is interesting to note that the first water pumped does not correspond chemically to the lake water but the latter was sampled five months prior to the test.

Assuming that the chloride ion (Cl) is conservative i.e. it does not become involved in chemical changes during the testing, the first water pumped out is slightly enriched in Ca, Na, Mg and HCO₃ relative to the lake water (Fig. 36). If the lake analysis is representative of injected water then this suggests that solution of some aquifer material has occurred. During the pump-out test, especially near its beginning, quartz sand and shell fragments were produced thus it is possible that some of the aquifer cementing material was indeed dissolved. Cation to bicarbonate ratio variations are given in Figure 37, and this shows the gradual return to lake water quality with time.

Cation to sulphate ratios behave strangely in that both the calcium and magnesium to sulphate ratios are initially higher than the injected water suggesting mixing with groundwater but then decrease as pumping proceeds (Fig. 38). The native

groundwater shows these ratios as 6 to 8 times higher than the injected water. The sodium to sulphate ratio starts slightly higher than the injected water but shows no significant increase with time, and does not approach the native groundwater. (Fig. 38).

LOSS OF WELL EFFICIENCY

During deep well injection into an aquifer for artificial recharge the potential exists for clogging of the aquifer pore spaces by physical methods (particulate matter, clay dispersion, dissolved gases) and chemical/biological methods (e.g. precipitation of calcite, bacterial slime growth).

This results in a decline in injection rate with time in any one recharge cycle and it may not to be entirely reversible i.e. after pumping of a recharge well its hydraulic efficiency may not be totally regained. The lack of adequate step-drawdown tests prior to and after an injection phase preclude the quantifying of this phenomena but there are indications that some loss of well efficiency occurred.

The Transmissivity, measured in the injection/pump well showed a gradual decline from the first to the third pump-out test (Tables 3 to 5). Whilst the field data were not ideal this appears to be a definite trend suggesting some blocking of the aquifer pore spaces.

The Specific Capacity (S.C.) of a pumped well is a measure of the yield obtained per unit drawdown (m^3/day per metre) and is thus to some degree a measure of its efficiency. For a particular well, pumping at a lower rate should give a higher S.C. since there is an added non-linear component of drawdown related to turbulence in the well (this additional drawdown due to turbulence is commonly proportional to the square of the

pumping rate. The second pump-out test, was performed at a lower pumping rate than the first pump-out test. However, the S.C. recorded for the second test was significantly lower than that recorded for the first (Fig. 9), suggesting a decrease in well efficiency. The third pump-out test at an even lower pumping rate showed an intermediate value of S.C. (Fig. 9) indicating that the well had not recovered its efficiency.

Considering the porosity and permeability of the aquifer one would expect that any particulate matter contained within the recharge water would be recovered during pumping. If the content of suspended solids in lake water remained constant at 48 mg/L during the recharge phases then for the first and second injections 233 kg of suspended material was introduced to the well during each injection. No monitoring of suspended solids in the pump-out water was done.

Lake Alexandrina water is probably saturated with oxygen and other dissolved gases. As recharge occurred under gravity (free fall) the water obviously contained a significant concentration of dissolved gases. Blocking of pore spaces by air bubbles is thus probable and how much would be removed by pumping is unknown.

The possibility of pore blocking by bacterial growth is also possible since lake water is biologically active and the injected water is oxygenated.

Whilst a reduction in well efficiency is indicated, recharge rates were still excellent with 1500 m³/day being accepted at the end of the injection test.

Long term artificial recharge via wells requires that the recharge water has a very low suspended solids content, is chlorinated to remove bacteria, contains little dissolved gases and is similar in chemical quality to the native ground water.

ENHANCED RECHARGE AS A MANAGEMENT OPTION

The pumping of the confined aquifer for irrigation purposes has significantly altered the ground water flow regime of the Angas-Bremer irrigation area. Now there is no natural outflow of water from the confined aquifer since a cone of depression of varying extent exists permanently. Consequently the aquifer is a salt trap with no natural removal of salt apart from a negligible amount contained in exported plant matter. Groundwater salinity in the confined aquifer will inevitably rise from the combined effects of downward leakage from the unconfined aquifer and lateral inflow of more saline groundwater.

To reduce the imbalance between inflows and outflows to the confined aquifer system some form of artificial or enhanced recharge has been suggested. This is in conjunction with or separate from non-structural approaches eg. quota reductions, improved irrigation efficiency, change of crop types etc.

Four methods of additional or enhanced recharge are suggested:

1. Artificial recharge direct to the confined aquifer via private wells or specially constructed wells using Lake Alexandrina water or excess flows in the Angas and Bremer Rivers.
2. The construction of drainage wells in swamps adjacent the Angas and Bremer Rivers which fill when the rivers flood (often controlled by privately operated weirs on the rivers)

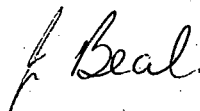
3. The construction of diversion channels leading away from and returning to the rivers in areas where adequate infiltration rates could be achieved.
4. The construction of temporary weirs in the river channels to increase the time for infiltration.

The four possible methodologies vary widely in cost of construction and maintenance, and their hydraulic efficiency which determines the time required for benefits to occur. Some of the advantages and disadvantages of each method are listed in Tables 6 to 9. No detailed analysis of the cost/benefit of any of the possibilities, either alone or in combination, has been attempted, since it is felt that non-structural changes and their potential benefits should be assessed initially. It must be remembered, and the point is stressed, that recharge with any water is adding salt to the system unless the cone of depression is eliminated for portion of the year. Only then will groundwater flow remove an amount of salt from the confined groundwater system in the irrigation area under consideration.



M.A. Cobb

Acting Senior Geologist



J. Beal

Geologist III

TABLE 6
Advantages/disadvantages of artificial recharge down wells, proposal 1

Advantages	Disadvantages
1. Water is injected directly into the required aquifer and thus hydraulic efficiency is good. 2. Lower salinity water than the native groundwater can be temporarily stored for use next irrigation season. 3. Wells can be sited to provide the best overall effect on the system re hydraulic heads, hydraulic barriers to minimise lateral movement of more saline water etc. 4. High injection rates can generally be achieved especially if the system is pressurised.	1. Well construction costs are high or existing private wells may require extensive modification. 2. Depending on location/spacing of wells a significant distribution system may be required with high capital costs and continuing running costs (pumping). 3. In existing wells without pressure cemented casing erosion around the outside of the casing may be induced. 4. Too high an injection rate may cause fretting of the well walls resulting in fine sands etc being dragged outwards into the aquifer and clogging it, or even resulting in well collapse. 5. Air bubbles carried down in the water cause violent vibrations when they escape upwards or can be lodged in the pores of the aquifer and effectively clog them. Thus the injection system must be operated in such a way that the pressure, in its entirety, must always exceed atmospheric pressure. 6. Suspended material in the recharge water may rapidly clog the sediment pore spaces with a consequent rapid decrease in recharge rates. Redevelopment of the well by pumping can generally correct this situation. In the case in question the waters of the Angas-Bremer Rivers would require careful managing because of this effect. 7. Clogging of the well-wall by bacterial growths may occur even if water of drinking standards is used. Periodic pumping to waste from the well can improve the situation

8. When water of different chemical composition is injected into native groundwaters subtle chemical changes can take place. These could either cause precipitation of salts leading to aquifer blocking, solution of aquifer matrix leading to increased permeability or wall stability problems, or even deflocculation of clays if present.
9. Large scale usage of Lake Alexandrina water is obviously subject to administrative control as part of the River Murray system. It does however, offer the best quality water available in the region and would be easier to manage than the rivers.
10. The salinity and sediment loading of the Angas and Bremer Rivers is such that very careful management of their use as recharge waters would be essential.

TABLE 7
Advantages/disadvantages of drainage wells in swamps, proposal 2

Advantages

Disadvantages

1. As for Table 6 items 1 and 2.
2. Less injection wells required than proposal 1 thus lower initial cost.
3. Most swamps already have some form of control structure to allow water ingress and egress from the rivers. Thus apart from well construction little capital works may be required.
4. With properly designed headworks the wells could be self-operating and solid and particulate matter minimised. Operating costs, apart from regular well rehabilitation, could be minimised.

1. As for Table 6 items 5, 6, 7, 8, 10.
2. Whilst the wells would allow storage of generally better quality water they would not be in areas that lend themselves to equipping for later use. Since such wells would be distant from irrigation wells they would have no impact on water quality obtained from these latter wells for a long time.
3. Flows in the rivers are erratic and there is no guarantee that the swamps would consistently fill.
4. Total storage in the swamps is estimated at 3.4% of the annual groundwater extraction of 25 000 Ml. Thus all swamps would have to fill several times each year to have any effect on the resource.
5. The recharge is limited to specific areas close to the two rivers and would be of no benefit to any irrigator even a moderate distance away.
6. There would be no impact on the regional cone of depression and hence on vertical and lateral migration of more saline water.
7. Careful monitoring of river quality needed since salinity, suspended solids etc are flow dependent.

TABLE 8

Advantages/disadvantages of spreading channels away from the rivers - proposal 3

Advantages	Disadvantages
1. Less prone to silting etc problems than recharge wells since part of the suspended matter together with some residual water can be rejected out of the system. 2. The land surface is relatively flat causing no difficulties for earthworks. 3. Once constructed require minimal maintenance apart from de-silting and weed control. 4. Since it is only recharge enhancement no chemical incompatibility will arise. 5. Infiltration volumes could be improved by having infiltration basins distributed along the channels where soil properties are suitable.	1. A long term solution only as short term effects on the confined aquifer system would be negligible. 2. Considerable disruption to existing farming practice may result because of extensive channel networks. 3. The cost/benefit ratio may be poor because of the hydraulic inefficiency relative to the confined aquifer system. 4. Limited to areas where the soil and sub-soil properties are suitable ie extensive soil surveys are needed to define these areas. 5. Must be operated intermittently in order to allow drying to reobtain original infiltration capacities. 6. Unless flows in the rivers are carefully monitored then adverse environmental effects may be felt in the existing swamps and in areas where flood irrigation is practiced by river flow diversion.

TABLE 9

Advantages/disadvantages of temporary weirs across the rivers in defined recharge areas-proposal 4

Advantages	Disadvantages
1. As for Table 8 items 1, 4. 2. Low construction cost of temporary weirs eg rapid bulldozing of river bed material 3. Should not aggravate flood situations since would be destroyed by high flows. 4. No deleterious effects on adjacent landowners. 5. Bed material found in both of the rivers suggests good infiltration rates. 6. More permanent concrete weirs are an alternative to be considered. These can be designed to maximise flow retention time whilst minimising any possible aggravation of flooding.	1. Enhancing recharge to the water table in a somewhat localised area only thus benefits on the confined aquifer system are long term. 2. Need to be rebuilt after destruction by floods if using bed material.

REFERENCES

- CARASONE, F., 1973. Artificial recharge: suggestions for an experiment in the Milang Basin. Min. Res. Rev. S. Aust. 138: 43-47.
- WATERHOUSE, J.D., SINCLAIR, J.A., and GERGES, N.Z., 1978. The hydrogeology of the Angas-Bremer Irrigation Area. S. Aust. Dept. Mines unpub. rept. 78/8.

Appendix A
Water Quality Data

APPENDIX A1

WATER SAMPLE ANALYSES

1. First Pump-Out Test 25.9.80-28.9.80

Time after test start mins.	Total dissolved solids (salinity) mg/l	pH	Analysis No. W
1440	2580	7.4	3608/80
2160	2660	7.3	3609/80
2880	2680	7.3	3610/80
4320	2690	7.3	3611/80

2. First Injection Test 15.10.80-18.10.80

A. Lake water

Time after test start mins.	Total dissolved solids (salinity) mg/l	pH	Analysis No. W
50	1000	8.0	3797/80
425	525	8.3	3796/80
785	525	8.2	3800/80
1145	525	8.2	3799/80
1505	525	8.1	3798/80
2285	525	8.2	3802/80
2585	525	8.2	3802/80
3305	525	8.2	3803/80
3800	525	8.2	3805/80
3980	525	8.2	3806/80
4265	525	8.1	3804/80

B. Bailed samples from observation wells

	Time after test start mins	Total dissolved solids (salinity) mg/l	pH	Analysis No. W	Remarks
Well OB1	100	4110	12	3815/80	Probably contaminated with drilling fluid (high pH)
Well OB2	90	2580	8.7	3816/80	No time given
	425	2630	7.9	3807/80	
	?	2705	7.6	3808/80	
	4300	2640	7.7	3809/80	
Well OB3	90	6500	7.3	3817/80	Obviously incorrect
	205	2705	7.8	3810/80	
	425	6500	7.1	3811/80	
Well OB4	85	5500	11.2	3818/80	Probably contaminated with drilling fluid (high pH)
	1515	7000	10.0	3812/80	
	3305	6800	10.2	3813/80	
	3800	6000	10.4	3814/80	
Well OB5	80	2335	10.0	3819/80	
	200	2390	7.8	3784/80	
	425	2420	7.6	3773/80	
	800	2410	7.9	3775/80	
	1505	2420	8.4	3792/80	
	1865	2425	7.9	3786/80	
	2300	2410	7.6	3778/80	
	2600	2410	7.6	3779/80	
	3320	2420	8.1	3790/80	
	3800	2440	8.6	3795/80	
	4320	2440	8.6	3794/80	
	350R	2425	8.4	3793/80	
					After 350 mins recovery ie mound decay after pump off.
Well OB6	80	1620	8.5	3820/80	
	200	1710	7.8	3772/80	
	425	1750	8.0	3785/80	
	800	1750	8.0	3788/80	
	1505	1775	8.0	3774/80	
	1865	1750	8.5	3777/80	
	2300	1775	8.1	3789/80	
	2600	1775	8.3	3791/80	
	3320	1750	8.4	3780/80	
	3800	1765	8.6	3782/80	
	4320	1750	8.6	3783/80	
	350R	1745	8.6	3781/80	
					After 350 mins recovery ie mound decay after pump off.

3. Second Pump Out Test 23.10.80-26.10.80

A. Field salinity measurements were taken regularly on the pumped water throughout the test and these are shown on Fig. 22. They consistently underestimated the salinity compared with samples tested in the laboratory and listed below. Samples from injection/pumped well only (IB1).

Time after test start mins	Total dissolved solids (salinity) mg/l	pH	Analysis No. W
100	580	8.0	3951/80
200	605	8.1	3952/80
300	635	8.0	3953/80
400	670	8.0	3954/80
500	705	8.0	3955/80
600	740	8.0	3956/80
700	790	8.0	3957/80
800	810	8.1	3927/80
900	850	8.1	3928/80
1000	890	8.1	3929/80
1100	965	8.0	3930/80
1200	1040	8.0	3931/80
1300	1070	8.0	3932/80
1400	1105	7.9	3933/80
1500	1180	7.9	3934/80
1600	1235	7.9	3935/80
1700	1295	7.8	3936/80
1800	1355	7.8	3937/80
1900	1415	7.8	3938/80
2000	1465	7.9	3939/80
2300	1620	7.9	3940/80
2600	1800	7.7	3941/80
3200	2085	7.8	3958/80
3500	2175	7.8	3959/80
3800	2219	7.6	3943/80
4100	2270	7.6	3944/80
4260	2300	7.6	3942/80

B. Bailed samples from observation wells.

		Time after test start mins	Total dissolved solids (salinity) mg/l	pH	Analysis No. W
Well	OB1	3630	7000	12.2	3945/80
	OB2	3630	2670	8.6	3946/80
	OB3	3630	6900	8.0	3947/80
	OB4	3630	5790	10.5	3948/80
	OB5	3630	2390	9.5	3949/80
	OB6	3630	1715	9.3	3950/80

4. Second Injection Test 12.11.80-15.11.80A. Lake water

Time after test start min	Total dissolved solids (salinity) mg/l	pH	Analysis No. W	Remarks
50	545	8.2	4227/80	
1880	545	8.2	4228/80	
3200	545	8.2	4226/80	

B. Bailed samples from observation wells taken at end of injection

IB1	1215	8.1	4220/80	Injection well
OB2	2705	7.8	4216/80	
OB4	7000	9.0	4218/80	
OB5	2420	8.1	4217/80	
OB6	1745	9.1	4219/80	

5. Third pump-out test 9.12.80-12.12.80

A. Field salinity measurements were taken regularly on the pumped water throughout the test and these are shown on Fig. 22. There is in general good agreement between the field and laboratory results with the field results showing more variation, probably reflecting more accurately the actual mixing of lake water and ground water.

Time after test start mins.	Total dissolved solids (salinity) mg/l	pH	Analysis No.	Remarks
5	691	7.4	4514/80	Full chemical analysis
30	649	7.6	4515/80	Full chemical analysis
300	675	8.0	4498/80	
350	690	8.0	4499/80	
400	705	8.0	4500/80	
450	715	8.0	4501/80	
500	735	8.0	4502/80	
550	740	8.0	4503/80	
600	755	8.0	4504/80	
700	930	8.0	4505/80	
800	820	8.0	4506/80	
900	860	8.0	4507/80	
1000	930	8.0	4508/80	
1200	940	8.0	4509/80	
1300	980	8.0	4551/80	
1400	1010	7.9	4552/80	
1500	1070	7.9	4553/80	
1600	1100	7.9	4554/80	
1700	1140	7.9	4555/80	
1800	1180	7.9	4556/80	
1900	1225	7.9	4557/80	
2000	1265	7.9	4558/80	

2300	1435	7.9	4559/80
2600	1530	7.8	4560/80
2900	1620	7.8	4561/80
3200	1745	7.8	4562/80
3500	1865		4563/80
3800	1960	7.7	4564/80
4100	2020	7.7	4565/80
4320	2146	7.6	4590/80

Full chemical analysis

WATER ANALYSIS REPORT

SAMPLE No. 4514/80

JOB No. 3356/81

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE mg/l	MILLEQUIVS. PER LITRE me/l
<u>CATIONS</u>			
CALCIUM	(Ca)	53.5	2.7
MAGNESIUM	(Mg)	31.5	2.6
SODIUM	(Na)	170.0	7.4
POTASSIUM	(K)	6.5	0.2
IRON	(Fe)		
<u>ANIONS</u>			
HYDROXIDE	(OH)	-	-
CARBONATE	(CO ₃)	-	-
BICARBONATE	(HCO ₃)	237	3.9
SULPHATE	(SO ₄)	39	0.8
CHLORIDE	(Cl)	273	7.7
FLUORIDE	(F)	0.3	-
NITRATE	(NO ₃)	<1	-
PHOSPHATE	(PO ₄)	0.06	-

TOTALS AND BALANCE

CATIONS	(me/l)	12.8	DIFF = 0.4
ANIONS	(me/l)	12.4	SUM = 25.2

$$\frac{\text{DIFF } 100}{\text{SUM}} = 1.6\%$$

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.) MICRO-S/cm AT 25 DEG.C	1290
TOTAL DISSOLVED SOLIDS	MILLIGRAMS PER LITRE mg/l
A. BASED ON E.C.	
B. CALCULATED (HCO ₃ =CO ₃)	691
C. RESIDUE ON EVAP. AT 180 DEG.C	
TOTAL HARDNESS AS CaCO ₃	263
CARBONATE HARDNESS AS CaCO ₃	194
NON-CARBONATE HARDNESS AS CaCO ₃	69
TOTAL ALKALINITY AS CaCO ₃	194
FREE CARBON DIOXIDE (CO ₂)	
SUSPENDED SOLIDS	
SILICA (SiO ₂)	
BORON (B)	0.17
REACTION - pH	<u>UNITS</u> 7.4
TURBIDITY (JACKSON)	
COLOUR (HAZEN)	
SODIUM TO TOTAL CATION RATIO(me/l)	57.7%

THIRD PUMP OUT TEST SAMPLE COLLECTED 5 MINS AFTER TEST START

NAME - DEPT. MINES & ENERGY

ADDRESS

DATE COLLECTED 9/12/80

SAMPLE COLLECTED BY: C. PENHAL

ANGAS - BREMER IRRIGATION AREA RECHARGE EXPERIMENT

FIELD TEMP.

FIELD pH

FIELD COND.

°C

@ °C

µ-S/cm

OBS. No.

HOLE No. 6727-400-02101

D.M. No.

HUNDRED = FREELING

SECTION = 3374

WATER ANALYSIS REPORT

SAMPLE No. 4515/80

JOB No. 3356/81

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE mg/l	MILLEQUIVS. PER LITRE me/l
<u>CATIONS</u>			
CALCIUM	(Ca)	44	2.2
MAGNESIUM	(Mg)	29	2.4
SODIUM	(Na)	165	7.2
POTASSIUM	(K)	6.3	0.2
IRON	(Fe)		
<u>ANIONS</u>			
HYDROXIDE	(OH)	-	-
CARBONATE	(CO ₃)	-	-
BICARBONATE	(HCO ₃)	203	3.3
SULPHATE	(SO ₄)	44	0.9
CHLORIDE	(Cl)	258	7.3
FLUORIDE	(F)	0.32	-
NITRATE	(NO ₃)	2	-
PHOSPHATE	(PO ₄)	0.05	-

TOTALS AND BALANCE

CATIONS	(me/l)	11.9	DIFF =	0.3
ANIONS	(me/l)	11.6	SUM =	23.5

$$\frac{\text{DIFF } 100}{\text{SUM}} = 1.5\%$$

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.) MICRO-S/cm AT 25 DEG.C	1198	
TOTAL DISSOLVED SOLIDS		MILLIGRAMS PER LITRE mg/l
A. BASED ON E.C.		
B. CALCULATED (HCO ₃ =CO ₃)		64.9
C. RESIDUE ON EVAP. AT 180 DEG.C		
TOTAL HARDNESS AS CaCO ₃		22.9
CARBONATE HARDNESS AS CaCO ₃		16.7
NON-CARBONATE HARDNESS AS CaCO ₃		6.2
TOTAL ALKALINITY AS CaCO ₃		16.7
FREE CARBON DIOXIDE (CO ₂)		
SUSPENDED SOLIDS		
SILICA (SiO ₂)		
BORON (B)		0.15
REACTION - pH		UNITS 7.6
TURBIDITY (JACKSON)		
COLOUR (HAZEN)		
SODIUM TO TOTAL CATION RATIO(me/l)		60.2%

THIRD PUMP OUT TEST, SAMPLE COLLECTED 30 MINS AFTER TEST START

NAME - DEPT. MINES & ENERGY

ADDRESS

DATE COLLECTED 9/12/80

SAMPLE COLLECTED BY: C. PENHAL

ANGAS - BREMER IRRIGATION AREA RECHARGE EXPERIMENT

FIELD TEMP.

FIELD pH

FIELD COND.

°C

@

°C

µ-S/cm

OBS. No.

HOLE No. 6727-400-02101

D.M. No.

HUNDRED = FREELING

SECTION = 3374

WATER ANALYSIS REPORT

SAMPLE No. W 4590/80

JOB No. 3356/81

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE mg/ℓ	MILLEQUIVS. PER LITRE me/ℓ
CATIONS			
CALCIUM	(Ca)	125	6.2
MAGNESIUM	(Mg)	72	5.9
SODIUM	(Na)	565	24.6
POTASSIUM	(K)	14.5	0.4
IRON	(Fe)		
ANIONS			
HYDROXIDE	(OH)	-	-
CARBONATE	(CO ₃)	-	-
BICARBONATE	(HCO ₃)	317	5.2
SULPHATE	(SO ₄)	137	2.9
CHLORIDE	(Cl)	1074	30.3
FLUORIDE	(F)	0.45	-
NITRATE	(NO ₃)	2	-
PHOSPHATE	(PO ₄)		

TOTALS AND BALANCE

CATIONS	(me/ℓ)	37.1	DIFF = 1.3
ANIONS	(me/ℓ)	38.4	SUM = 75.5

$$\frac{\text{DIFF } 100}{\text{SUM}} = 1.7\%$$

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.) MICRO-S/cm AT 25 DEG.C	3468
TOTAL DISSOLVED SOLIDS	MILLIGRAMS PER LITRE mg/ℓ
A. BASED ON E.C.	
B. CALCULATED (HCO ₃ =CO ₃)	2146
C. RESIDUE ON EVAP. AT 180 DEG.C	
TOTAL HARDNESS AS CaCO ₃	608
CARBONATE HARDNESS AS CaCO ₃	260
NON-CARBONATE HARDNESS AS CaCO ₃	349
TOTAL ALKALINITY AS CaCO ₃	260
FREE CARBON DIOXIDE (CO ₂)	
SUSPENDED SOLIDS	
SILICA (SiO ₂)	
BORON (B)	0.33

UNITS

REACTION - pH	
TURBIDITY (JACKSON)	7.6
COLOUR (HAZEN)	
SODIUM TO TOTAL CATION RATIO(me/ℓ)	66.2%

THIRD PUMP-OUT TEST

SAMPLE COLLECTED 4320 MINS. AFTER TEST START

NAME - DEPT. MINES & ENERGY
ADDRESS
DATE COLLECTED 12/12/80
SAMPLE COLLECTED BY: M. COBB

FIELD TEMP.
FIELD pH
FIELD COND.

