DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

GEOLOGICAL SURVEY
ENGINEERING DIVISION

AN ASSESSMENT OF THE HYDROGEOLOGY OF THE SOUTHERN FROME EMBAYMENT WITH PARTICULAR RESPECT TO POSSIBLE EXPLOITATION OF URANIUM DEPOSITS

by

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DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

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ABSTRACT

A study of the hydrogeology of the southern Frome Embayment has been carried out to assess any possible effects upon groundwater of exploitation of uranium deposits in the area.

Water quality in Tertiary palaeochannel aquifers is unacceptable for all consumptive uses wherever there are significant uranium concentrations.

Lake Frome is an evaporative sink for all the major aquifer systems in the area. The uranium-rich waters of the palaeochannel aquifers move naturally towards the Lake, with much of the uranium precipitated en route in reducing environment traps. Water at the Honeymoon site is estimated to take at least 2,000 years to reach its discharge zone, at a rate of approximately 50 metres per year.

In-situ leaching techniques pose no threat either to the aquifer in which the deposit occurs, or to the other aquifer systems in the Frome Embayment, provided that appropriate well construction methods are used, and there is a net removal of water from the orebody over the period of leaching operations. The technique is being used successfully in Texas, U.S.A. to mine from aquifers storing domestic quality groundwater. There, effective control of leaching solutions prevents problems of water quality impairment away from the uranium orebody itself.

Well yields in the palaeochannel aquifers may be restricted by inelastic behaviour of the aquifer material under the stress of pumping.

INTRODUCTION

Exploration by several companies has led to the discovery of several uranium deposits in the sediments of the Frome Embayment (Fig. 1) with potential for more discoveries if further work is undertaken. Serious consideration of using in-situ leaching techniques to extract the uranium led to a study of the hydrogeology of the area, so that the impact of such an operation on the groundwater resources could be assessed.

Work has included sampling of test holes and drilling a cable-tool exploration well at the Honeymoon Deposit (Fig. 1), together with a reappraisal of existing data and reports.

REGIONAL GEOLOGY

The Frome Embayment contains shallow marine and non-marine sandstones and shales of upper Jurassic and Cretaceous age, overlain by Tertiary and Quaternary terrestrial sediments. Near the Honeymoon ore deposit, the Tertiary-Recent sediments are slightly more than 120 metres thick, and they rest on pre-Cambrian metamorphic rocks.

The Tertiary sediments in the southern portion of the embayment are of particular interest. The early Tertiary deposits (Palaeocene-Eocene Eyre Formation sands and clays) are found within distinct palaeochannels incised into the older sediments and sometimes the basement rocks, and contain widespread low grade uranium mineralisation. They are blanketed by lacustrine silts and clays of the Miocene Namba Formation, and then by Quaternary sands and clays (Figure 2).

The Yarramba Channel (Brunt, 1976), which contains the Honeymoon and East Kalkaroo uranium deposits, contains a thickness of up to 55 metres of channel fill deposits, incised into weathered Cretaceous and Precambrian material, and overlain by Tertiary and Quaternary clays and silts with minor sands and gravels 60-70 metres thick. The main uranium mineralisation in the Honeymoon Deposit coats coarse quartz sand grains in the lowest of three sand beds within the channel.

REGIONAL HYDROGEOLOGY

The area is arid, with little possibility of groundwater recharge except where runoff is concentrated.

Low salinity water (less than 10,000 mg/l) is mainly restricted to zones of local recharge near the Flinders Ranges and to aquifers of the Great Artesian Basin, deriving water from New South Wales and Queensland.

Groundwater is stored in several separate aquifer systems in the Frome Embayment.

1. Cambrian and pre-Cambrian rocks form the basement to the sedimentary sequence. Where penetrated by drilling they are extremely weathered, and they can be ignored as potential aquifers.

These rocks also form the boundaries of the system, as ranges to the west, south and east (Fig. 3). Significant groundwater resources occur there in an upflow direction from the basin sediments, and therefore they cannot be affected by mining operations in the basin, and need not be considered further.

2. Confined aquifers of the Great Artesian Basin (GAB) occur in much of the Frome Embayment.

(a) Jurassic aquifers

These are the main artesian aquifers of the GAB, and have been developed east and north east of Lake Frome (Fig. 3). There is some evidence for limited occurrences west of the Lake. Although well heads are frequently in an appalling state of repair, most have been levelled (Edwards, 1970) and some have had shut-in pressure recorded. Potentiometric contours and flow-lines (Fig. 4) can be drawn, revealing flow towards Lake Frome where mound-springs presumably localise some of the discharge.

Water salinities are generally less than 2,000 mg/l and the water is characterised by high bicarbonate and low sodium, chloride and sulphate concentrations.

(b) Cretaceous aquifers

Confined aquifers within Cretaceous sediments have been developed by a few wells (plotted on Figure 5), but very little recorded information is available.

They are probably GAB aquifers, but Ker (1966, p. 8) considered that some local intake was possible. The southern limit of the Cretaceous sediments is less reliably defined than that of the Jurassic, and suggests onlap, with Cretaceous shales blanketing the margins of the Jurassic aquifers.

Salinities are high, 15,000 to 50,000 mg/1 or greater, with sodium chloride the dominant dissolved salt.

3. Aquifers in Tertiary and Quaternary sediments dominate the area west and south-west of Lake Frome, and have been documented in a small area east of the Benagerie Ridge (Fig. 3).

Near the Flinders Ranges water salinities are as low as 1,500 mg/1, increasing towards Lake Frome. Sodium chloride and sulphate are the dominant ions in solution, except where recharge comes from runoff in limestone areas, in which case more calcium bicarbonate is found.

In the south, particularly near the Benagerie Ridge, there are occasional occurrences of shallow, usually saline groundwater, associated with minor local recharge. Recent recognition of the Tertiary palaeochannel systems explains the occasional penetration of deep sand sequences in the area. These are aquifer systems which have been intersected by very little water well drilling, and there is virtually no water level or salinity information except at and near the Honeymoon Deposit. There, salinities were as high as 16,000 mg/1 and the water radioactive.

Shallow wells tap isolated occurrences of variable quality groundwater near drainage lines. These aquifers are probably discontinuous, and are not significant in the context of uranium leaching.

Table 1 summarises the aquifer systems.

TABLE 1

HYDROGEOLOGICAL SUMMARY

UNIT	LITHOLOGY	DISTRIBUTION	GROUNDWATER
Undifferentiated surficial Tertiary-Quaternary sediments	Clays, silts, sands and gravels	Throughout study area	Small well yields of greater than 10,000 mg/l east of Benagerie Ridge. Variable supplies of better quality water to the west, especially on the flanks of the Flinders Ranges. Data poor except west and south west of Lake Frome.
Tertiary Eyre Fm.	Sands, with clay interbeds	Confined to channel fill in southern part of area, correlated with blanket sands to north	Potential well yields of 500+ Kl/day of greater than 10,000 mg/l water where suitable sands occur. Too radioactive for stock where uranium deposits located. Very little data available except at Honeymoon Deposit.
Cretaceous and Jurassic Formations	Sandstones and shales	1. Cretaceous absent only near Olary, Barrier and Flinders Ranges 2. Jurassic occurs east and north-east of Lake Frome	1. Cretaceous GAB aquifer. Flowing wells only near Lake Frome. Water quality variable and data limited in study area. 2. Jurassic GAB aquifer. All wells flow with salinities less than 2,000 mg/l. Data adequate to draw potentiometric contours.
Cambrian and pre-Cambrian rocks	Variety of metasediments and crystalline rocks	Form ranges to west, south and east of area, and basement to sediments in the study area	Can be ignored as aquifers within study area, but yield generally small supplies of variable quality water in the ranges.

REGIONAL GROUNDWATER FLOW

The Lake Frome area is an internally draining basin, with evaporation removing the surface water discharged into the Lake, leaving an accumulation of the dissolved salts.

Potentiometric contours for the Jurassic and Tertiary/Quaternary aquifers (where data is available) are shown on Figures 5 and 7, together with groundwater flowlines. This demonstrates that the Lake is also a sink for groundwater in the area. Flowlines for the data-scarce Cretaceous aquifer have been drawn on Figure 6 on that basis.

As a result any material carried in solution by an aquifer in the area will eventually reach Lake Frome, and stay there. There may be natural mixing of water from separate aquifers near the Lake (for example where mound-springs suggest structural discontinuities) but in most of the area the confining beds separating the three systems will ensure that one aquifer cannot mix significantly with another.

The area between the Honeymoon site and Lake Frome is devoid of data for the palaeochannel aquifers, but it is reasonable to infer regional, if tortuous, flow towards the Lake (Appendix IV). This applies to other palaeochannels, and means that movement of uranium towards the Lake is a natural phenomenon. In the absence of geochemical conditions favouring concentration of the uranium in the channel Lake Frome is therefore the natural point of accumulation of uranium derived from the ranges.

INVESTIGATIONS AT THE HONEYMOON SITE

1. General

A cable-tool exploration well was drilled (Appendix 1) with careful supervision, to weathered basement. All aquifers were carefully sampled, and the lowest, the Basal Sand of the Tertiary Eyre Formation, was tested to determine its transmissivity to enable calculations of natural groundwater velocity to be made.

No water was intersected in the Quaternary and Tertiary sediments overlying the Eyre Formation. Weathered (?)Precambrian metamorphic rocks underlie the Tertiary, and groundwater of usable quality or quantity is almost certainly unobtainable from them.

Three confined aquifers were intersected in the palaeochannel sands, and details are summarised in Table 2.

Details of well construction may be found on Figures 1 and 2, in Appendix I.

2. Water Quality

Water samples were also taken during a testing programme carried out by Mines Administration Pty. Ltd. in early 1977, and water quality at the site is therefore well documented. These are by far the best data available for the palaeochannel aquifers in the southern Frome Embayment, as presented in Appendix II, and discussed below.

TABLE 2

HONEYMOON SITE HYDROGEOLOGY

AQUIFER From	AQUIFER To	AQUICLUDE From	AQUICLUDE To	THICKNESS (m)	WATER LEVEL (m below TOC* at time of drilling)	SALINITY (mg/1)	TOTAL RADON-222 (pci/1)	NOTES
-	-	30	74	44	-	-	-	Namba Fm. clays. Quite dry until near their base.
74	81	-	-	7	57.02 (64.13 m above AHD)	10,500 10,500	760 (top) 410 (bottom)	Eyre Fm. upper sand. Water at 25°C. Loose, med.-coarse 76-81 m.
-	-	81	90.3	9.3	-	-	-	Eyre Fm. clay. Stiff, dry-damp, effective confining bed at site.
90.3	96	-	-	5.7	58.63 (63.82 m above AHD)	11,500 12,000	210 (top) 170 (bottom)	Eyre Fm. middle sand. Water at 26°C. Loose, coarse and oxidised brown 90.3-93.3 m, then some clay matrix.
-	-	96	106.60	10.7	-	-	-	Eyre Fm. clay. Soft, sandy, moist - not particularly effective confining bed at site.
106.60	118.85	-	-	12.3	55.69 (65.47 m above AHD)	16,350	95,600	Eyre Fm. basal sand. Orebody from 107 to 113 m.
-	-	118.85	?	Indefinite	-	-	-	Clayey base of Eyre Fm. and weathered Precambrian rock.

*TOC : Top of casing (same elevation as flange of well head now used as reference point for water level monitoring)

The purpose for obtaining the water quality data was to assess possible uses of the water resource at the Honeymoon site, and to decide what importance should be placed upon pollution control in any future mining operation. The area is arid, and the main use to which it has been put since European settlement is grazing, water availability for stock being a major controlling factor. Table 3 shows limiting values for various ions for stock water supplies (after Hart, 1974), compared with those measured in samples from the three aquifers. Constituents found to be below detection limit or very low in concentration in samples taken during the push-pull tests in February, 1977 were not analysed in samples from the later cable-tool hole, and values for the table were then taken from the earlier analyses. Where more than one sample was taken from one aquifer the values were rounded off, if similar, or the range given if dissimilar.

All three aquifers at the site contain water that is quite unsuitable for stock because of high activities of radium-226. However the radon and radium analyses suggest that there is little or no mixing of water from the separate aquifers. The levels of radioactivity are two to three orders of magnitude higher in the basal sand aquifer, in approximate correspondence with the gamma log (Figure 1 in Appendix 1).

TABLE 3

WATER ANALYSIS SUMMARY COMPARED WITH LIVESTOCK WATER QUALITY CRITERIA (from Hart, 1974)

Element	Maximum Recommended (mg/1)	Upper Sand *	Middle Sand *	Basal Sand **
Total Dissolved Solids	13,000	10,000	11,500	16,350
Arsenic (as As)	1.0	-	-	-
Boron (as B)	At least 50 mg/1	-	-	5.45
Cadmium (as Cd)	0.01	-	-	0.001-0.004
Calcium (as Ca)	1,000	487	550	877
Chromium (as Cr)	1 to 5	-	-	0.004
Copper (as Cu)	0.5 to 2.0	-	-	0.004
Fluoride (as F)	2	0.95, 2.50	2.8	-
Iron (as Fe)	10	Uncertain	Uncertain	0.93
Lead (as Pb)	0.5	-	-	0.009-0.018
Magnesium (as Mg)	250 to 500	280	320	406
Mercury (as Hg)	0.002	-	-	<0.0002
Molybdenum (as Mo)	0.01	-	-	0.002-0.006
Nitrate (as NO_3)	90 to 200	0-2	4	23
Selenium (as Se)	0.02	-	-	0.002
Sulphate (as SO_4)	1,000	1,400	1,600	1,856
Uranium	Not Listed	Uncertain	Uncertain	1.2
Zinc (as Zn)	20	Uncertain	Uncertain	-
Radium-226	3 pci/1	10-40	60-210	2,600-3,600

* Values taken from cable-tool hole samples

** Values taken from push-pull test samples where not available from cable-tool hole sample

The upper aquifers would be marginally suitable for stock if the radioactivity were acceptably low, and the prospects elsewhere in the channel system are reasonable, although as yet untested.

It is hard to judge what future uses other than for stock may be found for the relatively high salinity groundwaters in the southern Frome Embayment.

Leaching operations in the basal sand present no hazard to that aquifer adjacent to the orebody, as the water is virtually unusable because of the orebody itself, especially if a slightly greater volume is extracted than injected.

The contrast in water quality between the basal and middle sand aquifers demonstrates the usefulness of careful water sampling. The water in the upper aquifers is nearly acceptable for stock (on the basis of samples from one point). Had the radioactivity been lower, rigorous pollution control measures would have been recommended in the interests of protecting local stock supplies, but in this case minor upward leakage will not matter.

Very little water quality information is available from other wells in the area as most holes known to penetrate the palaeochannel system have not been completed as water wells. One drilled 3 km east of the site has lower salinity water but radium-226 activity is unknown, and the well construction allows an unknown amount of mixing between the aquifers.

3. Aquifer and Well Test Summary

Following development a three stage step-drawdown test was conducted to establish the time-drawdown-discharge relationship for the well so that the optimum production rate for the aquifer test could be determined. Figure 1 in Appendix III shows the relative locations of production and observation wells.

The results suggested a change in aquifer transmissivity during the second or third stages of pumping, and a production rate of about 700 Kl/day^{-1} was somewhat arbitrarily selected for the main test.

The drawdown in the main test was considerably greater than expected, indicating a further decrease in transmissivity. The drawdown caused a 20% reduction in production rate because the engine driving the pump was at its r.p.m. limit, and the main test was halted after 2 hours.

Operations were suspended temporarily to interpret and discuss the unusual results. During this time gale-force winds damaged the storage dam lining. Since it was considered essential to store all discharged water in the dam for return to the aquifer on completion of the test, all further testing was abandoned.

Drawdown curves are presented on Figures 2-17, at the rear of Appendix III and the interpretation discussed in detail there.

Transmissivity values are in the range 200-1,000 $m^3day^{-1}m^{-1}$. Storage Coefficients range from 10^{-4} to 10^{-5}. Both are reasonable values for the hydrogeological environment, and are best quoted to one significant figure.

A drastic reduction in transmissivity was observed during the testing at the production well, but not at the observation wells. Figure 17 shows the drawdown versus log time straight line relationships for all four periods of testing, with the corresponding values of transmissivity.

The results are interpreted as being caused by a slight collapse and repacking of the aquifer material in the zone adjacent to the production well. Confined aquifers compress under the influence of reduction in pressure caused by withdrawal of water from them. This aquifer is unconsolidated, with a soft clay confining bed, and is likely to behave inelastically under such conditions. Drawdown during the main test was as great as 70% of that available and the pressure reduction near the well (within 5-10 m) appears to have been great enough for significant collapse and repacking to have taken place.

This has important implications for future production wells in the aquifer, and an additional criterion for the safe yield of a well is that drawdown must not exceed some arbitrary percentage of that available.

On the present data it would seem wise to limit pumping from any well to a rate which induces a maximum of 20 metres of drawdown. Further testing of a new well would be needed to improve this interpretation.

By extrapolating the distance-drawdown plot to the zero drawdown distance, a measure of the area sampled by the aquifer test can be obtained. In this case $r_o = 430$ m, which means that most of the orebody zone was influenced by the testing.

4. Groundwater Flow in the palaeochannel aquifers

Two drillholes 3 km east of the Honeymoon deposit have been cased and completed in the channel sand aquifer system, and were levelled accurately with respect to the four wells penetrating the Basal Sand aquifer at the orebody (data in Appendix IV). Data for the wells is poor, and it is unlikely that they penetrate only one aquifer within the channel system. It was hoped to measure the natural hydraulic gradient in the area, and to calculate the natural velocity of flow of the groundwater. The complicating factor is the known difference in head between the three aquifers at the Honeymoon site. This could mask the lateral flow gradient if wells measured were completed in separate aquifers. Figure 1 in Appendix III shows the relative locations of the wells, with elevations of casing tops and of potentiometric levels.

It was concluded (Appendix IV) that water in the palaeochannel systems is moving naturally at a rate of 50 metres per year (order of magnitude). The direction of flow at the Honeymoon site is probably from west to east, but this is not certain, and is opposite to the expected regional direction of flow if the aquifer were not restricted to an infilled channel.

If the water in the aquifer moved in the most direct path to Lake Frome, it would take 2,000 years to travel the 100 km.

URANIUM EXTRACTION

Methods

The most attractive methods for extracting uranium from the Honeymoon orebody (5-10 metres thick, 80 x 500 metres in areal extent, and at a depth of 100 metres) are open-cut mining and in-situ leaching.

A large open-cut mine would require major dewatering of the aquifers to overcome stability problems. This would in turn create a disposal problem as the water is saline and radioactive.

Whilst technically possible, this would be a difficult operation, and Mines Administration Pty. Ltd. have actively been investigating the possibility of using in-situ leaching techniques instead (Lackey, 1974).

In-situ leaching is a proven technique, causes minimal surface disruption, avoids most of the waste disposal problems of other mining methods, and allows rapid development of an operation (Hunkin, 1975). In the Frome Embayment sedimentary uranium situation, if economically feasible, it is by far the best method of extraction from an environmental viewpoint.

Effects

A major dewatering exercise would have the effect of intercepting most, if not all, of the natural flow through the palaeochannel aquifers with the cone of depression it would cause. This is shown diagrammatically on Figure 7. Removal of the orebody by mining would remove one concentrated source of natural groundwater pollution, but would not affect the more diffuse sources which are widespread. The effect on the groundwater quality would probably be a negligible improvement on the regional scale. There is no chance of the water being improved to a standard suitable for any consumptive use by removal of a few economic orebodies.

The hydraulic effects of in-situ leaching would be similar to open-cut mining, but the cone of depression would be much shallower and smaller, as the net removal of water from the aquifer system would only be large enough to ensure that costly leaching solutions were not lost from the ore-body. The localised source of pollution would be removed, as in the open-cut case. The water quality is so poor that there would be no need to insist on complete extraction of leaching chemicals at the conclusion of mining at the Honeymoon site.

DISCUSSION

The impact of in-situ uranium leaching on groundwater resources has to be considered in the context of potential uses of the groundwater i.e. the quality of the water and potential yields.

In the southern Frome Embayment the only aquifers associated with uranium deposits are those infilling the Tertiary palaeochannels. The palaeochannels have not been thoroughly investigated either as potential ore bearers or aquifers and data from the Honeymoon site is the only reliable hydrogeological information available. Low grade uranium mineralisation is widespread in the channel sands where they have been drilled, and the Honeymoon data suggests that the water quality will be very poor wherever significant uranium is found.

Leaching operations in Texas are carried out satisfactorily in aquifers containing potable water, by ensuring that more water is extracted from the deposit than is injected (Texas Water Quality Board, 1976). Rigorous monitoring of water levels and water quality is applied in Texas because the aquifer contains good quality water which is utilised near a leaching operation. This is a necessary commercial requirement as well, to control the direction of flow of leaching solutions.

At Honeymoon the only possibility of degrading water quality would be by upward leakage into the upper channel sand aquifers, which are in any case too radioactive for consumptive use.

The storage capacity of the aquifer systems is enormous compared with the volumes used in a leaching operation, and minor leakage of leaching solutions is not a problem. Major leakage will be avoided for commercial reasons and would in any case be small if considered in the context of the aquifer system's storage capacity.

RECOMMENDATIONS

1. No further investigations are warranted at this stage.
2. Monitoring of leaching operations at the Honeymoon site is not necessary, provided
   (1) that close liaison is maintained with the mining company, and
   (2) that wells are pressure cemented from the top of the Basal Sand to the surface, with Department of Mines field inspection of all cementing operations. Appendix V gives details of the required construction techniques.

3. Any future proposals to extract uranium in the southern Frome Embayment must be considered in the light of local hydrogeological conditions. Although the non-Tertiary aquifer systems are considered safe from degradation water quality distributions within the palaeochannels are unknown, and usable water resources may exist.

4th January, 1978.

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PHOTOGRAPHS

Plate 1. Cable tool rig on site. Slide No. 13133

Plate 2. View of storage dam, camp and (far left) well site.
Slide No. 13119.

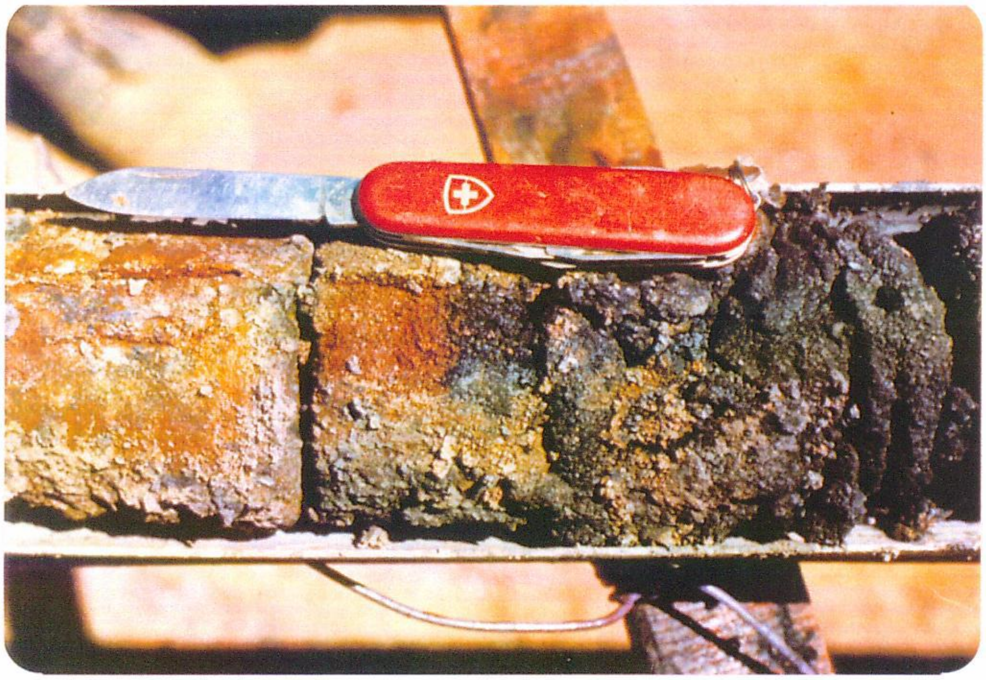


Plate 3. Contact between oxidised zone (brown) and orebody (black). Slide No. 13122.

Plate 4. Storage dam showing wind damage to plastic lining. Slide No. 13230.

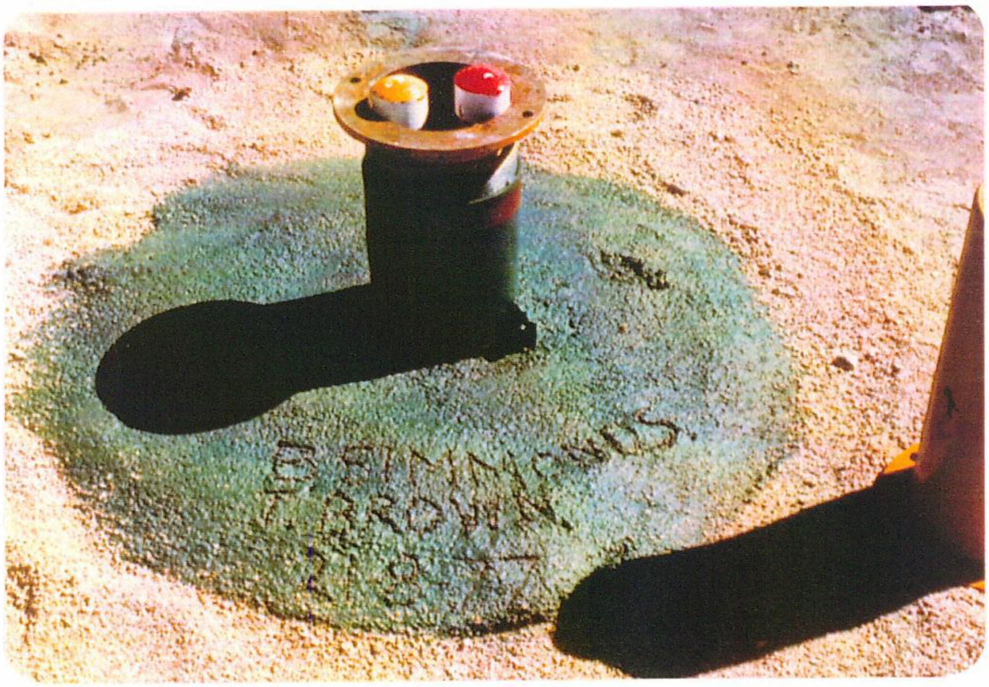


Plate 5. Final completion of test well showing two strings of P.V.C. to Basal and Middle Sand Units. Slide No. 13118.