°C
°C
μ-S/cm

OBS. No.
HOLE No. 6727-400-02101
D.M. No.
HUNDRED = FREELING
SECTION = 3374

ANGAS - BREMER IRRIGATION AREA RECHARGE EXPERIMENT

WATER ANALYSIS REPORT

SAMPLE No. 1542/80

JOB No. 5131/80

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE mg/l	MILLEQUIVS. PER LITRE me/l
<u>CATIONS</u>			
CALCIUM	(Ca)	23.4	1.2
MAGNESIUM	(Mg)	17.4	1.4
SODIUM	(Na)	104	4.5
POTASSIUM	(K)	5.8	0.1
IRON	(Fe)		
<u>ANIONS</u>			
HYDROXIDE	(OH)	-	
CARBONATE	(CO ₃)	-	
BICARBONATE	(HCO ₃)	111	1.8
SULPHATE	(SO ₄)	35	0.7
CHLORIDE	(Cl)	177	5.0
FLUORIDE	(F)		
NITRATE	(NO ₃)	1	-
PHOSPHATE	(PO ₄)		

TOTALS AND BALANCE

CATIONS	(me/l)	7.3	DIFF =	0.3
ANIONS	(me/l)	7.6	SUM =	14.8

$$\frac{\text{DIFF}}{\text{SUM}} \times 100 = 1.9\%$$

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.) MICRO-S/cm AT 25 DEG.C	821
TOTAL DISSOLVED SOLIDS	MILLIGRAMS PER LITRE mg/l
A. BASED ON E.C.	
B. CALCULATED (HCO ₃ =CO ₃)	418
C. RESIDUE ON EVAP. AT 180 DEG.C	
TOTAL HARDNESS AS CaCO ₃	130
CARBONATE HARDNESS AS CaCO ₃	91
NON-CARBONATE HARDNESS AS CaCO ₃	39
TOTAL ALKALINITY AS CaCO ₃	91
FREE CARBON DIOXIDE (CO ₂)	
SUSPENDED SOLIDS	
SILICA (SiO ₂)	
BORON (B)	
REACTION - pH	UNITS 8.0
TURBIDITY (JACKSON)	
COLOUR (HAZEN)	
SODIUM TO TOTAL CATION RATIO(me/l)	62.2%

LAKE ALEXANDRINA WATER

NAME -
ADDRESS
DATE COLLECTED 16/4/80
SAMPLE COLLECTED BY: J. BEAL

FIELD TEMP. °C
FIELD pH °C
FIELD COND. µ-S/cm

OBS. No.
HOLE No. 6727-400
D.M. No.
HUNDRED = FREELING
SECTION = C

Appendix B
Calculation of Volume of
Lake Water Recovered

APPENDIX B1

To estimate the amount of the injected lake water recovered during the 72 hour pumping period following the 72 hour injection period, use was made of the known lake and groundwater salinities and the salinity recorded at any time during pumping.

Using the lake salinity and the pre-injection groundwater salinity as end points a straight line graph was drawn relating salinity to proportion of lake water (Fig. 22). Referring to this figure it shows that if a water sample is made up to 20% lake water and 80% native groundwater then the resultant salinity should be 2260 mg/L. This idea was used in reverse to obtain the percentage of lake water in the pumped out water.

Smoothed curves were drawn through the recorded salinity change graphs obtained during the pump out tests (Fig. 22). Dividing the pump out phase into two hour increments an 'average salinity' of pumped water was determined for this two hour period. From Fig. 23 the proportion of the pumped water that could be considered as lake water was then determined. Knowing the total amount pumped in this period then a volume of lake water recovered was obtained. This was repeated until the end of the test and accumulated as given in Tables B-1 to B-3.

Two calculations were performed for the third pump-out test i.e. after the second injection. Firstly the same salinity vs. % lake water graph as used above was used and the results are given in Table B-2.

Since not all of the lake water was removed during the second pump out test after the first injection, then the near-well salinity was lower than that experienced before any testing whatsoever. The second injection lake water was also slightly higher than that used in the first. Thus a second salinity vs. % lake volume graph was drawn using these new end points and the exercise repeated. The results using this graph are tabulated in Table B-3.

TABLE B-1

CALCULATION OF VOLUME OF LAKE WATER RECOVERED
SECOND PUMP OUT TEST (AFTER FIRST INJECTION)
USING ORIGINAL SALINITY VS VOLUME OF LAKE WATER GRAPH

Hours Since pump started	Average Salinity mg/L	Ratio Lake water to aquifer water	Volume pumped out in time	Vol. Lake water pumped in interval	Accumulated vol. lake H ₂ O pumped
			gallons	gallons	
0	2	568	45850	44474.5	44474.5
2	4	598	"	44016	88490.5
4	6	640	"	43099	131589.5
6	8	680	"	42182	173771.5
8	10	720	"	41494	215266
10	12	760	"	40577	255843
12	14	805	"	39660	295503
14	16	860	"	38514	334017
16	18	923	"	37139	371156
18	20	988	"	35763	406919
20	22	1053	"	34388	441306
22	24	1118	"	33012	474318
24	26	1185	"	31637	505955
26	28	1250	"	30261	536216
28	30	1315	"	29115	565331
30	32	1385	"	27510	592841
32	34	1455	"	26135	618975
34	36	1523	"	24759	643734
36	38	1588	"	23384	667118
38	40	1655	"	22008	689126
40	42	1723	"	20403	709529
42	44	1790	"	19028	728557
44	46	1855	"	17652	746209
46	48	1913	"	16506	762715
48	50	1968	"	15360	778075
50	52	2023	"	14214	792288
52	54	2075	"	13067	805355
54	56	2118	"	12380	817735
56	58	2153	"	11463	829197
58	60	2180	"	11004	840201
60	62	2200	"	10546	850747
62	64	2220	"	10087	860834
64	66	2240	"	9629	870462
66	68	2260	"	9170	879632
68	70	2280	"	8941	888573
70	72	2295	"	8482	897055

Volume injected = 1066060 gallons (4846 m³)

Volume recovered = 897055 gallons (4078 m³)

Loss = 169015 gallons (768 m³)

% Loss = 16%

TABLE B-2

CALCULATION OF VOLUME OF LAKE WATER RECOVERED
THIRD PUMP OUT TEST (AFTER SECOND INJECTION) USING
ORIGINAL SALINITY VS VOLUME OF LAKE WATER GRAPH.

Hours pump	Since started	Average Salinity mg/L	Ratio lake water to aquifer water	Volume pumped out in time	Vol. lake water pumped in interval	Accumulated vol. lake H ₂ O pumped
				gallons	gallons	
0	2	540	0.985	38800	38218	38218
2	4	580	0.97	"	37636	75854
4	6	625	0.95	"	36860	112714
6	8	670	0.925	"	35890	148604
8	10	715	0.905	"	35114	183718
10	12	760	0.885	"	34338	218056
12	14	800	0.87	"	33756	251812
14	16	845	0.85	"	32980	284792
16	18	875	0.835	"	32398	317190
18	20	940	0.805	"	31234	348424
20	22	980	0.785	"	30458	378882
22	24	1020	0.77	"	29876	408758
24	26	1070	0.745	"	28906	437664
26	28	1120	0.725	"	28130	465794
28	30	1155	0.705	"	27354	493148
30	32	1195	0.69	"	26772	519920
32	34	1235	0.67	"	25996	545916
34	36	1280	0.65	"	25220	571136
36	38	1330	0.625	"	24250	595386
38	40	1380	0.6	"	23280	618666
40	42	1420	0.585	"	22698	641364
42	44	1460	0.57	"	22116	663480
44	46	1510	0.545	"	21146	684626
46	48	1560	0.52	"	20176	704802
48	50	1605	0.5	"	19400	724202
50	52	1645	0.48	"	18624	742826
52	54	1690	0.46	"	17848	760674
54	56	1740	0.44	"	17072	777746
56	58	1785	0.42	"	16296	794042
58	60	1835	0.395	"	15326	809368
60	62	1885	0.375	"	14550	823918
62	64	1930	0.355	"	13774	837692
64	66	1980	0.33	"	12804	850496
66	68	2025	0.31	"	12028	862524
68	70	2070	0.29	"	11252	873776
70	72	2120	0.265	"	10282	884058
End of pumping						
Extrapolated						
72	74	2160	0.25	"	9700	893758
74	76	2200	0.23	"	8924	902182
76	78	2240	0.21	"	8148	910830
78	80	2280	0.195	"	7566	918396
80	82	2320	0.175	"	6790	925186
82	84	2360	0.16	"	6208	931394
84	86	2400	0.14	"	5432	936826

Table B-2 cont.

Hours pump	Since started	Average Salinity mg/L	Ratio lake water to aquifer water	Volume pumped out in time	Vol. lake water pumped in interval	Accumulated vol. lake H ₂ O pumped
86	88	2440	0.12	"	4656	941482
88	90	2480	0.105	"	4074	945556
90	92	2520	0.085	"	3298	948854
92	94	2560	0.065	"	2522	951376
94	96	2600	0.05	"	1940	953316
96	98	2640	0.03	"	1164	953316
98	100	2680	0.01	"	388	954868
100	102	2720	0	"		

Volume injected = 1064954 gallons (4841 m³)
 Volume lake water recovered = 884058 gallons (4018 m³)
 Loss = 180896 gallons (823 m³)

Percentage loss = 17%

Total volume pumped in the 72 hrs was 139800 gallons
 or 6349 m³ which is 31% more than the volume injected.

TABLE B-3

CALCULATION OF VOLUME OF LAKE WATER RECOVERED,
THIRD PUMP OUT TEST USING MODIFIED SALINITY
VS VOLUME OF LAKE WATER GRAPH.

Hours pump	Since started	Average Salinity mg/L	Ratio lake water to aquifer water	Volume pumped out in time	Vol. lake water pumped in interval	Accumulated vol. lake H ₂ O pumped
				gallons	gallons	
0	2	540	1	38800	38800	38800
2	4	580	0.47	"	37636	76436
4	6	625	0.95	"	36860	113296
6	8	670	0.925	"	35890	149186
8	10	715	0.905	"	35114	184300
10	12	760	0.88	"	34144	218444
12	14	800	0.855	"	33174	251618
14	16	845	0.83	"	32204	283822
16	18	875	0.815	"	31622	315444
18	20	940	0.775	"	30070	345514
20	22	980	0.755	"	29294	374808
22	24	1020	0.73	"	28324	403132
24	26	1070	0.70	"	27160	430292
26	28	1120	0.68	"	26384	456676
28	30	1155	0.655	"	25414	452096
30	32	1195	0.63	"	24444	506534
32	34	1235	0.605	"	23474	530008
34	36	1280	0.58	"	22504	552512
36	38	1330	0.555	"	21534	574046
38	40	1380	0.525	"	20370	594416
40	42	1420	0.5	"	19400	613816
42	44	1460	0.48	"	18624	632440
44	46	1510	0.45	"	17460	649900
46	48	1560	0.42	"	16296	666196
48	50	1605	0.395	"	15326	681522
50	52	1645	0.375	"	14550	696072
52	54	1690	0.35	"	13580	709652
54	56	1740	0.32	"	12416	722068
56	58	1785	0.295	"	11446	733514
58	60	1835	0.265	"	10282	743796
60	62	1885	0.24	"	9312	753108
62	64	1930	0.21	"	8148	761256
64	66	1980	0.18	"	6984	768240
66	68	2025	0.155	"	6014	774254
68	70	2070	0.13	"	5044	779298
70	72	2120	0.1	"	3880	783178

Volume injected = 1064954 gallons (4840 m³)
 Volume lake water recovered = 783178 gallons (3560 m³)
 Loss = 281776 gallons (1280 m³)

Percentage loss = 26%

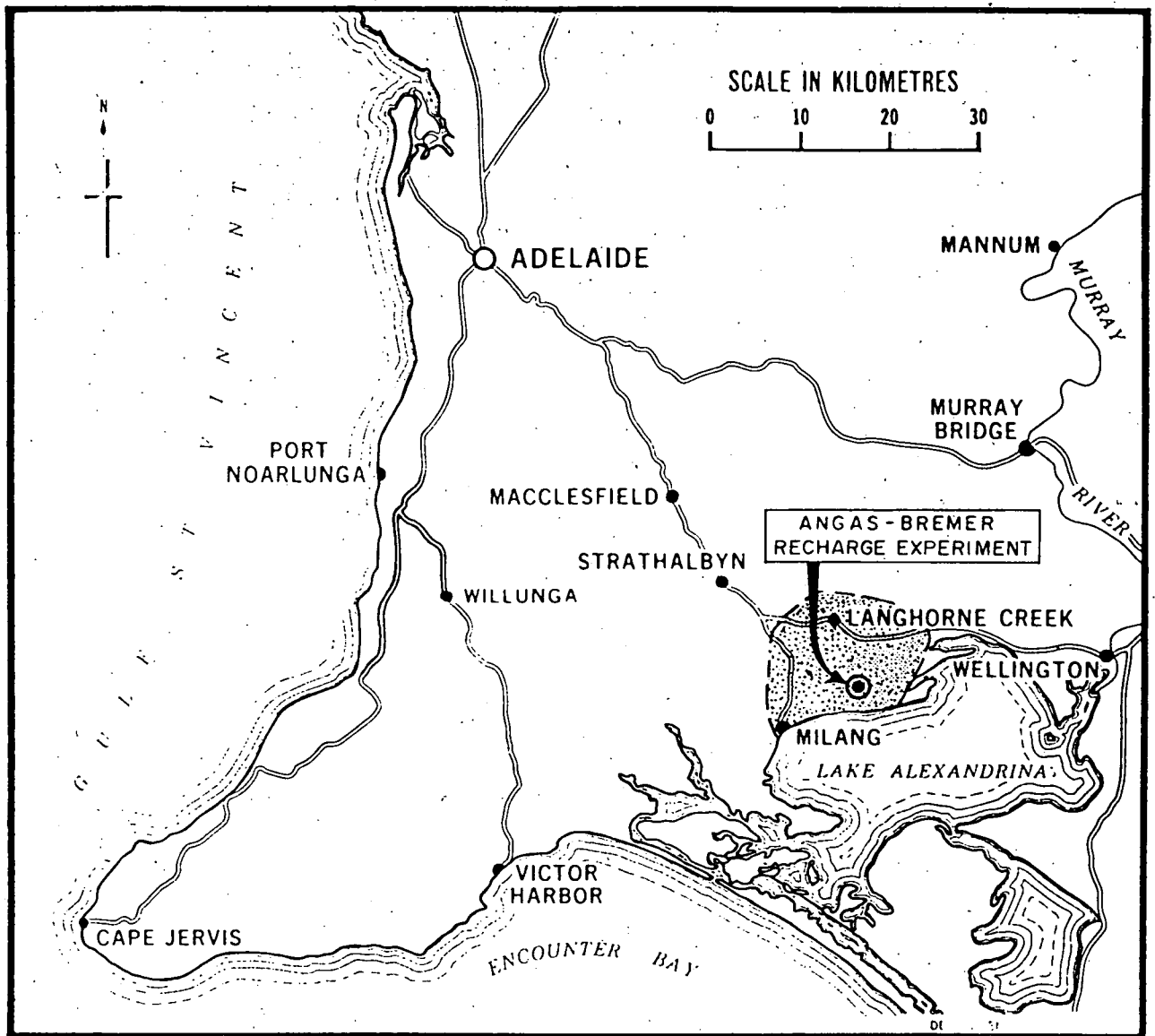
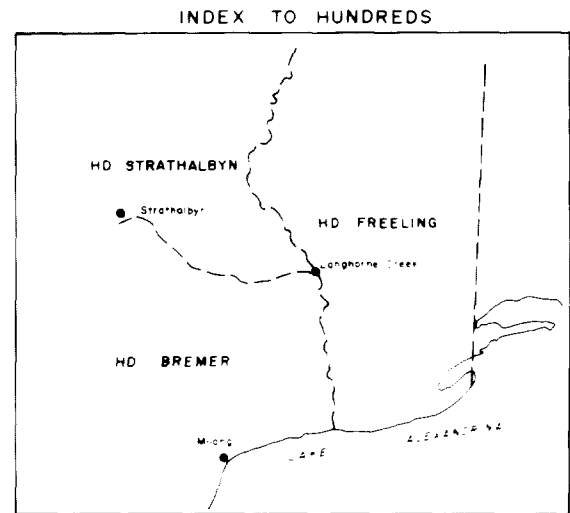
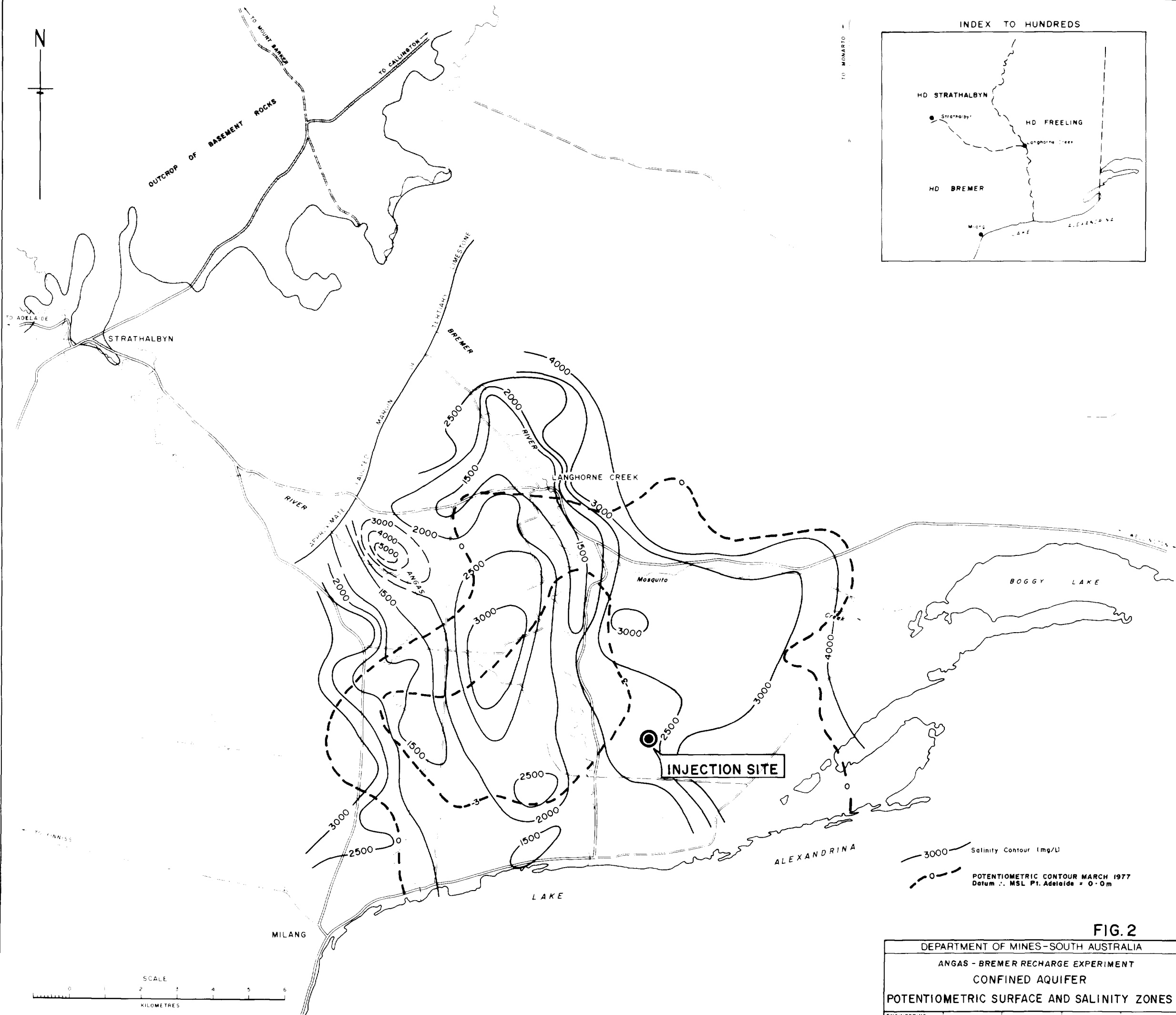


FIG. 1

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED MAC	<i>WR</i> 15.12.82 C.D.O. DATE
	ANGAS - BREMER RECHARGE EXPERIMENT LOCALITY PLAN		DRAWN AD	SCALE 1: 800 000
			DATE SEPT '82	PLAN NUMBER
			CHECKED	S16428

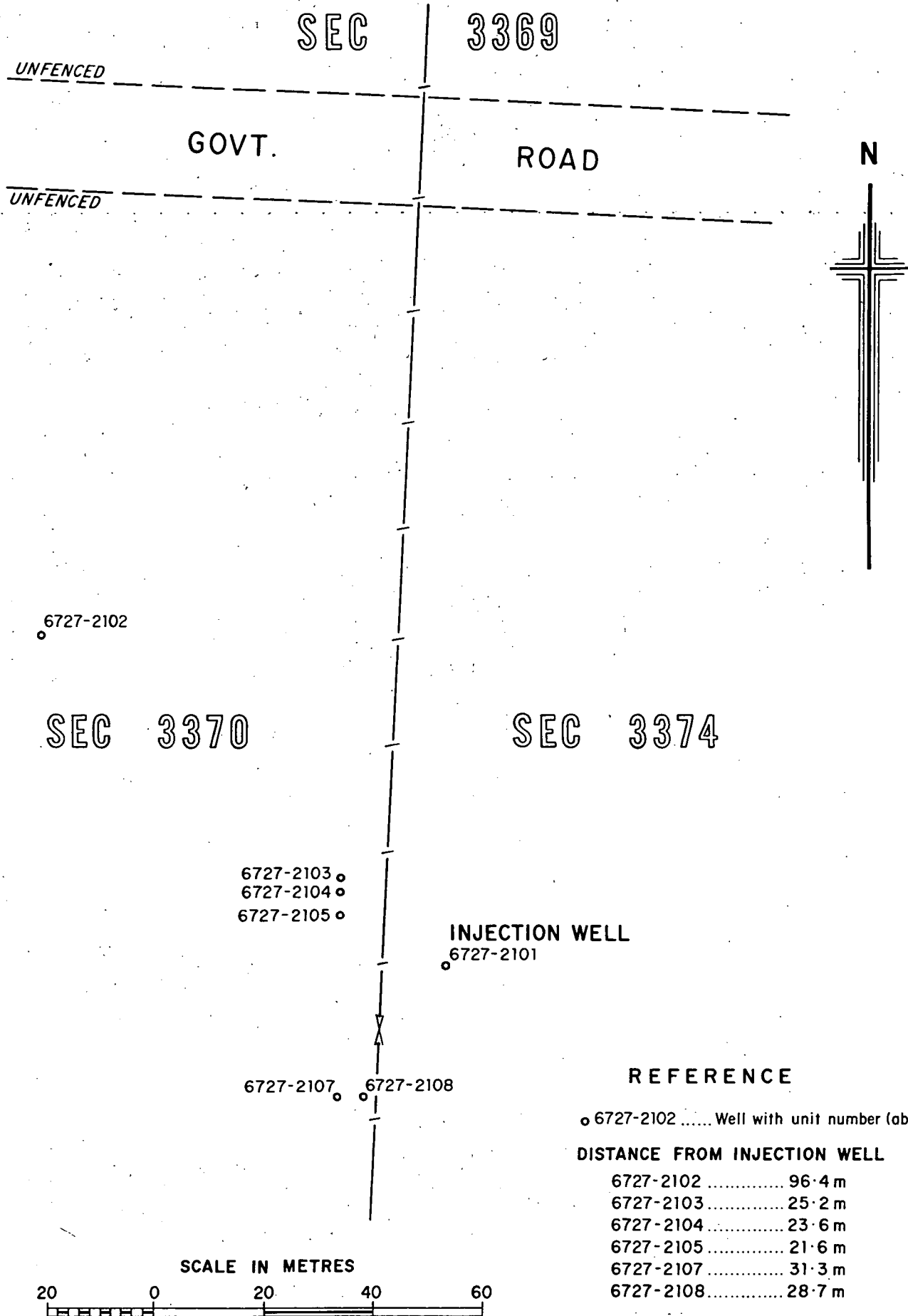


— 3000 — Salinity Contour (mg/L)
 - - - - - POTENTIOMETRIC CONTOUR MARCH 1977
 Datum : MSL Pt. Adelaide = 0.0m

FIG. 2

DEPARTMENT OF MINES—SOUTH AUSTRALIA			
ANGAS - BREMER RECHARGE EXPERIMENT			
CONFINED AQUIFER			
POTENTIOMETRIC SURFACE AND SALINITY ZONES			
ENGINEERING DIVISION	COMPILED MAC	DRN AD	SCALE 1:50,000
DIRECTOR OF MINES	UR	CKD	DATE SEPT '82

82-508



REFERENCE

○ 6727-2102 Well with unit number (abbrev)

DISTANCE FROM INJECTION WELL

6727-2102	96.4 m
6727-2103	25.2 m
6727-2104	23.6 m
6727-2105	21.6 m
6727-2107	31.3 m
6727-2108	28.7 m

FIG.3



DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

ANGAS-BREMER RECHARGE EXPERIMENT HUNDRED OF FREELING LOCATION OF WELLS

COMPILED
A. B. H.

LR 16.12.82
C.D.O. DATE

DRAWN
N. R. S.