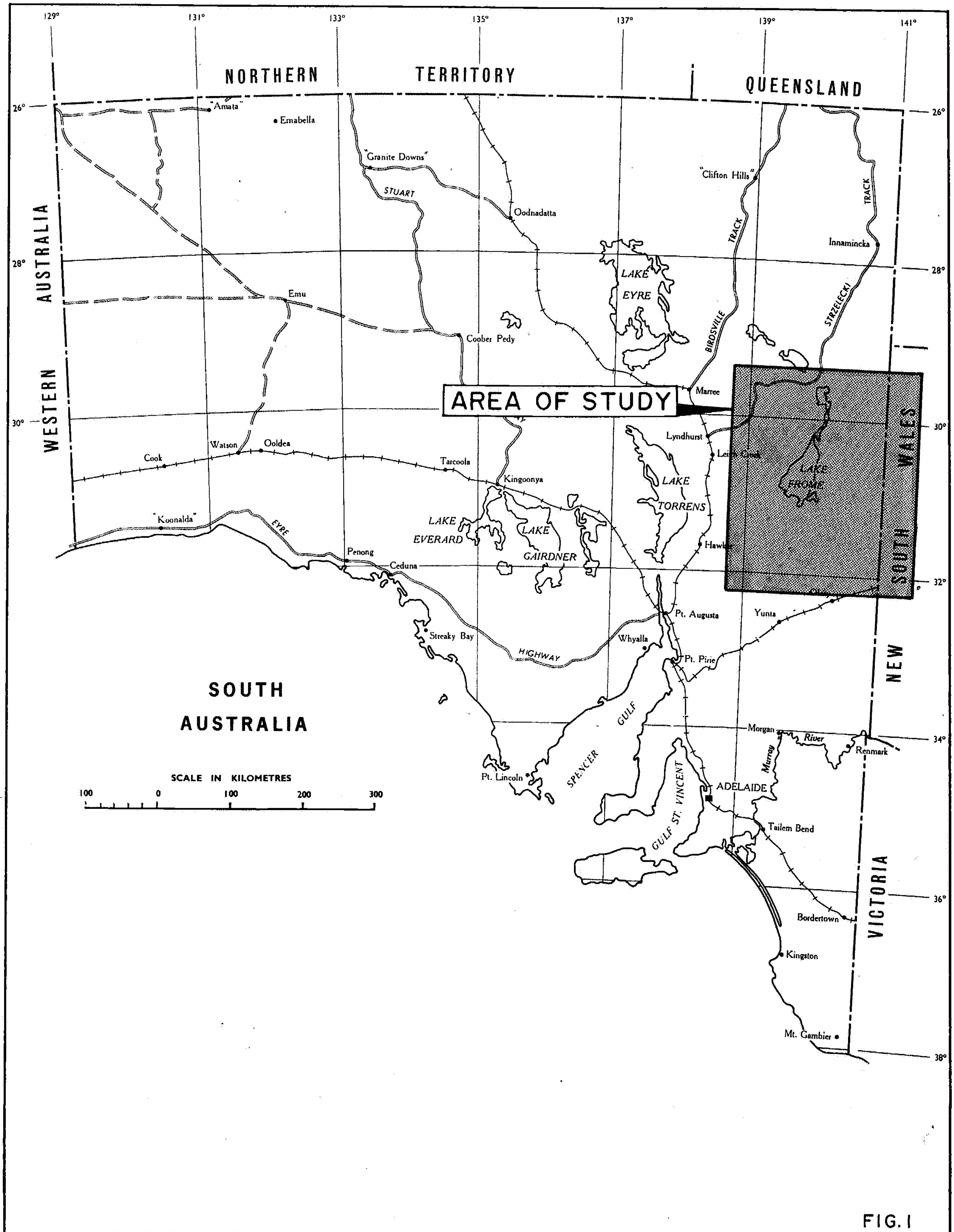


FIG. 1

DEPARTMENT OF MINES —— SOUTH AUSTRALIA

Compiled. J.W.	SOUTHERN FROME EMBAYMENT GROUNDWATER ASSESSMENT LOCALITY PLAN	Date: 10/12/77
Drn. P.D. Ckd.		Drg. No. S 13150

P.F. No. 55850 994.2

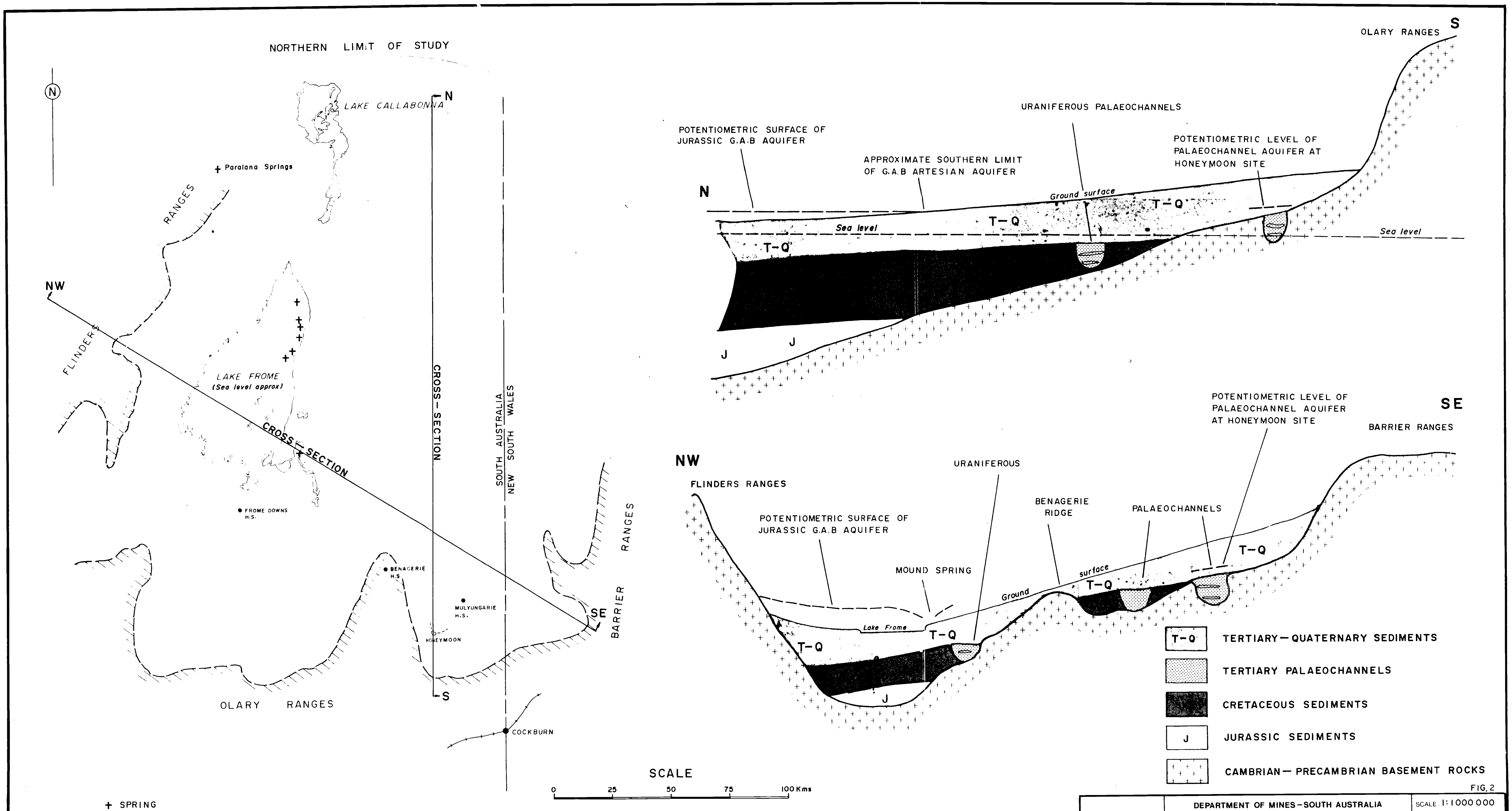
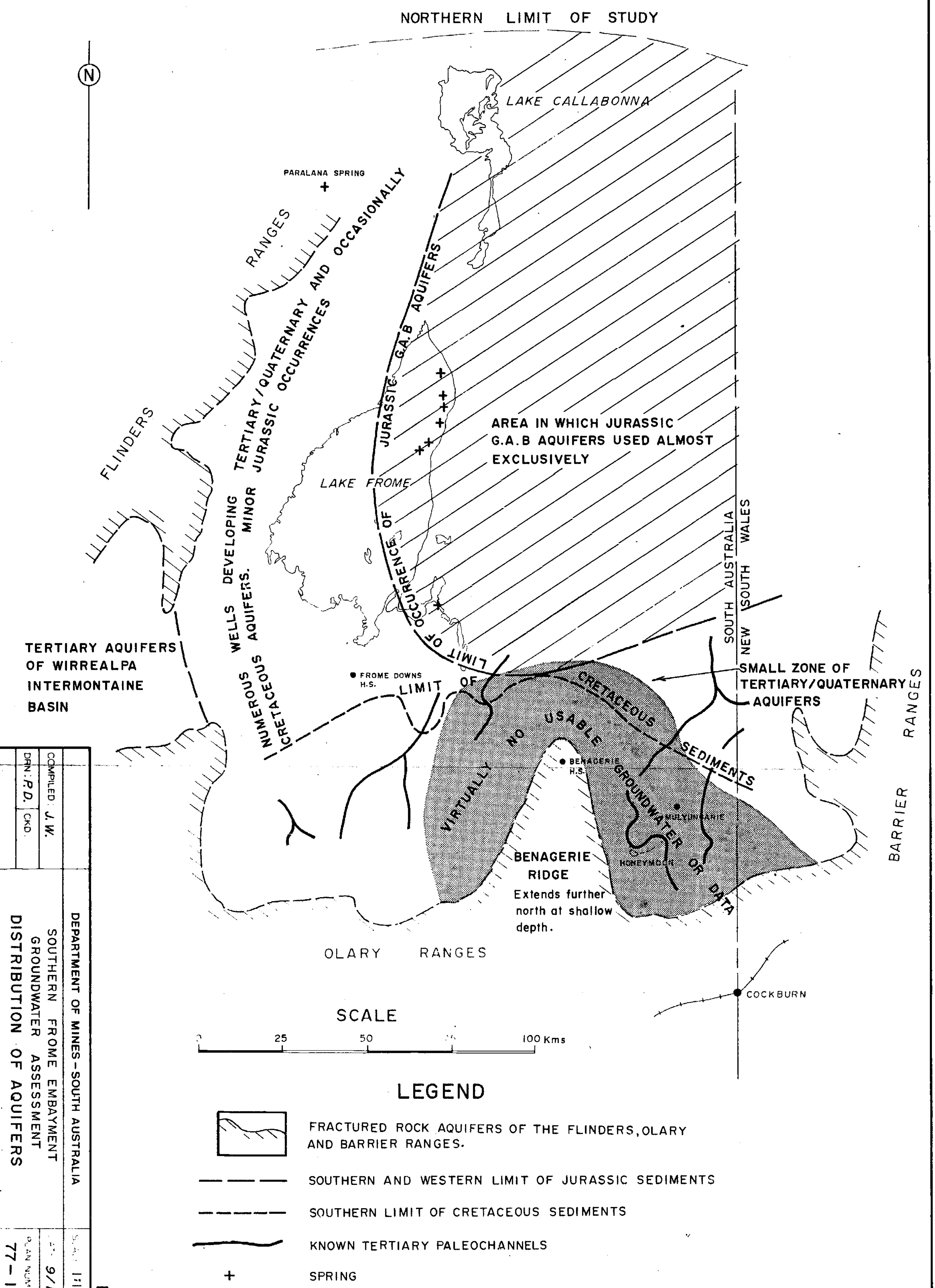


FIG. 2

	DEPARTMENT OF MINES—SOUTH AUSTRALIA	SCALE 1:1000 000
COMPILED: J.W.	SOUTHERN FROME EMBAYMENT GROUNDWATER ASSESSMENT	DATE 6/12/77
DRN: P.D. CKD.	DIAGRAMMATIC GEOLOGICAL SECTIONS	PLAN NUMBER 77-1074



NOTE: JURASSIC AND CRETACEOUS BOUNDARIES ARE BASED ON BEST AVAILABLE, BUT LIMITED, DATA.

DEPARTMENT OF MINES–SOUTH AUSTRALIA	SCALE 1:1000 000
COMPILED: J.W.	DATE 9/11/77
DRN: P.D. CKD.	PLAN NUMBER 77-1075
SOUTHERN FROME EMBAYMENT GROUNDWATER ASSESSMENT DISTRIBUTION OF AQUIFERS	FIG. 3

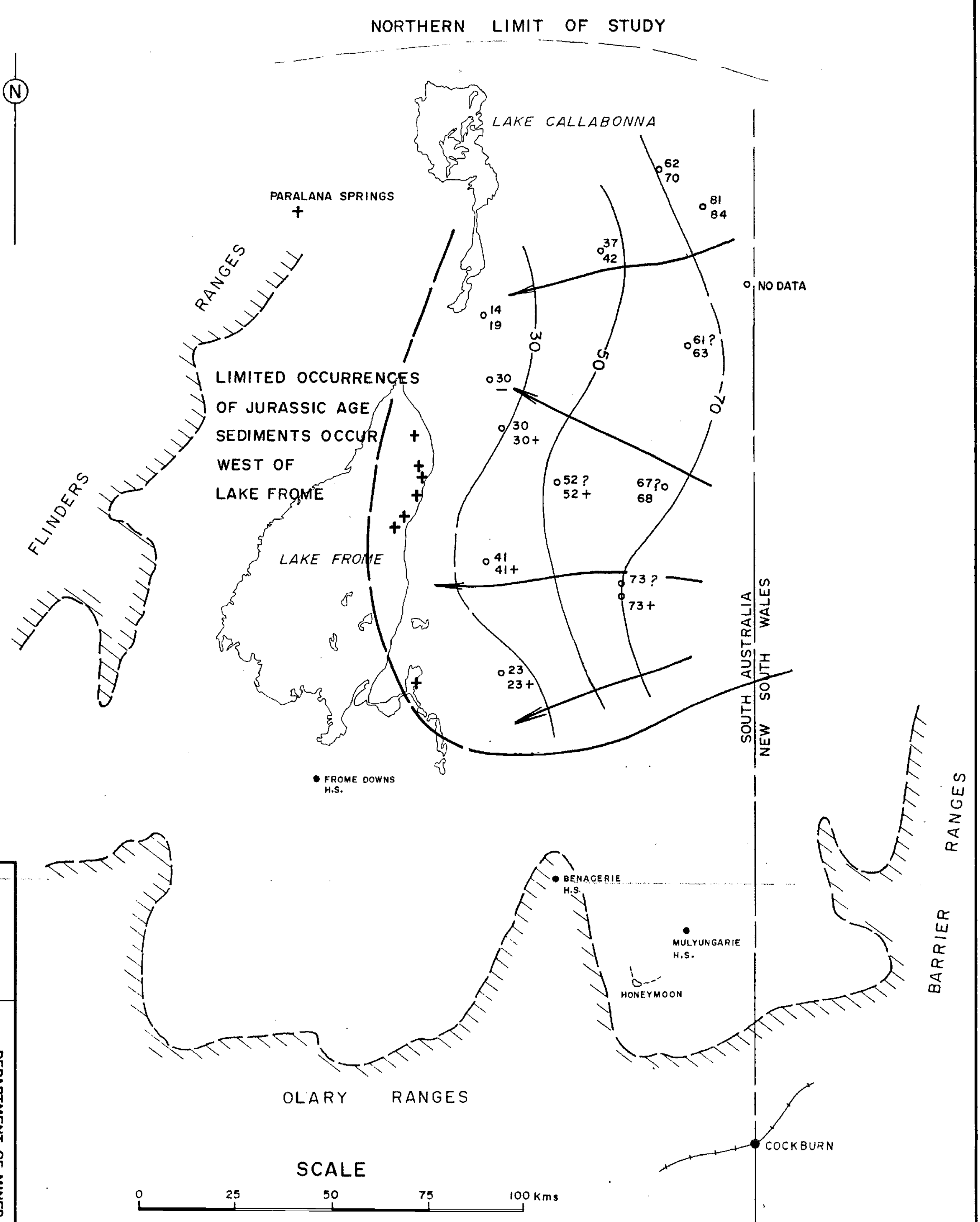


FIG. 4

DEPARTMENT OF MINES-SOUTH AUSTRALIA

SOUTHERN FROME EMBAYMENT
GROUNDWATER ASSESSMENT
POTENTIOMETRIC CONTOURS FOR
JURASSIC AQUIFER SYSTEM

COMPILED: J W
DRN: P.D. CKD.
SCALE 1:1 000 000
DATE 2/12/77
PLAN NUMBER 77-1076

LEGEND

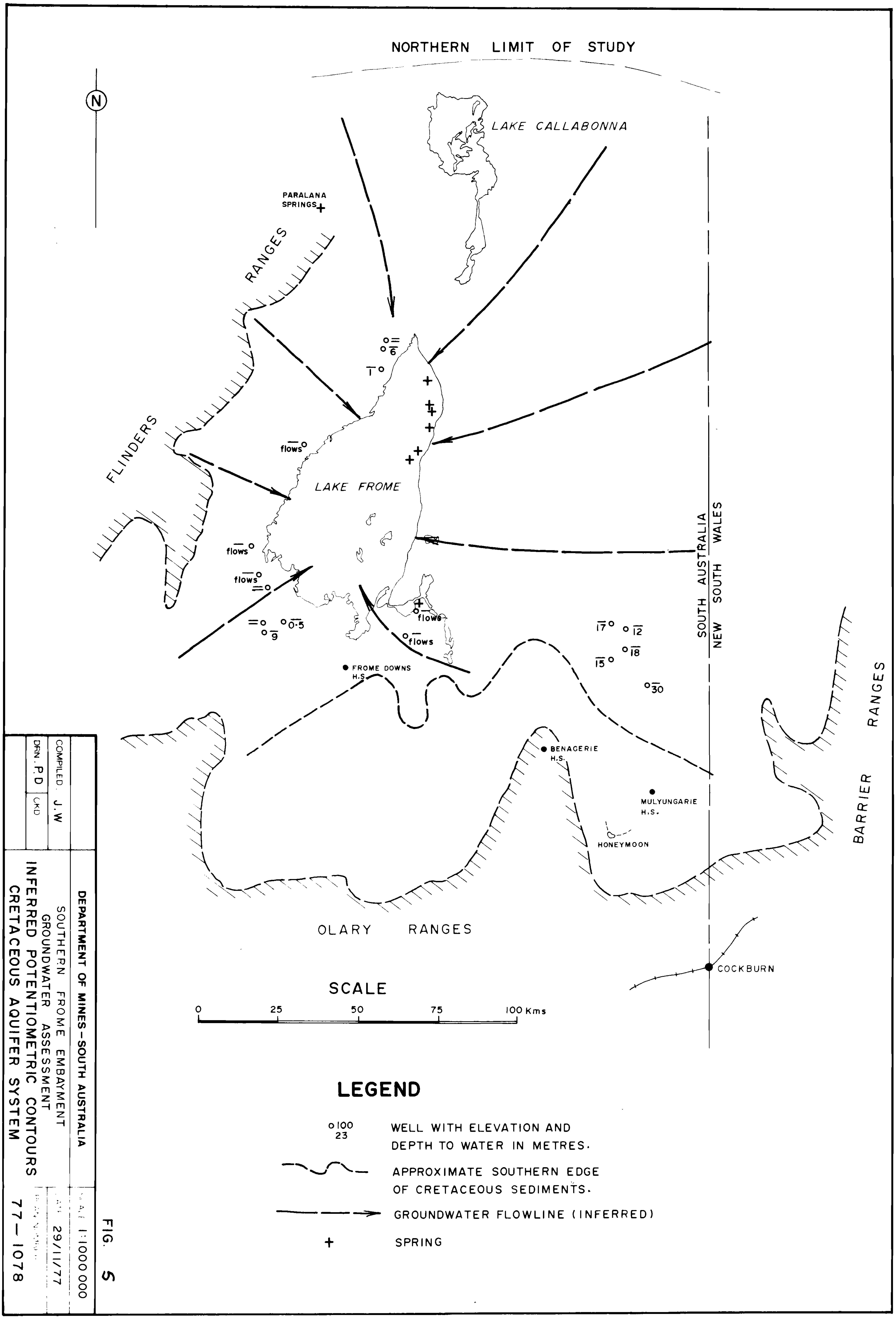
°23 46 — WELL KNOWN TO INTERSECT G.A.B ARTESIAN AQUIFER, WITH REFERENCE ELEVATION AND ELEVATION OF WATER LEVEL (lower) IN METRES ABOVE M.S.L PT. ADELAIDE.

—30— POTENTIOMETRIC CONTOURS, JURASSIC G.A.B AQUIFER (METRES ABOVE M.S.L PORT ADELAIDE)

→ GROUNDWATER FLOWLINE

— — EDGE OF MAIN JURASSIC AQUIFER (APPROX).

\+ SPRING



DEPARTMENT OF MINES – SOUTH AUSTRALIA

SOUTHERN FROME EMBAYMENT GROUNDWATER ASSESSMENT

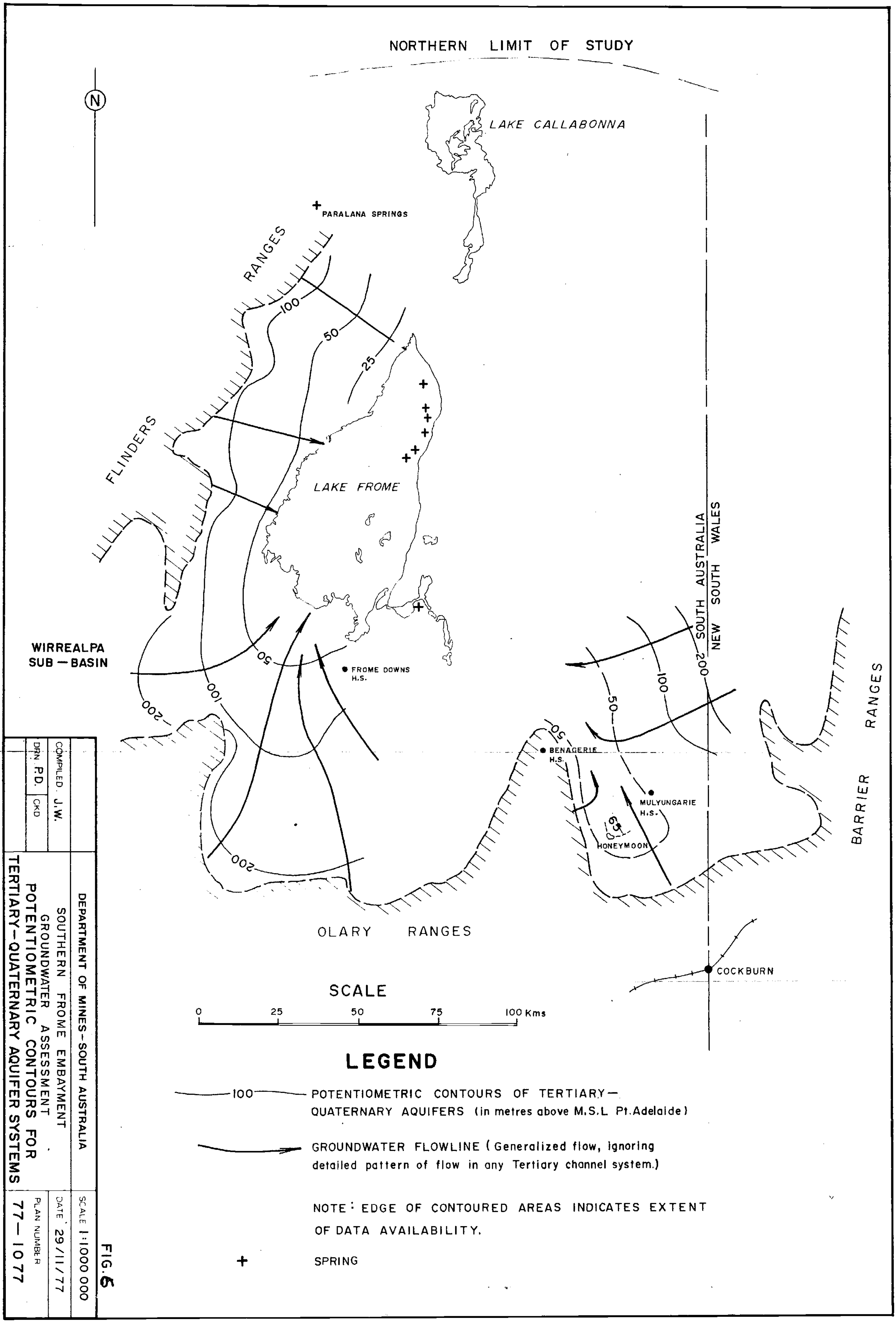
INFERRED POTENTIOMETRIC CONTOURS CRETACEOUS AQUIFER SYSTEM

COMPILED. J.W | DRN. P.D | CKD

SCALE 1:1000 000 | DATE 29/11/77

FIG. 5

77–1078


NORTHERN LIMIT OF STUDY
N
LAKE CALLABONNA
PARALANA SPRINGS
FLINDERS
RANGES
100
50
25
LAKE FROME
WIRREALPA
SUB — BASIN
50
100
200
FROME DOWNS
H.S.
200
SOUTH AUSTRALIA
NEW SOUTH WALES
200
100
50
50
BENAGERIE
H.S.
MULYUNGARIE
H.S.
65
HONEYMOON
BARRIER
RANGES
OLARY RANGES
COCKBURN
SCALE
0 25 50 75 100 Kms
LEGEND
100 POTENTIOMETRIC CONTOURS OF TERTIARY— QUATERNARY AQUIFERS (in metres above M.S.L Pt.Adelaide)
GROUNDWATER FLOWLINE (Generalized flow, ignoring detailed pattern of flow in any Tertiary channel system.)
NOTE: EDGE OF CONTOURED AREAS INDICATES EXTENT OF DATA AVAILABILITY.
SPRING
DEPARTMENT OF MINES–SOUTH AUSTRALIA
SOUTHERN FROME EMBAYMENT
GROUNDWATER ASSESSMENT
POTENTIOMETRIC CONTOURS FOR
TERTIARY–QUATERNARY AQUIFER SYSTEMS
COMPILED J.W.
DRN. P.D.
CKD
SCALE 1:1000 000
DATE 29/11/77
PLAN NUMBER
77— 1077
FIG. 6

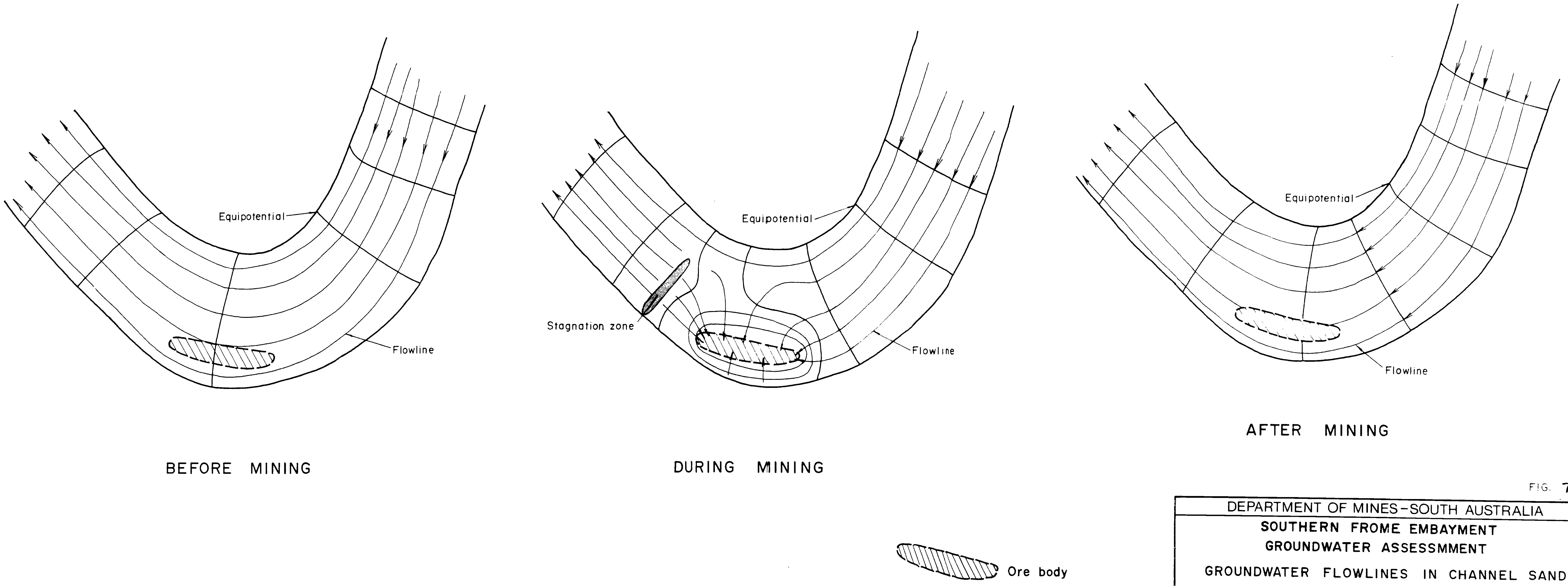


FIG. 7

DEPARTMENT OF MINES–SOUTH AUSTRALIA

SOUTHERN FROME EMBAYMENT
GROUNDWATER ASSESSMMENT

GROUNDWATER FLOWLINES IN CHANNEL SAND

	COMPILED: J.W.	DRN: P.D.	SCALE:	PLAN NUMBER
DIRECTOR OF MINES		CKD:	DATE: 9/11/77	77 - 1079

APPENDIX I

DESCRIPTION OF WELL CONSTRUCTION METHOD, AND DRILLING SPECIFICATIONS

APPENDIX I

CONTENTS | PAGE

PLANS

Description of well construction

The well was drilled with a cable-tool plant to obtain representative water and strata samples. Specifications may be found at the end of this Appendix.

Casing was kept within 1-2 metres of the bit at all times when drilling sands, however open-hole drilling up to 5 metres ahead of the bit was sometimes acceptable in stiff clays (particularly in the interval 30-74 metres).

The first string of 250 mm casing was run to 70 metres, slightly above the first aquifer, and then 200 mm casing was used to 122 metres, slightly beyond the base of the Tertiary sediments at 119.90 metres.

At 105 metres the basal sand was intersected, and the hole mudded up with Hydropol to control the loose sands whilst coring.

It was planned to tube 0.30 m intervals, and then carefully ream the hole and drive the casing to the bottom, so that a second representative (but disturbed) sample could also be obtained for each interval. The second set of samples was given to Mines Administration. This procedure was followed, and virtually 100% recovery was achieved. Coring up to 1 metre below the casing shoe was usually possible. The 200 mm casing was driven about 1 metre into basement to stabilise the well whilst further tube samples were taken to identify basement rock type. The casing was then jacked back whilst simultaneously backfilling the hole with sand in the basal sand interval, with the aim of reaming the hole through the middle and upper sands and establishing circulation around the casing so that it could be pressure-cemented. Unfortunately the casing shoe jammed at 103.5 m (just above the aquifer to be tested), and it was impossible to cement outside the 200 mm casing. The clays separating the aquifers were sealed tightly against the casing, and it was considered satisfactory to test the aquifer without cementing.

A Surescreen Wellmaster stainless steel wirewound screen was used, with apertures of 0.38 mm (0.015"), a diameter of 170 mm (6 5/8") and a length of 12.25 m (from 106.60 to 118.85 m). Surescreen information sheets were used to select an aperture that would retain about 40% of the aquifer material. The larger of the two possible apertures was selected, as it was not considered worth using a variable aperture screen.

Following development and testing, completion was planned in a way to allow the well to be used to monitor water levels in all three aquifers, by stage cementing three strings of 50 mm PVC inside the steel casing. This was decided upon because one string of casing had to be cemented inside the jammed steel casing to ensure hydraulic separation of the three aquifers because it could not be externally pressure cemented. The well could not have been used for pumping at high rates, as casing with a maximum diameter of 100 mm would have been necessary, and little was sacrificed by using 50 mm casing to the basal sand aquifer.

The hole was mudded up with Revert, the steel casing perforated with explosives, and the first string of 50 mm PVC run in. A 40 gallon cement plug was set above the flange of the central string to seal off the Basal Sand aquifer and allow better mud control of the Middle and Upper Sands. Gravel pack was slowly poured down the open-ended casing string, but locked inside the pipe, perhaps because of the slow velocity of the grains through the mud. The pipe parted whilst being withdrawn from the hole, and it was not considered feasible to fish for it without risking damage to the two correctly set lengths of pipe. The second string was therefore gravel-packed over the perforated interval across the Middle Sand aquifer, and a 40 gallon cement plug set above it to 75 m. The Upper Sand aquifer interval was gravel-packed to 70 m (about 15 m below its potentiometric level). Any future work in the area could include running-in and gravel-packing a line of 12 mm PVC to the upper aquifer, but this is not necessary for the stability of the well and aquifer separation.

A 35-40 mm diameter bailer was run inside the PVC to clean out some of the drilling mud, and both strings were found to have constricted at about 70 metres. They were both open to their total depths for a water level probe, and the slight constriction is probably due to uneven pressure where the casing is squeezed between the steel casing and the gravel pack.

Figure 3 shows details of the final completion.

Geological Sampling

Tube samples were taken from the surface to 7 metres, at 54 metres in the Namba Formation, and in the weathered basement from 119.90 to 120.65 metres for the Regional Surveys Division of the Department of Mines.

The Basal Sand was tube-sampled from 104.23 to 119.90 metres, using drilling mud to stabilise the formation and minimise fluid loss, to enable the best screen aperture to be selected.

Reamed samples were taken every 0.30 metres where possible, to provide Mines Administration with further material for testing.

Sludge were taken every 2 metres and bit samples where appropriate or available.

Water samples were taken at several levels within the upper two aquifers, with the casing driven to the bottom of the hole in each case. The use of drilling mud prevented sampling of the basal sand aquifer during drilling, however this was not considered serious as pump-testing was to follow, and oxidised sand was not present above the ore zone. It had been planned to sample water if the top zone of the aquifer had been oxidised, and then to mud up the hole for coring.

DOCKET NO. .E.L. 259 .... PROPOSED HOLE NO. ....
FILE NO. ....

SOUTH AUSTRALIAN DEPARTMENT OF MINES

PROPOSAL FOR CABLE TOOL/~~ROTARY/HAMMER~~ DRILL HOLE

CLIENT : Mines Administration Pty. Ltd.

CLIENT'S REPRESENTATIVE : Mr. D. Brunt

PROJECT : Honeymoon Deposit Groundwater testing

LOCATION : (SEC. HD. 10 km SE of
(DESCRIPTIVE : Yarramba H.S
(Southern Frome Embayment)

OBJECTIVE OF DRILLING : Production bore fully penetrating "Basal Sand" in Yaramba Channel. Collection of hydrogeological data during drilling

AUTHORIZATION OR INITIATION : JDW

TELEPHONE : Brisbane 221-2366

WATER/~~DRAINAGE~~

MILITARY SHEET
PHOTO RUN.
NO.
SURVEY

REQUIRED FINAL SIZE OF HOLE : 200 mm
METHOD OF COMPLETION : screw cap 0.5 m above G.L
ANTICIPATED DEPTH : 125 m
REQUIRED DEPTH (IN TERMS OF OBJECTIVES) : Full penetration of Tertiary sequence
CASING PROGRAMME : 200 mm casing run or driven within 2 m of bit throughout to allow water sampling. Pressure cemented to "Lower clay" at 100-105 m. 150 mm stainless steel wirewound screen from approx, 105-115m, with sump resting on basement at 120-125 m

SAMPLING : Open Tube :
Sealed Tube :
Cores : Continuous 105-115 if possible
Others : Sludge samples every 2m Bulk samples for sieve analysis every 0.5 m in sand sections.

WATER SAMPLING :

All waters cut - as directed by site geologist.

ANTICIPATED DRILLING CONDITIONS

FROM (m)	To (m)	LITHOLOGY	Quality (mg/l)	Water Level (m)
0	75	Sandy clay	10 000	50 approx.
75	115	Clay with sand beds	?	?
115	125	Hard clay		
125	-	Basement rock		

STORAGE OF SAMPLES : Core boxes, linen bags for sand samples
SEALED TUBES : To be despatched to Thebarton

GEOLOGIST : J.D. Waterhouse
J.C. Beal

DRILL SITE INDICATION : Geologist on site

NOTE :

This proposal has been prepared solely for use by officers of the Department of Mines; it is not an agreement between the client and the Department.

Date 25 June, 1976........

DRILLING ENGINEER :

Date ....

-19 7a

DEPARTMENT OF MINES - SOUTH AUSTRALIA
ENGINEERING DIVISION
COMPOSITE WELL LOG - GROUNDWATER

HOLE No.	QD 14
UNIT/STATE No.	7034000WW00018
SERIAL No.	175/77
FOLDER No.	
DRG. No.	77-980
SHEET	1 OF 1

CONSTRUCTION DETAILS

DRILLING TECHNIQUE Cable tool
CIRCULATION Water to 105 m Mud to 122 30 m
START 9 5 77
FINISH 8 7 77
TOTAL DEPTH 122 30 m

	Inches	mm	From (m)	To (m)
HOLE DIAMETER	10½		0	72
	9⅞		72	105
	8		105	122 30
CASING DIAMETER (Cemented)	8	200	0	105
CASING DIAMETER (Uncemented)				
SCREEN DETAILS Make / Model Dimensions	6⅝ blank		103 60	106 8
	6⅝ screen		160 80	121
	6⅝ sump		121	123

PROJECT Honeymoon Deposit Uranium Leaching Project

LOCATION Mulyungarie 1 100000 (7034) KALKAROO STN
CURNAMONA 1 250000 sheet

CO-ORDINATES

REFERENCE ELEV. 121 16 (TOC)
SURFACE ELEV. 120 82
DATUM A H D

LOGGED BY J D Waterhouse
DATE August 1977
TRACED BY L Rummer
DATE October, 1977

TYPE OF LOG	16 IN NORMAL	64 IN NORMAL	6FT LATERAL	S P	POINT RES-ISTIVITY	NEUTRON	GAMMA RAY	TEMP-ERATURE	
DATE OF RUN						21 6 77	20 6 77		20 6 77
FIRST READING (m)						0	0		0
LAST READING (m)						121 6	121 6		121 6
INTERVAL MEASURED (m)						121 6	121 6		121 6
CASING LOGGER (m)						250 mm 0-	70 m		
CASING DRILLER (m)						200 mm 1-	120 m		
DEPTH REACHED (m)						121 6	121 6		121 6
BOTTOM DRILLER (m)						122 30	122 30		122 30
MUD TYPE						Hydropol	Hydropol		Hydropol
MUD RESISTIVITY						—	—		—
RECORDED BY						B P Taylor	B P Taylor		B P Taylor

WELL SYMBOLS

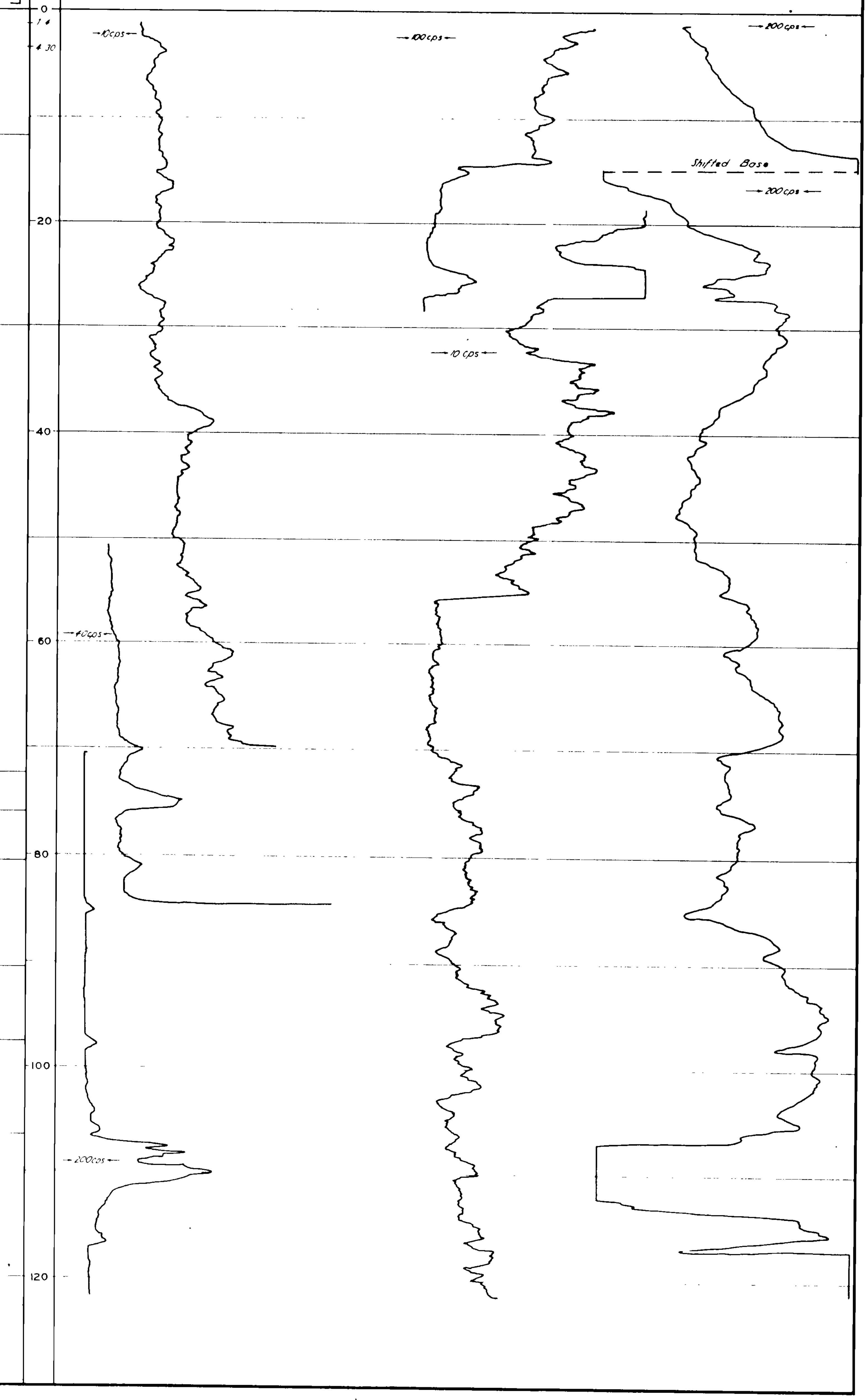
CONSTRUCTION LOG
- Casing seal
- Casing shoe
- Wire wound screen
- Slotted casing
- Cemented Interval
- Gravel packed Interval

HYDROGEOLOGICAL LOG
- ■ Core Interval
- Aq Aquifer
- Cb Confining bed
- T Transmissivity, m²/day
- S Storage Coefficient/Specific yield
- θ Porosity
- K Hydraulic conductivity, m/day

DEPTH TO WATER (m)	DEPTH TO S W L (m)	YIELD m³/day	YIELD Method of Test	TOTAL DISSOLVED SOLIDS mg / litre	TOTAL DISSOLVED SOLIDS Analysis W No
14	57 03	100+	Bailer	10 500	61/77
90 3	58 63	100+	Bailer	11 450	63/77
106 6	55 69	500+	pump	16 350	65/77

REMARKS All depths from TOC approximately 0 35 above G L

CONSTRUCTION LOG	WATER CUT (m)	WATER LEVEL (m)	CORE	HYDRO. DATA	AGE	UNIT	LITHOLOGY DESCRIPTION
FOR WELL CONSTRUCTION DETAILS SEE FIG 4 PLAN S13042					QUATERNARY — TERTIARY	UNDIFFERENTIATED	SAND-CLAY Red-brown sandy clays Grades to conglomerate of metamorphic rock fragments by 4 30 m Gypsiferous and silty with green-brown mottling
							SAND Quartz, silt - 3mm, angular to subrounded, mainly orange-stained, some colourless and red. Minor fine white mica, fine black opaques. Varying proportion of silty clay matrix, light grey and brown. 12-24 m 25-50% clay. 24-28 m Clay matrix less than 10%. At base graded to grey kaolinitic clay
					TERTIARY — MIOCENE	NAMBA FORMATION	CLAY-CLAYSTONE Grey to purple, silty kaolinitic, moderately cemented. Common rounded particles of grey, red-brown and yellowish siltstone-claystone
				Cb			
							CLAY silt, light grey, kaolinitic. At least 30% fine silt, minor quartz sand to 1mm, angular, colourless
							SILT Very fine light grey, brown, unconsolidated. Grades to sand size at base. Common fine white mica, a few moderately cemented orange brown particles 3 5mm
				Aq			SAND Quartz, silt size to 1 5mm, subangular to rounded, colourless and yellow-brown stained. Common fine black opaques, white mica flakes to 1 5mm and minor brown silt
				Cb			CLAY Stiff, grey-white kaolinitic, silty. Varying proportions quartz sand, silt size to 2mm subangular, colourless and brown. Common fine black opaques, fine white mica. Minor dark green-black silty layers
				Aq	TERTIARY — EOCENE	EYRE FORMATION	SAND Quartz, silt size to 4mm angular to subangular, not colourless, a few brown. Common angular muscovite flakes to 4mm. Rare rock fragments and fine black opaques
				Cb			CLAY Soft kaolinitic grey. Varying proportion of quartz sand, usually greater than 20%, to 3mm, angular to subangular. Common fine black opaques, white mica flakes. Near base layers and pods of dark green grey [illegible]
				Aq			SAND Quartz. Poorly sorted with grains silt size to 1cm but varying throughout the interval. Angular to subrounded, colourless, blue and milky. Upper section very [illegible] and carbonaceous [illegible]
				Co			CLAY Weathered basement. Grey [illegible] with [illegible] and a few amphibole grains [illegible]



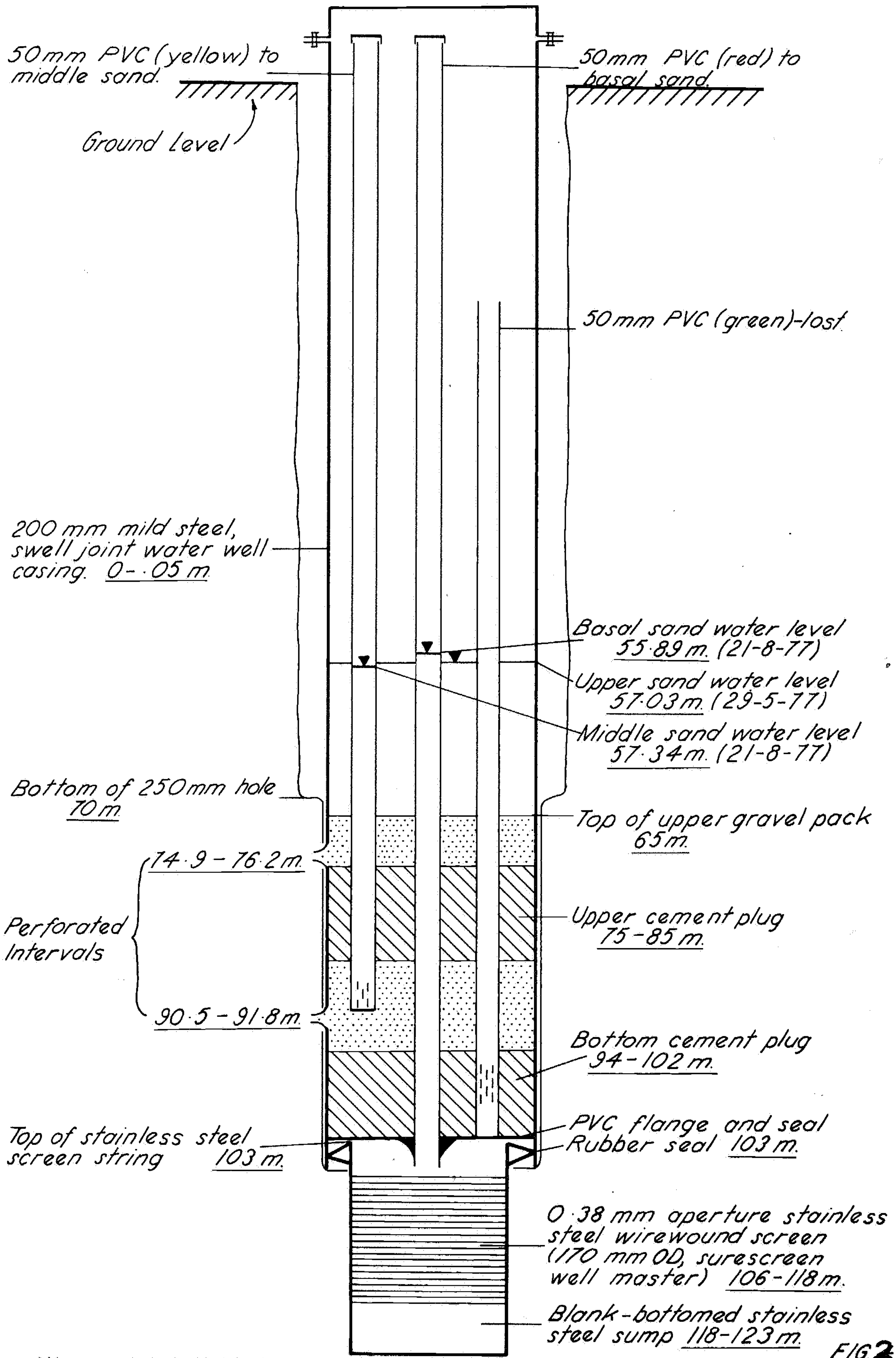


FIG. 2

	DEPARTMENT OF MINES—SOUTH AUSTRALIA	SCALE. Appendix 1 Fig 2
COMPILED: J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE: SEPT. 1977
DRN: L.P.R. CKD.	WELL CONSTRUCTION DETAILS	PLAN NUMBER:
	UNIT NO. 7034000WW00018	S13042

APPENDIX II

WATER QUALITY DATA

WATER QUALITY STUDY

Water samples from "push-pull" tests - February 1977

Tests involving extraction of formation water, addition of leaching reagents, reinjection, and later extraction of uranium rich fluid were carried out by Minad on three wells in February 1977 (Figure 1 in Appendix III). Representative water samples were collected by the authors during the initial pump-out stages of these tests.

About 20 kilolitres of water was pumped out of each well for the push-pull test, at a rate of about 200 Kl day^{-1}. Each sample was collected after 30-60 minutes of pumping, by coiling the discharge line horizontally into the bottom of a 90 litre plastic bin, and filling the sample bottle by immersion in the overflowing bin. This seemed the best way of minimising radon gas loss from the sample. Two bottles were filled in this way, one being acidified to 5% HNO_3 for metallic ion analyses, and both were tightly sealed and despatched promptly to AMDEL for analysis.

Water samples collected from cable-tool hole

The upper two aquifers were sampled by bailing during drilling. As a result the samples contained significant suspended solids, which may have increased the analysed values of heavy metals due to acid extraction from the solids. Some radon gas may have escaped during the bailer sampling process, compared with the pumped samples from the basal sand.

The basal sand aquifer was sampled during an aquifer test after several hours pumping.

Samples were bottled, acidified and despatched promptly to AMDEL for analysis.

WATER ANALYSIS REPORT

AMDEL COMPUTE

SAMPLE NO. W28/77 QD 10

JOB NO. 2620-77

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE MG/L	MILLIEQUIVS. PER LITRE ME/L
CATIONS			
CALCIUM	(CA)	945	47.2
MAGNESIUM	(MG)	410	33.7
SODIUM	(NA)	4520	196.6
POTASSIUM	(K)	18	.5
IRON	(FE)		
ANIONS			
HYDROXIDE	(OH)		
CARBONATE	(CO3)		
BICARBONATE	(HCO3)	135	2.2
SULPHATE	(SO4)	1774	36.9
CHLORIDE	(CL)	8444	238.1
BROMIDE	(BR)		
FLUORIDE	(F)	.85	.0
NITRATE	(NO3)	10	.2
PHOSPHATE	(PO4)		

TOTALS AND BALANCE

CATIONS (ME/L) 278.0 DIFF = .5
ANIONS (ME/L) 277.5 SUM = 555.4

DIFF*100. / SUM = .1 %

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.)
MICRO-S/CM AT 25 DEG. C 19146.