SCALE 1:1000

DATE
4-6-81
CHECKED

PLAN NUMBER

S15599

COMPOSITE WELL LOG – GROUNDWATER

HOLE No. IB1

UNIT/STATE No.
67274000W02101

SERIAL No. 916/81

DRG No. 82 - 510

CONSTRUCTION DETAILS

DRILLING TECHNIQUE: ROTARY
CIRCULATION: MUD
START:
FINISH:
TOTAL DEPTH: 127m

HOLE DIAMETER	Inches	m.m	From(m)	To(m)
		250	0	29
		187	29	127
CASING DIAMETER (Cemented)		203	G.L.	29
CASING DIAMETER (Uncemented)				
SCREEN DETAILS Make / Model Dimensions				

PROJECT ANGAS - BREMER IRRIGATION AREA RECHARGE EXPERIMENT

LOCATION

SECTION 3374 HUNDRED FREELING

CO-ORDINATES

LOGGED BY J.BEAL

REFERENCE ELEV. 8.21m DATE 30-7-80

SURFACE ELEV. 7.95m TRACED BY

DATUM AHD DATE

TYPE OF LOG	16 IN. NORMAL	64 IN. NORMAL	6 FT. LATERAL	S. P.	POINT RES- ISTIVITY	NEUTRON	GAMMA RAY	TEMP- ERATURE	
DATE OF RUN			7-8-80	7-8-80	7-8-80	7-8-80	7-8-80		7-8-80
FIRST READING (m)			79.4	79.4	79.4	80	80		80
LAST READING (m)			30	30	30	0	0		0
INTERVAL MEASURED(m)									
CASING : LOGGER (m)									
CASING : DRILLER (m)									
DEPTH REACHED (m)			79.4	79.4	79.4	80	80		80
BOTTOM : DRILLER (m)			127	127	127	127	127		127
MUD TYPE			WATER	WATER	WATER	WATER	WATER		WATER
MUD RESISTIVITY									
RECORDED BY			B. TRAEGER	B. TRAEGER	B. TRAEGER	B. TRAEGER	B. TRAEGER		B. TRAEGER

WELL SYMBOLS

CONSTRUCTION LOG

HYDROGEOLOGICAL LOG

Casing seal

Casing shoe

Wire wound screen

Slotted casing

Cemented Interval

Gravel packed Interval

Core Interval

Aq Aquifer

Cb Confining bed

T Transmissivity m³/day m⁻¹

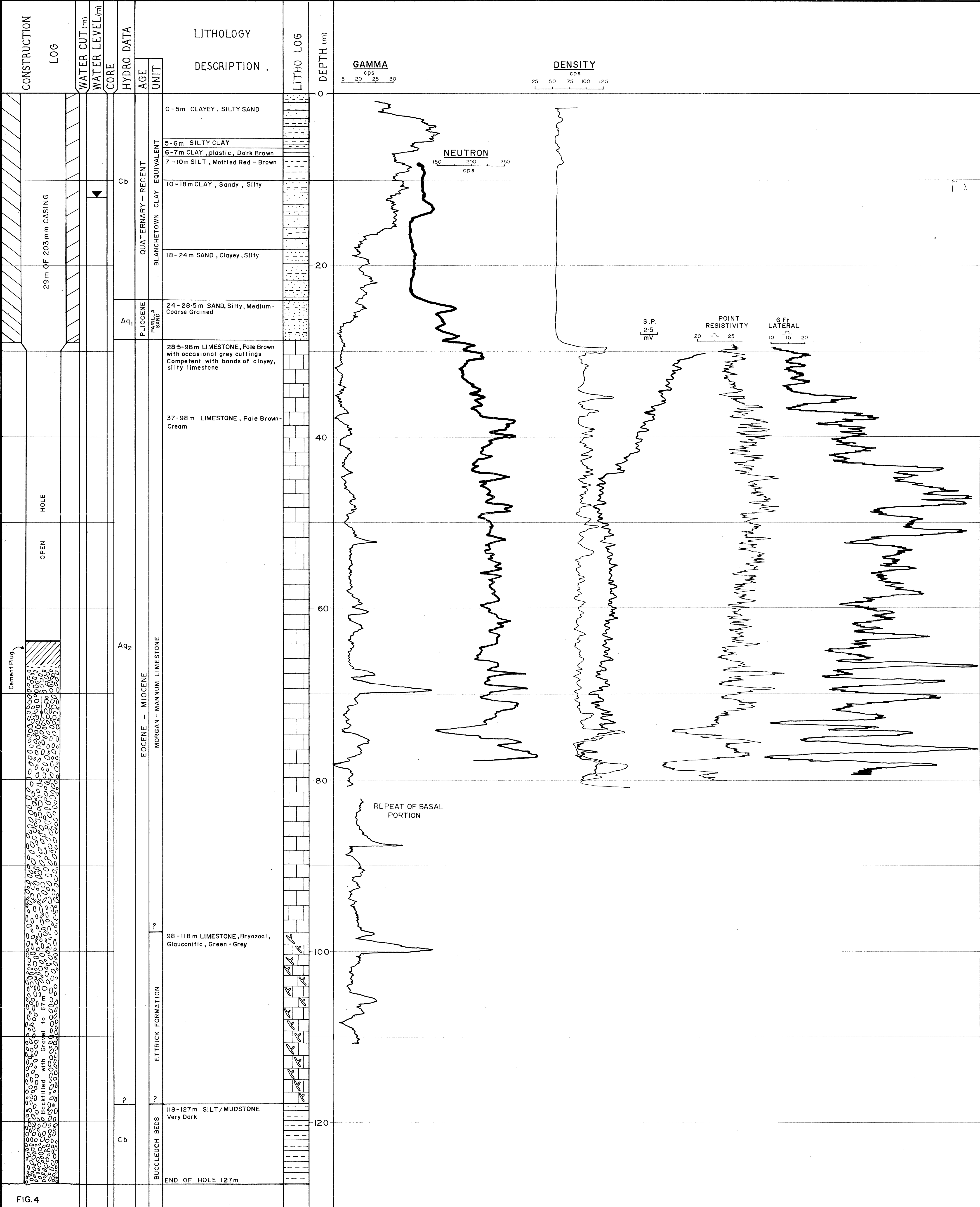
S Storage Coefficient/Specific Yield

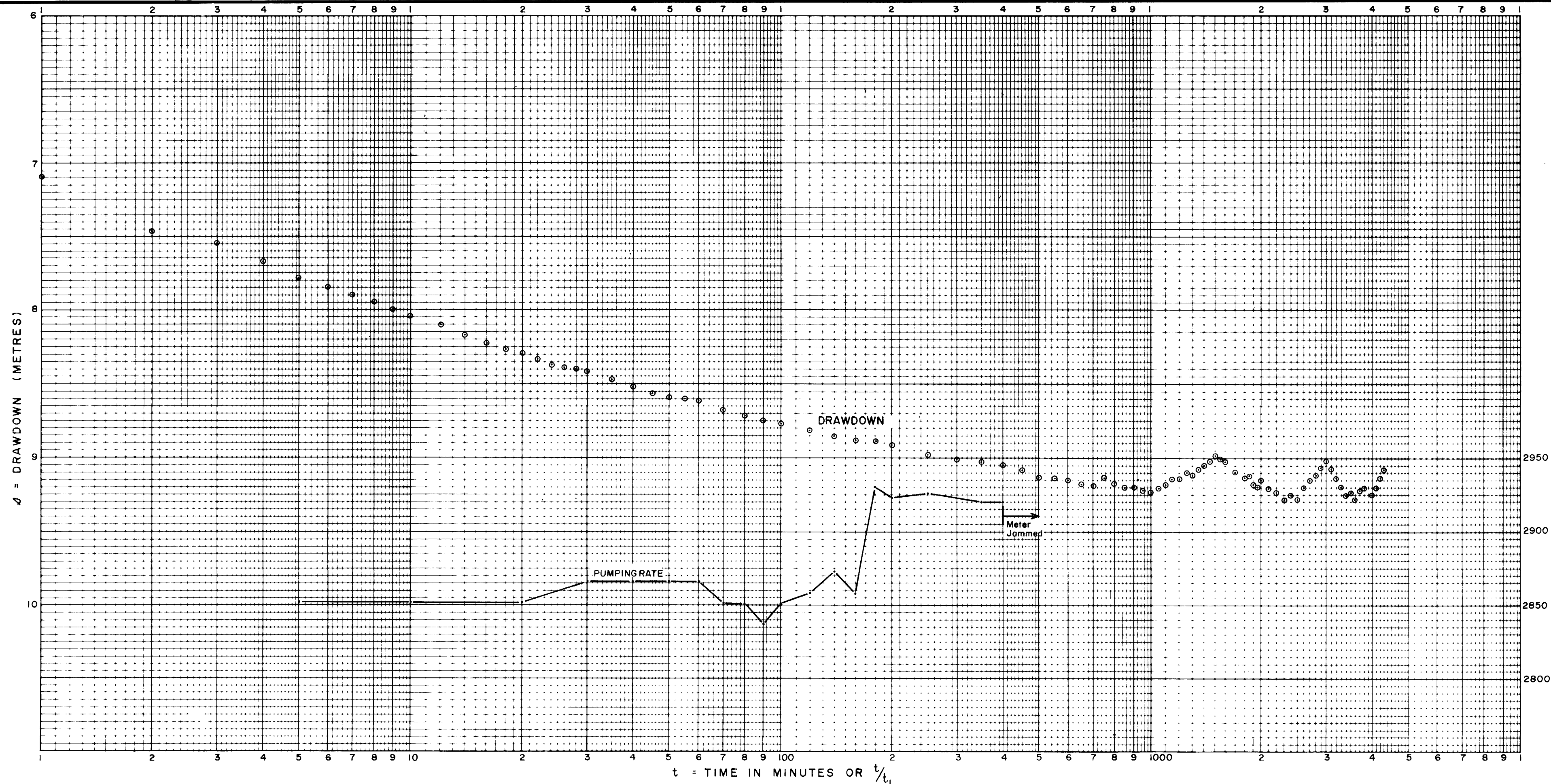
θ Porosity

K Hydraulic conductivity m/day

DEPTH TO WATER(m)	DEPTH TO SWL (m)	YIELD		TOTAL DISSOLVED SOLIDS	
		m ³ /day	Method of Test	mg / litre	Analysis W. No.
	12	2500	PUMP	2690	

REMARKS : Back filled with gravel to 67m then cement plug to 64m. Injection / Pump-Out Well
Permit 90876





BOREHOLE STATE/UNIT No. 67274000W02101
REF. PT. (m) above ground
AQUIFER FROM 29 TO 118 (m)
HOLE DEPTH 64 (m)

TYPE OF PUMP TURBINE
LENGTH OF TEST 72 hours
DEPTH WATER LEVEL AT TEST START (l₂) (m)
DEPTH PUMP INTAKE (l₁) (m)
* AVAILABLE DRAWDOWN (m)

EQUATIONS

$$T = \frac{0.183 \times Q}{\Delta_d} \quad S = \frac{2.25 \times T t_0}{r^2}$$

In which
T = Transmissivity (m³/day/m)
Q = Pumping Rate (m³/day)
Δ_d = Drawdown per log cycle (m)

S = Storage Coefficient
t₀ = Zero drawdown time (mins)
r = Distance to Observation Bore (m)
1 day = 8.64 × 10⁴ secs.

DATA

Q	Δ _d	t ₀	r
2900 m³/day	0.90	-	0

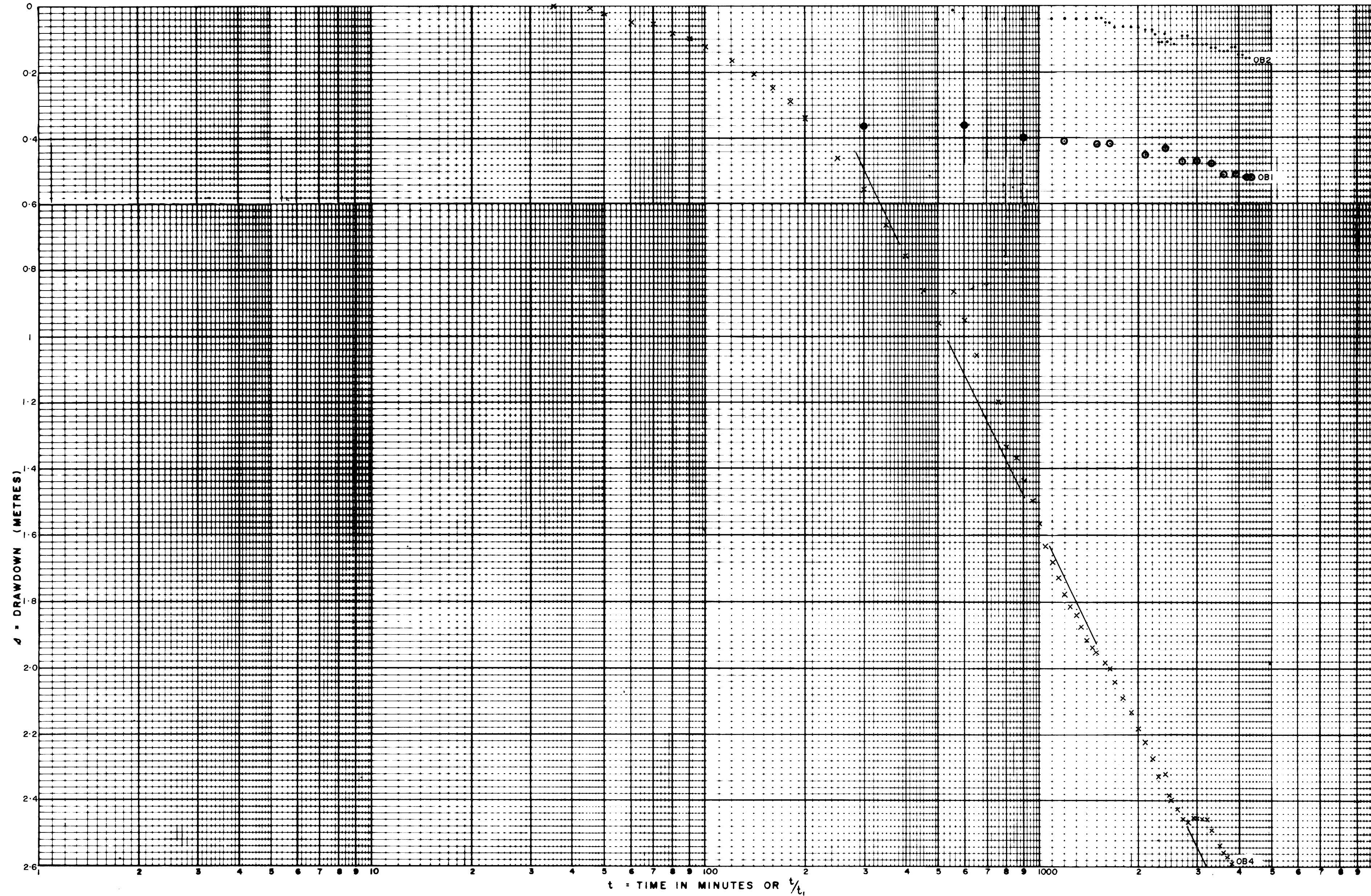
CALCULATIONS

$$T = \frac{0.183 \times 2900}{0.90} = 590 \text{ m}^3/\text{day}/\text{m}$$

* Available drawdown = l₁ - l₂

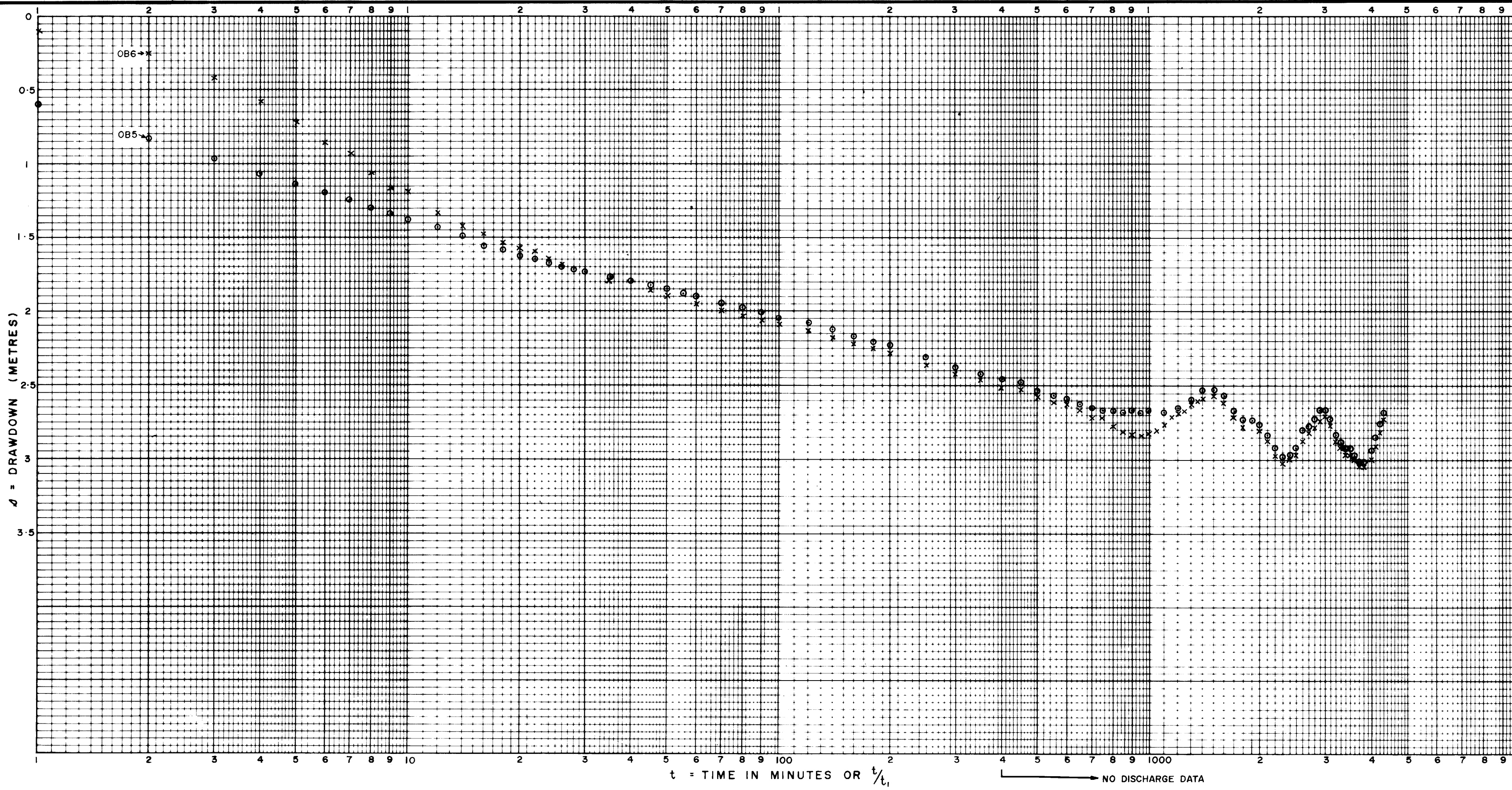
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		SCALE
ANGAS-BREMER RECHARGE EXPERIMENT		DATE AUG '82
FIRST PUMP-OUT TEST		PLAN NUMBER
DRAWDOWN & PUMPING RATE OF PUMPED WELL		82-511

FIG.5



		COMPILED MAC 16.12.82 DATE
ANGAS - BREMER RECHARGE EXPERIMENT		SCALE
FIRST PUMP-OUT TEST		PLAN NUMBER
SEMI-LOG DRAWDOWN OF OBSERVATION WELLS OBI, 2 AND 4		CHECKED 82-512

FIG.6



BOREHOLE STATE/UNIT No 67274000W02107,02108
REF. PT. (m) above ground
AQUIFER FROM TO (m)
HOLE DEPTH (m)
TYPE OF PUMP TURBINE
LENGTH OF TEST 72 hours
DEPTH WATER LEVEL AT TEST START (l_2) (m)
DEPTH PUMP INTAKE (l_1) (m)
* AVAILABLE DRAWDOWN (m)

EQUATIONS

$T = \frac{0.183 \times Q}{\Delta_d}$
In which
T = Transmissivity ($m^3/day/m$)
Q = Pumping Rate (m^3/day)
 Δ_d = Drawdown per log cycle (m)
 $S = \frac{2.25 \times T t_0}{r^2}$
S = Storage Coefficient
 t_0 = Zero drawdown time (mins)
r = Distance to Observation Bore (m)
1 day = 8.64×10^4 secs.

DATA

	Q	Δ_d	t mins	r
For 67274000W02107 (OB5)	2897 m^3/day	0.79	20	31.3

CALCULATIONS

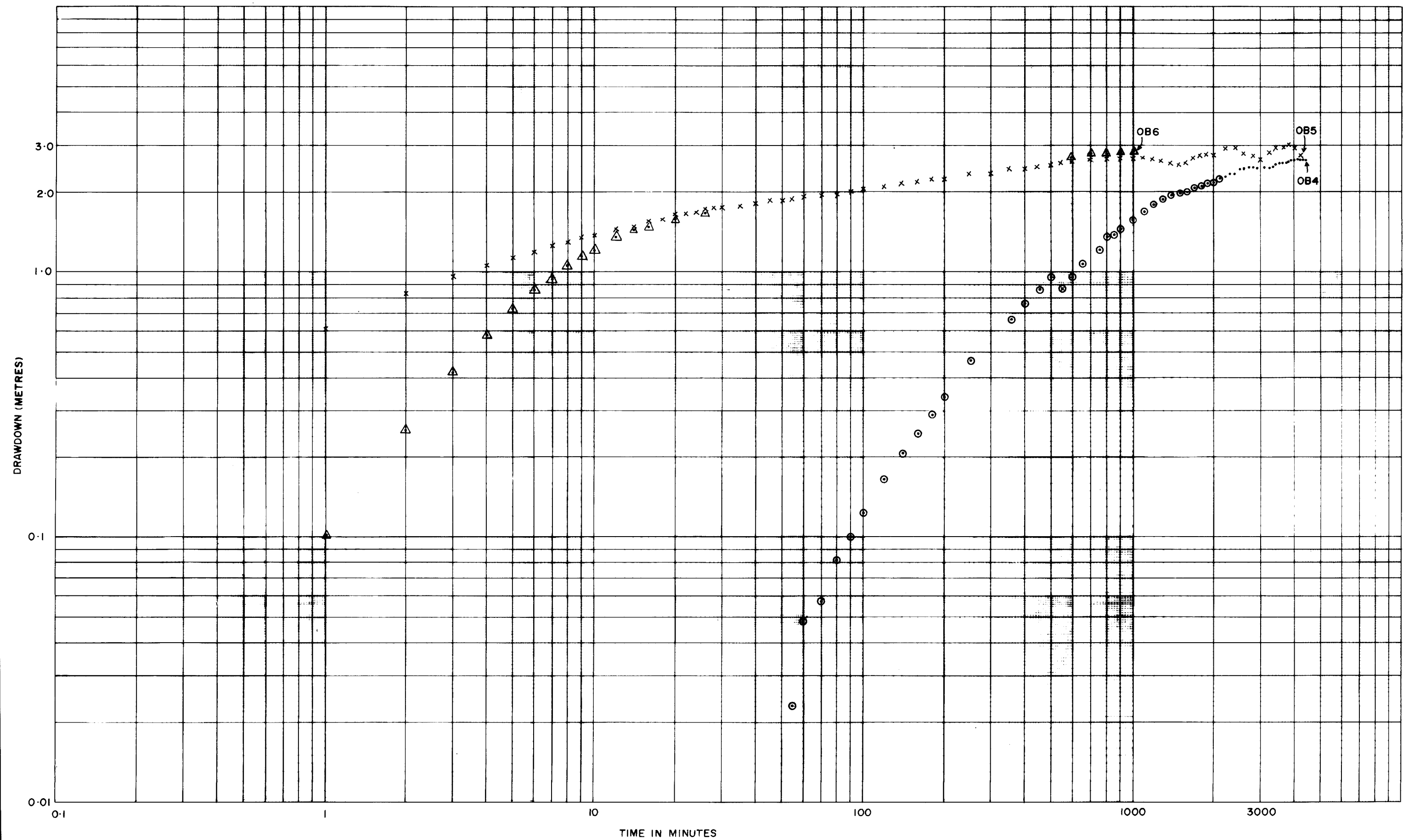
$T = \frac{0.183 \times Q}{\Delta_d} = 670 m^3/day/m$
 $S = \frac{2.25 \times 670 t}{r^2 \times 10^4 \Delta_d}$ At t = 20 mins. $\Delta = 1.62$ $\therefore \Delta/\Delta_d = 2.05$
 $\therefore S = \frac{2.25 \times 670 \times 20}{(31.3)^2 \times 112.37 \times 1440} = 1.9 \times 10^{-4}$

For 672740002108 (OB6) Cannot be analysed by this method.

* Available drawdown = $l_1 - l_2$

FIG. 7

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		SCALE
ANGAS-BREMER RECHARGE EXPERIMENT		DATE SEPTEMBER 1982
FIRST PUMP-OUT TEST		PLAN NUMBER
SEMI-LOG DRAWDOWN OF OBSERVATION WELLS OB5 AND OB6		82-513



CALCULATIONS

WELL No. 67274000W02105,02107,02108 (OB4,OB5,OB6)
OBSERVATION WELL OB5

$Q = 2897 \text{ m}^3/\text{day}$
 $r = 31.3 \text{ m}$
 $m = 1.8 \text{ m}$
 $r_B = 0.015$
Match Point $u = 1.0$ $W(u) = 1.0$ $s = 0.33$ $t = 6.94 \times 10^{-5} \text{ days}$

$T = \frac{Q W(u, r_B)}{4 \pi s} = 700 \text{ m}^3/\text{day}/\text{m}$

$S = \frac{4 T u t}{r^2} = 2.0 \times 10^{-4}$

$P' = \frac{T m' (r_B)^2}{r^2} = 3 \times 10^{-3} \text{ m}^3/\text{day}/\text{m}^2$

FIG.8

 DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED M A C	<i>MR</i> 16.12.82 C D O DATE
	DRAWN A D	SCALE
	DATE AUG'82	PLAN NUMBER
	CHECKED	82-514

ANGAS - BREMER RECHARGE EXPERIMENT
FIRST PUMP - OUT TEST
LOG-LOG DRAWDOWN PLOT OF OBS WELLS 4,5 & 6

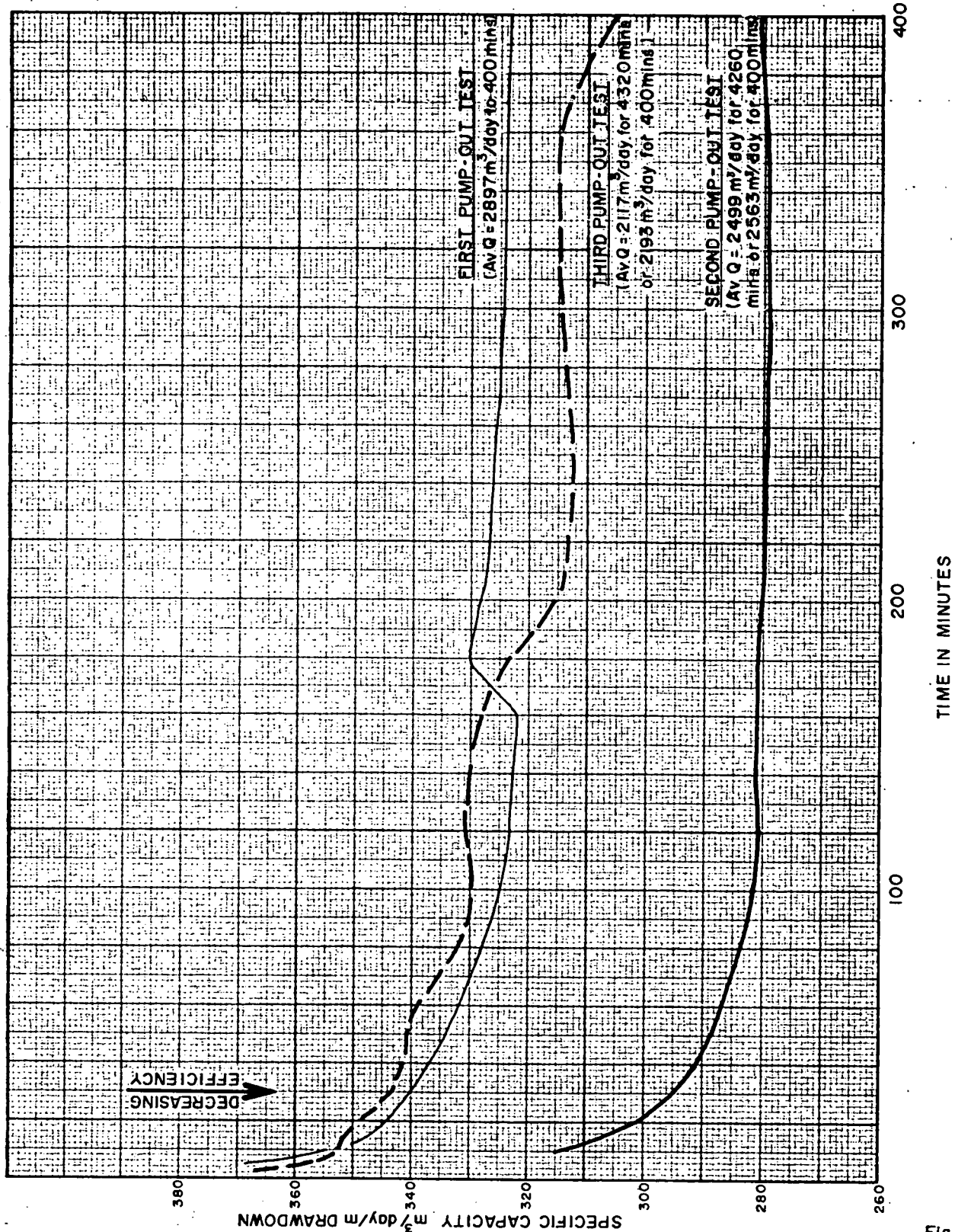


Fig. 9



**DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA**

**ANGAS - BREMER RECHARGE EXPERIMENT
FIRST, SECOND AND THIRD PUMP-OUT TESTS
VARIATIONS IN SPECIFIC CAPACITY OF PUMPED WELL**

COMPILED
MAC

UR 15. 12. 82
C.D.O. DATE

DRAWN
AD

SCALE

DATE
AUG '82

PLAN NUMBER

CHECKED

S16429

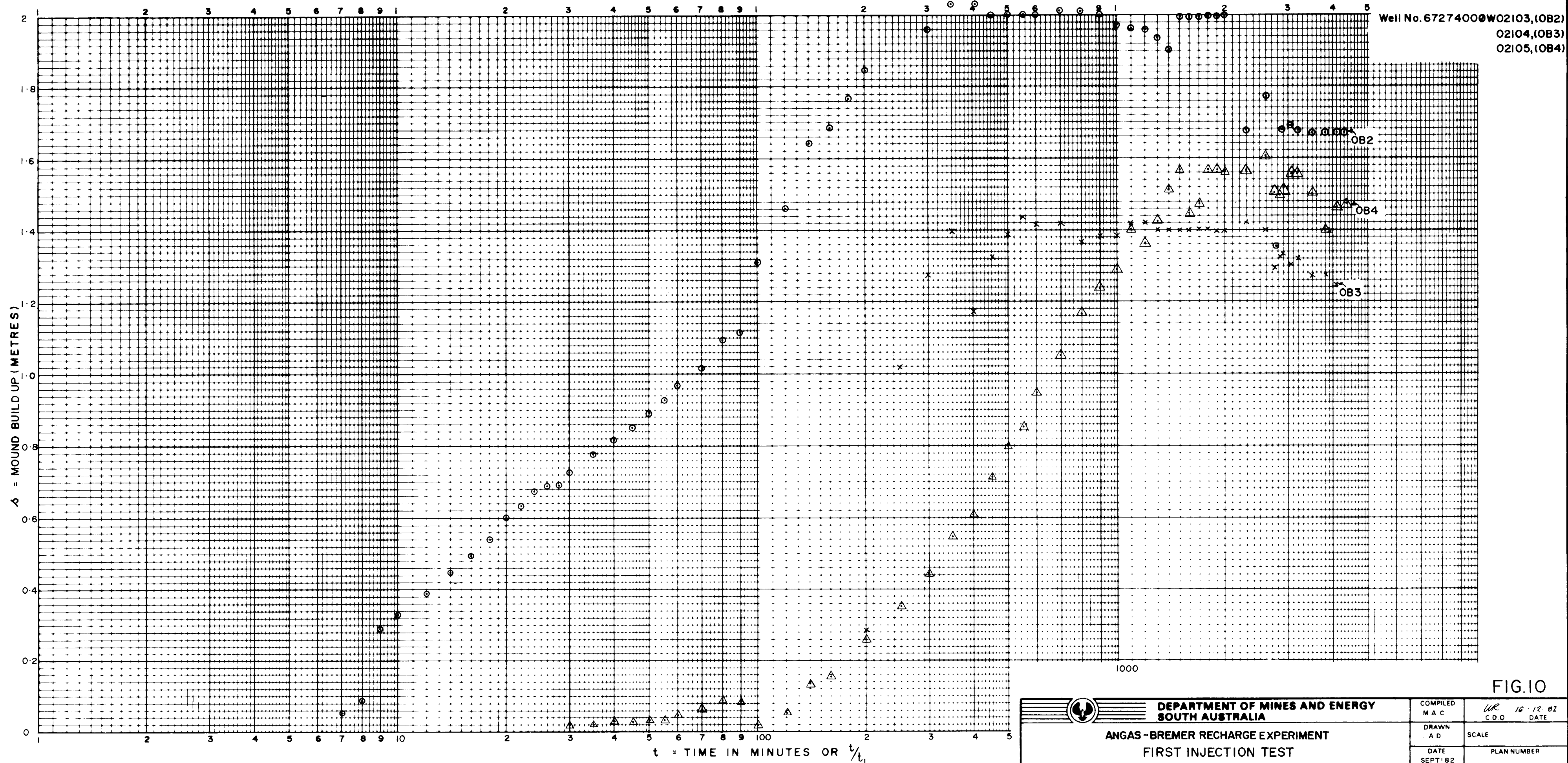


FIG.10

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED M A C	16.12.82 C.D.O. DATE
		DRAWN A D	SCALE
ANGAS-BREMER RECHARGE EXPERIMENT FIRST INJECTION TEST MOUND RISE OF OBSERVATION WELLS OB2,3 AND 4		DATE SEPT '82	PLAN NUMBER
		CHECKED	82-515

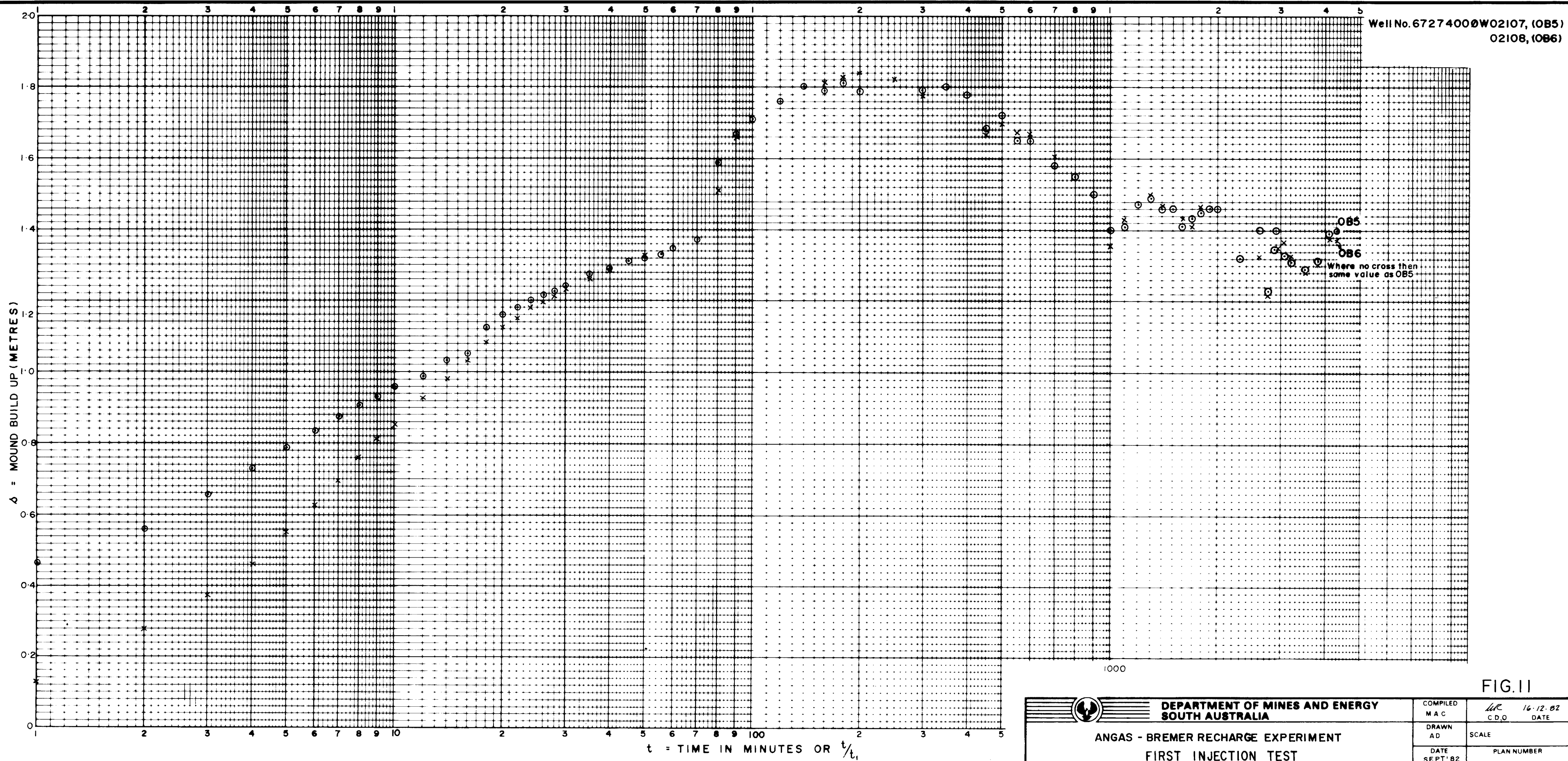
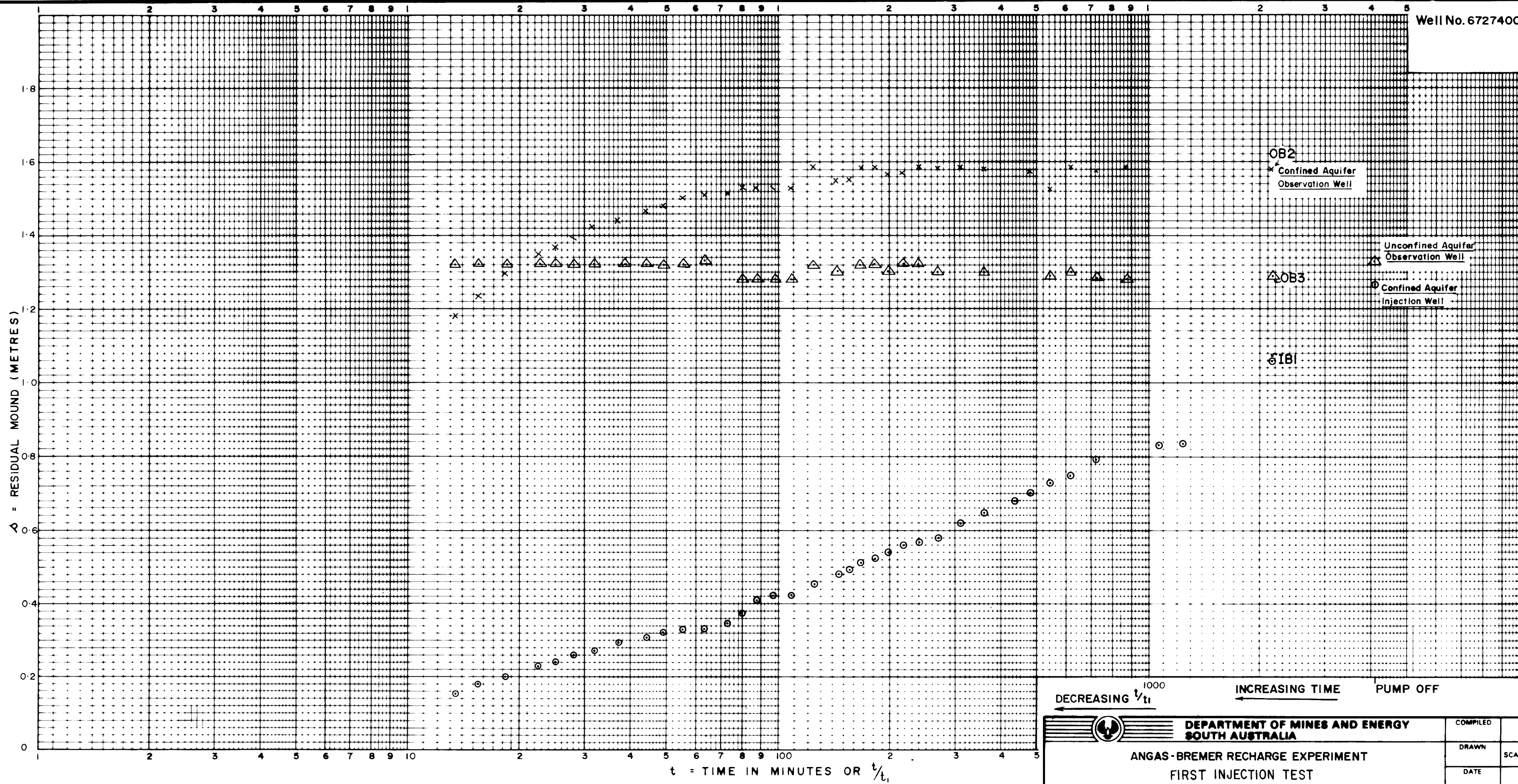


FIG.11

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED M A C	16.12.82 DATE
		DRAWN AD	SCALE
ANGAS - BREMER RECHARGE EXPERIMENT FIRST INJECTION TEST		DATE SEPT '82	PLAN NUMBER
		CHECKED	82-516
MOUND RISE OF OBSERVATION WELLS OB5 AND 6			



Well No. 67274000W02101, (IB1)
02103, (OB2)
02104, (OB3)

FIG. 12

		DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED	MR 16.12.02 C.D.O. DATE
ANGAS-BREMER RECHARGE EXPERIMENT FIRST INJECTION TEST				DRAWN	SCALE
MOUND DECAY OF INJECTION WELL IBI AND OBSERVATION WELLS OB2 AND 3				DATE	PLAN NUMBER
				CHECKED	82-517

2927

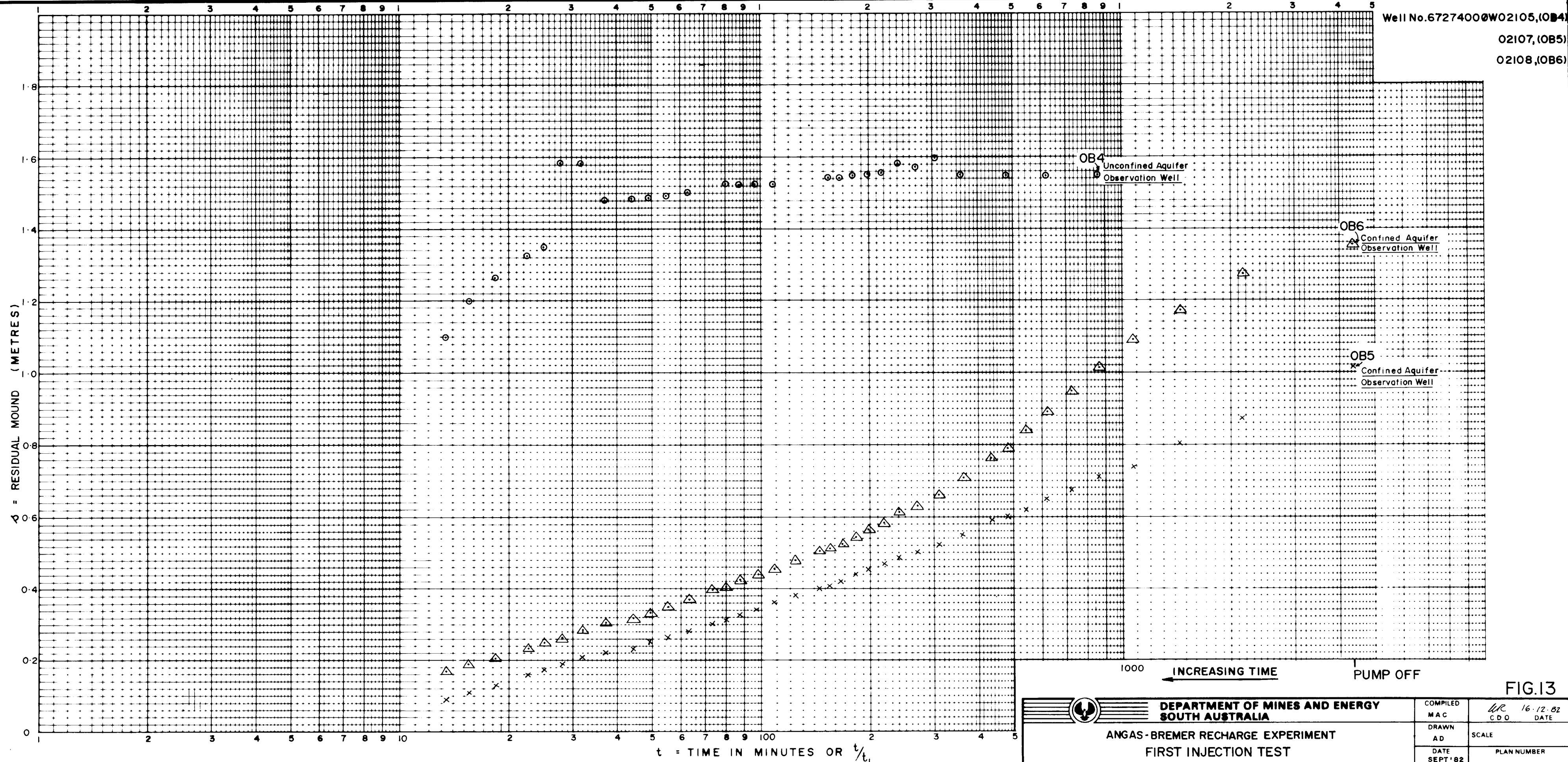


FIG.13

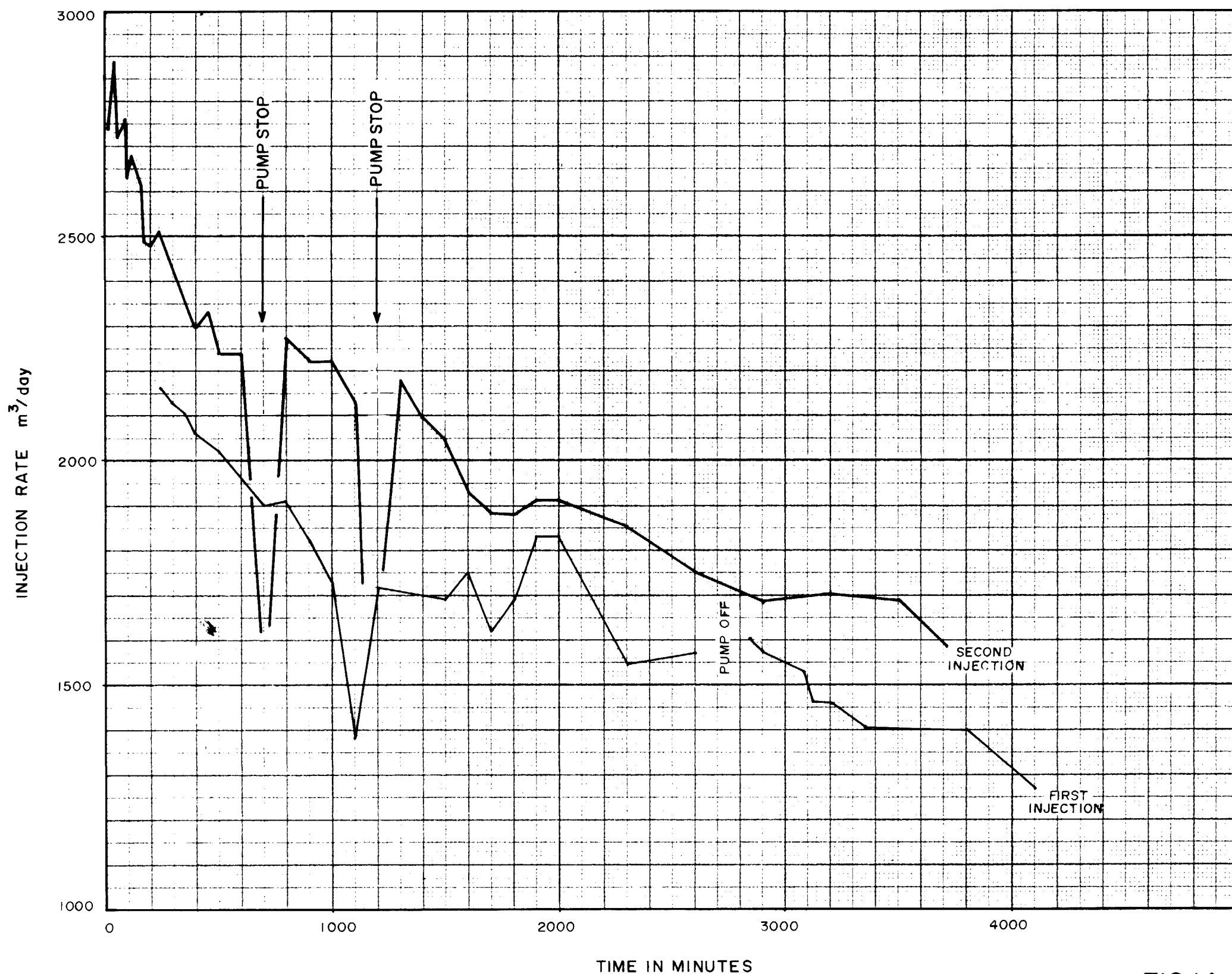


FIG.14

 DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED MAC	<i>MR</i> 16.12.82 C D O DATE
	DRAWN A D	SCALE
	DATE AUG'82	PLAN NUMBER
	CHECKED	82-535