TOTAL DISSOLVED SOLIDS	MILLIGRAMS PER LITRE MG/L
A. BASED ON E.C.	
B. CALCULATED (HCO3=CO3)	16188.
C. RESIDUE ON EVAP. AT 180 DEG. C	16804
TOTAL HARDNESS AS CACO3	4047.
CARBONATE HARDNESS AS CACO3	111.
NON-CARBONATE HARDNESS AS CACO3	3936.
TOTAL ALKALINITY AS CACO3	111.
FREE CARBON DIOXIDE (CO2)	
SUSPENDED SOLIDS	
SILICA (SIO2)	
BORON (B)	3.50

	UNITS
REACTION - PH	6.8
TURBIDITY (JACKSON)	
COLOUR (HAZEN)	
SODIUM TO TOTAL CATION RATIO (ME/L)	70.7 %

NAME-
ADDRESS-

DATE COLLECTED 23-2-77
DATE RECEIVED

HUNDRED-
SECTION-
HOLE NO-QD 10 HC 2
SUPPLY-
SAMPLE COLLECTED BY-J.D.W.

WATER CUT-
WATER LEVEL-
DEPTH HOLE-

WATER ANALYSIS REPORT — AMDEL COMP[...]

SAMPLE NO. QD 11 — JOB NO. 2620-77

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE MG/L	MILLIEQUIVS. PER LITRE ME/L
CATIONS			
CALCIUM	(CA)	785	39.2
MAGNESIUM	(MG)	345	28.4
SODIUM	(NA)	4150	180.5
POTASSIUM	(K)	17	.4
IRON	(FE)		
ANIONS			
HYDROXIDE	(OH)		
CARBONATE	(CO3)		
BICARBONATE	(HCO3)	164	2.7
SULPHATE	(SO4)	1706	35.5
CHLORIDE	(CL)	7530	212.3
BROMIDE	(BR)		
FLUORIDE	(F)	1.00	.1
NITRATE	(NO3)	26	.4
PHOSPHATE	(PO4)		

TOTALS AND BALANCE

CATIONS (ME/L) 248.5 DIFF = 2.5
ANIONS (ME/L) 251.0 SUM = 499.5

DIFF*100. / SUM = .5 %

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.)
MICRO-S/CM AT 25 DEG. C 16363.

TOTAL DISSOLVED SOLIDS	MILLIGRAMS PER LITRE MG/L
A. BASED ON E.C.	
B. CALCULATED (HCO3=CO3)	14640.
C. RESIDUE ON EVAP. AT 180 DEG. C	15436
TOTAL HARDNESS AS CACO3	3380.
CARBONATE HARDNESS AS CACO3	134.
NON-CARBONATE HARDNESS AS CACO3	3246.
TOTAL ALKALINITY AS CACO3	134.
FREE CARBON DIOXIDE (CO2)	
SUSPENDED SOLIDS	
SILICA (SIO2)	
BORON (B)	3.30

	UNITS
REACTION - PH	6.9
TURBIDITY (JACKSON)	
COLOUR (HAZEN)	
SODIUM TO TOTAL CATION RATIO (ME/L)	72.6 %

NAME- DEPT OF MINES
ADDRESS-

HUNDRED-
SECTION-
HOLE NO-QD 11 3/5/1
SUPPLY-
SAMPLE COLLECTED BY-J.C.W.

WATER CUT-
WATER LEVEL-
DEPTH HOLE-

DATE COLLECTED
DATE RECEIVED

WATER ANALYSIS REPORT   AMDEL COMPU

SAMPLE NO. QD 12 W18/77   JOB NO. 2620-77

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE MG/L	MILLIEQUIVS. PER LITRE ME/L
CATIONS			
CALCIUM	(CA)	1086	54.2
MAGNESIUM	(MG)	459	37.7
SODIUM	(NA)	4915	213.8
POTASSIUM	(K)	27	.7
IRON	(FE)		
ANIONS			
HYDROXIDE	(OH)		
CARBONATE	(CO3)		
BICARBONATE	(HCO3)	130	2.1
SULPHATE	(SO4)	1901	39.6
CHLORIDE	(CL)	9679	272.9
BROMIDE	(BR)		
FLUORIDE	(F)	.95	.0
NITRATE	(NO3)	10	.2
PHOSPHATE	(PO4)		

TOTALS AND BALANCE

CATIONS (ME/L) 306.4   DIFF = 8.4
ANIONS (ME/L) 314.8   SUM = 621.3

DIFF*100. / SUM = 1.4 %

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.) MICRO-S/CM AT 25 DEG. C 20052.

TOTAL DISSOLVED SOLIDS	MILLIGRAMS PER LITRE MG/L
A. BASED ON E.C.	
B. CALCULATED (HCO3=CO3)	18141.
C. RESIDUE ON EVAP. AT 180 DEG. C	18695
TOTAL HARDNESS AS CACO3	4601.
CARBONATE HARDNESS AS CACO3	106.
NON-CARBONATE HARDNESS AS CACO3	4494.
TOTAL ALKALINITY AS CACO3	106.
FREE CARBON DIOXIDE (CO2)	
SUSPENDED SOLIDS	
SILICA (SIO2)	
BORON (B)	4.00

	UNITS
REACTION - PH	6.8
TURBIDITY (JACKSON)	
COLOUR (HAZEN)	
SODIUM TO TOTAL CATION RATIO (ME/L)	69.8 %

NAME-
ADDRESS-

HUNDRED-
SECTION-
HOLE NO-QD 12 H/C 3
SUPPLY-
SAMPLE COLLECTED BY-J.D.W.

WATER CUT-
WATER LEVEL-
DEPTH HOLE-

DATE COLLECTED 17-2-77
DATE RECEIVED

ANALYSIS

pico curies per litre

SAMPLE MARK			RADIUM (^{226}Ra)	EXCESS RADON (^{222}Rn)	RADON (^{222}Rn) due to Radium (^{226}Ra)	TOTAL RADON (^{222}Rn)
HC1	QD11	W16/77 W17/77	2600	68600	2600	71200
HC3	QD12	W18/77 W27/77	3600	116000	3600	119600
HC2	QD10	W28/77 W29/77	3000	180000	3000	183000

METHOD: J6

THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

FORM 38

REPORT AN 2620/77

ANALYSIS mg/l – ACIDIFIED SAMPLES.

Sample No			HC-2 QD10	HC-1 QD11	H-3 QD12	HNO_3		Method
Cadmium	Cd		0.001	0.001	0.004	<0.003		Q2/3
Copper	Cu		0.004	0.004	0.004	0.003		Q2/3
Chromium	Cr		0.004	0.004	0.004	0.175		Q2/3
Iron	Fe		0.33	0.49	0.68	<0.003		Q2/3
Manganese	Mn		0.004	0.008	0.014	0.002		Q2/3
Molybdenum	Mo		0.004	0.006	0.002	<0.002		Q2/3
Nickel	Ni		0.044	0.028	0.088	0.015		Q2/3
Selenium	Se		0.002	<0.002	<0.002	*		Q3
Silver	Ag		<0.002	<0.002	<0.002	0.014		Q2/3
Vanadium	V		<0.02	<0.02	<0.02	0.02		Q2/3
Zinc	Zn		0.062	0.030	0.135	0.006		Q2/3
Arsenic	As		0.004	0.010	0.008	*		Q3
Ammonia	NH_3		2	15	3	*		01
Lead	Pb		0.012	0.018	0.009	0.006		Q2/3
Mercury	Hg		<0.0002	<0.0002	<0.0002	*		Q3
Uranium	U.		<1	1	<1	*		J4

* ANALYSIS FOR THESE ELEMENTS IS UNAVAILABLE ON THE NITRIC ACID.

DUE TO TECHNICAL DIFFICULTIES IN ANALYSING CONC. NITRIC ACID, THE BEST DETECTION LIMITS AVAILABLE HAVE BEEN QUOTED.

METHOD:

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE MG/L	MILLIEQUIVS. PER LITRE ME/L
CATIONS			
CALCIUM	(CA)	487	24.3
MAGNESIUM	(MG)	275	22.6
SODIUM	(NA)	3075	133.8
POTASSIUM	(K)	19	.5
IRON	(FE)		
ANIONS			
HYDROXIDE	(OH)		
CARBONATE	(CO3)		
BICARBONATE	(HCO3)	172	2.8
SULPHATE	(SO4)	1414	29.4
CHLORIDE	(CL)	5171	145.8
BROMIDE	(BR)		
FLUORIDE	(F)	.95	.0
NITRATE	(NO3)	<1	.0
PHOSPHATE	(PO4)	<0.02	

TOTALS AND BALANCE

CATIONS (ME/L) 181.2 DIFF = 3.0
ANIONS (ME/L) 178.1 SUM = 359.3

DIFF*100. / SUM = .8 %

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.)
MICRO-S/CM AT 25 DEG. C 16416.

TOTAL DISSOLVED SOLIDS	MILLIGRAMS PER LITRE MG/L
A. BASED ON E.C.	
B. CALCULATED (HCO3=CO3)	10527.
C. RESIDUE ON EVAP. AT 180 DEG. C	
TOTAL HARDNESS AS CACO3	2348.
CARBONATE HARDNESS AS CACO3	141.
NON-CARBONATE HARDNESS AS CACO3	2207.
TOTAL ALKALINITY AS CACO3	141.
FREE CARBON DIOXIDE (CO2)	
SUSPENDED SOLIDS	
SILICA (SIO2)	
BORON (B)	2.95

	UNITS
REACTION - PH	7.1
TURBIDITY (JACKSON)	
COLOUR (HAZEN)	
SODIUM TO TOTAL CATION RATIO (ME/L)	73.8 %

SAMPLE DEP

NAME- DEPT MINES
ADDRESS-ADELAIDE

DATE COLLECTED 29-5-77
DATE RECEIVED

HUNDRED-MULYUNGARIE
SECTION-
HOLE NO-QD 14
SUPPLY-
SAMPLE COLLECTED BY-WATERHOUSE

WATER CUT-
WATER LEVEL-75m
DEPTH HOLE-

SAMPLE ID. ...

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE MG/L	MILLIEQUIVS. PER LITRE ME/L
CATIONS			
CALCIUM	(CA)	482	24.1
MAGNESIUM	(MG)	282	23.2
SODIUM	(NA)	3162	137.5
POTASSIUM	(K)	19	.5
IRON	(FE)		
ANIONS			
HYDROXIDE	(OH)		
CARBONATE	(CO3)		
BICARBONATE	(HCO3)	192	3.1
SULPHATE	(SO4)	1430	29.8
CHLORIDE	(CL)	5090	143.5
BROMIDE	(BR)		
FLUORIDE	(F)	2.50	.1
NITRATE	(NO3)	2	.0
PHOSPHATE	(PO4)	.05	.0

TOTALS AND BALANCE

CATIONS (ME/L) 185.3 DIFF = 8.7
ANIONS (ME/L) 176.6 SUM = 361.9

DIFF*100. / SUM = 2.4 %

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.)
MICRO-S/CM AT 25 DEG. C 16080.

	MILLIGRAMS PER LITRE MG/L
TOTAL DISSOLVED SOLIDS	
A. BASED ON E.C.	10564.
B. CALCULATED (HCO3=CO3)	
C. RESIDUE ON EVAP. AT 180 DEG. C	
TOTAL HARDNESS AS CACO3	2364.
CARBONATE HARDNESS AS CACO3	157.
NON-CARBONATE HARDNESS AS CACO3	2207.
TOTAL ALKALINITY AS CACO3	157.
FREE CARBON DIOXIDE (CO2)	
SUSPENDED SOLIDS	
SILICA (SIO2)	
BORON (B)	2.40

	UNITS
REACTION - PH	7.6
TURBIDITY (JACKSON)	
COLOUR (HAZEN)	

SODIUM TO TOTAL CATION RATIO (ME/L) 74.2 %

SAMPLE DEF

NAME- DEPT MINES
ADDRESS-ADELAIDE

DATE COLLECTED 30-5-77
DATE RECEIVED

HUNDRED-MULYUNGARIE
SECTION-
HOLE NO-QD 14
SUPPLY-
SAMPLE COLLECTED BY-WATERHOUSE

WATER CUT-
WATER LEVEL-
DEPTH HOLE-

SAMPLE ID. W637/77

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE MG/L	MILLIEQUIVS. PER LITRE ME/L
CATIONS			
CALCIUM	(CA)	522	26.0
MAGNESIUM	(MG)	315	25.9
SODIUM	(NA)	3325	144.6
POTASSIUM	(K)	23	.6
IRON	(FE)		
ANIONS			
HYDROXIDE	(OH)		
CARBONATE	(CO3)		
BICARBONATE	(HCO3)	186	3.1
SULPHATE	(SO4)	1555	32.4
CHLORIDE	(CL)	5616	158.4
BROMIDE	(BR)		
FLUORIDE	(F)	2.80	.1
NITRATE	(NO3)	4	.1
PHOSPHATE	(PO4)	.04	.0

TOTALS AND BALANCE

CATIONS (ME/L) 197.2 DIFF = 3.2
ANIONS (ME/L) 194.0 SUM = 391.2

DIFF*100. / SUM = .8 %

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.)
MICRO-S/CM AT 25 DEG. C 17648.

TOTAL DISSOLVED SOLIDS	MILLIGRAMS PER LITRE MG/L
A. BASED ON E.C.	
B. CALCULATED (HCO3=CO3)	11454.
C. RESIDUE ON EVAP. AT 180 DEG. C	
TOTAL HARDNESS AS CACO3	2600.
CARBONATE HARDNESS AS CACO3	153.
NON-CARBONATE HARDNESS AS CACO3	2447.
TOTAL ALKALINITY AS CACO3	153.
FREE CARBON DIOXIDE (CO2)	
SUSPENDED SOLIDS	
SILICA (SIO2)	
BORON (B)	2.40

	UNITS
REACTION - PH	7.8
TURBIDITY (JACKSON)	
COLOUR (HAZEN)	
SODIUM TO TOTAL CATION RATIO (ME/L)	73.4 %

SAMPLE D

NAME- DEPT MINES
ADDRESS-ADELAIDE

HUNDRED-MULYUNGARIE
SECTION-
HOLE NO-QD 14
SUPPLY-
SAMPLE COLLECTED BY-WATERHOUSE

WATER CUT-
WATER LEVEL-
DEPTH HOLE-

DATE COLLECTED 1-6-77
DATE RECEIVED

SAMPLE ID. W64/77

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE MG/L	MILLIEQUIVS. PER LITRE ME/L
CATIONS			
CALCIUM	(CA)	572	28.5
MAGNESIUM	(MG)	331	27.2
SODIUM	(NA)	3500	152.2
POTASSIUM	(K)	23	.6
IRON	(FE)		
ANIONS			
HYDROXIDE	(OH)		
CARBONATE	(CO3)		
BICARBONATE	(HCO3)	180	3.0
SULPHATE	(SO4)	1574	32.8
CHLORIDE	(CL)	5979	168.6
BROMIDE	(BR)		
FLUORIDE	(F)	2.75	.1
NITRATE	(NO3)	4	.1
PHOSPHATE	(PO4)	.07	.0

TOTALS AND BALANCE

CATIONS (ME/L) 208.6 DIFF = 4.1
ANIONS (ME/L) 204.5 SUM = 413.1

DIFF*100. / SUM = 1. %

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.)
MICRO-S/CM AT 25 DEG. C 18528.

	MILLIGRAMS PER LITRE MG/L
TOTAL DISSOLVED SOLIDS	
A. BASED ON E.C.	
B. CALCULATED (HCO3=CO3)	12074.
C. RESIDUE ON EVAP. AT 180 DEG. C	
TOTAL HARDNESS AS CACO3	2790.
CARBONATE HARDNESS AS CACO3	148.
NON-CARBONATE HARDNESS AS CACO3	2642.
TOTAL ALKALINITY AS CACO3	148.
FREE CARBON DIOXIDE (CO2)	
SUSPENDED SOLIDS	
SILICA (SIO2)	
BORON (B)	2.45

	UNITS
REACTION - PH	7.8
TURBIDITY (JACKSON)	
COLOUR (HAZEN)	
SODIUM TO TOTAL CATION RATIO (ME/L)	73.0 %

SAMPLE DEP

R

NAME- DEPT MINES
ADDRESS-ADELAIDE

DATE COLLECTED 1-6-77
DATE RECEIVED

HUNDRED-MULYUNGARIE
SECTION-
HOLE NO-QD 14
SUPPLY-
SAMPLE COLLECTED BY-WATERHOUSE

WATER CUT-
WATER LEVEL-
DEPTH HOLE-

amdel

ANALYSIS AN 3800/77

SAMPLE MARK	Fe mg/1	Zn mg/1	NH_3 mg/1	U µg/1
ACIDIFIED SAMPLES				
W53/77	12.0	0.38	-	45
W54/77	100	112	-	490
W55/77	48	103	-	1790
W56/77	0.25	8.0	-	55
NON ACIDIFIED SAMPLES				
W61/77	-	-	<1	45
W62/77	-	-	1	55
W63/77	-	-	1	485
W64/77	-	-	2	45
METHOD:	Q2/1	Q2/1	Q6	J4

NOTE: When received, these samples (particularly W54/77; W55/77 and W62/77; W63/77) contained significant sediments.

For this reason, uranium has been determined on both the acidified samples as well as the non acidified samples. Uranium values for the acidified samples with sediment are considerably higher than the corresponding non acidified samples - possibly due to extraction by the acid. Similarly, Fe and Zn values may be unduly high.

It is recommended that samples be filtered prior to acidification.

amdel

ANALYSIS
pCi/l

AN 3800/77

SAMPLE MARK	RADIUM $^{-226}$ (^{226}Ra)	EXCESS (a) RADON $^{-222}$ (^{222}Rn)	RADON $^{-222}$ (b) DUE TO RADIUM $^{-226}$ (^{222}Rn)	TOTAL RADON $^{-222}$ (^{222}Rn)
W53/77	10		10	760
W61/77		750		
W54/77	40		40	410
W62/77		370		
W55/77	210		210	210
W63/77		<10		
W56/77	60		60	170
W64/77		110		

(a) Radon $^{-222}$ that diffused into the water during its passage through sediments

(b) Radon $^{-222}$ derived from radium $^{-226}$ in solution

METHODS: J6/1 and J6/2

amdel

ANALYSIS
pico curies per litre

AN 3800/77

SAMPLE MARK	RADIUM (^{226}Ra)	EXCESS RADON (^{222}Rn)	RADON DUE TO RADIUM (^{222}Rn)	TOTAL RADON (^{222}Rn)
QD14 W65/77 & W57/77	8100	87500	8100	95600
METHOD:	J6/1		J6/2	

QD14

SUMMARY OF WATER SAMPLING-FIELD TESTS

DEPTH TAKEN	CONDUCTIVITY (mS cm^{-1})	COND. AT 25°C (2% /°C assumed)	NOTES
	UPPER SAND		
74-77 m	12,000 at 17°C	14,300	When water cut.
74-77 m	13,000 at 17°C	15,500	After overnight recovery and bailing.
77 m	11,000 at 17°C	13,100	During drilling.
80 m	12,300 at 18°C	14,300	During drilling.
	AQUICLUDE		
	MIDDLE SAND		
90.3 m	12,000 at 25°C	12,000	At water cut after overnight recovery and bailing.
93 m	14,000 at 20°C	15,600	During drilling.
96 m	11,000 at 9°C	16,200	During drilling.
	AQUICLUDE		
	BASAL SAND		
106-118 m	17,000 at 22°C	18,100	Bailed sample after development.
	BASEMENT		

Spare,

WATER ANALYSIS REPORT   AMDEL COMPUTER SERVICES

SAMPLE ID. W65/77   JOB NO. 3800-77

CHEMICAL COMPOSITION

		MILLIGRAMS PER LITRE MG/L	MILLIEQUIVS. PER LITRE. ME/L
CATIONS			
CALCIUM	(CA)	877	43.8
MAGNESIUM	(MG)	406	33.4
SODIUM	(NA)	4625	201.2
POTASSIUM	(K)	19	.5
IRON	(FE)		
ANIONS			
HYDROXIDE	(OH)		
CARBONATE	(CO3)		
BICARBONATE	(HCO3)	138	2.3
SULPHATE	(SO4)	1856	38.6
CHLORIDE	(CL)	8475	239.0
BROMIDE	(BR)		
FLUORIDE	(F)		
NITRATE	(NO3)	23	.4
PHOSPHATE	(PO4)	.08	.0

TOTALS AND BALANCE

CATIONS (ME/L) 278.8   DIFF = 1.5
ANIONS (ME/L) 280.3   SUM = 559.1

DIFF*100. / SUM = .3 %

DERIVED AND OTHER DATA

CONDUCTIVITY (E.C.) MICRO-S/CM AT 25 DEG. C 23530.

TOTAL DISSOLVED SOLIDS	MILLIGRAMS PER LITRE MG/L
A. BASED ON E.C.	
B. CALCULATED (HCO3=CO3)	16349.
C. RESIDUE ON EVAP. AT 180 DEG. C	
TOTAL HARDNESS AS CACO3	3861.
CARBONATE HARDNESS AS CACO3	113.
NON-CARBONATE HARDNESS AS CACO3	3747.
TOTAL ALKALINITY AS CACO3	113.
FREE CARBON DIOXIDE (CO2)	
SUSPENDED SOLIDS	
SILICA (SIO2)	
BORON (B)	5.45

	UNITS
REACTION - PH	6.6
TURBIDITY (JACKSON)	
COLOUR (HAZEN)	
SODIUM TO TOTAL CATION RATIO (ME/L)	72.2 %

REMARKS

BASAL SAND AQUIFER

SAMPLE DEPTH 106M
AMMONIA (NH3) 2MG/L
URANIUM (U) 5MG/L
IRON (FE) 0.93MG/L
ZINC (ZN) 1.2 MG/L

NAME- DEPT MINES
ADDRESS-ADELAIDE
DATE COLLECTED 22-7-77
DATE RECEIVED

HUNDRED-
SECTION-
HOLE NO-QD 14
SUPPLY-
SAMPLE COLLECTED BY-WATERHOUSE

WATER CUT-
WATER LEVEL-
DEPTH HOLE-

APPENDIX III

DETAILS OF TESTING

APPENDIX III

<u>CONTENTS</u> <u>PAGE</u>

PLANS

1. DEVELOPMENT

Most development was carried out by several days bailing and surging, not by jetting and air-lifting, or pumping, because of problems of disposal of dirty, saline, radioactive water in the area, which grades towards a nearby surface storage of stock water.

A six stage lineshaft turbine pump was used for testing, and was initially set at 80 m, giving 25 metres of available drawdown. First pumping gave a yield of 400 kl day^{-1} of clean water with a drawdown of nearly 20 metres. The well was then alternately pumped and backflushed in an attempt to improve the yield by further development. Little development was apparent, and the pump was set at 99.5 metres to optimise available drawdown. The nearest observation well, HC-2A, was found to respond with 0.5 metres of drawdown, and together with HC-1 it was monitored during step-drawdown testing (Fig. 1).

STEP-DRAWDOWN TESTING

Three 100-minute production tests were carried out to predict the time-drawdown relationships for various pumping rates in order to decide upon the best production rate for the main test. The capacity of the storage dam (750 m^3 approximately) was the limiting factor, and the main test was aimed at attaining 75% of available drawdown by the time the dam filled. The remaining 25% was a safety factor to allow for any impermeable hydraulic boundaries which have the effect of increasing drawdown.

The semilog plots of drawdown versus log time are shown on Figures 2, 3 and 4. The main result of the tests was that the constants a, b and C for the well equation $s(t) = (a + b \log t)Q + CQ^2$ could not be determined reliably, because the rate of drawdown per log cycle of time was found to be not proportional to the pumping rate. The constant b is related to the drawdown rate and the pumping rate ($\Delta s = bQ$) and should not vary substantially for different pumping rates. The values obtained however, were 1.13, 0.58 and 7.6 for Stages I, II and III respectively.

The third stage (920 m^3day^{-1}) gave 34 metres of drawdown after 100 minutes pumping, and would have filled the dam (estimated capacity 750 m^3) in about 8 hours. The extrapolated drawdown for 20 hours pumping was 39 metres, or 90% of the available drawdown. It was therefore decided to run the main test at 600 m^3day^{-1} to provide an adequate safety margin.

Both observation wells HC-1 and HC-2A responded satisfactorily within 10 seconds of the start of pumping, (see Figures 5, 6, 7 and 8) and it was decided to use them for the main test.

MAIN TEST

The test was intended to run for the longest time possible to try and determine whether any leakage through the confining beds was occurring, using the type curve method.

A third observation well, HC-3, was spaced 302 m from the production well, and was not expected to respond measurably in the first few minutes of testing. For this reason it was decided to measure HC-3 at several times in the 100-1,000 minute interval at a lower level of importance than the two nearer wells.

The test rate of 600 m^3day^{-1} was estimated to fill the storage dam in 20-25 hours, using 75% of the available drawdown in the production well, with 5 to 10 metres of drawdown for contingencies such as impermeable hydraulic boundaries.

Pumping commenced at 1200 hours on 21.7.77, at a rate of 620 m^3day^{-1}. Drawdown in the production well was considerably greater in magnitude and rate than it had been for the Stage II test with a similar production rate. The production rate decreased to 480 m^3day^{-1} after 120 minutes pumping, because the motor driving the pump could not be speeded up to compensate for the increased pumping head. Testing was temporarily suspended to allow interpretation of the results. Gale-force winds irreparably damaged the plastic lining of the dam in early August and further testing was not carried out.

INTERPRETATION OF RESULTS

1. Aquifer Parameters from step-drawdown tests

The results from the production well for all three tests, and the observation wells HC-2A and HC-1 for Stages II and III respectively, were plotted on semi-log and log-log graph paper to calculate parameters by the straight line and type curve methods (Figs. 2 to 8 inclusive).

Values are tabulated below.