ANGAS-BREMER RECHARGE EXPERIMENT
FIRST & SECOND PUMP - OUT TESTS
INJECTION RATES

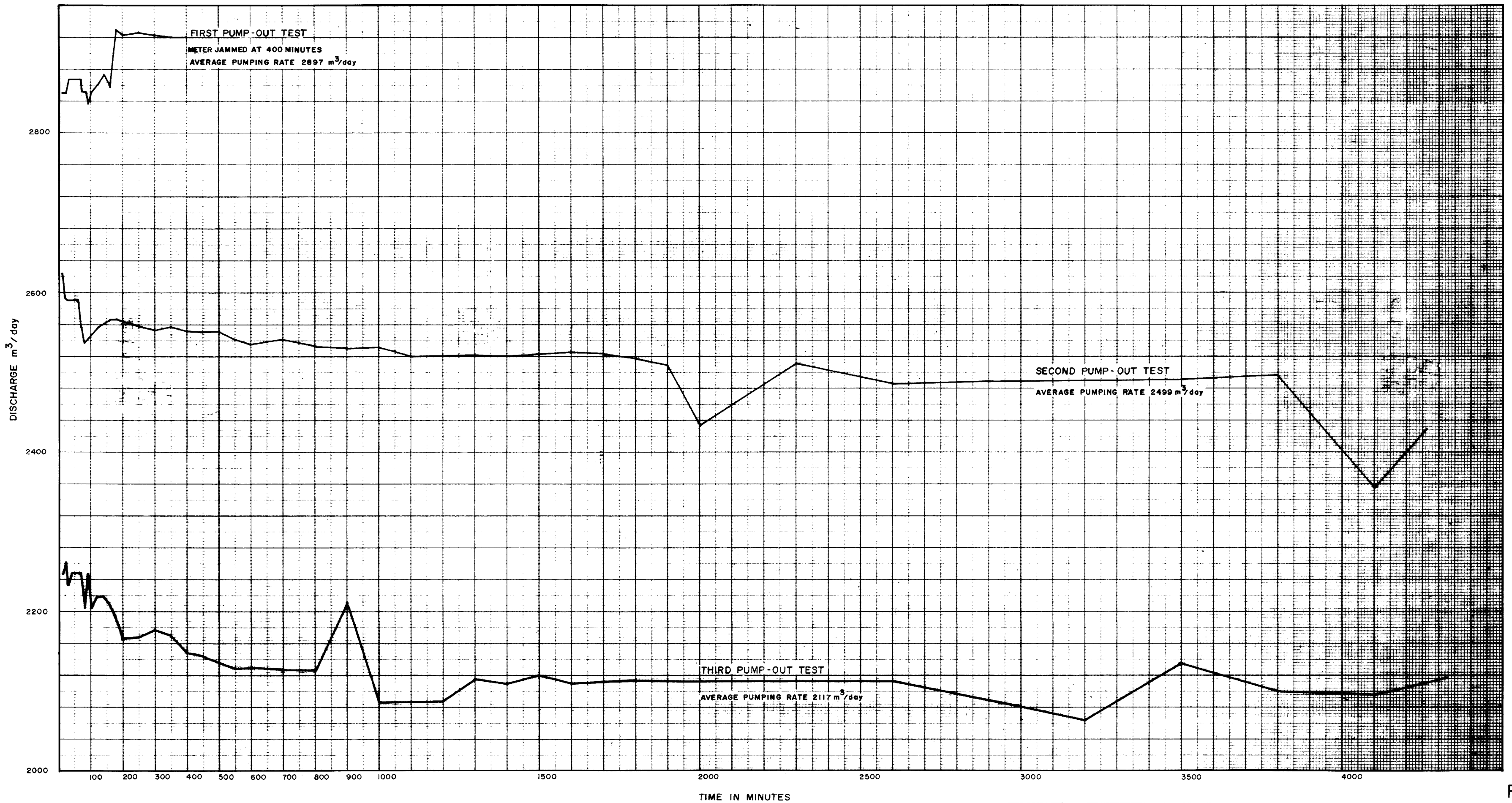


FIG.15

 DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED MAC	16.12.82 C.D.O. DATE
ANGAS-BREMER RECHARGE EXPERIMENT		DRAWN A D	SCALE
FIRST, SECOND & THIRD PUMP - OUT TESTS		DATE AUG '82	PLAN NUMBER
DISCHARGE RATES		CHECKED	82-536

WELL No. 6727 400 WW 02101
CONSTANT DISCHARGE TEST

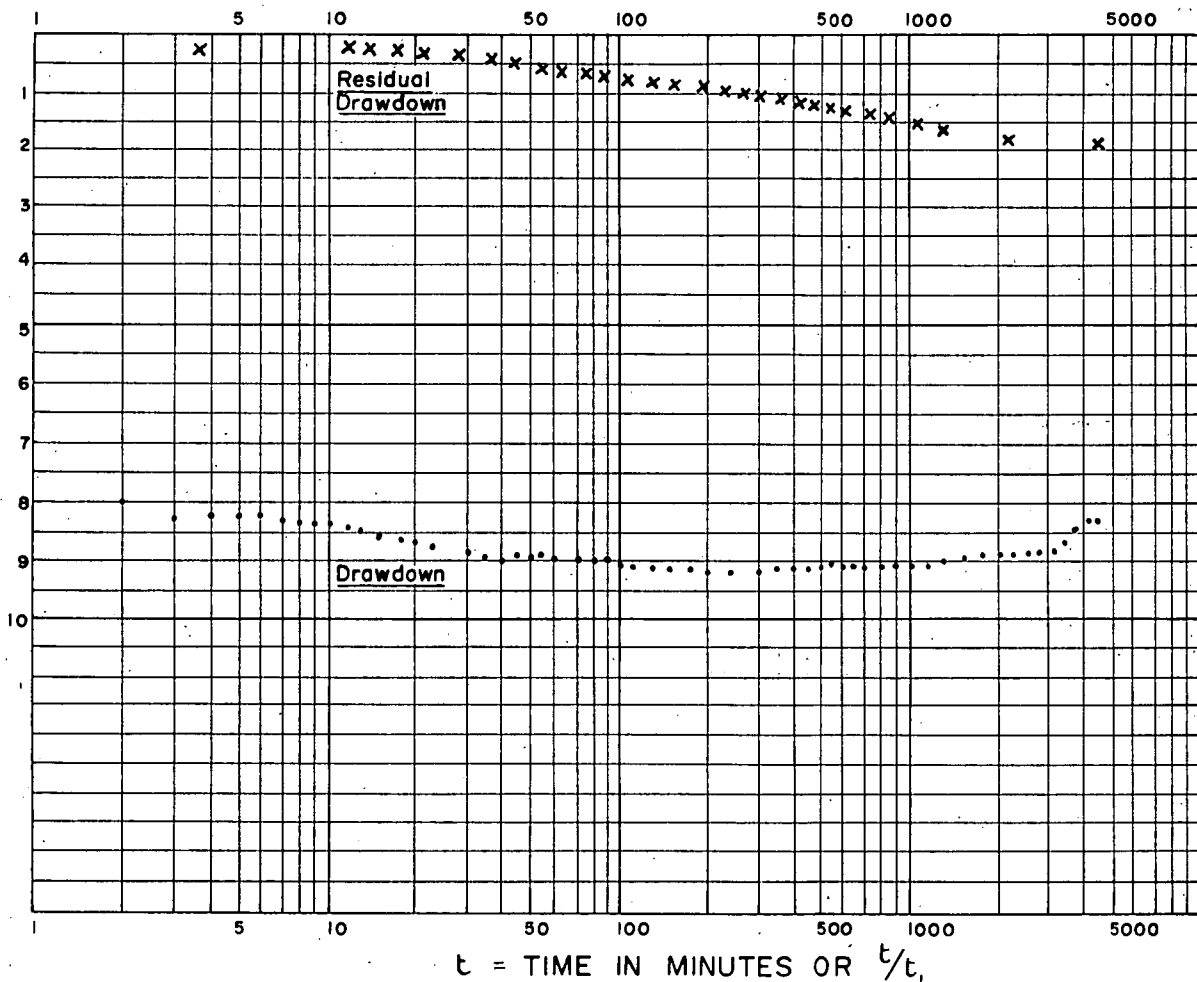
SECOND PUMP - OUT TEST

ANGAS - BREMER RECHARGE EXPERIMENT

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA



(S.E. 1.1.1.1) NWQDWDWD = P



DATA

Q = 2499 m³/day
ΔΔ = 0.84
t₀ = -
r = Residual Drawdown

CALCULATIONS

$$T = \frac{0.183 \times 2499}{0.84} = 544 \text{ m}^3 \text{ day / m}$$

/UNIT No. 6727 400 WW 02101 (181)

INJECTION WELL

INTERVAL TESTED

From 29 m. to 64 m.

HOLE DEPTH 64 m.

AQUIFER THICKNESS 89 m.

DEPTH OF PUMP INTAKE m.

DEPTH OF WATER LEVEL

AT TEST START 9.14 m.

AVAILABLE DRAWDOWN m.

JACOB EQUATIONS*

$$T = \frac{0.183 \times Q}{\Delta\Delta} \text{ in which}$$

T = Transmissivity (m³/day/m.)

Q = Pumping rate (m³/day)

ΔΔ = Drawdown per log cycle (m.)

$$S = \frac{2.25 \times T t_0}{1440 r^2} \text{ in which}$$

S = Storage coefficient

t₀ = Zero drawdown time (minutes)

r = Distance to Observation Well (m.)

Figure 16

* Check applicability of this method

COMPILED
MAC
DRAWN
AD
DATE
AUG 82
CHECKED

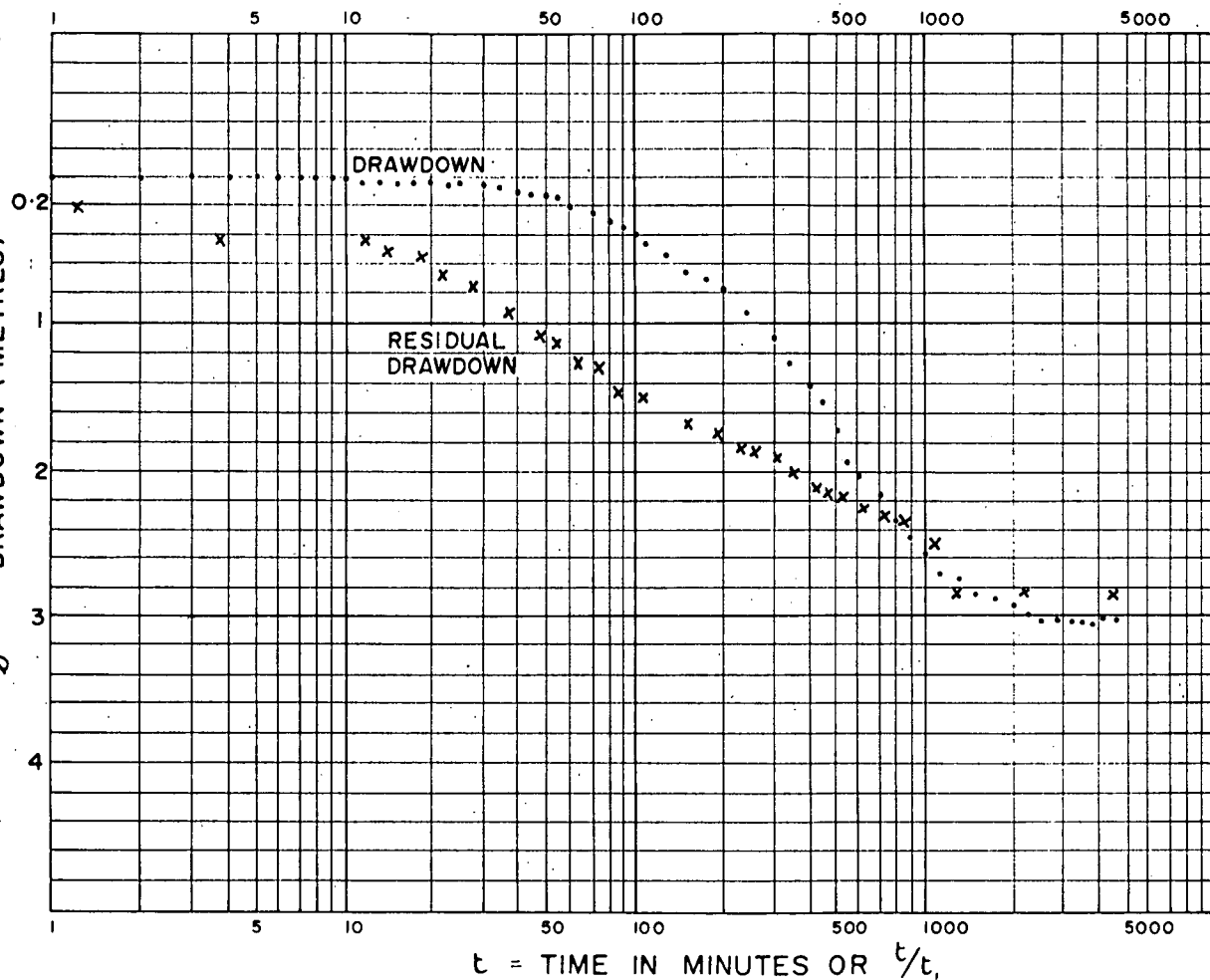
PLAN NUMBER
S16430

SCALE
C.D.O.
DATE
16.12.82

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA
ANGAS - BREMER RECHARGE EXPERIMENT
SECOND PUMP - OUT TEST
WELL No. 6727 400 WW 02103
CONSTANT DISCHARGE TEST

(SERIES) NMOWDWD = P

Figure 17



DATA

Q 2499 m³/day
Δd 0.98
t₀ -
r 25.2

CALCULATIONS

$$T = \frac{0.183 \times 2499}{0.98} = 467 \text{ m}^3/\text{day}/\text{m}$$

UNIT No. 6727 400 WW 02103 (0B2)

OBSERVATION WELL

INTERVAL TESTED

From m. to m.

HOLE DEPTH m.

AQUIFER THICKNESS m.

DEPTH OF PUMP INTAKE m.

DEPTH OF WATER LEVEL

AT TEST START 9.315 m.

AVAILABLE DRAWDOWN m.

JACOB EQUATIONS*

$$T = \frac{0.183 \times Q}{\Delta d} \text{ in which}$$

T = Transmissivity (m³/day/m.)Q = Pumping rate (m³/day)

Δd = Drawdown per log cycle (m.)

$$S = \frac{2.25 \times T t_0}{1440 r^2} \text{ in which}$$

S = Storage coefficient

t₀ = Zero drawdown time (minutes)

r = Distance to Observation Well (m.)

* Check applicability of this method

COMPILED
MAC
DRAWN
A D
DATE
AUG '82
CHECKED
SCALE
PLAN NUMBER
S16431

16.12.82
C D O
DATE

(SHEET 1) NMOOWARD = P

Figure 18



DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

ANGAS - BREMER RECHARGE EXPERIMENT

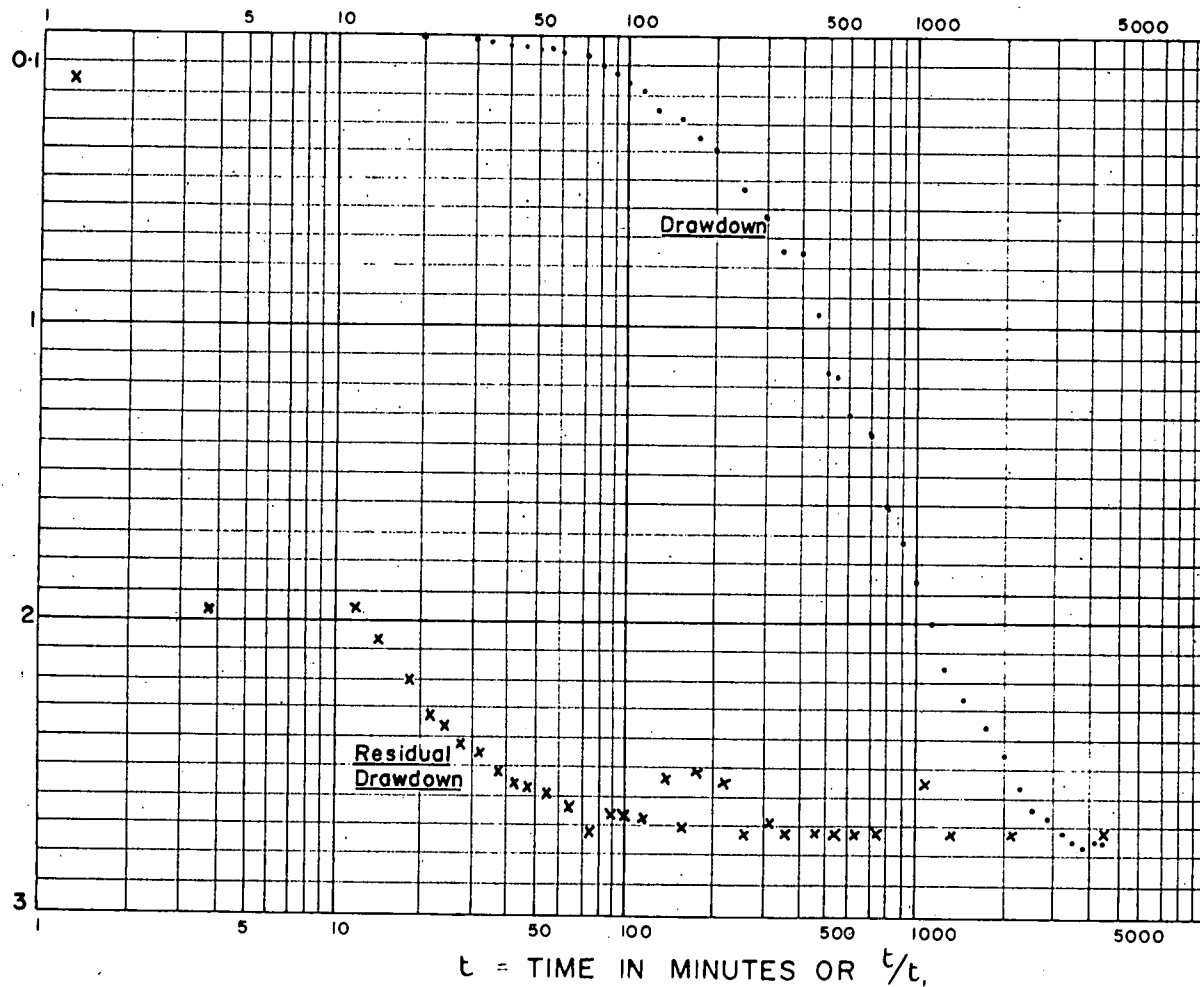
SECOND PUMP - OUT TEST

WELL No. 6727 400 WW 02105

CONSTANT DISCHARGE TEST

CHECKED	DATE	PLAN NUMBER
	AUG '82	
DRAWN	MAC	SCALE
	AD	
COMPILED	MAC	DATE
		16/12/82

S16432



DATA

CALCULATIONS

UNIT No. 6727 400 WW 02105 (084)

OBSERVATION WELL

INTERVAL TESTED

From m. to m.

HOLE DEPTH m.

AQUIFER THICKNESS m.

DEPTH OF PUMP INTAKE m.

DEPTH OF WATER LEVEL

AT TEST START 9:235 m.

AVAILABLE DRAWDOWN m.

JACOB EQUATIONS*

$$T = \frac{0.183 \times Q}{\Delta d} \quad \text{in which}$$

T = Transmissivity ($\text{m}^3/\text{day}/\text{m}$)Q = Pumping rate (m^3/day) Δd = Drawdown per log cycle (m.)

$$S = \frac{2.25 \times T t_0}{1440 r^2} \quad \text{in which}$$

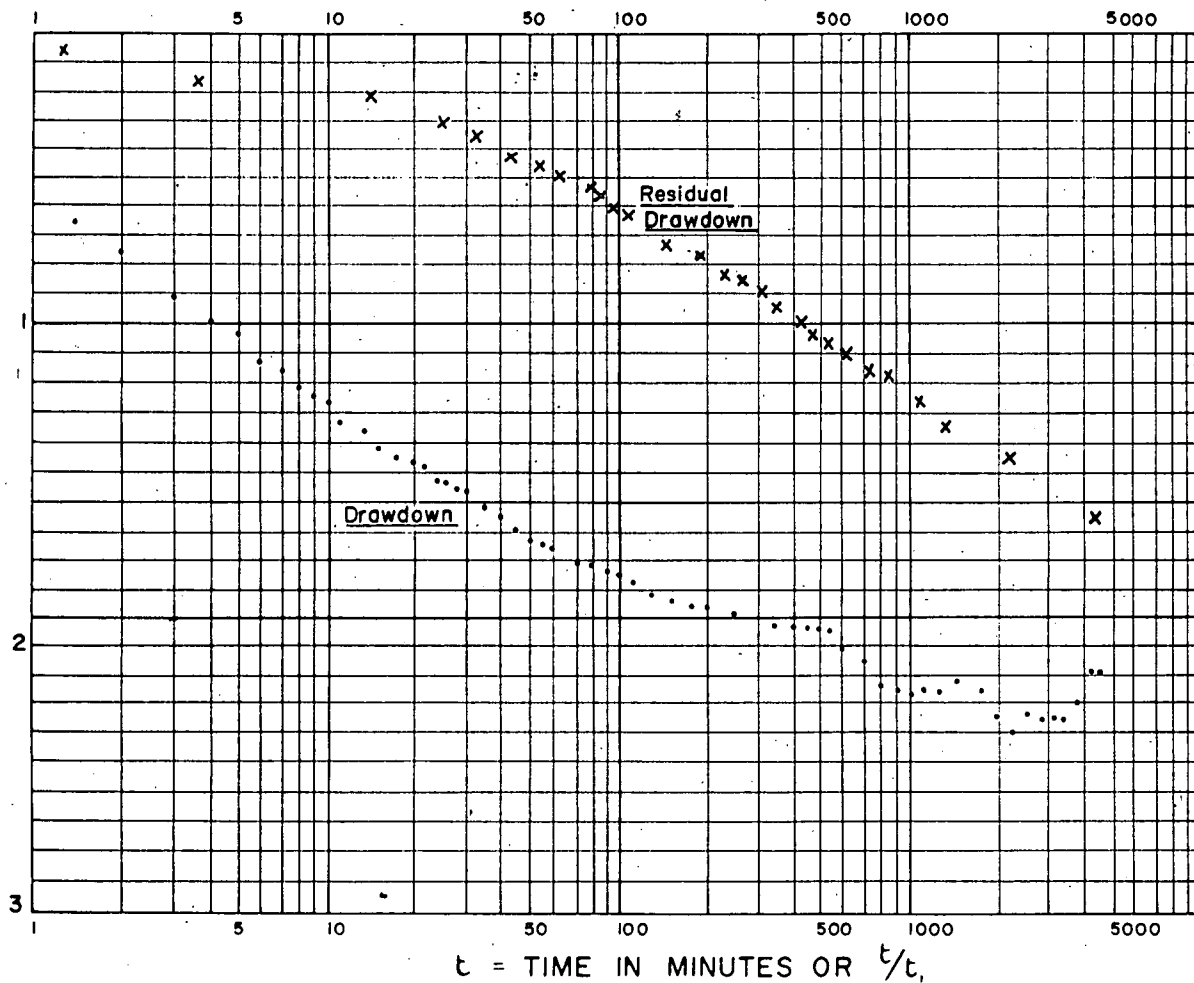
S = Storage coefficient

 t_0 = Zero drawdown time (minutes)

r = Distance to Observation Well (m.)

* Check applicability of this method

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA
ANGAS - BREMER RECHARGE EXPERIMENT
SECOND PUMP - OUT TEST
WELL No. 6727 400 WW 02107
CONSTANT DISCHARGE TEST

(SETEM) NWDRAWN = ρ **DATA**

Q 2499 m³/day
Delta 0.67
0.655

r 31.3 Drawdown
31.3 Residual Drawdown

CALCULATIONS

Drawdown $T = \frac{0.183 \times 2499}{0.67} = 683 \text{ m}^3/\text{day/m}$
Residual Drawdown $T = \frac{0.183 \times 2499}{0.655} = 698 \text{ m}^3/\text{day/m}$

$S = \frac{2.25 T t_0}{r^2 10^{0.5/\Delta\delta}} = 1.7 \times 10^{-2}$

UNIT No. 6727 400 WW 02107 (085)

OBSERVATION WELL

INTERVAL TESTED

From m. to m.

HOLE DEPTH m.

AQUIFER THICKNESS m.

DEPTH OF PUMP INTAKE m.

DEPTH OF WATER LEVEL

AT TEST START 8.815 m.

AVAILABLE DRAWDOWN m.

JACOB EQUATIONS*

$$T = \frac{0.183 \times Q}{\Delta\delta} \quad \text{in which}$$

T = Transmissivity (m³/day/m.)Q = Pumping rate (m³/day) $\Delta\delta$ = Drawdown per log cycle (m.)

$$S = \frac{2.25 \times T t_0}{1440 r^2} \quad \text{in which}$$

S = Storage coefficient

t₀ = Zero drawdown time (minutes)

r = Distance to Observation Well (m.)

* Check applicability of this method

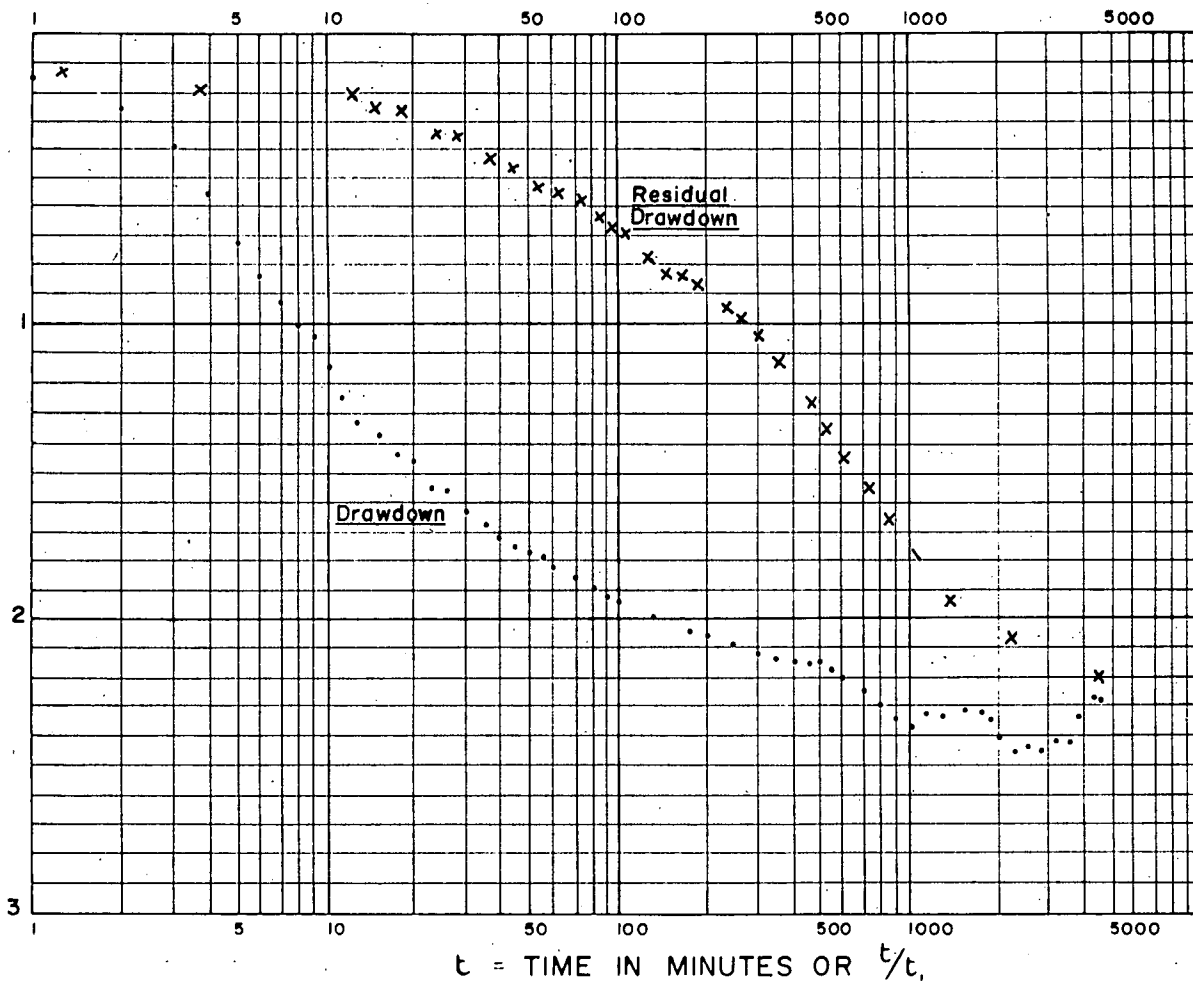
Figure 19

COMPILED
MAC
DRAWN
AD
DATE
AUG. 82
CHECKED
SCALE
PLAN NUMBER
S16433

16/12/82
C.D.O.
DATE

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA
ANGAS - BREMER RECHARGE EXPERIMENT
SECOND PUMP - OUT TEST
WELL No. 6727 400 WW 02108
CONSTANT DISCHARGE TEST

(SET) (METRE) (METRE) = ρ



DATA

CALCULATIONS

/UNIT No. 6727 400 WW 02108 (086)

/OBSERVATION WELL

INTERVAL TESTED

From m. to m.

HOLE DEPTH m.

AQUIFER THICKNESS m.

DEPTH OF PUMP INTAKE m.

DEPTH OF WATER LEVEL

AT TEST START 8.870 m.

AVAILABLE DRAWDOWN m.

JACOB EQUATIONS*

$$T = \frac{0.183 \times Q}{\Delta d} \quad \text{in which}$$

T = Transmissivity (m³/day/m.)

Q = Pumping rate (m³/day)

Δd = Drawdown per log cycle (m)

$$S = \frac{2.25 \times T t_0}{1440 r^2} \quad \text{in which}$$

S = Storage coefficient

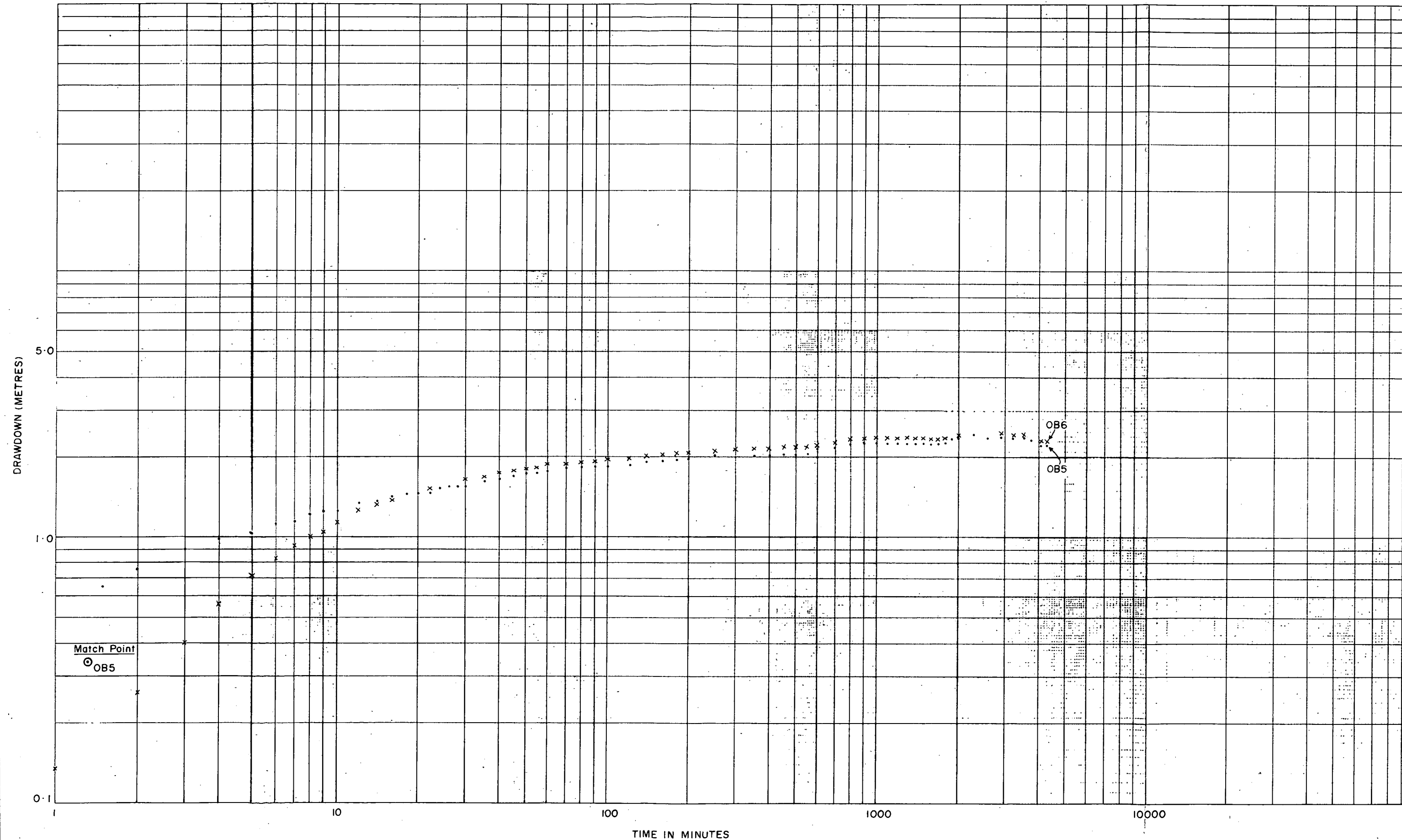
t_0 = Zero drawdown time (minutes)

r = Distance to Observation Well (m.)

Δ = RESIDUAL DRAWDOWN (METRES)

Figure 20

COMPILED MAC	SCALE	PLAN NUMBER
DRAWN AD	CD O	16-12-02
DATE AUG-82		
CHECKED		S16434



CALCULATIONS

WELL No. 67274000W02107
OBSERVATION WELL OB5

$$Q = 2499 \text{ m}^3/\text{day}$$

$$r = 31.3 \text{ m}$$

$$m' = 18 \text{ m}$$

$$r/B = 0.05$$

Match Point $u = 0.1$ $W(u, r/B) = 1$ $s = 0.34$ $t = 9.03 \times 10^{-4} \text{ days}$

$$T = \frac{Q W(u, r/B)}{4 \pi s} = \frac{2499}{4 \pi \times 0.34} = 585 \text{ m}^3/\text{day}/\text{m}$$

$$S = \frac{4 T u t}{r^2} = 2.16 \times 10^{-4}$$

$$P' = \frac{T m' (r/B)^2}{r^2} = \frac{585 \times 18 (0.05)^2}{(31.3)^2} = 0.027 \text{ m}^3/\text{day}/\text{m}^2$$

FIG. 21

		COMPILED M A C	<i>WR</i> C.D.O.	16.12.82 DATE
ANGAS - BREMER RECHARGE EXPERIMENT		DRAWN A D	SCALE	
SECOND PUMP-OUT TEST		DATE AUG '82	PLAN NUMBER	
LOG-LOG DRAWDOWN PLOT OF OBS WELLS 5 & 6		CHECKED	82-519	

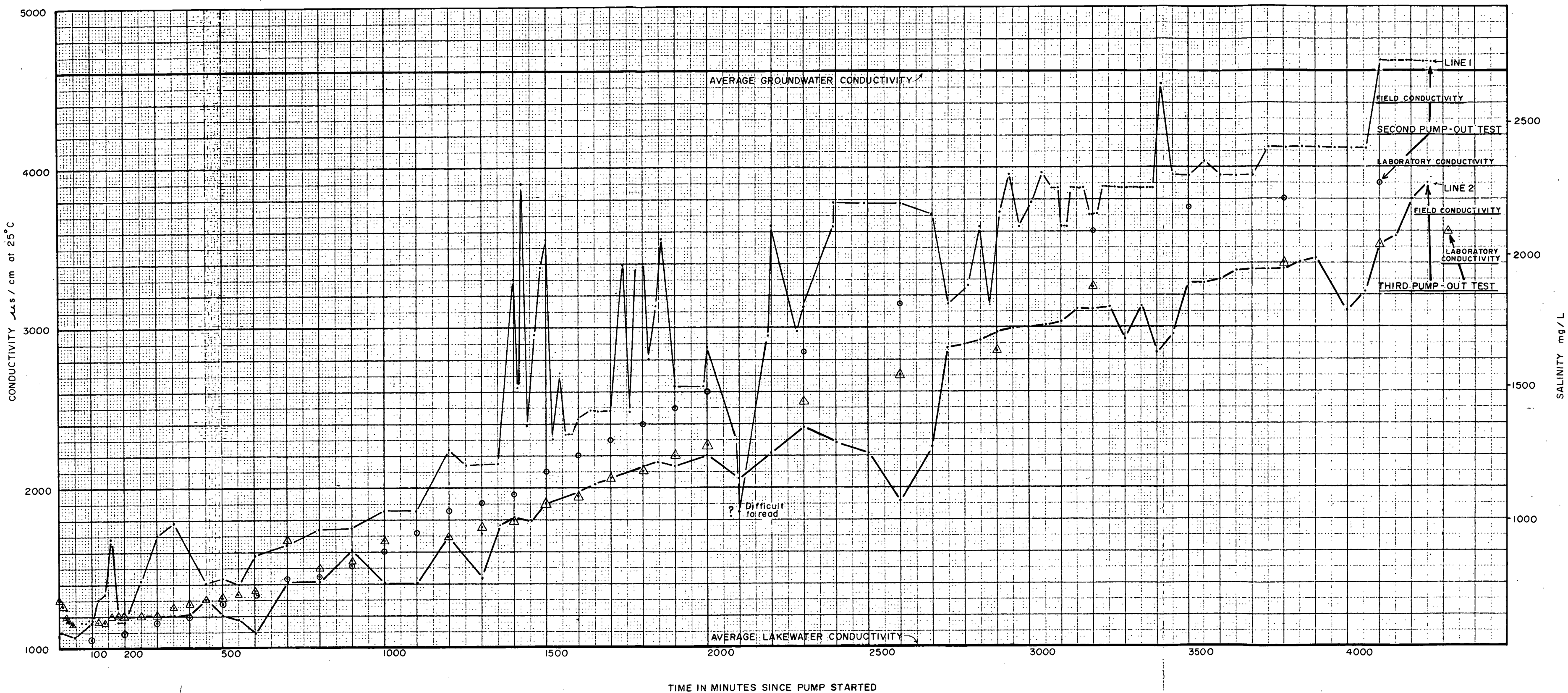


FIG.22

 DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED MAC	UR 16.12.82 C.D.O. DATE
ANGAS-BREMER RECHARGE EXPERIMENT SECOND & THIRD PUMP-OUT TESTS CONDUCTIVITY vs TIME		DRAWN AD	SCALE
		DATE AUG '82	PLAN NUMBER
		CHECKED	82-520

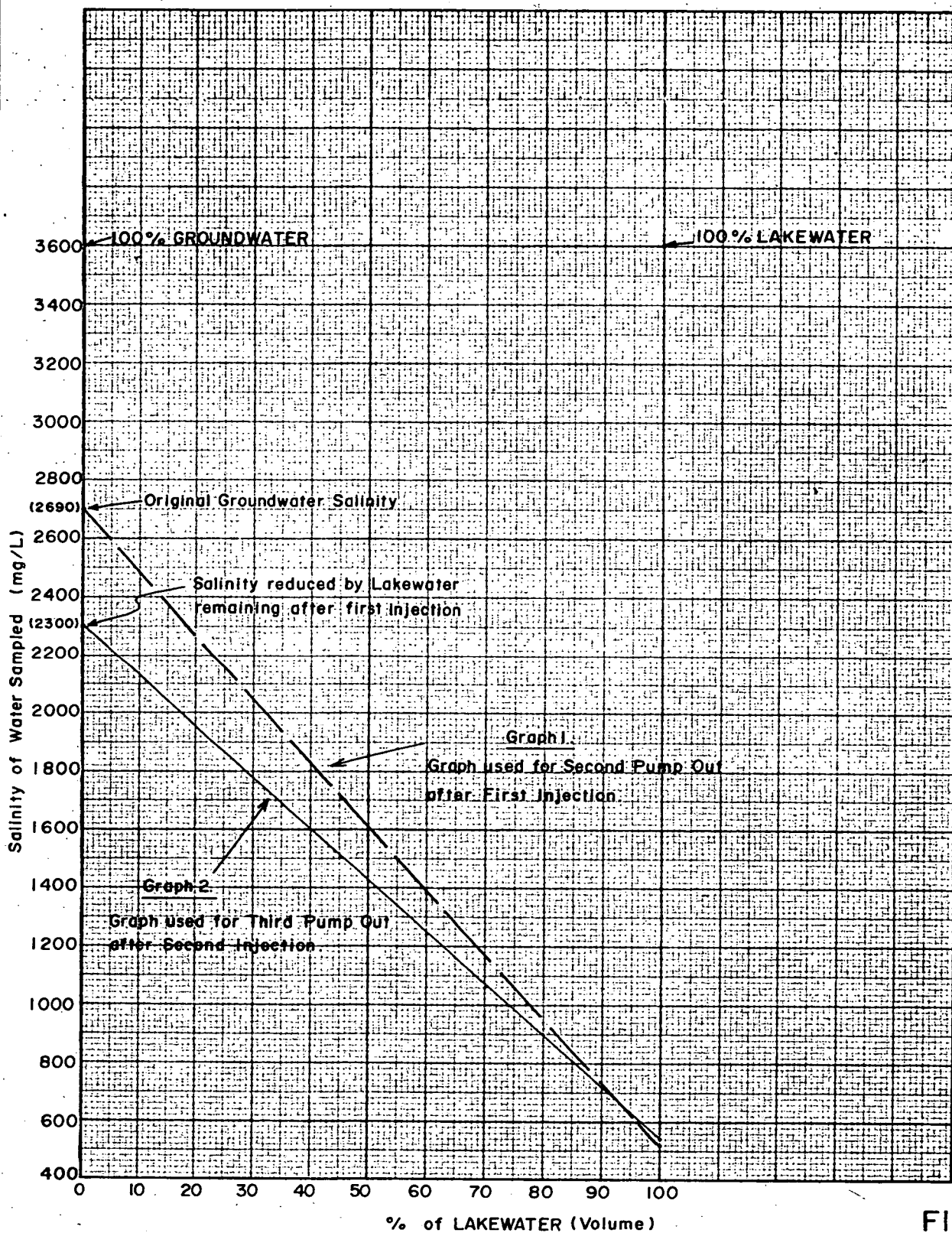


FIG.23



DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COMPILED
M A C

W 16.12.82
C.D.O. DATE

DRAWN
A D

SCALE

DATE
SEPT '82

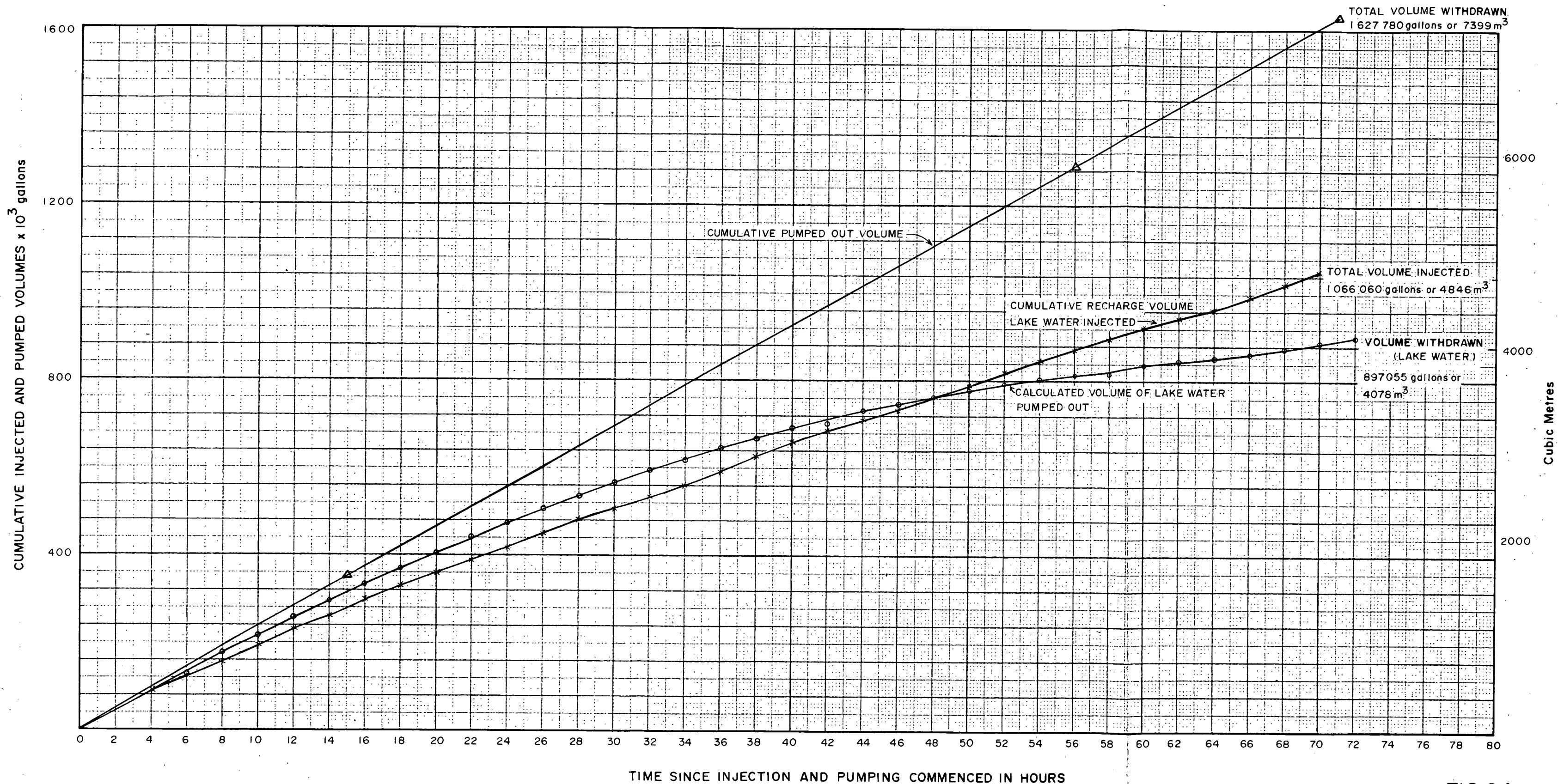
PLAN NUMBER

CHECKED

S16435

ANGAS - BREMER RECHARGE EXPERIMENT
SECOND AND THIRD PUMP-OUT TESTS

SALINITY OF PUMPED WATER vs % VOLUME OF LAKEWATER



LAKE WATER LOST = 1 066 060 - 897 055 gallons
 = 1 69 005 gallons
 = 15.85% Loss

(After 70 Hours of Pumping and Injected Water being Underground approx. 30 days.)

FIG.24

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED MAC	<i>ur</i> 16.12.82 C.D.O. DATE
		DRAWN A.D.	
ANGAS - BREMER RECHARGE EXPERIMENT FIRST INJECTION AND SECOND PUMP-OUT TEST INJECTION TOTAL INJECTED AND WITHDRAWN AND LAKEWATER WITHDRAWN vs TIME		DATE SEPT '82	PLAN NUMBER 82-521
		CHECKED	

Well No. 67274000W02103, (OB2)
02105 (OB4)

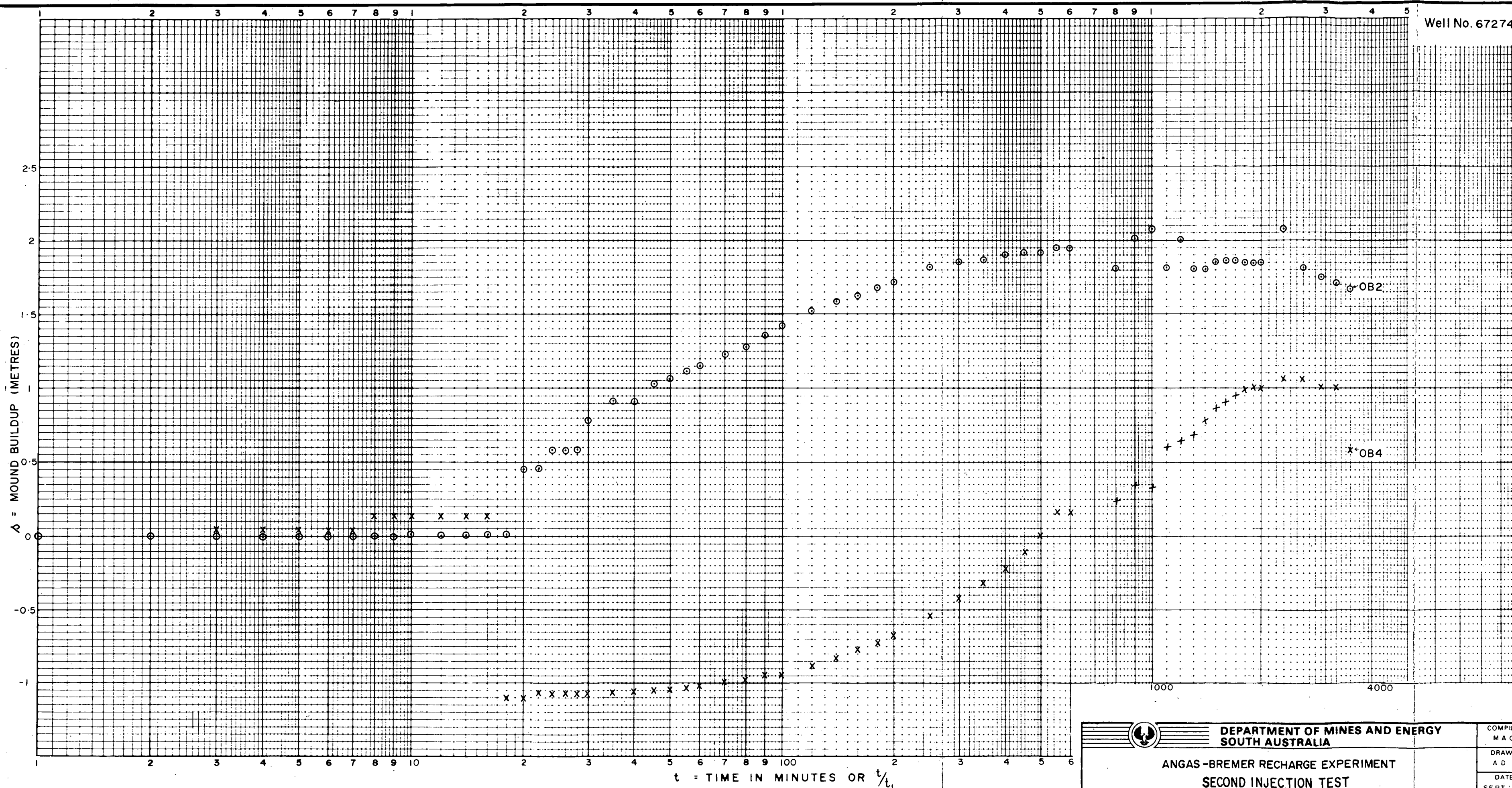
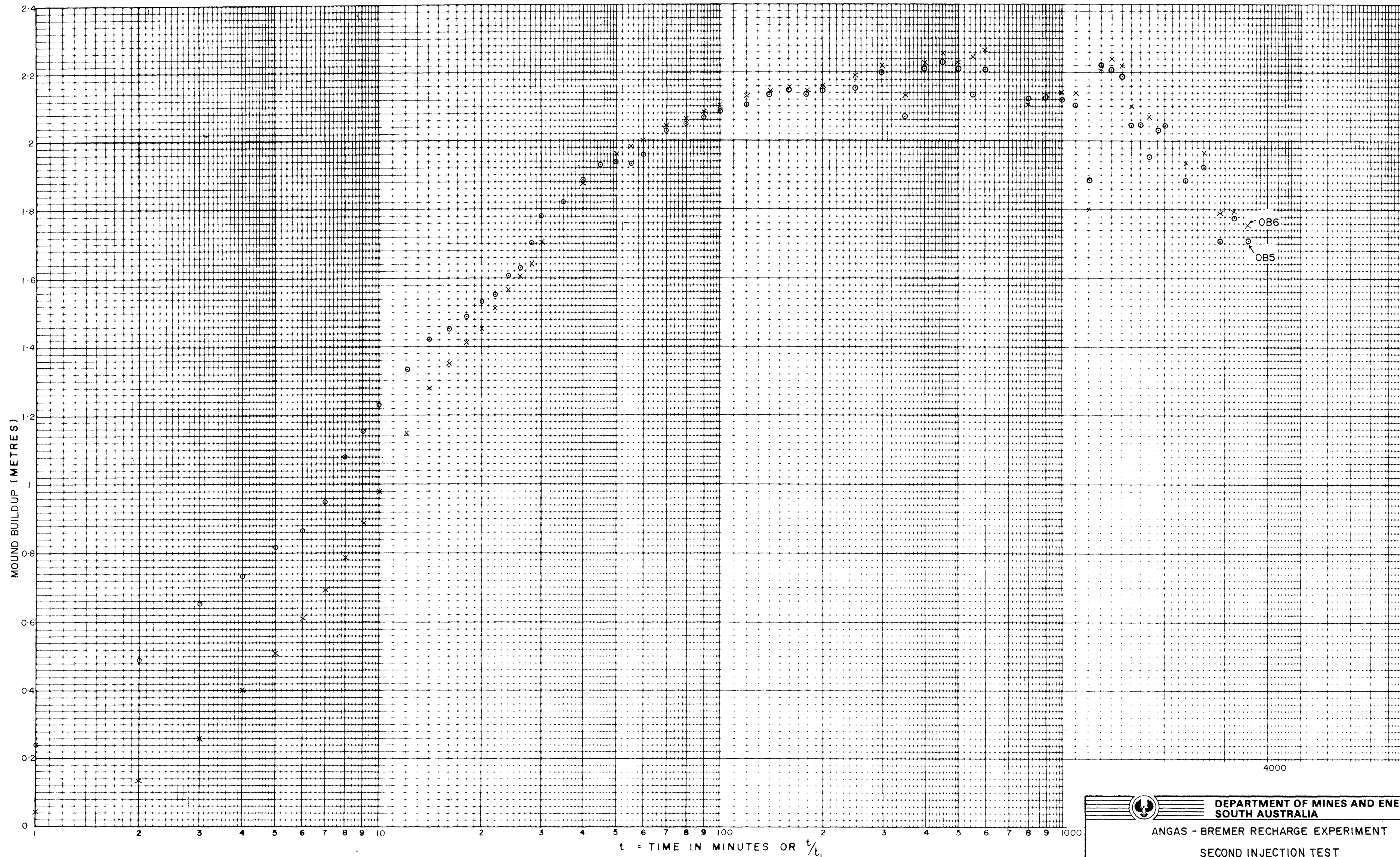