3 STAGE TEST AQUIFER PARAMETER VALUES

Test	Well	Transmissivity $m^3 day^{-1} m^{-1}$	Storage Coefficient	Remarks
Stage I (100 min)	Production	240	-	Irregular Plot (Jacob's method)
Stage II (100 min)	Production	450	-	Reasonable Plot (Jacob's method)
Stage III	Production	34	-	Good Plot (Jacob's method)
Stage II (100 min)	Observation HC-2A	436	6.5×10^{-5}	Jacob's method, but $s/\Delta s < 1.75$
Stage III (100 min)	Observation HC-1	495	7.5×10^{-5}	Jacob's method but $s/\Delta s < 1.75$
Stage II (100 min)	Observation HC-2A	274	1.1×10^{-4}	Type-curve solution
Stage III	Observation HC-1	498	1.0×10^{-4}	Type-curve solution

		Kl/h	gall/h	$m^3 day^{-1}$
Stage I	15.5 Kl in 100 min	9.3	2,050	220
Stage II	43.3 Kl in 100 min	26	5,700	620
Stage III	57.4 Kl in 90 min	38	8,400	920

The straight-line solutions for Stages I and II for the main test are not reliable to better than one significant figure because of fluctuations in the measured water level. The first few minutes were irregular because of variations in the pumping rate as the pump column filled, however no explanation for the slight recovery in the 10-20 minute time interval can be given other than incomplete development of the well. (This feature was noticed in the main test as well).

Both observation wells responded smoothly to pumping, and although total drawdowns of only 0.5 m were recorded, changes of drawdown of 2-3 mm were detectable with the electric probes. Both Stage II and III gave good straight line semi-log plots, however the type curve solutions are more reliable because the drawdown/slope ratio ($s/\Delta s$) was less than 1.75, and Jacob's assumptions were therefore not necessarily valid.

The transmissivity values for production and observation wells are of the same order of magnitude (200-500 $m^3 day^{-1} m^{-1}$), with the exception of the low value derived from Stage III measurements in the production well. The specific capacity values (pumping rate per unit drawdown), were very similar for all three tests, indicating that the well was properly developed, and is efficient. The only obvious explanations for the aberrant T value is that the Stage I and II drawdown measurements in the production well are quite unreliable, or that the transmissivity of the aquifer has decreased by an order of magnitude in the vicinity of the production well since the start of testing. There is no reason to doubt the low T value for Stage III at the production well, as both methods of calculation were used, with good plots of data and consistent results.

2. Main Test

Values of transmissivity, storage coefficient and hydraulic conductivity of confining bed were calculated for the test. Jacob's straight line solutions gave similar values to the type-curve methods, although the latter are more reliable because of small values of $s/\Delta s$. ($s/\Delta s$ must be greater than 1.75 for the mathematical basis of Jacob's method to be reliable).

Time- and distance-drawdown plots for the test are presented on Figures 10 to 16 inclusive, and the calculated parameters tabulated below.

AQUIFER PARAMETERS - MAIN TEST

WELL	T	S	*p'	Comments
Production	12	-	-	Straight-line method
HC-1	340	1.4×10^{-5}		Straight-line, $s/\Delta s$ too low
HC-2A	340	6.5×10^{-5}		" " " " "
HC-3	1860	1.1×10^{-4}		" " " " "
3 Obs.	405	1.7×10^{-4}		Distance-drawdown relationship
HC-1	297	7.0×10^{-5}	1.5×10^{-2}	" " "
HC-2A	186	9.0×10^{-5}	8.1×10^{-2}	" " "
HC-3	(860 (1280	2.0×10^{-4} 1.8×10^{-4}	2.4×10^{-2}) 0)	Type curve method Extremes of possible matchpoints calculated as curve matching difficult

*p' = vertical hydraulic conductivity of confining beds

It is clear that the observation well data give much higher values of transmissivity than the production well data. The transmissivity values from Stages I and II are approximate, because of irregularities in the drawdown, but are of the same order of magnitude as those calculated from observation well data, and are considered reliable to one significant figure. The observation wells sample the aquifer in a section between each of them and the production well, and different values of transmissivity are to be expected in different directions for sediments deposited in a riverine environment. Observation well transmissivities of 400, 300 and 1,000 $m^3 day^{-1} m^{-1}$ can reasonably be assigned to HC-1, HC-2 and HC-3 respectively, when the step-drawdown data is also considered. More than one significant figure would give an unrealistic sense of reliability in such an environment.

The problem to be resolved is the variation in transmissivity value calculated from the production well drawdown data. The value of 12 $m^3 day^{-1} m^{-1}$ for the straight line solution is 1-2 orders of magnitude lower than those calculated from the Stage I and II data of the step-drawdown test (240 and 450 $m^3 day^{-1} m^{-1}$), but much nearer to the value of 32 $m^3 day^{-1} m^{-1}$ calculated for the stage III test.

The data suggests that the transmissivity near the production well decreased from several hundred to several tens of $m^3 day^{-1} m^{-1}$ between Stage II and Stage III, and then it decreased further to about 10 $m^3 day^{-1} m^{-1}$ for the main test.

The increased drawdown in the production well is caused by an increase in the <u>rate</u> of drawdown, rather than by a decrease in well efficiency (compare the Stage II straight-line plot with the main test plot on Figure 17). This demonstrates that the change in well performance is controlled by the aquifer, because the slope of the straight line is proportional to pumping rate, and inversely proportional to transmissivity. The two plots compared (Stage II and main test) have similar pumping rates, so it can only be the aquifer transmissivity varying. This is unusualand may have important implications for future extraction wells in the area.

The aquifer is confined, and water is therefore released from storage in it by collapse of the aquifer and expansion of the water, both because of the decrease in water pressure caused by pumping out of the well. The water level is only 50 metres above the top of the aquifer, and it is possible that aquifer collapse is the dominant component. The aquifer material is unconsolidated and largely uncemented with a soft clay confining bed, and pumping in the main test reduced the water level (i.e. pressure) by 70% in the production well. The aquifer may have collapsed inelastically near the well under these reduced pressure conditions. This could have had the effect of repacking the sand grains, especially in the developed zone from which the fines had been removed, thus changing the transmissivity by reducing the hydraulic conductivity.

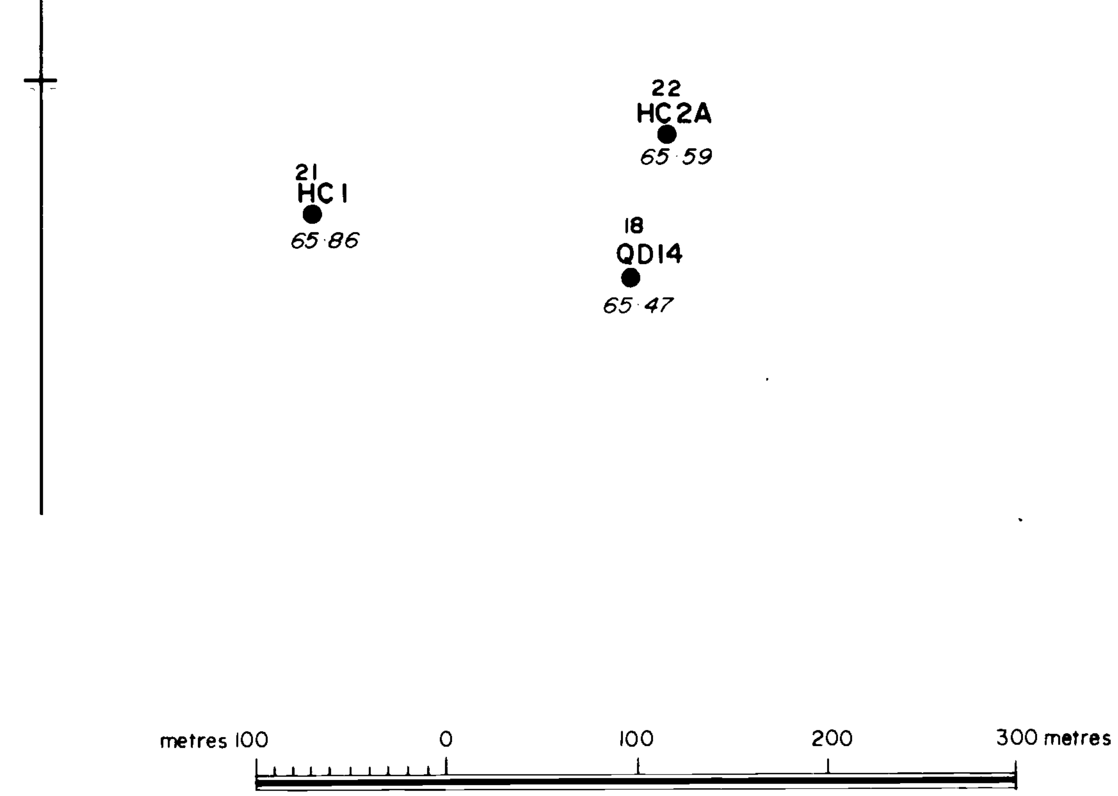
The straight-line slope from which transmissivity of 12 $m^3day^{-1}m^{-1}$ was calculated is probably that associated with drawdown after the cone of depression had expanded beyond the limited zone of compaction near the well, and thus will give an overestimate of transmissivity near the well.

A technical opinion about the test results was sought from the Queensland Water Conservation and Irrigation Commission by Mr. Bryan of Mines Administration. The WC and IC considered that the well may not have been properly developed, and that progressively increasing well loss was the most likely cause of the aberrant results. This interpretation is not an unreasonable one, however the site geology, in particular the very unconsolidated nature of the sands, lead the authors to prefer their own conclusions.

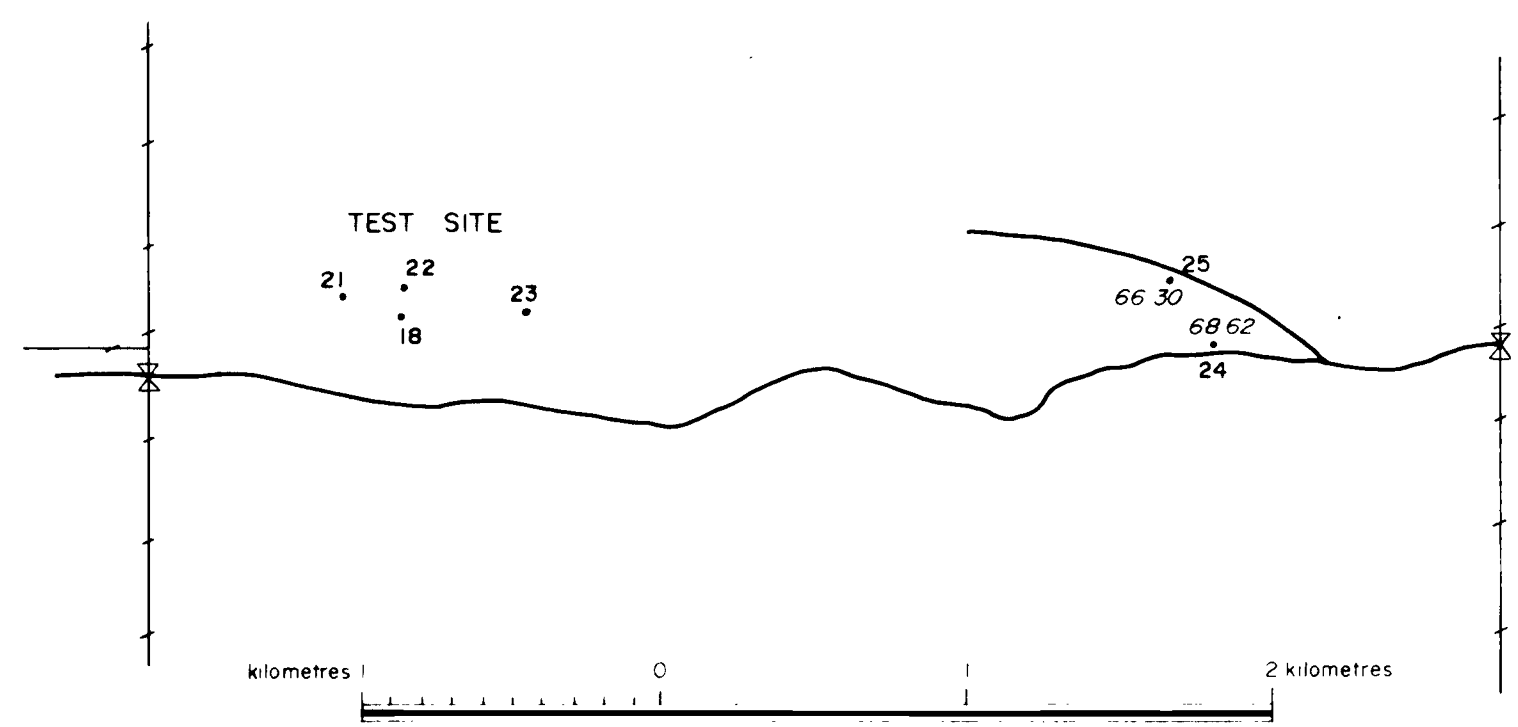
1. PUSH-PULL TESTS

2. CABLE-TOOL HOLE

TEST SITE



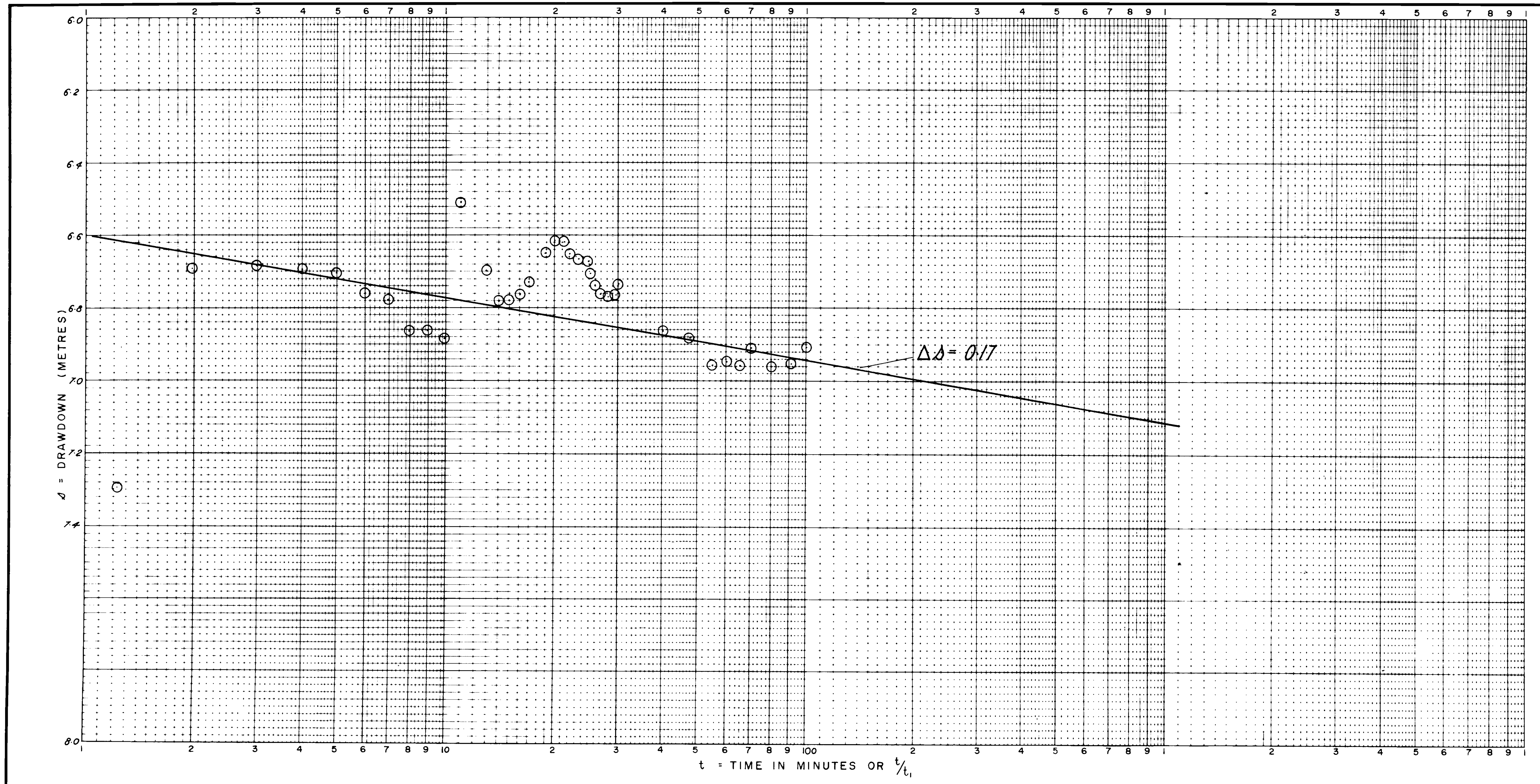
HYDRAULIC GRADIENT WELLS



TEMPORARY NUMBER	UNIT NUMBER	E.L. Ref. PT.	SWL (August 77)	E.L. of SWL (mAHD)	REMARKS
HC 1	7034000WW00021	119·86	54·00	65·86	
HC 2A	7034000WW00022	120·48	54·89	65·59	
HC 3	7034000WW00023	119·79	54·30	65·49	
QD 14	7034000WW00018	121·16	55·69	65·47	level before testing
1 [illegible]	7034000WW00025	120·08	51·46	68·62	
2 [illegible]	7034000WW00024	120·14	53·84	66·30	

APPENDIX III FIG. 1

	DEPARTMENT OF MINES—SOUTH AUSTRALIA	SCALE 173/77
COMPILED: J D W	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE: Sept 1977
DRN: L PR / CKD.	LOCATION OF AQUIFER TEST WELLS AND HYDRAULIC GRADIENT MEASUREMENT WELLS	PLAN NUMBER: 77-817



BOREHOLE STATE/UNIT No. 7034000WW00018 TYPE OF PUMP TURBINE

REF. PT. TOC (m) above ground

LENGTH OF TEST 100 min

AQUIFER FROM 106·6 TO 120 (m)

HOLE DEPTH 122·30 (m)

DEPTH WATER LEVEL AT TEST START (ℓ_2) 55·69 (m)

DEPTH PUMP INTAKE (ℓ_1) 99·50 (m)

* AVAILABLE DRAWDOWN 43·81 (m)

EQUATIONS

$$T = \frac{0{\cdot}183 \times Q}{\Delta_s} \qquad S \quad \frac{2{\cdot}25 \times T t_0}{r^2}$$

In which

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

Q = Pumping Rate (m^3/day)

Δ_s = Drawdown per log cycle (m)

S = Storage Coefficient

t_0 = Zero drawdown time (mins)

r = Distance to Observation Bore (m)

1 day = $8{\cdot}64 \times 10^4$ secs.

DATA

Q	Δ_s	t_0	r
220 $m^3 day^{-1}$ ($0{\cdot}15 m^3 min^{-1}$)	0·17m	—	—

CALCULATIONS

$$T = \frac{0{\cdot}183 \times 220}{0{\cdot}17} = 240\ m^3 day^{-1} m^{-1}$$

Solving $s(t) = (a + b \log t) Q + CQ^2$ (Q in $m^3 min^{-1}$)
Slope $\Delta s = bQ$ i.e. $b = 1{\cdot}13$

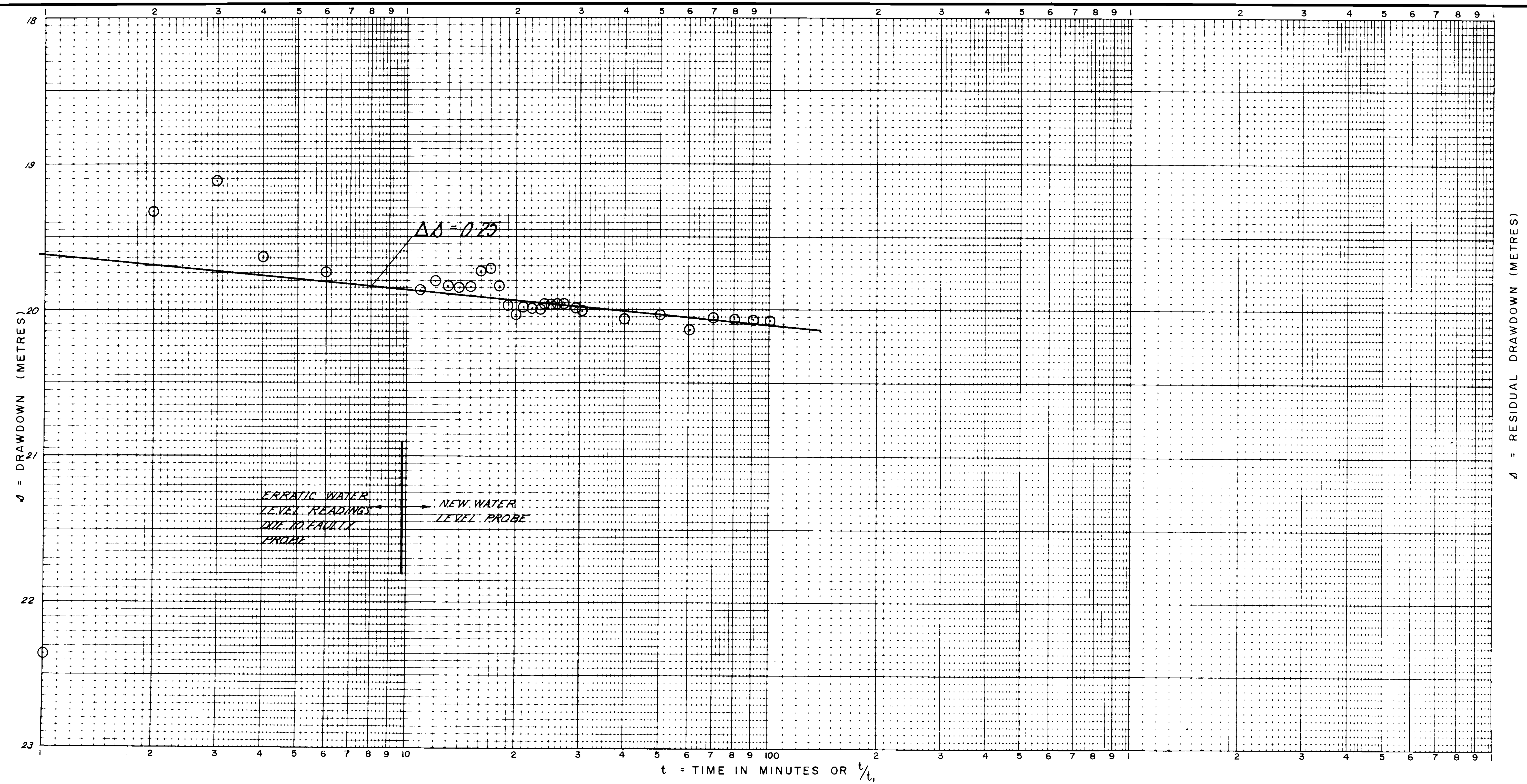
For $\log t = 0$ (minutes) $s = aQ + CQ^2$
$6{\cdot}6 = 0{\cdot}15 a + 0{\cdot}0225 C$

* Available drawdown = $\ell_1 - \ell_2$

APP. III FIG. 2

ENGINEERING DIVISION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	D.M. 173/77
COMPILED J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE 17-7-77
DRN L.P.R. CKD	STAGE 1 OF STEP-DRAWDOWN TEST PRODUCTION WELL	PLAN NUMBER 77-818

P.F. No. 69–953 MH



BOREHOLE STATE/UNIT No. *7034000WW00018*

REF. PT. *TOC* (m) above ground

AQUIFER FROM *106·6* TO *120* (m)

HOLE DEPTH *122·30* (m)

TYPE OF PUMP *TURBINE*

LENGTH OF TEST *100 min*

DEPTH WATER LEVEL AT TEST START (ℓ_2) *55·69* (m)

DEPTH PUMP INTAKE (ℓ_1) *99·5* (m)

* AVAILABLE DRAWDOWN *43·81* (m)

EQUATIONS

$$T = \frac{0{\cdot}183 \times Q}{\Delta_s} \qquad S \quad \frac{2{\cdot}25 \times Tt_o}{r^2}$$

In which

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

Q = Pumping Rate (m^3/day)

Δ_s = Drawdown per log cycle (m)

S = Storage Coefficient

t_o = Zero drawdown time (mins)

r = Distance to Observation Bore (m)

1 day = $8{\cdot}64 \times 10^4$ secs.