FIG.25

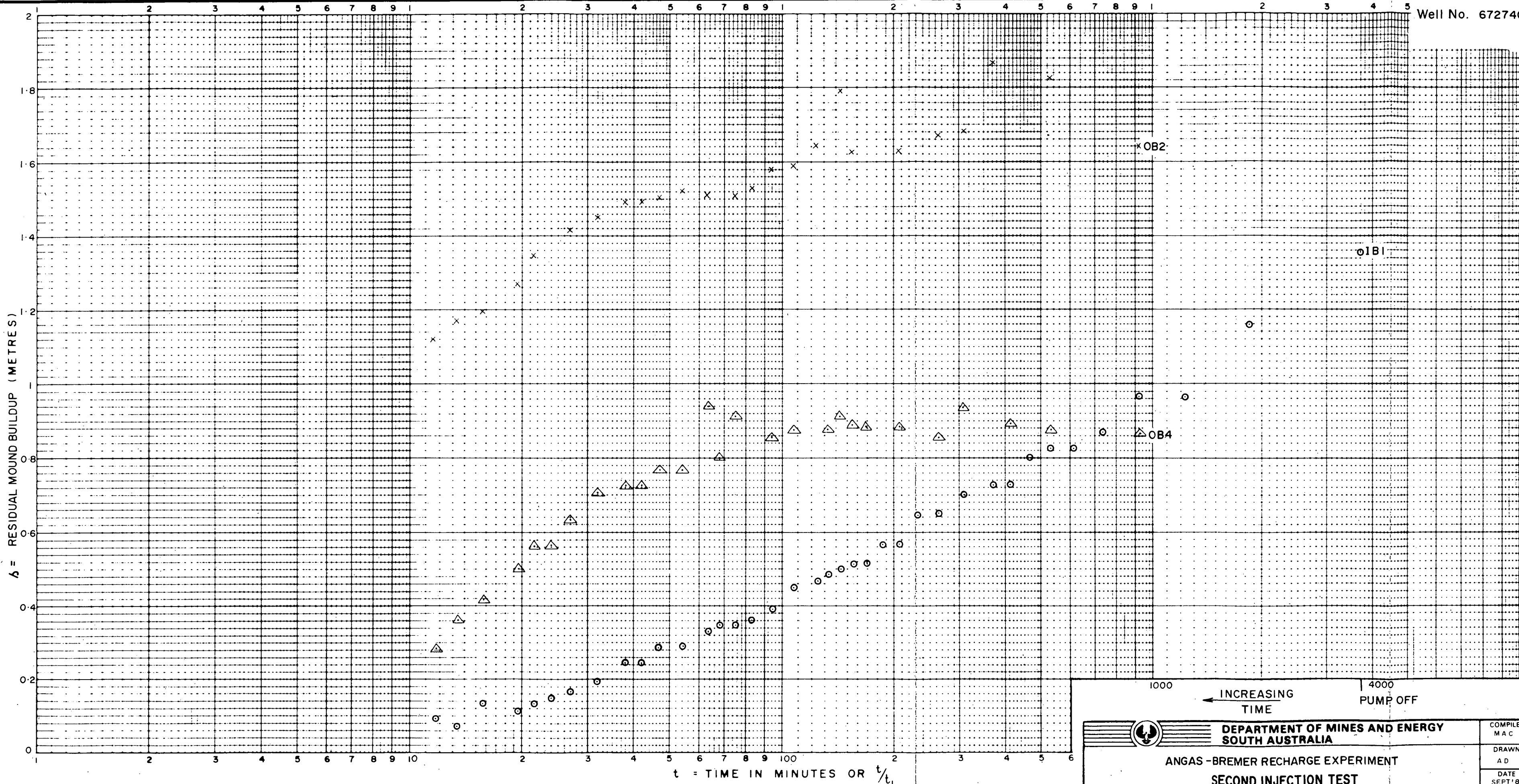
		COMPILED M A C	16.12.82 C D O DATE
ANGAS-BREMER RECHARGE EXPERIMENT SECOND INJECTION TEST MOUND BUILDUP OF OBSERVATION WELLS OB2 AND OB4		DRAWN A D	SCALE
		DATE SEPT '82 CHECKED	PLAN NUMBER 82-522



WELL No. 67274000W02107,(OB5)
67274000W02108,(OB6)

FIG.26

 DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED M A C	<i>MR</i> 16.12.82 C D O DATE
ANGAS - BREMER RECHARGE EXPERIMENT		DRAWN A D	SCALE
SECOND INJECTION TEST		DATE SEPT '82	PLAN NUMBER
MOUND BUILDUP OF OBSERVATION WELLS OB5 AND OB6		CHECKED	82-523



DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED M A C	16-12-82 C.D.O. DATE
		DRAWN A D	SCALE
ANGAS-BREMER RECHARGE EXPERIMENT SECOND INJECTION TEST MOUND DECAY OF INJECTION WELL AND OBSERVATION WELLS OB2 AND OB4		DATE SEPT '82	PLAN NUMBER
		CHECKED	82-524

FIG. 27

Δ = RESIDUAL MOUND BUILDUP (METRES)

t = TIME IN MINUTES OR t/t_1

1000 INCREASING TIME

14000 PUMP OFF

FIG.28

 DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED M A C	<i>MAC</i> 16.12.82 C.D.O. DATE
		DRAWN A D	SCALE
ANGAS-BREMER RECHARGE EXPERIMENT SECOND INJECTION TEST MOUND DECAY OF OBSERVATION WELL OB5		DATE SEPT '82	PLAN NUMBER 82-525
		CHECKED	

Δ = DRAWDOWN (METRES)

t = TIME IN MINUTES OR t/t_1

BOREHOLE STATE/UNIT No. 67274000W02101
REF. PT. (m) above ground
AQUIFER FROM TO (m)
HOLE DEPTH (m)

TYPE OF PUMP
LENGTH OF TEST
DEPTH WATER LEVEL AT TEST START (l_2) (m)
DEPTH PUMP INTAKE (l_1) (m)
* AVAILABLE DRAWDOWN (m)

EQUATIONS

$$T = \frac{0.183 \times Q}{\Delta_d}$$

$$S = \frac{2.25 \times T t_0}{r^2}$$

In which

T = Transmissivity ($m^3/day/m$)

Q = Pumping Rate (m^3/day)

Δ_d = Drawdown per log cycle (m)

S = Storage Coefficient

t_0 = Zero drawdown time (mins)

r = Distance to Observation Bore (m)

1 day = 8.64×10^4 secs.

DATA

Q	Δ_d	t_0	r
2117 m^3/day	0.75	-	0

CALCULATIONS

$$T = \frac{0.183 \times 2117}{0.75} = 517 m^3/day/m$$

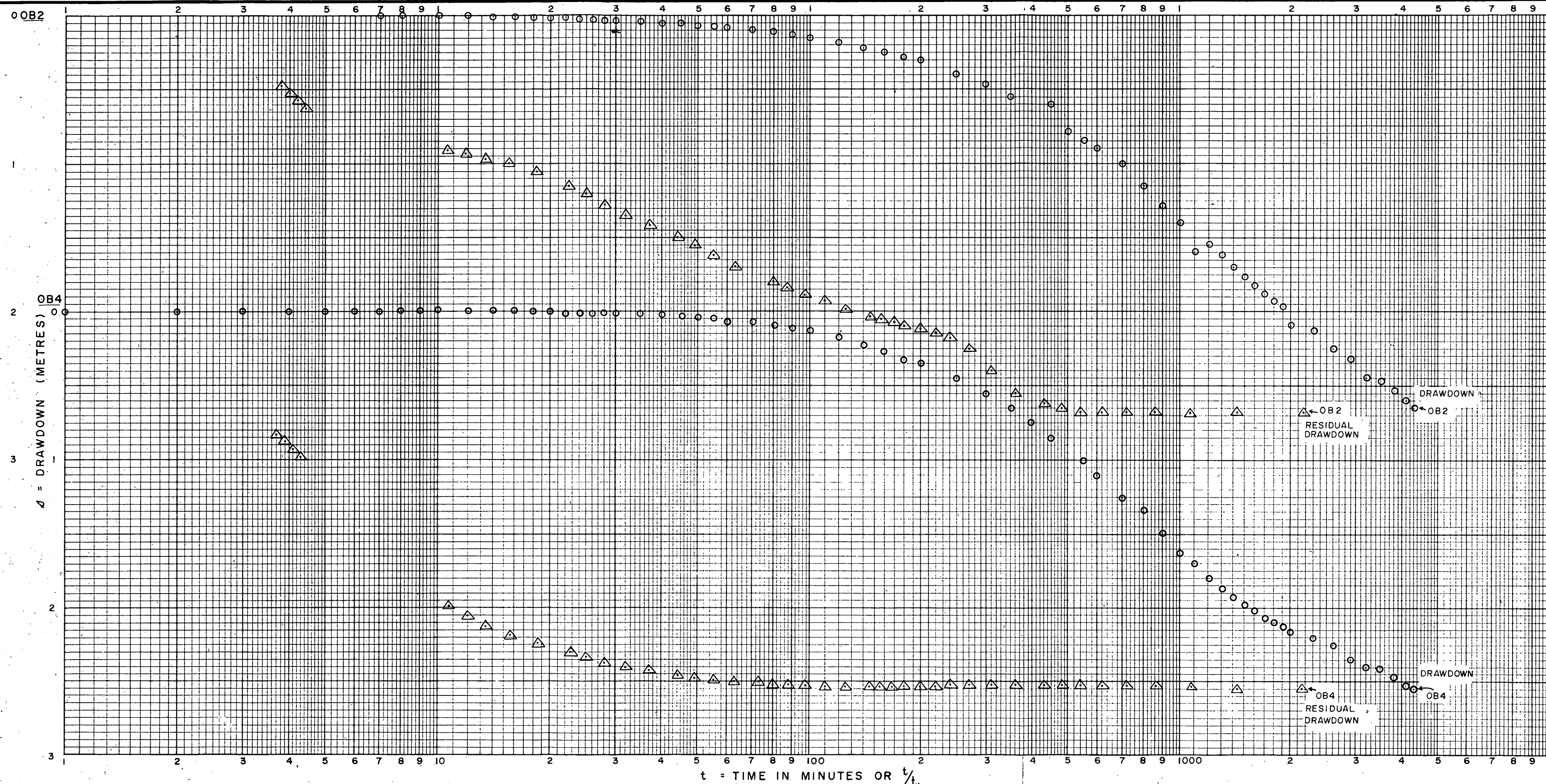
* Available drawdown = $l_1 - l_2$

FIG.29

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		SCALE
ANGAS BREMER RECHARGE EXPERIMENT		DATE
THIRD PUMP-OUT TEST FOLLOWING SECOND INJECTION TEST		PLAN NUMBER
DRAWDOWN vs TIME OF PUMP WELL IBI		82-526

Δ = RESIDUAL DRAWDOWN (METRES)

2927



BOREHOLE STATE/UNIT No. 67274000W02103, (OB2)
02105, (OB4)
REF. PT. (m) above ground
AQUIFER FROM TO (m)
HOLE DEPTH (m)
TYPE OF PUMP
LENGTH OF TEST
DEPTH WATER LEVEL AT TEST START (l₂) (m)
DEPTH PUMP INTAKE (l₁) (m)
* AVAILABLE DRAWDOWN (m)

EQUATIONS

$T = \frac{0.183 \times Q}{\Delta_d}$ $s = \frac{2.25 \times T t_0}{r^2}$

In which
T = Transmissivity (m³/day/m)
Q = Pumping Rate (m³/day)
Δ_d = Drawdown per log cycle (m)
S = Storage Coefficient
t₀ = Zero drawdown time (mins)
r = Distance to Observation Bore (m)
1 day = 8.64 x 10⁴ secs.

DATA

Q	Δ _d	t ₀	r
2117	2.05	218	33
For t = 2000mins Δ/Δ _d = 0.98 i.e. Method not valid			

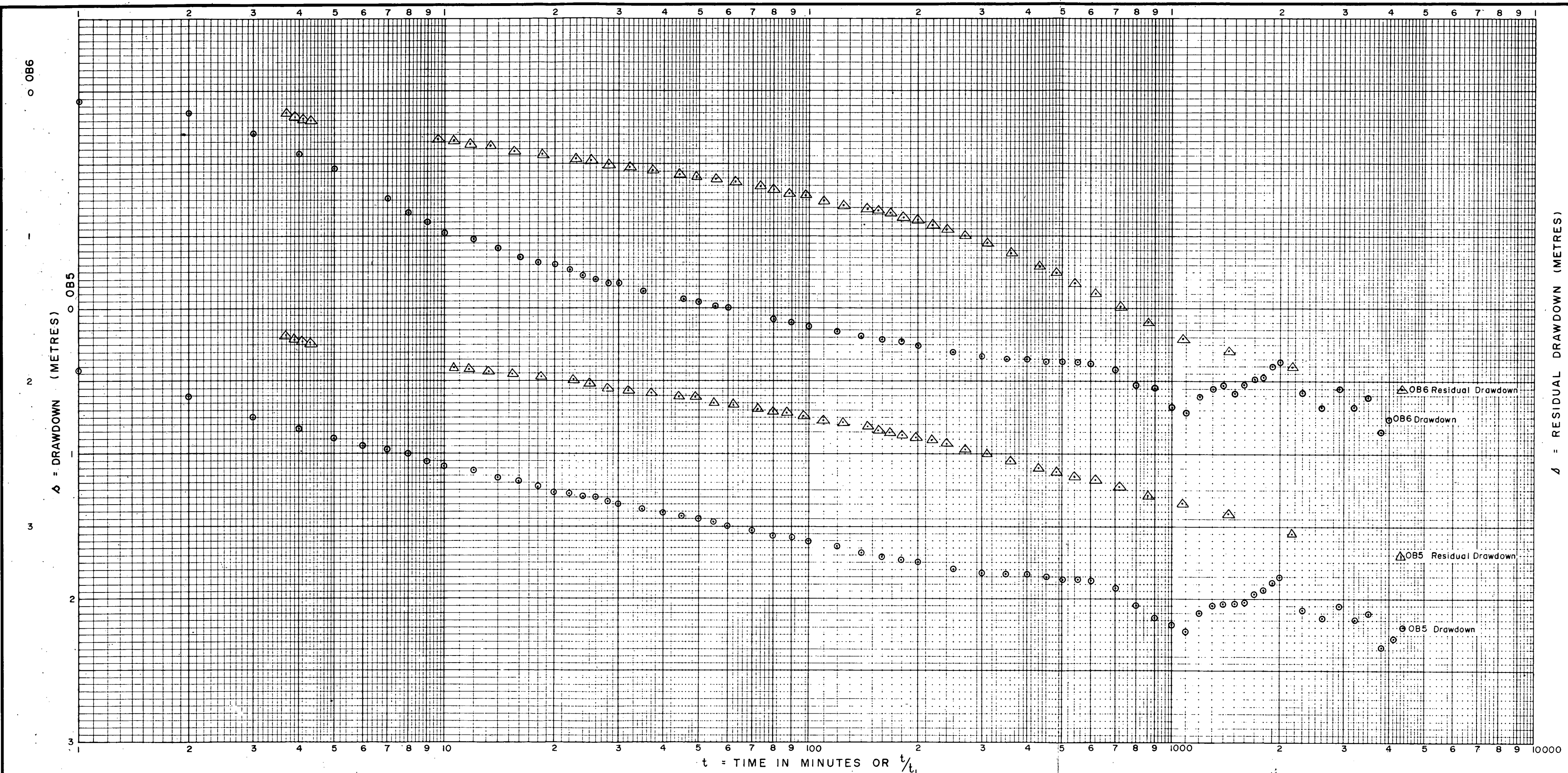
CALCULATIONS

* Available drawdown = l₁ - l₂

FIG.30

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		SCALE:
ANGAS-BREMER RECHARGE EXPERIMENT		DATE: SEPTEMBER 1982
THIRD PUMP-OUT TEST FOLLOWING SECOND INJECTION TEST		PLAN NUMBER
DRAWDOWN vs TIME OF OBSERVATION WELLS OB2 AND OB4		82-527

2927



BOREHOLE STATE/UNIT No 67274000W02107, (OB5)
02108, (OB6)
REF. PT. (m) above ground
AQUIFER FROM TO (m)
HOLE DEPTH (m)

TYPE OF PUMP
LENGTH OF TEST
DEPTH WATER LEVEL
AT TEST START (l_2) (m)
DEPTH PUMP INTAKE (l_1) (m)
* AVAILABLE DRAWDOWN (m)

EQUATIONS

$$T = \frac{0.183 \times Q}{\Delta_d}$$

In which
 T = Transmissivity ($m^3/day/m$)
 Q = Pumping Rate (m^3/day)
 Δ_d = Drawdown per log cycle (m)

$$S = \frac{2.25 \times T t_0}{r^2} \text{ or } \frac{2.25 \times T t}{r^2 \times 10^4 / \Delta_d}$$

 S = Storage Coefficient
 t_0 = Zero drawdown time (mins)
 r = Distance to Observation Bore (m)
1 day = 8.64×10^4 secs.

DATA

Q	Δ_d	t_0	r
2117 m^3/day	0.59	-	31.3 OB5 Drawdown
	0.60	-	31.3 OB5 Residual Drawdown

At $t = 50$ mins = $50/1440$ days, $\Delta = 1.47$

CALCULATIONS

For OB5
Drawdown $T = \frac{0.183 \times 2117}{0.59} = 657 m^3/day/m$

$$S = \frac{2.25 \times T t}{r^2 \times 10^4 / \Delta_d} = 1.69 \times 10^{-4}$$

Residual Drawdown $T = \frac{0.183 \times 2117}{0.6} = 646 m^3/day/m$

* Available drawdown = $l_1 - l_2$

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		SCALE
ANGAS BREMER RECHARGE EXPERIMENT		DATE SEPTEMBER, 1982
THIRD PUMP-OUT TEST FOLLOWING SECOND INJECTION TEST		PLAN NUMBER
DRAWDOWN vs TIME OF OBSERVATION WELLS OB5 AND OB6		82-528

FIG.31

CALCULATIONS

WELL No. 67274000W02103, (OB 2)
02105, (OB 4)

No Match Point can be found.

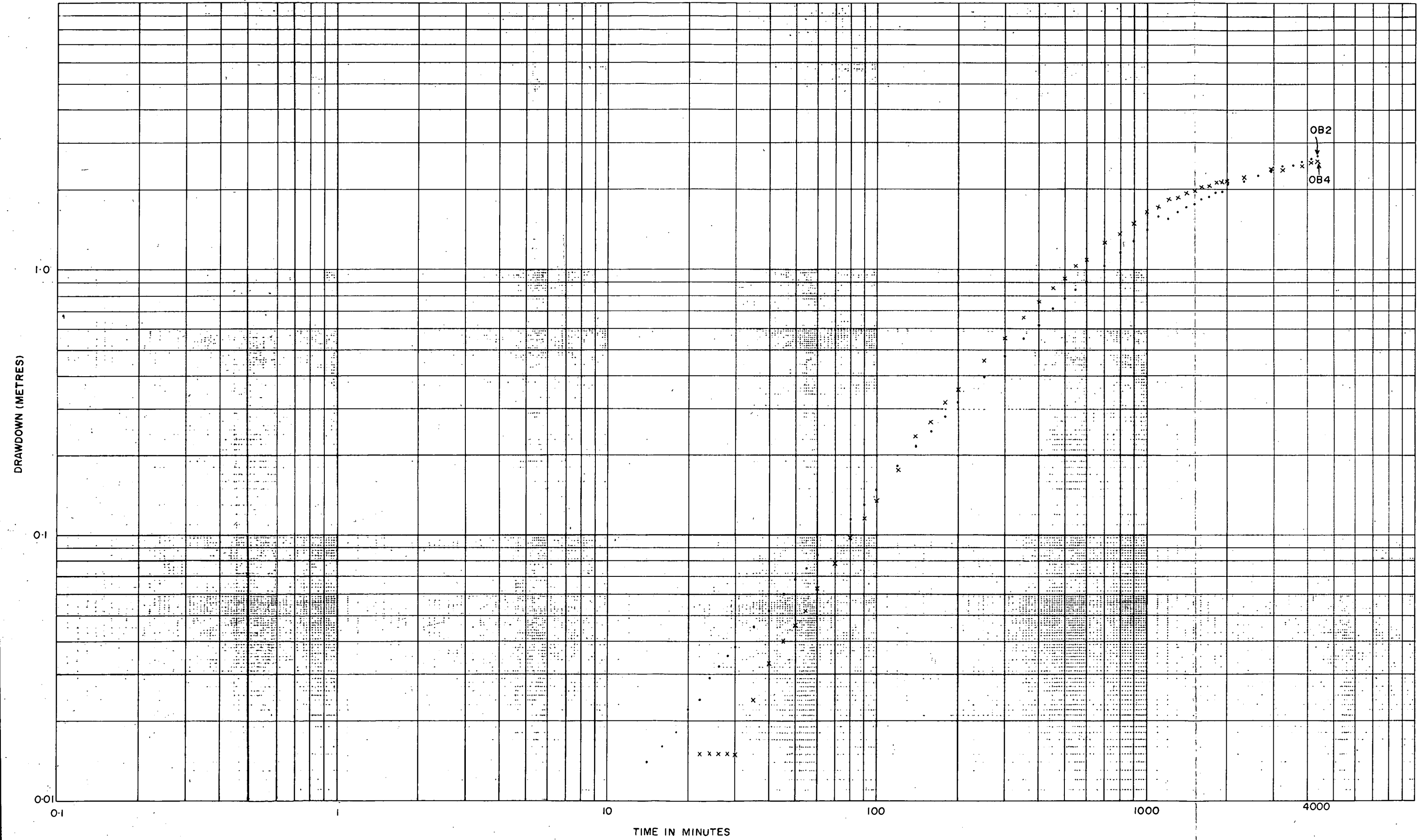
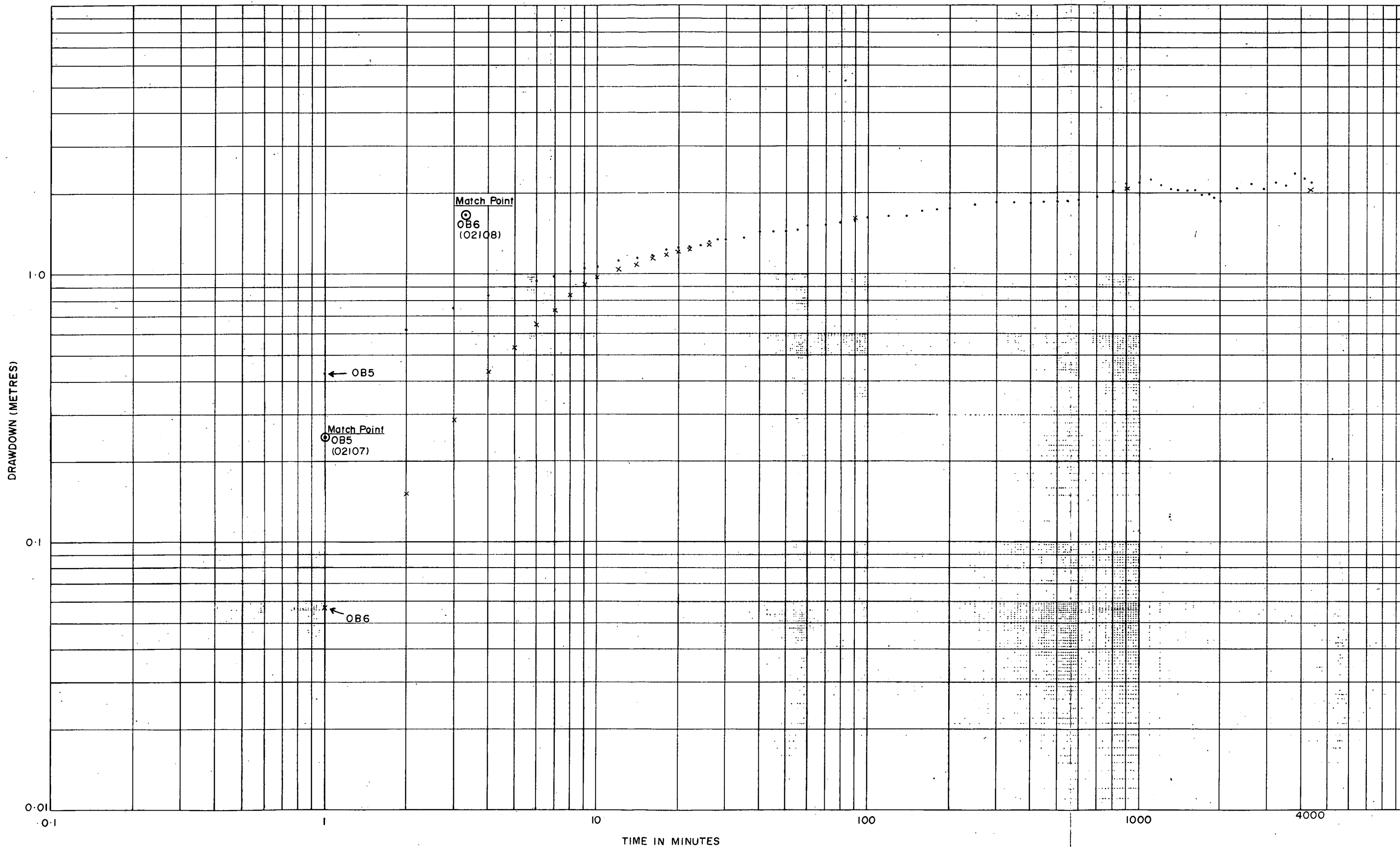


FIG.32

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED M A C	<i>MR</i> 16.12.82 C D O DATE
	ANGAS - BREMER RECHARGE EXPERIMENT THIRD PUMP - OUT TEST LOG-LOG DRAWDOWN PLOT OF OBS WELLS 2 AND 4		DRAWN A D	SCALE
			DATE AUG '82	PLAN NUMBER 82-529
			CHECKED	

**CALCULATIONS**

WELL No. 6727 400 ØW 02107, 02108
OBSERVATION WELL OB5, OB6

OB5

$$\begin{aligned} r/B &= 0.015 \\ Q &= 2117 \text{ m}^3/\text{day} \\ r &= 31.3 \text{ m} \\ m' &= 18 \text{ m} \end{aligned}$$

$$\text{Match Point } u=0.1 \quad W(u, r/B) = 1 \quad \Delta = 0.25 \quad t = 6.94 \times 10^{-4} \text{ days}$$

$$T = \frac{Q W(u, r/B)}{4\pi\Delta} = \frac{2117}{4\pi \times 0.25} = 674 \text{ m}^3/\text{day/m}$$

$$S = \frac{4Tut}{r^2} = 1.9 \times 10^{-4}$$

$$P' = \frac{Tm'(r/B)^2}{r^2} = 2.79 \times 10^{-3} \text{ m}^3/\text{day/m}^2$$

OB6

$$\begin{aligned} Q &= 2117 \text{ m}^3/\text{day} \\ r &= 28.7 \text{ m} \\ m' &= 18 \text{ m} \end{aligned}$$

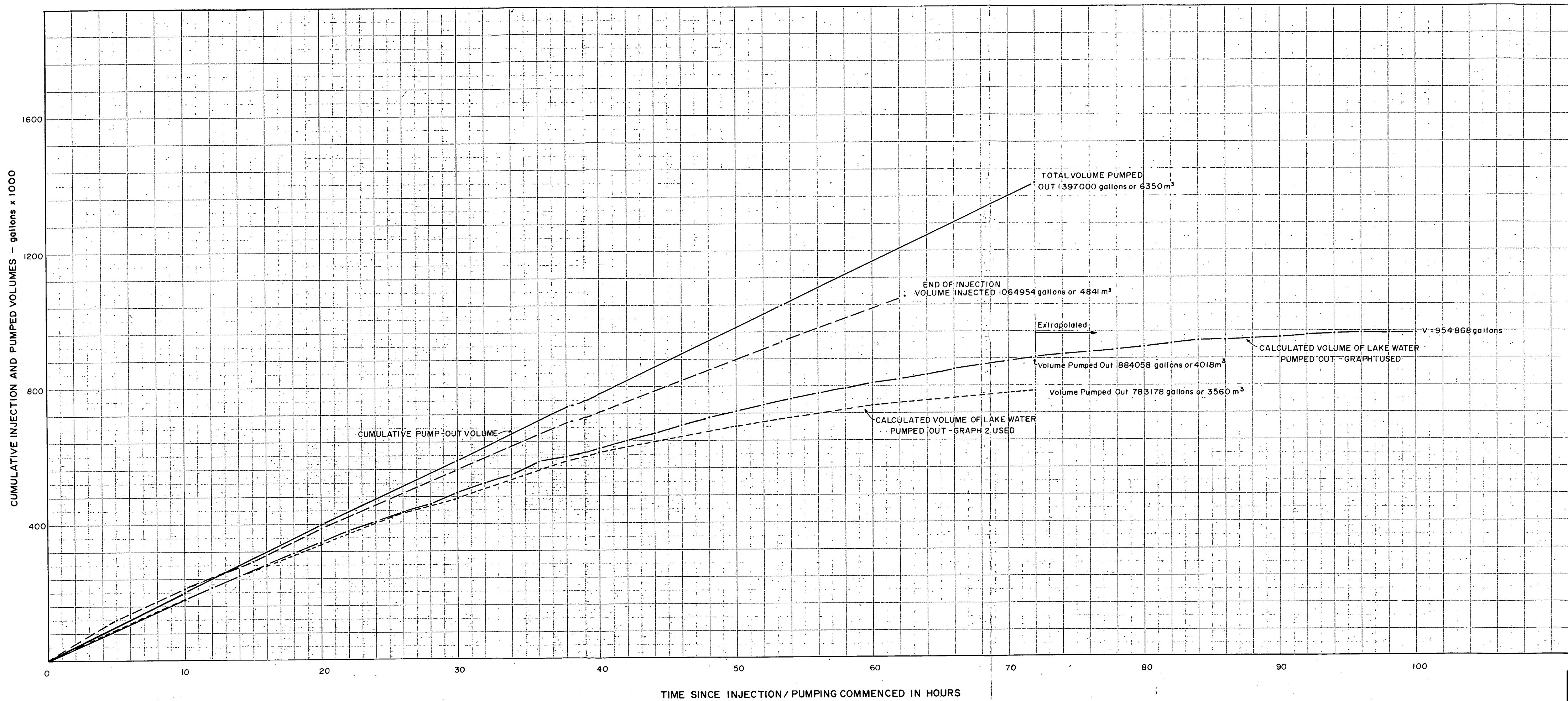
$$\text{Match Point } u=1 \quad W(u, r/B) = 1 \quad \Delta = 1.68 \quad t = 2.29 \times 10^{-3} \text{ days}$$

$$T = \frac{Q W(u, r/B)}{4\pi\Delta} = \frac{2117}{4\pi \times 1.68} = 100 \text{ m}^3/\text{day/m}$$

$$S = \frac{4Tut}{r^2} = 1.12 \times 10^{-3}$$

FIG.33

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED M.A.C.	16.12.82 DATE
	ANGAS-BREMER RECHARGE EXPERIMENT THIRD PUMP - OUT TEST		DRAWN A.D.	SCALE
	LOG-LOG DRAWDOWN PLOT OF OBS WELLS 5 AND 6		DATE AUG'82	PLAN NUMBER 82-530
			CHECKED	



USING GRAPH 1 (FIG. 23)

LAKE WATER LOST = 1064954 - 884058
 = 180896 gallons or 822 m³
 or 17% OF INJECTED WATER

Extrapolating Salinity vs Time Curve to aquifer salinity gives Volume of Lake Water that would have been pumped to reach this Salinity as 954868 gallons or 4340 m³

For This Value: Lake Water lost would equal 1064954 - 954868 gallons
 = 110086 gallons or 500 m³
 or 10% OF INJECTED WATER

USING GRAPH 2 (FIG. 23)

LAKE WATER LOST = 1064954 - 783178 gallons
 = 281776 gallons or 1281 m³
 or 26% OF INJECTED WATER

NOTE: GRAPHS 1 AND 2 REFER TO THE SALINITY vs % LAKE WATER (APPENDIX 1, FIG. 23)

GRAPH 1: Uses the Lake and Native Ground Water Salinities existing before the First Injection.

GRAPH 2: Uses the Lake Salinity recorded for the Second Injection and the Pumped Ground Water Salinity recorded at the end of the Second Pump-Out Test (After First Injection)

FIG.34

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED M.A.C.	16.12.82 DATE
ANGAS-BREMER RECHARGE EXPERIMENT		DRAWN A.D.	SCALE
SECOND INJECTION AND THIRD PUMP-OUT TEST INJECTION, TOTAL WITHDRAWN AND LAKE WATER WITHDRAWN vs TIME		DATE SEPT '82	PLAN NUMBER 82-531
		CHECKED	

REFERENCE

- LAKE ALEXANDRINA SAMPLE 8.5.80 TDS 418 mg/L.
- × GROUNDWATER NEAR RECHARGE SITE 8.5.80 TDS 2894 mg/L.
- △ THIRD PUMP-OUT TEST, 5 MINUTES AFTER PUMPING, TDS 691 mg/L.
- ⊙ THIRD PUMP-OUT TEST, 30 MINUTES AFTER PUMPING, TDS 649 mg/L.
- THIRD PUMP-OUT TEST, 4320 MINUTES AFTER PUMPING, TDS 2146 mg/L.

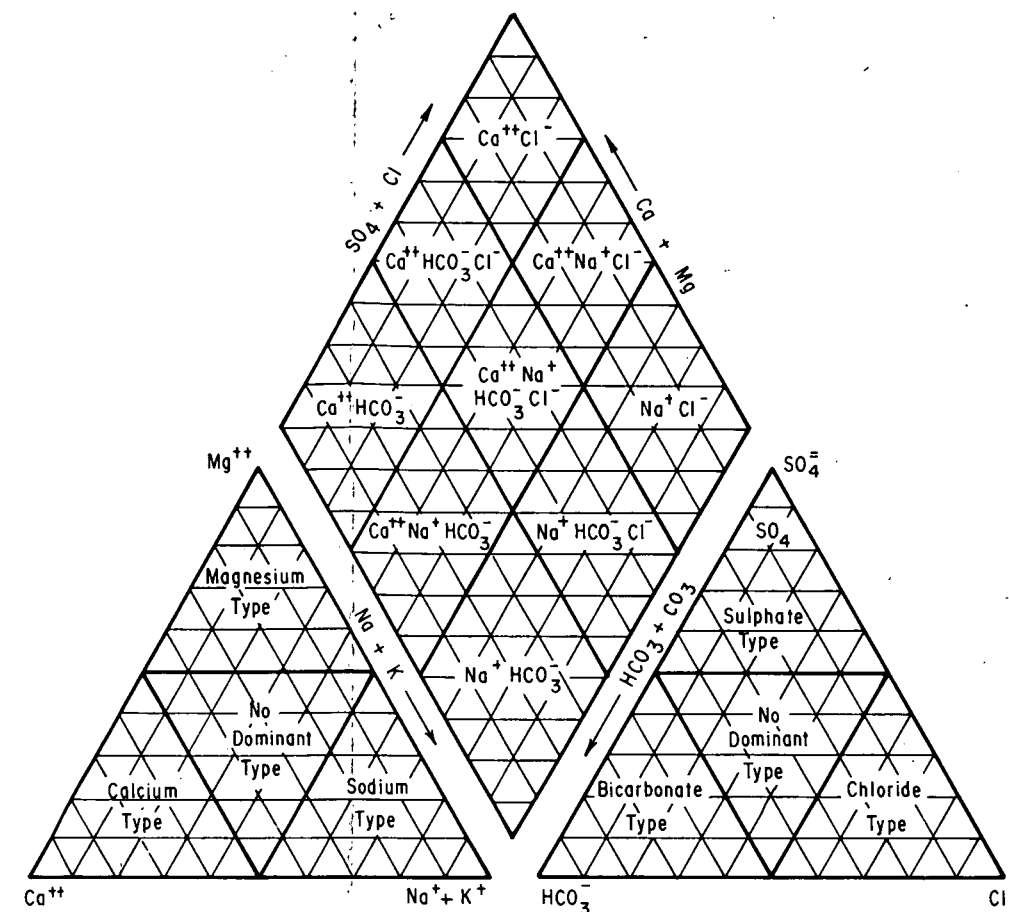
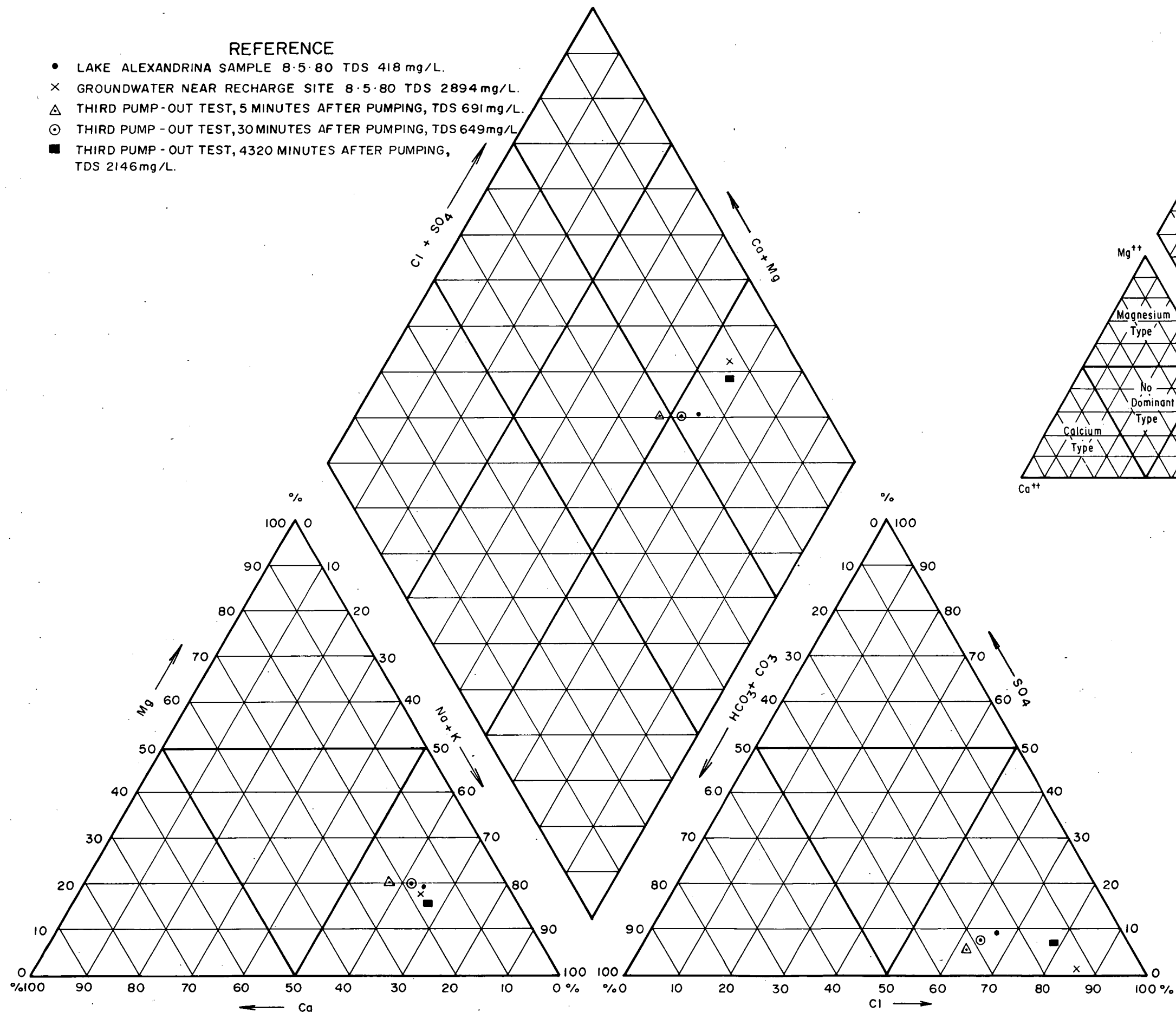


FIG.35

 DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA		COMPILED MAC	16.12.82 C.D.O. DATE
ANGAS-BREMER RECHARGE EXPERIMENT THIRD PUMP-OUT TEST		DRAWN AD	SCALE
CHEMICAL COMPOSITION OF LAKE ALEXANDRINA WATER, NATIVE AND PUMPED GROUNDWATER		DATE AUG '82	PLAN NUMBER
		CHECKED	82-532

Fig. 36

CATION / CHLORIDE

RATIOS	$\frac{\text{HCO}_3}{\text{Cl}}$	$\frac{\text{Ca}}{\text{Cl}}$	$\frac{\text{Na+K}}{\text{Cl}}$	$\frac{\text{Mg}}{\text{Cl}}$
LAKE WATER	0.36	0.24	0.92	0.28
NATIVE GROUND WATER	0.14	0.20	0.74	0.20

NOTE: The lake water sample was collected and analysed about 6 months before the 2nd injection test. Thus some variation in ion ratios to the actual recharge water could have occurred.

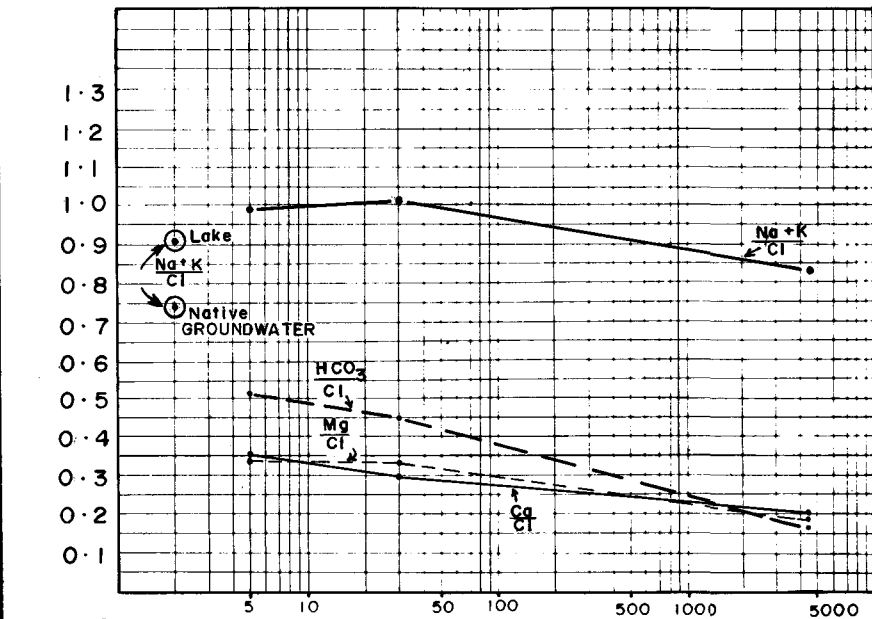


Fig. 37

CATION / CARBONATE

RATIOS	$\frac{\text{Ca}}{\text{HCO}_3}$	$\frac{\text{Na}}{\text{HCO}_3}$	$\frac{\text{Mg}}{\text{HCO}_3}$
LAKE WATER	0.67	2.5	0.78
NATIVE GROUND WATER	1.42	5.16	1.38

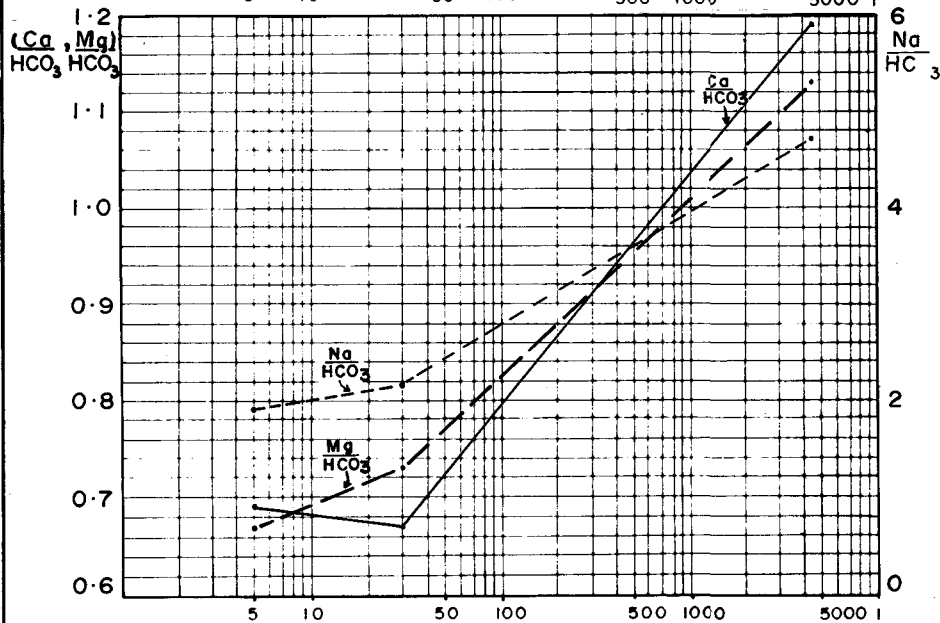
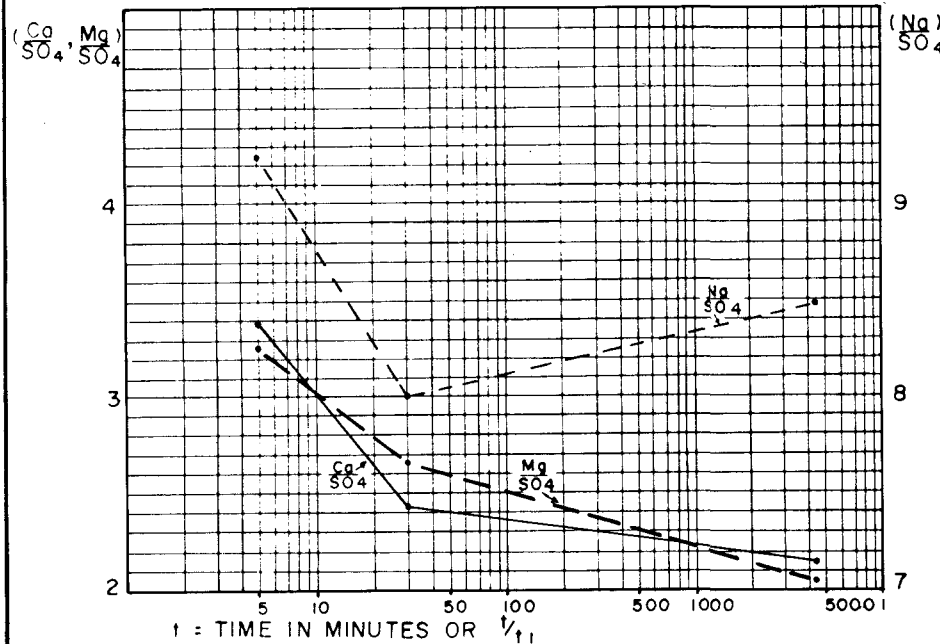


Fig. 38

CATION / SULPHATE

RATIOS	$\frac{\text{Ca}}{\text{SO}_4}$	$\frac{\text{Na}}{\text{SO}_4}$	$\frac{\text{Mg}}{\text{SO}_4}$
LAKE WATER	1.71	6.43	2
NATIVE GROUND WATER	13	47.14	12.57



DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

ANGAS - BREMER RECHARGE EXPERIMENT

THIRD PUMP - OUT TEST

CATION RATIO VARIATIONS WITH TIME

COMPILED

WR 16.12.82
C D O DATE

DRAWN
AD

SCALE

DATE
AUG '82

PLAN NUMBER

CHECKED

S16436