DATA

Q	Δ_s	t_o	r
620 $m^3 day^{-1}$ (0·43 $m^3 min^{-1}$)	*0·25*	–	–

CALCULATIONS

$$T = \frac{0{\cdot}183 \times 620}{0{\cdot}25} = 450\ m^3 day^{-1} m^{-1}$$

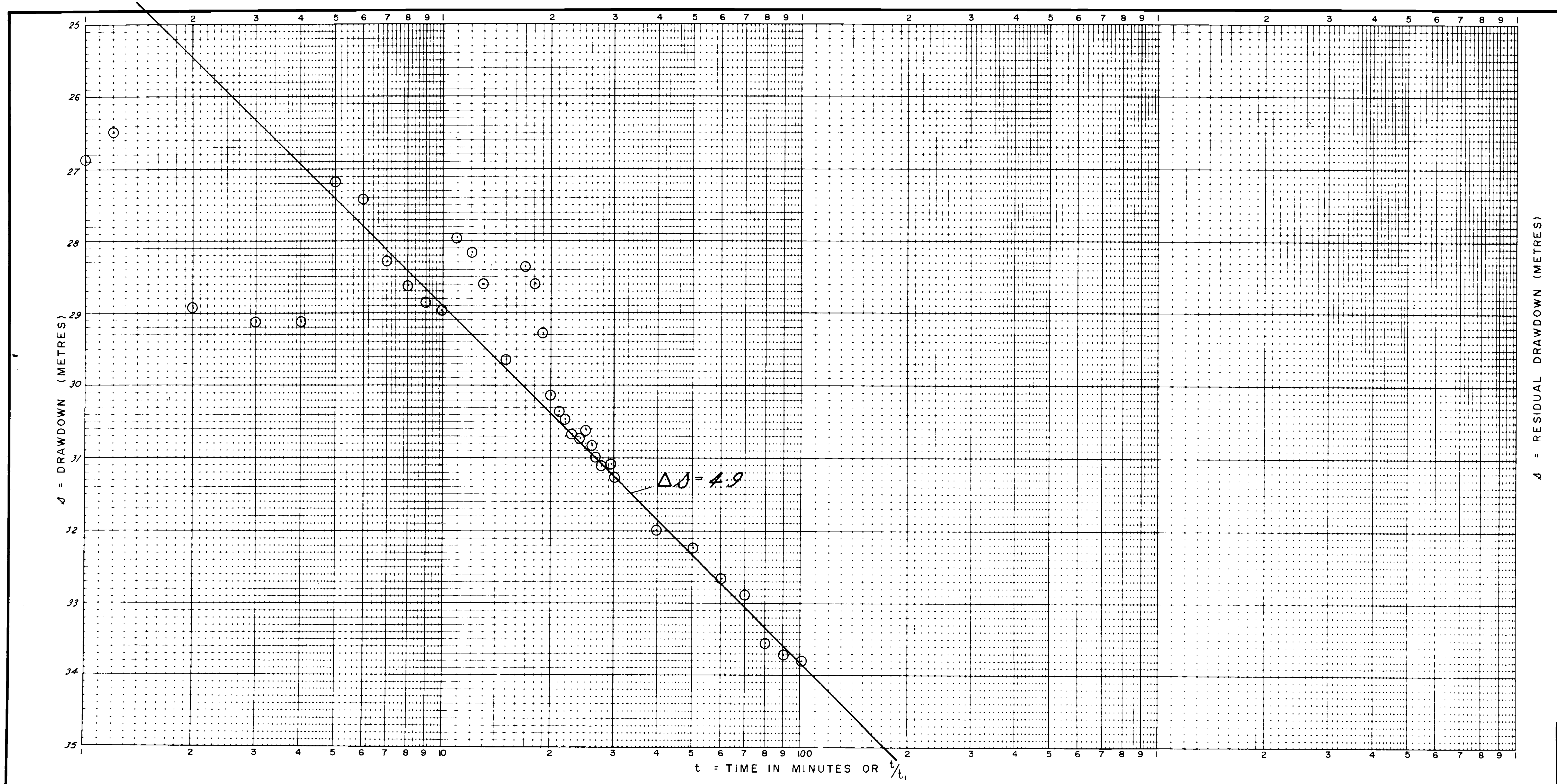
Solving $s(t) = (a + b \log t)\,Q + CQ^2$
Slope $\Delta s = bQ$ $\quad b = 0{\cdot}58$ (Q in $m^3 min^{-1}$)
For $\log t = 0$ (minutes) $\quad s = aQ + CQ^2$
$19{\cdot}6 = 0{\cdot}43a + 0{\cdot}185\,C$

* Available drawdown = $\ell_1 - \ell_2$

APP. III FIG. 3

ENGINEERING DIVISION		DEPARTMENT OF MINES – SOUTH AUSTRALIA	D.M. *173/77*
COMPILED *J.D.W.*		*HONEYMOON DEPOSIT URANIUM LEACHING PROJECT*	DATE *17-7-77*
DRN *L.P.R.*	CKD	*STAGE II OF STEP-DRAWDOWN TEST PRODUCTION WELL*	PLAN NUMBER *77-819*

P.F. No. 69–953 MH



BOREHOLE STATE/UNIT No. 7034000W00018

REF. PT. TOC (m) above ground

AQUIFER FROM 106·6 TO 120 (m)

HOLE DEPTH 122·3 (m)

TYPE OF PUMP TURBINE

LENGTH OF TEST 100 min

DEPTH WATER LEVEL AT TEST START (ℓ_2) 55·69 (m)

DEPTH PUMP INTAKE (ℓ_1) 99·5 (m)

* AVAILABLE DRAWDOWN 43·81 (m)

EQUATIONS

$$T = \frac{0{\cdot}183 \times Q}{\Delta_s} \qquad S = \frac{2{\cdot}25 \times T t_0}{r^2}$$

In which

- T = Transmissivity (m^3/day/m)
- Q = Pumping Rate (m^3/day)
- Δ_s = Drawdown per log cycle (m)
- S = Storage Coefficient
- t_0 = Zero drawdown time (mins)
- r = Distance to Observation Bore (m)
- 1 day = $8{\cdot}64 \times 10^4$ secs.

DATA

Q	Δ_s	t_0	r
920 $m^3 day^{-1}$ 0·64 $m^3 min^{-1}$	4·9	—	—

CALCULATIONS

$$\frac{T = 0{\cdot}183 \times 920}{4{\cdot}9} = 34\ m^3\ day^{-1} m^{-1}$$

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

Slope $\Delta s = bQ$ (Q in $m^3 min^{-1}$)

$b = 7{\cdot}6$

For $\log t = 0$ (minutes) $s = aQ + CQ^2$

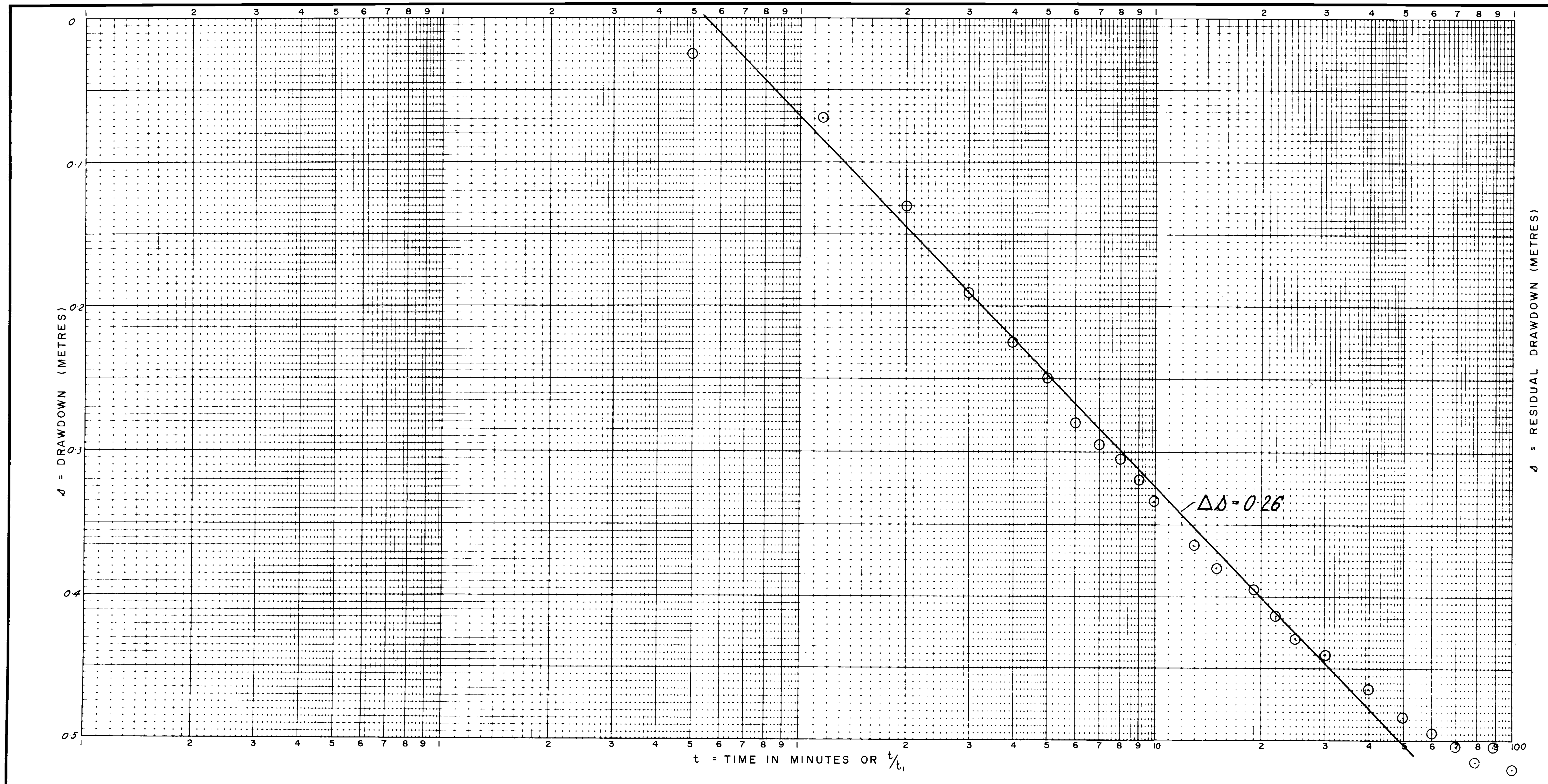
$24 = 0{\cdot}64a + 0{\cdot}41 Q^2$

* Available drawdown = $\ell_1 - \ell_2$

APP. III FIG. 4

ENGINEERING DIVISION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	D.M. 173/77
COMPILED J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE 17-7-77
DRN L.P.R. CKD	STAGE III OF STEP-DRAWDOWN TEST PRODUCTION WELL	PLAN NUMBER 77-820

P.F. No. 69-953 MH



BOREHOLE STATE/UNIT No. 7034000WW00022

REF. PT. TOC (m) above ground

AQUIFER FROM 106·6 TO 120 (m)

HOLE DEPTH 122·30 (m)

TYPE OF PUMP TURBINE

LENGTH OF TEST 100 min

DEPTH WATER LEVEL AT TEST START (ℓ_2) 55·69 (m)

DEPTH PUMP INTAKE (ℓ_1) 99·5 (m)

* AVAILABLE DRAWDOWN 43·81 (m)

EQUATIONS

$$T = \frac{0{\cdot}183 \times Q}{\Delta_s} \qquad S \quad \frac{2{\cdot}25 \times T t_0}{r^2}$$

In which

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

Q = Pumping Rate (m^3/day)

Δ_s = Drawdown per log cycle (m)

S = Storage Coefficient

t_0 = Zero drawdown time (mins)

r = Distance to Observation Bore (m)

1 day = $8{\cdot}64 \times 10^4$ secs.

DATA

Q	Δ_s	t_0	r
620 $m^3 day^{-1}$	0·26 m	0·55 min.	75·6 m

CALCULATIONS

$$T = \frac{0{\cdot}183 \times 620}{0{\cdot}26} = 436\ m^3\ day^{-1} m^{-1}$$

$$S = \frac{2{\cdot}25 \times 436 \times 0{\cdot}55}{1440(75{\cdot}6)^2} = 6{\cdot}5 \times 10^{-5}$$

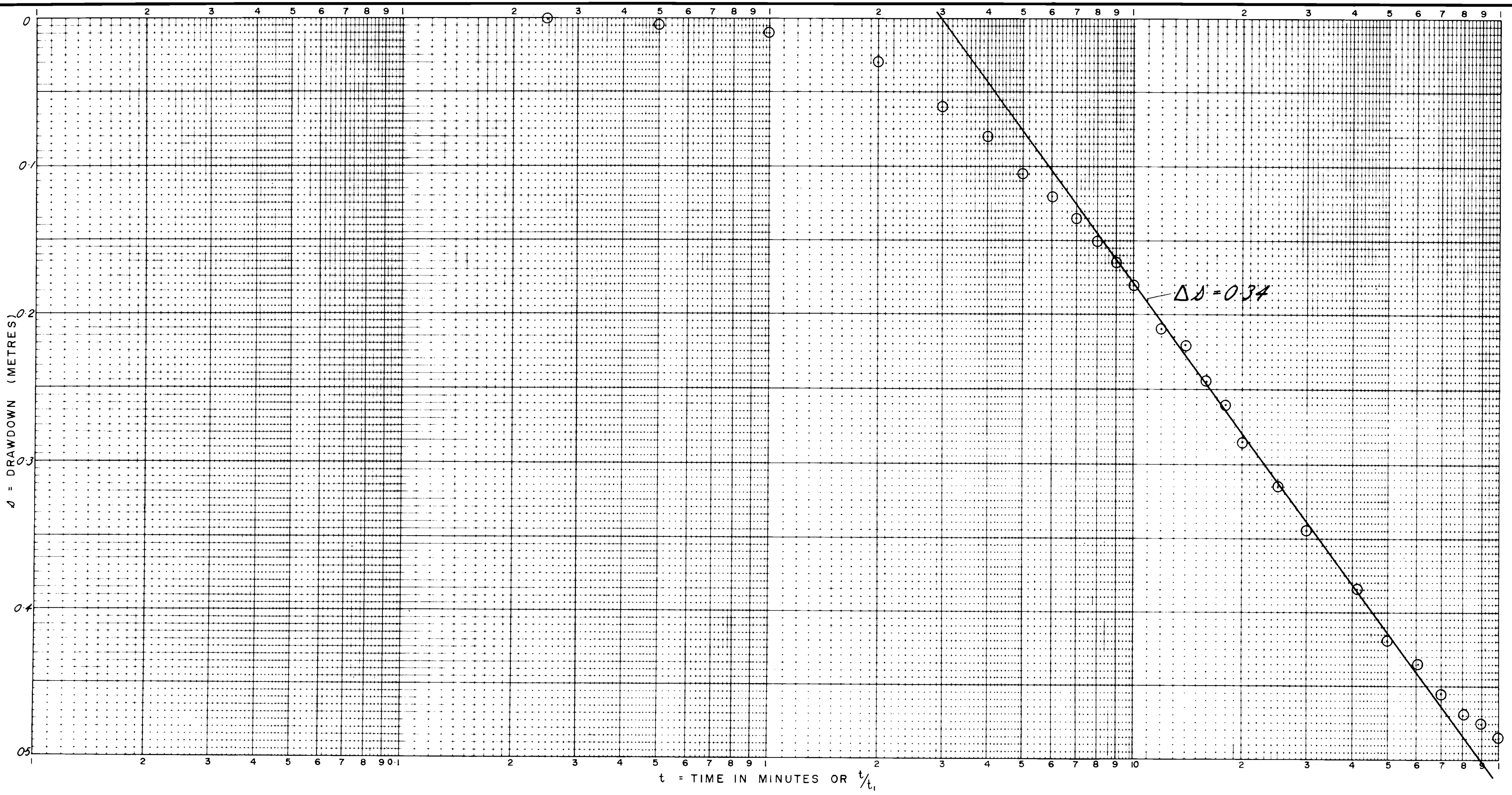
Note $s/\Delta s = \frac{0{\cdot}5}{0{\cdot}26} = 2$ at end of test only, therefore Jacob's assumptions may not be valid for calculation.

* Available drawdown = $\ell_1 - \ell_2$

APP. III FIG. 5

ENGINEERING DIVISION	DEPARTMENT OF MINES—SOUTH AUSTRALIA	D.M. 173/77
COMPILED J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE 17-7-77
DRN L.P.R. CKD	STAGE II OF STEP-DRAWDOWN TEST OBSERVATION WELL HC-2A	PLAN NUMBER 77-821

P.F. No. 69—953 MH



BOREHOLE STATE/UNIT No. 7034000WW00021

REF. PT. 70C (m) above ground

AQUIFER FROM 106.6 TO 120 (m)

HOLE DEPTH 122.3 (m)

TYPE OF PUMP TURBINE

LENGTH OF TEST 100 min

DEPTH WATER LEVEL AT TEST START (ℓ_2) 55.69 (m)

DEPTH PUMP INTAKE (ℓ_1) 99.5 (m)

* AVAILABLE DRAWDOWN 43.81 (m)

EQUATIONS

$$T = \frac{0.183 \times Q}{\Delta_s} \qquad S = \frac{2.25 \times T t_o}{r^2}$$

In which

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

Q = Pumping Rate (m^3/day)

Δ_s = Drawdown per log cycle (m)

S = Storage Coefficient

t_o = Zero drawdown time (mins)

r = Distance to Observation Bore (m)

1 day = 8.64×10^4 secs.

DATA

Q	Δ_s	t_o	r
920 $m^3 day^{-1}$	0.34	3 min	175.5 m

CALCULATIONS

$$T = \frac{0.183 \times 920}{0.34} = 495 \ m^3 day^{-1} m^{-1}$$

$$S = \frac{2.25 \times 495 \times 3}{1440 (175.5)^2} = 7.5 \times 10^{-5}$$

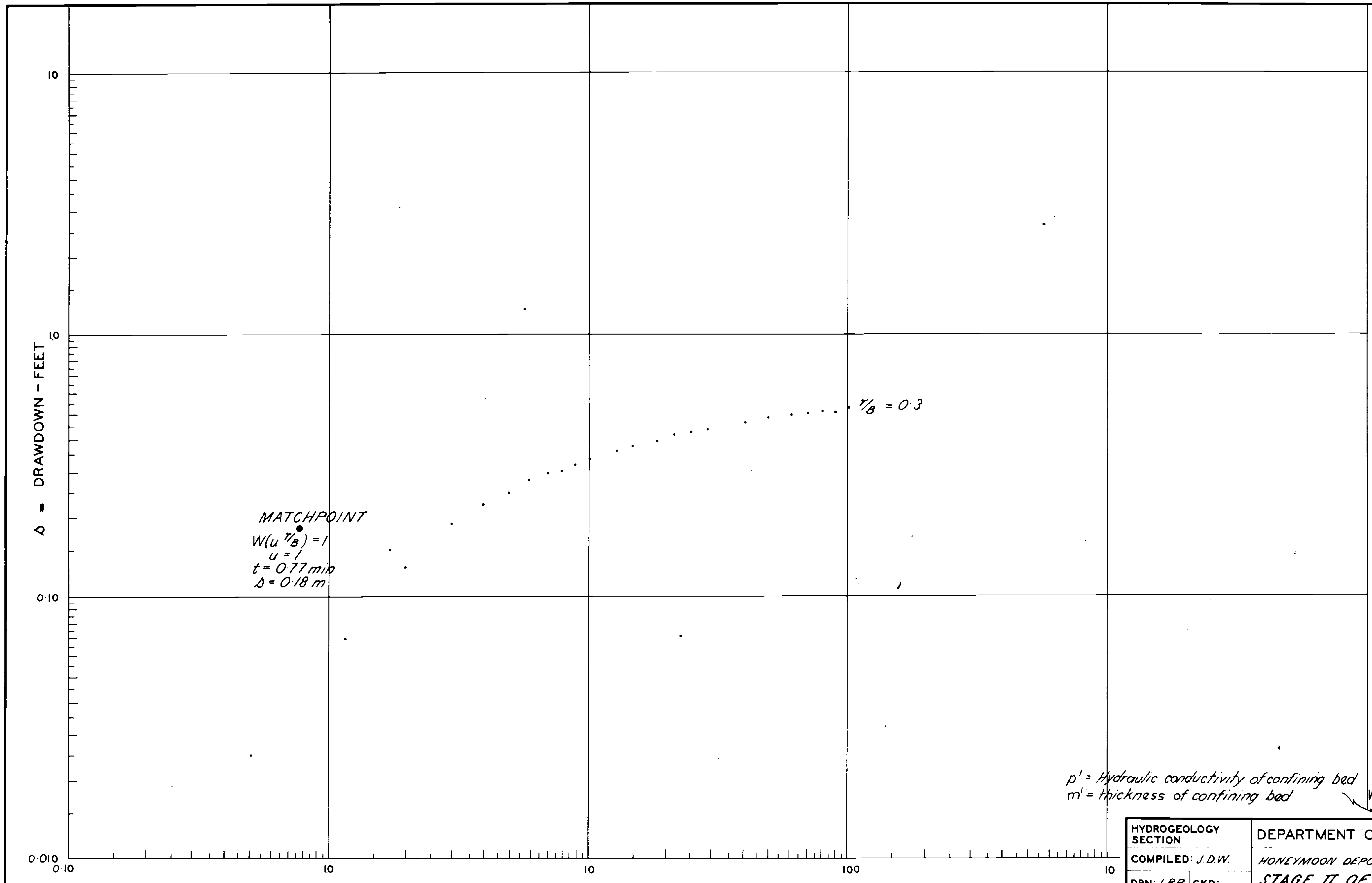
Note $\Delta/\Delta s = \frac{0.5}{0.34}$ = 1.7 at end of test i.e. Jacob's assumptions may not be valid for calculations.

* Available drawdown = $\ell_1 - \ell_2$

APP. III FIG. 6

ENGINEERING DIVISION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	D.M. 173/77
COMPILED J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE 18-7-77
DRN. L.P.R. CKD.	STAGE III OF STEP-DRAWDOWN TEST	PLAN NUMBER
	OBSERVATION WELL HC-1	77-822

P.F. No. 69–953 MH



BOREHOLE STATE Nº 7034000WW00022 HC2A
DEPTH TO WATER LEVEL
AT TEST START 55·69 m (L)*
PUMP INTAKE DEPTH 99·5 m (L)
AVAILABLE DRAWDOWN 43·81 m (L)
TYPE OF PUMP TURBINE
DISCHARGE STARTED AT 1321 hrs ON 17-7-77
DISCHARGE STOPPED AT 1401 hrs ON 17-7-77
AQUIFER FROM 106·60 TO 120 (L)
HOLE DEPTH 122·3 (L)

AT MATCHPOINT

Q = 620 $m^3 day^{-1}$
r = 74·6 m
Δ = 0·18 m
m' = 10·6 m
t = 0·77 min
W(u) = 1
u = 1

CALCULATIONS

DRAWDOWN:-

$$T = \frac{Q}{4\pi\Delta} W(u) = \frac{620}{4\pi \times 0{\cdot}18}$$

$$= 274\ m^3 day^{-1} m^{-1}$$

$$S = \frac{4Tut}{r^2} = \frac{4 \times 274 \times 0{\cdot}77}{74{\cdot}6^2 \times 1440}$$

$$= 1{\cdot}1 \times 10^{-4}$$

$$p' = \frac{Tm'(r/B)^2}{r^2} = \frac{274 \times 10{\cdot}6 \times 0{\cdot}3^2}{74{\cdot}6^2}$$

$$= 0{\cdot}047\ m^3 day^{-1} m^{-2}$$

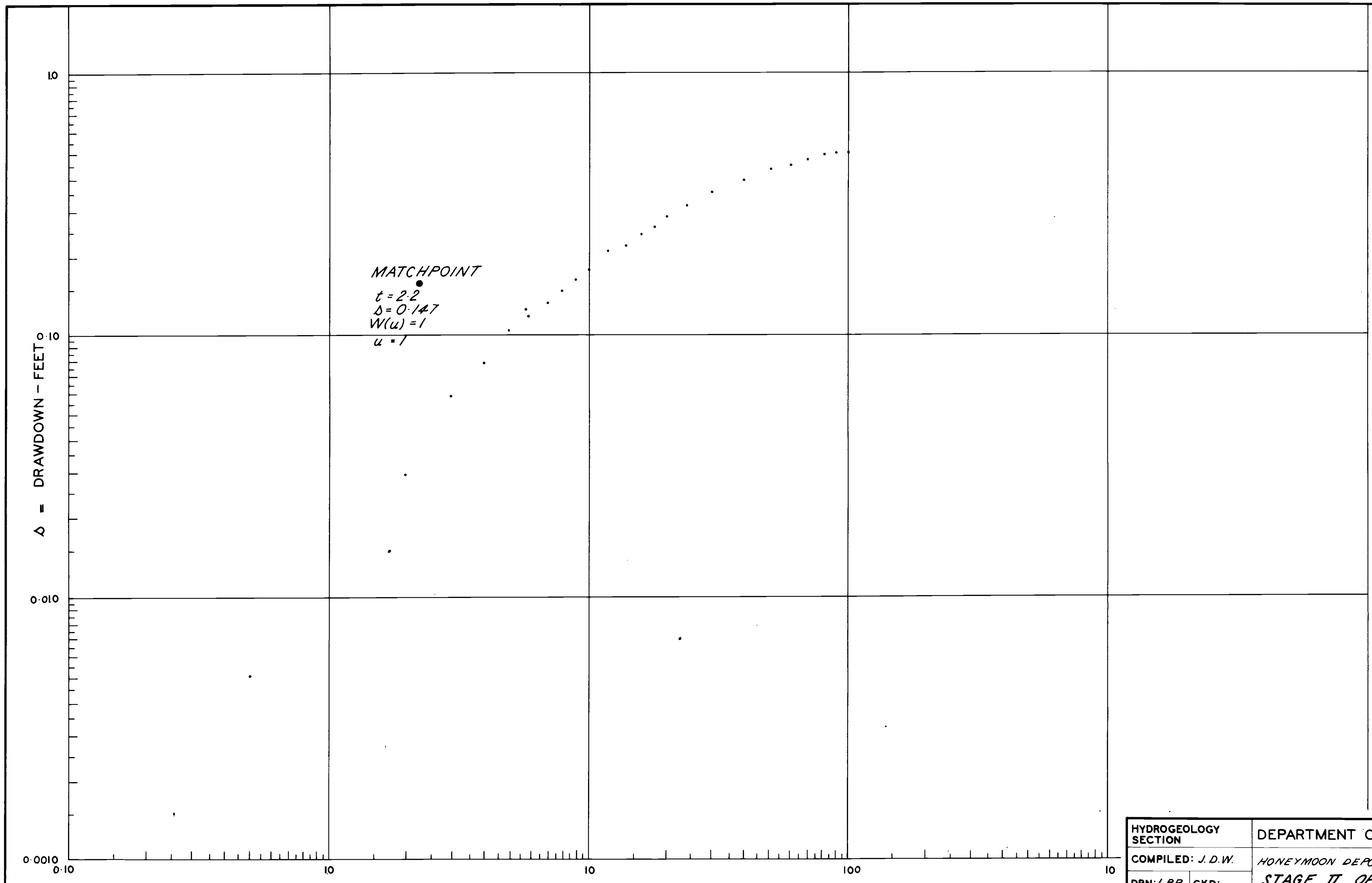
where
S = Storage Coefficient (dimensionless)
t = time
r = Distance to observation hole (L)
T = Transmissivity ($L^3 t^{-1} L^{-1}$)
Q = Pumping rate ($L^3 t^{-1}$)
Δ = Drawdown (L)
W(u r/B) = function of u (well function for leaky artesian aquifer)

p' = Hydraulic conductivity of confining bed
m' = thickness of confining bed

APP. III FIG. 7
* L = unit of Length
t = time unit

HYDROGEOLOGY SECTION	DEPARTMENT OF MINES - SOUTH AUSTRALIA	SCALE: 173/77
COMPILED: J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE: 18-7-77
DRN: L.P.R. CKD:	STAGE II OF STEP-DRAWDOWN TEST OBSERVATION WELL HC-2A	DRG. NO. 77-823

F Nº 70-494 MH



BOREHOLE STATE No. 7034000WW00021
DEPTH TO WATER LEVEL
AT TEST START (L)*
PUMP INTAKE DEPTH (L)
AVAILABLE DRAWDOWN (L)
TYPE OF PUMP
DISCHARGE STARTED AT ON
DISCHARGE STOPPED AT ON
AQUIFER FROM TO (L)
HOLE DEPTH (L)

AT MATCHPOINT

Q = 920 $m^3 day^{-1}$ t = 2·2 min = $\frac{2.2}{1440}$ days
r = 175·5 W(u) = 1
Δ = 0·147 m u = 1

CALCULATIONS

Δ = RECOVERY – FEET

DRAWDOWN :-

$$T = \frac{Q}{4\pi\Delta} W(u) = \frac{920}{4\pi \times 0.147} = 498 \; m^3 day^{-1} m^{-1}$$

$$S = \frac{4\,Tut}{r^2} = \frac{4 \times 498 \times 1 \times 2.2}{(175)^2} = 0.00010$$

$$= 1.0 \times 10^{-4}$$

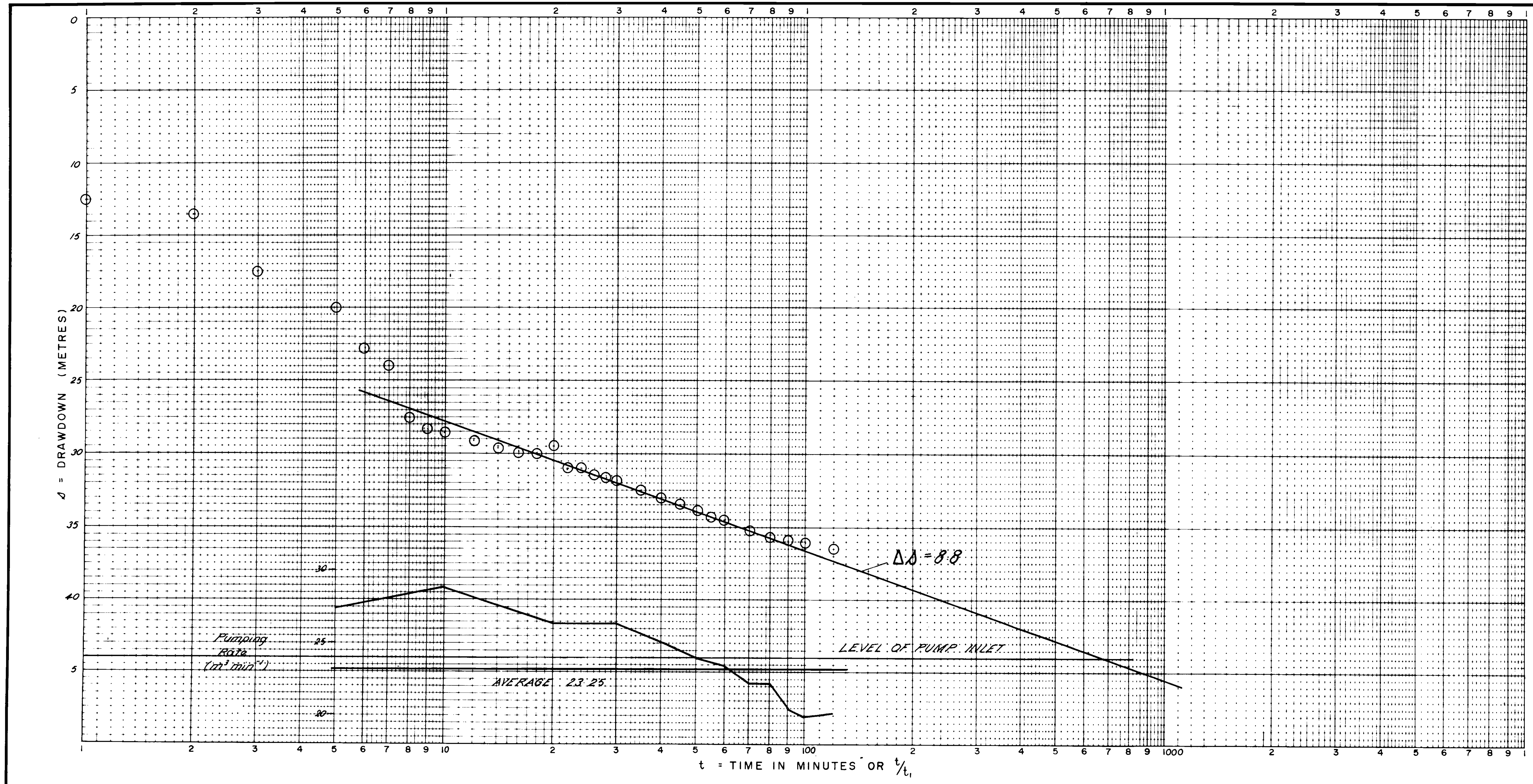
where
S = Storage Coefficient (dimensionless)
t = time
r = Distance to observation hole (L)
T = Transmissivity ($L^3 t^{-1} L^{-1}$)
Q = Pumping rate ($L^3 t^{-1}$)
Δ = Drawdown (L)
W(u) = function of u

APP. III FIG. 8

* L = unit of Length
t = time unit

HYDROGEOLOGY SECTION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	SCALE:
COMPILED: J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE: 18-7-77
DRN: L.P.R. CKD:	STAGE II OF STEP-DRAWDOWN TEST OBSERVATION WELL HC-1	DRG. NO. 77-824

F No. 70-494 MH



BOREHOLE STATE/UNIT No. 703400WW00018 TYPE OF PUMP TURBINE

REF. PT. TOC (m) above ground

LENGTH OF TEST 120 min

AQUIFER FROM 106.6 TO 120 (m)

DEPTH WATER LEVEL AT TEST START (ℓ_2) .... (m)

HOLE DEPTH 122.3 (m)

DEPTH PUMP INTAKE (ℓ_1) 93.5 (m)

* AVAILABLE DRAWDOWN .... (m)

EQUATIONS

$$T = \frac{0.183 \times Q}{\Delta_s} \qquad S = \frac{2.25 \times Tt_0}{r^2}$$

In which

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

Q = Pumping Rate (m^3/day)

Δ_s = 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_s	t_0	r
560 m^3day	8.8	—	—

CALCULATIONS

$$T = \frac{0.183 \times 560}{8.8} = 12\ m^3 day^{-1} m^{-1}$$

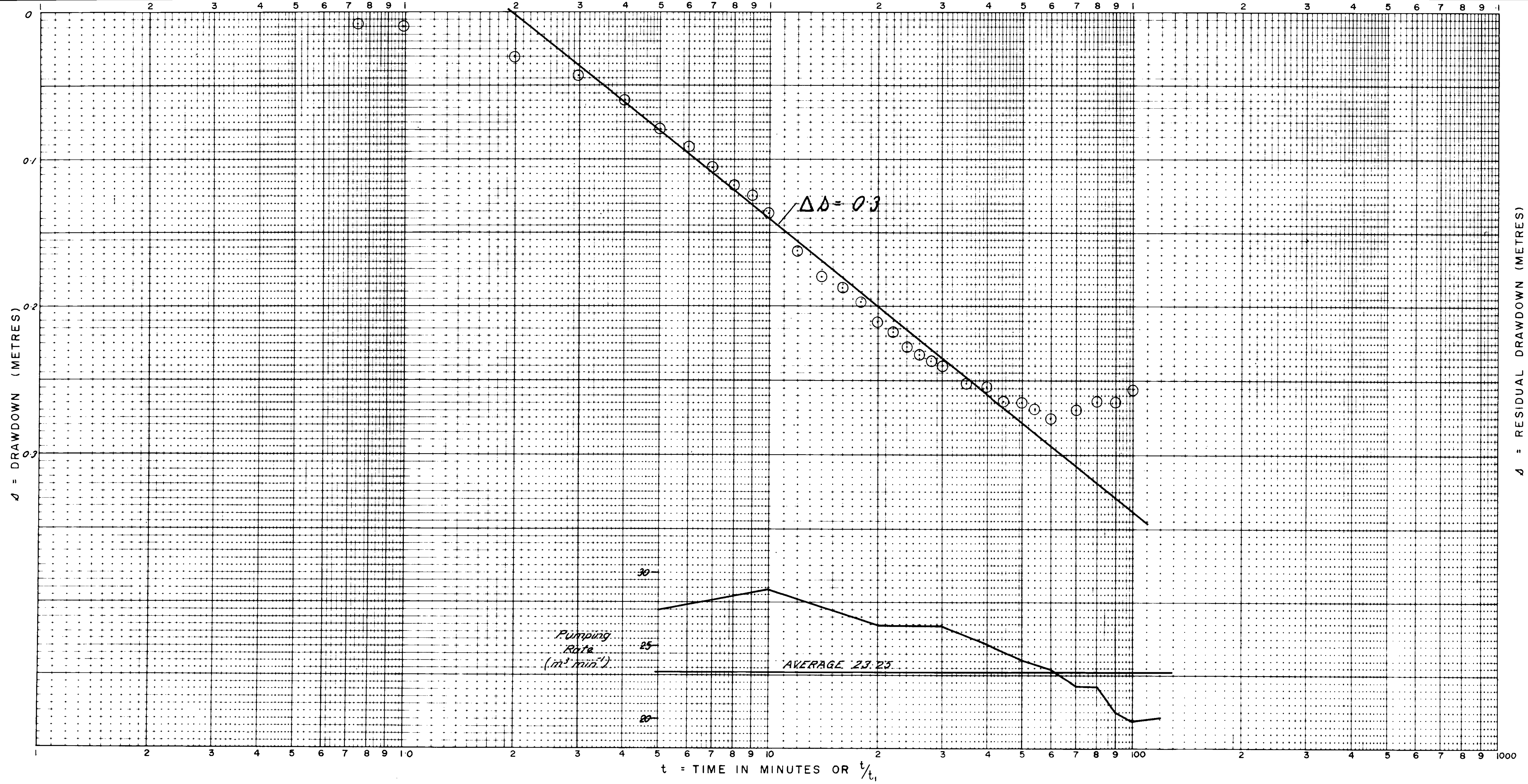
* Available drawdown = $\ell_1 - \ell_2$

APP. III

FIG. 9

ENGINEERING DIVISION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	D.M. 173/77
COMPILED J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE 21-7-77
DRN L.P.R. CKD	MAIN TEST PRODUCTION WELL	PLAN NUMBER 77-825

P.F. No. 69–953 MH



BOREHOLE STATE/UNIT No. 7034 OOOWW00021

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

$T = \frac{0{\cdot}183 \times Q}{\Delta_\Delta}$ $\quad$ $S = \frac{2{\cdot}25 \times Tt_o}{r^2}$

In which

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

Q = Pumping Rate (m^3/day)

Δ_Δ = Drawdown per log cycle (m)

S = Storage Coefficient

t_o = Zero drawdown time (mins)

r = Distance to Observation Bore (m)

1 day = $8{\cdot}64 \times 10^4$ secs.

DATA

Q	Δ_Δ	t_o	r
560 $m^3 day^{-1}$	0·3	2 min	175·5 m.

CALCULATIONS

$T = \frac{0{\cdot}183 \times 560}{0{\cdot}3} = 340\ m^3 day^{-1} m^{-1}$

$S = \frac{2{\cdot}25 \times 340 \times 2}{1440 (175{\cdot}5)^2} = 3{\cdot}4 \times 10^{-5}$

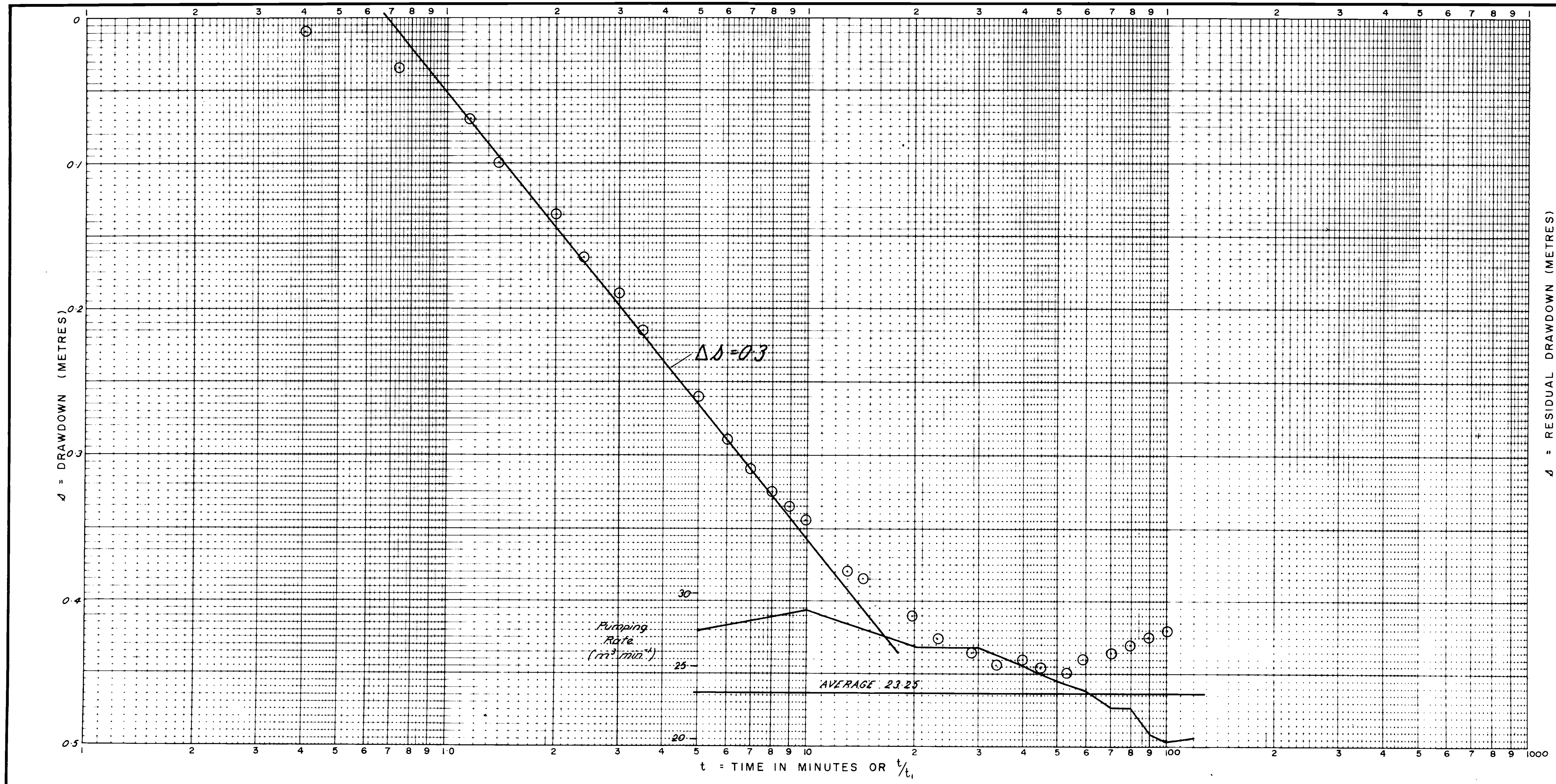
Note Δ/Δ_Δ = 0·8 at end of test ie. Jacob's assumption may not be valid for calculations.

* Available drawdown = $\ell_1 - \ell_2$

APP. III $\quad$ FIG 10

ENGINEERING DIVISION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	D.M. 173/77
COMPILED J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE 26-7-77
DRN L.P.R. CKD	MAIN TEST	PLAN NUMBER
	OBSERVATION WELL HC-1	77-826

P.F. No. G9—953 MH



BOREHOLE STATE/UNIT No. 7034000WW00023

REF. PT. TOC (m) above ground

AQUIFER FROM — TO (m)

HOLE DEPTH — (m)

TYPE OF PUMP TURBINE

LENGTH OF TEST 120 min

DEPTH WATER LEVEL AT TEST START (ℓ_2) 54.85 (m)

DEPTH PUMP INTAKE (ℓ_1) — (m)

* AVAILABLE DRAWDOWN — (m)

EQUATIONS

$$T = \frac{0{\cdot}183 \times Q}{\Delta_s} \qquad S \quad \frac{2{\cdot}25 \times Tt_o}{r^2}$$

In which

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

Q = Pumping Rate (m^3/day)

Δ_s = Drawdown per log cycle (m)

S = Storage Coefficient

t_o = Zero drawdown time (mins)

r = Distance to Observation Bore (m)

1 day = $8{\cdot}64 \times 10^4$ secs.

DATA

Q	Δ_s	t_o	r
560 $m^3 day^{-1}$ ($0{\cdot}39\ m^3 min^{-1}$)	0·3	0·07 min	75·8 m

CALCULATIONS

$$T = \frac{0{\cdot}183 \times 560}{0{\cdot}3} = 340\ m^3 day^{-1} m^{-1}$$

$$S = \frac{2{\cdot}25 \times 340 \times 0{\cdot}7}{1440(75{\cdot}8)^2} = 6{\cdot}5 \times 10^{-5}$$

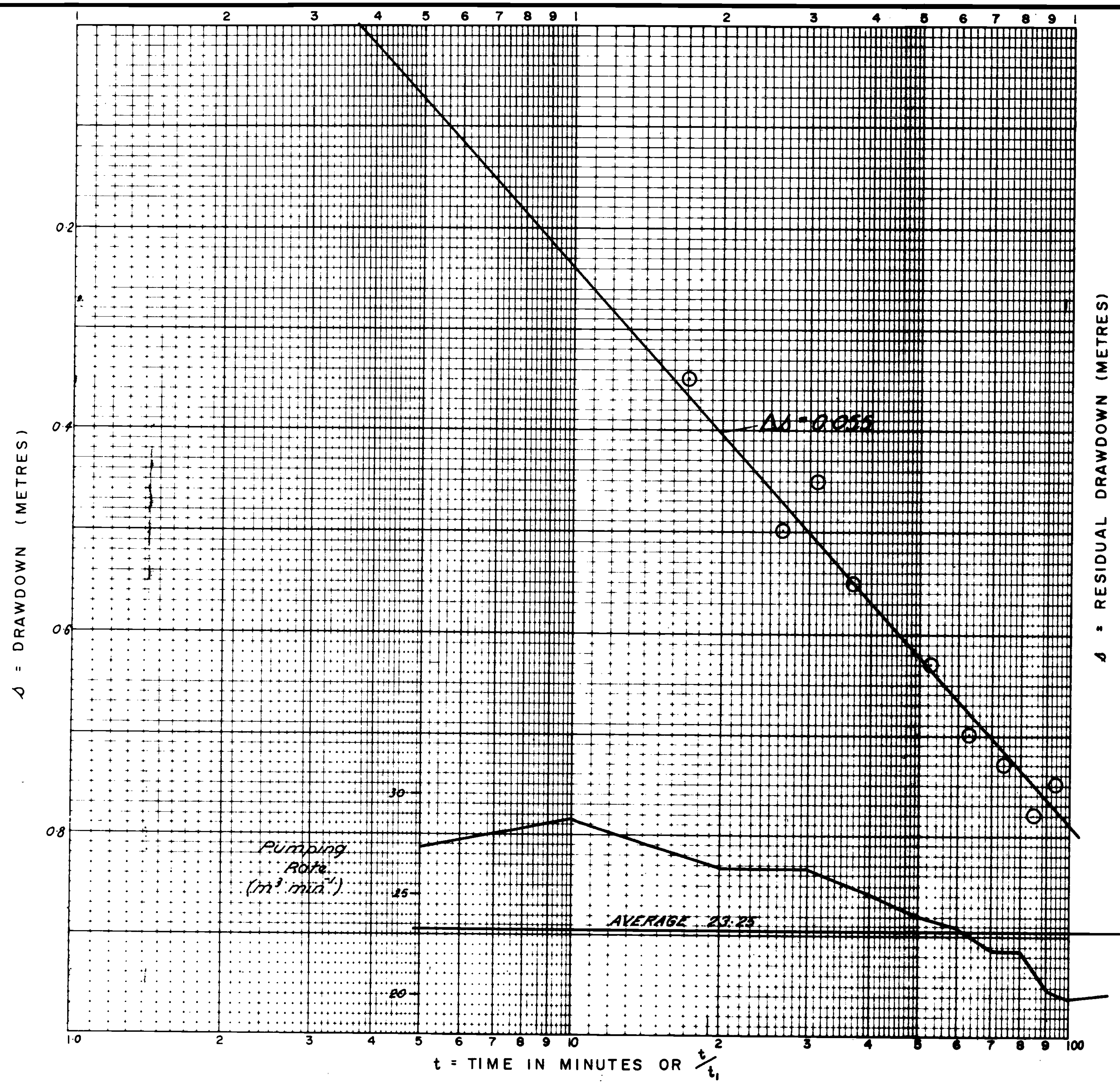
Note $s/\Delta s$ = 1·3 at end of test i.e. Jacob's assumption may not be valid for calculations.

* Available drawdown = $\ell_1 - \ell_2$

APP. III FIG. 11

ENGINEERING DIVISION	DEPARTMENT OF MINES—SOUTH AUSTRALIA	D.M. 173/77
COMPILED J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE 26-7-77
DRN L.P.R. CKD	MAIN TEST OBSERVATION WELL HC-2A	PLAN NUMBER 77-827

P.F. No. 69—953 MH



BOREHOLE STATE/UNIT No. *7034 0QQWW00023*

REF. PT. *TOC* (m) above ground

AQUIFER FROM — TO ...... (m)

HOLE DEPTH — (m)

TYPE OF PUMP *TURBINE*

LENGTH OF TEST *120 min*

DEPTH WATER LEVEL AT TEST START (ℓ_2) ...... (m)

DEPTH PUMP INTAKE (ℓ_1) *99.5* (m)

* AVAILABLE DRAWDOWN ...... (m)

EQUATIONS

$$T = \frac{0.183 \times Q}{\Delta_s} \qquad S \ \frac{2.25 \times Tt_0}{r^2}$$

In which

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

Q = Pumping Rate (m^3/day)

Δ_s = 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_s	t_0	r
560 $m^3 day^{-1}$ (0.39 $m^3\ min^{-1}$)	*0.055*	*3.6 min*	*302 m*

CALCULATIONS

$$T = \frac{0.183 \times 560}{0.055} = 1860\ m^3 day^{-1} m^{-1}$$

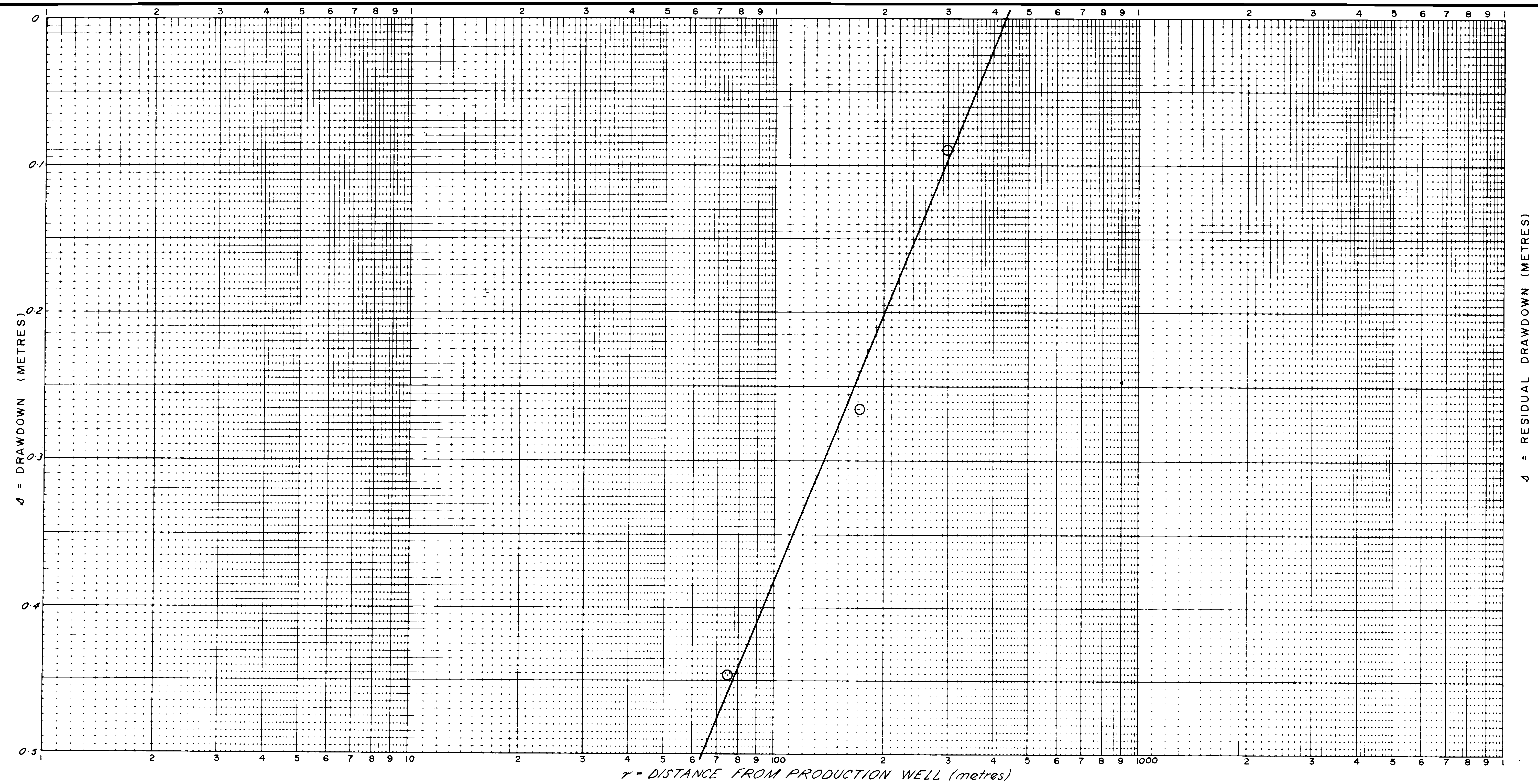
$$S = \frac{2.25 \times 1860 \times 3.6}{1440 (302)^2} = 1.1 \times 10^{-4}$$

Note: $s/\Delta s$ = 1.6 at end of test, i.e. Jacob's assumption may not be valid for calculation.

* Available drawdown = $\ell_1 - \ell_2$

APP. III FIG. 12

ENGINEERING DIVISION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	D.M. *173/77*
COMPILED *J.D.W.*	*HONEYMOON DEPOSIT URANIUM LEACHING PROJECT*	DATE *26-7-77*
DRN *L.P.R.* CKD	*MAIN TEST* *OBSERVATION WELL HC-3*	PLAN NUMBER *77-828*



BOREHOLE STATE/UNIT No. 703400QOWW0008

REF. PT. TOC (m) above ground

AQUIFER FROM — TO — (m)

HOLE DEPTH — (m)

TYPE OF PUMP TURBINE

LENGTH OF TEST 120 min

DEPTH WATER LEVEL AT TEST START (ℓ_2) — (m)

DEPTH PUMP INTAKE (ℓ_1) — (m)

* AVAILABLE DRAWDOWN — (m)

EQUATIONS

$T = \frac{0.366 \times Q}{\Delta_s}$ $S = \frac{2.25 \times Tt}{r_0^2}$

In which

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

Q = Pumping Rate (m^3/day)

Δ_s = 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_s	t	r_0
$560\ m^3 day^{-1}$ ($0.39\ m^3 min^{-1}$)	0.51	50 min	430 m

CALCULATIONS

$$T = \frac{0.366 \times 560}{0.5} = 405\ m^3 day^{-1} m^{-1}$$

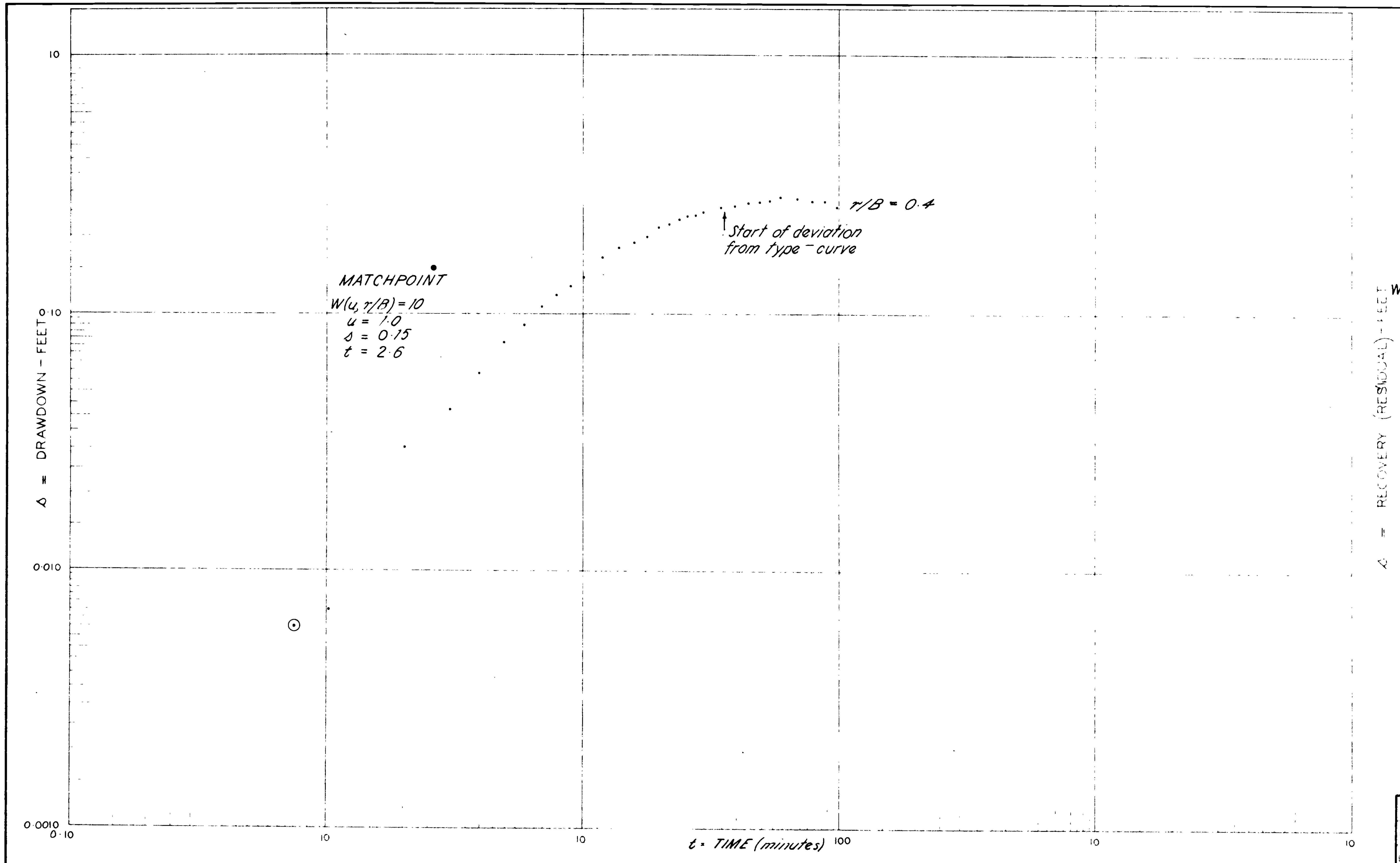
$$S = \frac{2.25 \times 405 \times 50}{1440\ (430)^2} = 1.7 \times 10^{-4}$$

* Available drawdown = $\ell_1 - \ell_2$

APP. III FIG. 13

ENGINEERING DIVISION	DEPARTMENT OF MINES—SOUTH AUSTRALIA	D.M. 173/77
COMPILED J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT MAIN TEST	DATE 27-7-77
DRN L.P.R. CKD	DISTANCE DRAWDOWN PLOT	PLAN NUMBER 77-829

P.F. No. 69—953 MH



BOREHOLE STATE Nº 7034000W00021
DEPTH TO WATER LEVEL AT TEST START 53·95 m. (L) *
PUMP INTAKE DEPTH — (L)
AVAILABLE DRAWDOWN — (L)

TYPE OF PUMP TURBINE
DISCHARGE STARTED AT 12·00 ON 21/7/77
" STOPPED AT 14·00 ON 21/7/77
AQUIFER FROM — TO (L)
HOLE DEPTH — (L)

BASIC EQUATIONS

$$T = \frac{Q}{4\pi\Delta} Wu \qquad S = \frac{4\,Tut}{r^2} \qquad \rho' = \frac{Tm'(r/B)^2}{r^2}$$

in which

T = Transmissivity ($L^3/t/L$)
Q = Pumping rate (L^3/t)
Δ = Drawdown (L)
W(u, r/B) = Well function of u, r/B
p'

S = Storage Coefficient (dimensionless)
t = time (t)
r = Distance to observation hole (L)
m=

DATA

Q	Δ	t	m'	Wu	r/B	u	r
560 m^3 day^{-1}	0·15	2·6 min	10 m.	1·0	0·4	1·0	175·5 m.

CALCULATIONS

$$T = \frac{560 \times 1{\cdot}0}{4\pi \times 0{\cdot}15} = 297\ m^3 day^{-1} m^{-1}$$

$$S = \frac{4 \times 297 \times 10 \times 2{\cdot}6}{1440\ (175{\cdot}5)^2} = 7{\cdot}0 \times 10^{-5}$$

$$\rho' = \frac{T m' (r/B)^2}{r^2} = 1{\cdot}5 \times 10^{-2}\ m^3 day^{-1} m^{-2}$$

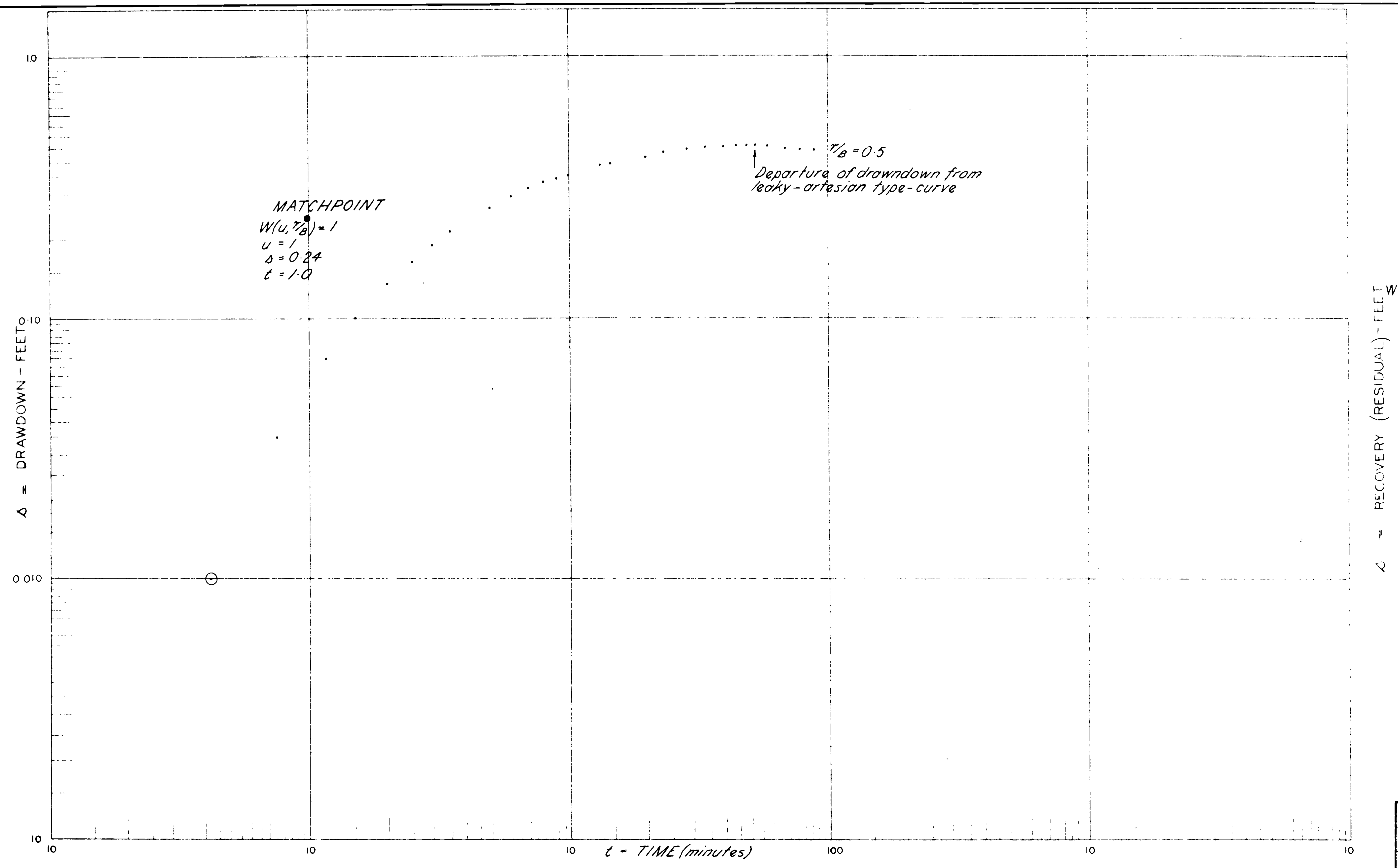
where
S = Storage Coefficient (dimensionless)
t = time
r = Distance to observation hole (L)
T = Transmissivity ($L^3t^{-1}L^{-1}$)
Q = Pumping rate (L^3t^{-1})
Δ = Drawdown (L)
W(u r/B) = function of u (well function for leaky artesian aquifer)
p' = Hydraulic conductivity of confining bed
m' = thickness of confining bed

* L = unit of Length
t = time unit

APP. III FIG. 14

HYDROGEOLOGY SECTION	DEPARTMENT OF MINES - SOUTH AUSTRALIA	DM /
COMPILED J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE 27/7/77
DRN L.P.R. CHD	MAIN TEST	DRG NO
	OBSERVATION WELL HC-1	77-830

No. 69 ...



BOREHOLE STATE Nº 7034000NW00022 TYPE OF PUMP TURBINE
DEPTH TO WATER LEVEL DISCHARGE STARTED AT 12·00 ON 21-7-77
AT TEST START 54·85 m. (L) * " STOPPED AT 14·00 ON 21-7-77
PUMP INTAKE DEPTH — (L) AQUIFER FROM — TO (L)
AVAILABLE DRAWDOWN — (L) HOLE DEPTH — (L)

BASIC EQUATIONS

$$T = \frac{Q}{4\pi\Delta} Wu \qquad S = \frac{4\,Tut}{r^2} \qquad p' = \frac{Tm'(r/B)^2}{r^2}$$

In which
T = Transmissivity ($L^3/t/L$)
Q = Pumping Rate (L^3/t)
Δ = Drawdown (L)
W(u, r/B) = Well function of u, r/B
p' = Hydraulic conductivity of confining bed
S = Storage Coefficient (dimensionless)
t = time (t)
r = Distance to observation hole (L)
m' = Thickness of confining bed (L)

DATA

Q	Δ	m'	t	W(u, r/B)	u	r/B	r
560 $m^3 day^{-1}$	0·24 m	10	1·0 min.	1·0	1·0	0·5	75·8

CALCULATIONS

$$T = \frac{560 \times 1 \cdot 0}{4\pi \times 0 \cdot 24} = 186\ m^3 day^{-1} m^{-1}$$

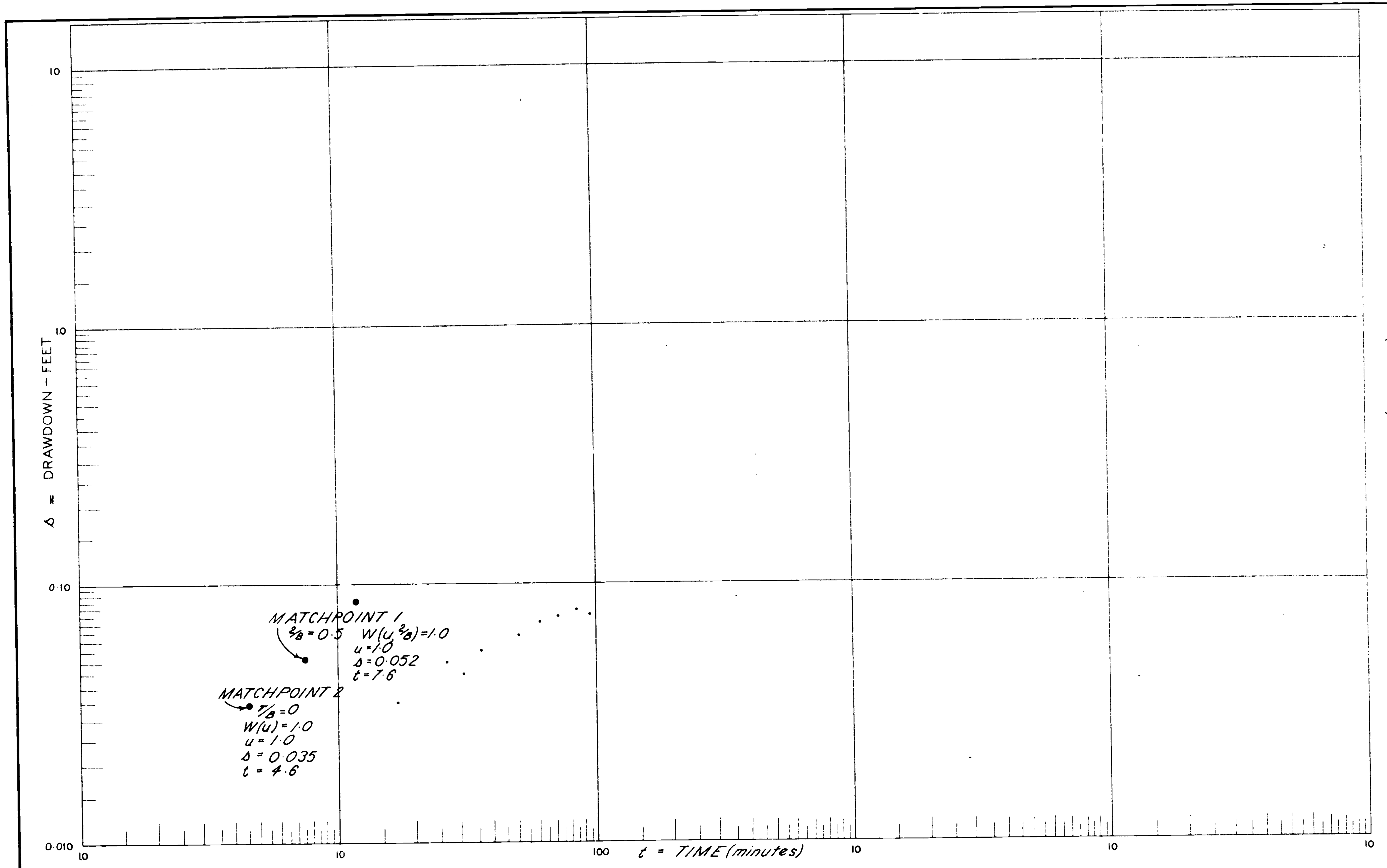
$$S = \frac{4 \times 186 \times 1 \cdot 0 \times 1 \cdot 0}{1440\,(75 \cdot 8)^2} = 9 \cdot 0 \times 10^{-5}$$

$$p' = \frac{186 \times 10 \times (0 \cdot 5)^2}{(75 \cdot 8)^2} = 81 \times 10^{-2}\ m^3 day^{-1} m^{-2}$$

where
S = Storage Coefficient (dimensionless)
t = time
r = Distance to observation hole (L)
T = Transmissivity ($L^3 t^{-1} L^{-1}$)
Q = Pumping rate ($L^3 t^{-1}$)
Δ = Drawdown (L)
W(u r/B) = function of u (well function for leaky artesian aquifer)
p' = Hydraulic conductivity of confining bed
m' = thickness of confining bed
* L = unit of Length
t = time unit

APP. III FIG. 15

HYDROGEOLOGY SECTION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	D.M. /
COMPILED J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE 27-7-77
DRN L.P.R. CHD	MAIN TEST	DRG NO.
	OBSERVATION WELL HC-2A	77-831



BOREHOLE STATE N° 7034000WW00023 TYPE OF PUMP TURBINE

DEPTH TO WATER LEVEL AT TEST START (L) *

DISCHARGE STARTED AT 12:00 ON 21/7/77

" STOPPED AT 14:00 ON 21/7/77

PUMP INTAKE DEPTH (L)

AQUIFER FROM — TO (L)

AVAILABLE DRAWDOWN (L)

HOLE DEPTH — (L)

BASIC EQUATIONS

$$T = \frac{Q}{4\pi\Delta} Wu \qquad S = \frac{4Tut}{r^2} \qquad p' = \frac{Tm'(\frac{r}{B})^2}{r^2}$$

In which

T = Transmissivity ($L^3/t/L$)

Q = Pumping Rate (L^3/t)

Δ = Drawdown (L)

W(u, r/B) = function of u

p' =

S = Storage Coefficient (dimensionless)

t = time (t)

r = Distance to observation hole (L)

m' =

DATA

	Q	Δ	t	m'	Wu	r/B	u	r
(1)	560 $m^3 day^{-1}$	0·052 m.	7·6 min.	10 m.	1·0	0·5	1·0	302 m.
(2)	560 $m^3 day^{-1}$	0·035 m.	4·6 min.	10 m.	1·0	—	1·0	302 m.

CALCULATIONS

MATCHPOINT 1

$$T = \frac{560 \times 1·0}{4\pi \times 0·052} = 860\ m^3 day^{-1} m^{-1}$$

$$S = \frac{4 \times 860 \times 1·0 \times 7·6}{1440 (302)^2} = 2·0 \times 10^{-4}$$

$$p' = \frac{860 \times 10 \times (0·5)^2}{(302)^2} = 2·4 \times 10^{-2}\ m^3 day^{-1} m^{-2}$$

MATCHPOINT 2

$$T = \frac{560 \times 1·0}{4\pi \times 0·035} = \ m^3 day^{-1} m^{-1}$$

$$S = \frac{4 \times 1280 \times 1·0 \times 4·6}{1440 \times (302)^2} = 1·8 \times 10^{-4}$$

$p' = 0$

where

S = Storage Coefficient (dimensionless)

t = time

r = Distance to observation hole

* L = unit of Length

t = time unit

T = Transmissivity ($L^3 t^{-1} L^{-1}$)

Q = Pumping rate ($L^3 t^{-1}$)

Δ = Drawdown (L)

W(u r/B) = function of u (well function for leaky artesian aquifer)

p' = Hydraulic conductivity of confining bed.

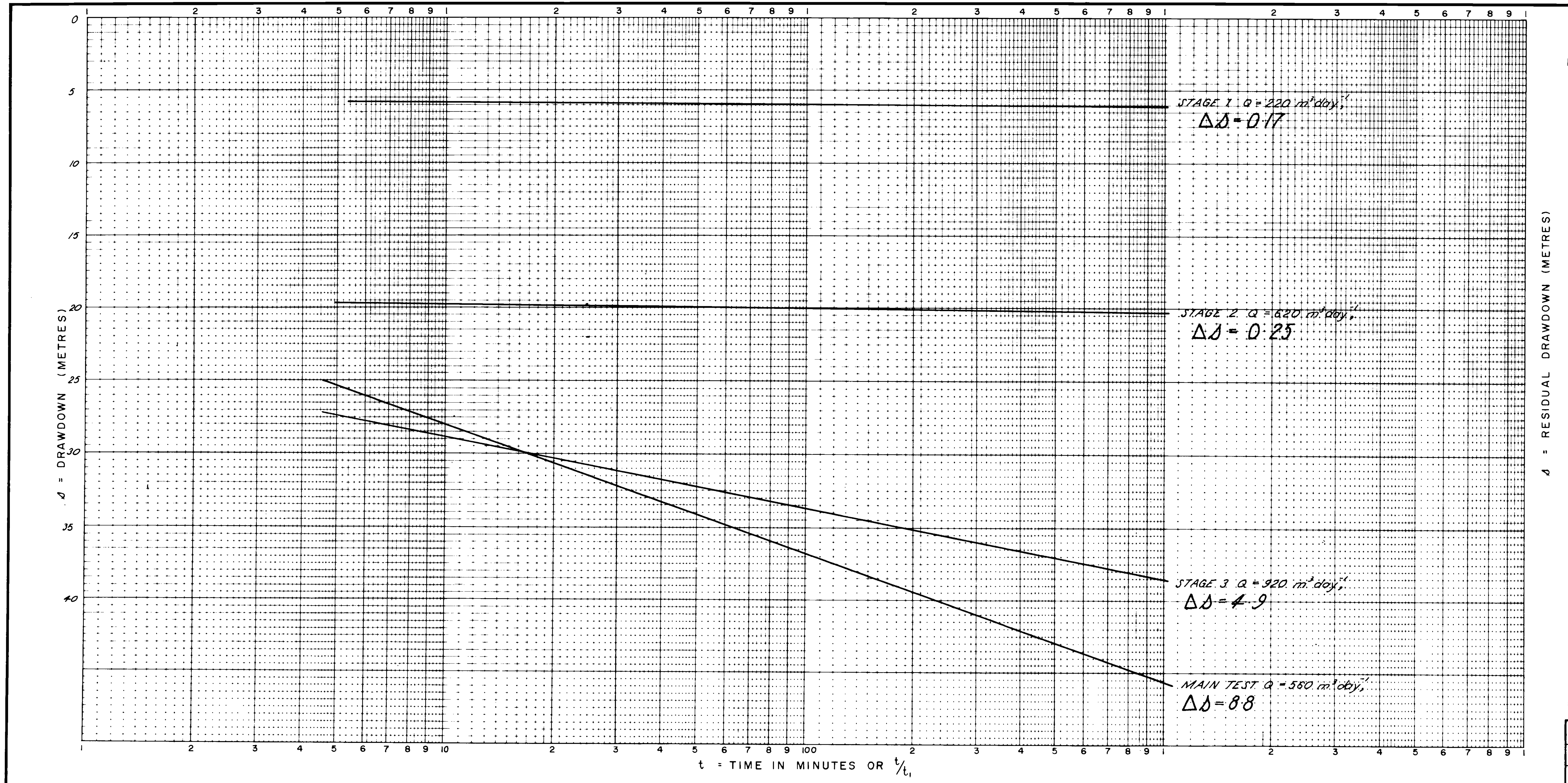
m' = thickness of confining bed

APP. III

FIG. 16

HYDROGEOLOGY SECTION	DEPARTMENT OF MINES - SOUTH AUSTRALIA	D.M. 173/77
COMPILED: J.D.W.	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE: 27/7/77
DRN: L.P.R. CHD:	MAIN TEST OBSERVATION WELL HC-3	DRG. NO. 77-832

No. C9 953 MH



BOREHOLE STATE/UNIT No. 7034.000.WW00018

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

$$T = \frac{0{\cdot}183 \times Q}{\Delta_s} \qquad S = \frac{2{\cdot}25 \times T t_o}{r^2}$$

In which

T = Transmissivity (m³/day/m)

Q = Pumping Rate (m³/day)

Δ_s = Drawdown per log cycle (m)

S = Storage Coefficient

t_o = Zero drawdown time (mins)

r = Distance to Observation Bore (m)

1 day = $8{\cdot}64 \times 10^4$ secs.

DATA

Q	Δ_s	t_o	r

CALCULATIONS

* Available drawdown = $\ell_1 - \ell_2$

APP. III FIG. 17

ENGINEERING DIVISION	DEPARTMENT OF MINES—SOUTH AUSTRALIA	D.M. 173/77
COMPILED J.D.W	HONEYMOON DEPOSIT URANIUM LEACHING PROJECT	DATE 5-9-77
DRN L.P.R. CKD	COMPARISON OF DRAWDOWN RATES IN PRODUCTION WELL	PLAN NUMBER 77-833

P.F. No. 69—953 MH

APPENDIX IV

WELL LEVELLING DATA AND DISCUSSION OF GROUNDWATER MOVEMENT AT THE HONEYMOON SITE

Groundwater movement at the test site

Prior to this study the question of groundwater movement was unresolved. Various opinions about movement directions and the possibility of zero movement had been expressed. This appendix presents and discusses the evidence for significant movement in the palaeochannel aquifers.

1. General considerations

The site is at an approximate elevation of 120 metres, on a gently sloping plain which drains towards Lake Frome which is at sea-level.

It is common in South Australia for groundwater recharge to occur where streams emerge from ranges and flow across plains underlain by essentially flat-lying sediments. In most cases studied the ultimate groundwater sink is the sea or the River Murray, but Lake Frome is no different in principle.

Some groundwater flow from all the ranges surrounding the Frome Embayment, towards the Lake is therefore to be expected.

Unfortunately there is no surface water measurement undertaken in the area, and neither losses from the ephemeral streams nor their water quality have been studied.

2. Potentiometric contours

Wherever adequate data is available, contours can be drawn from which flowlines can be deduced (Figs 4 and 6 of main report).

These all show flow from the ranges to lake, implying that active recharge does occur near the ranges. The Honeymoon area is not significantly different except that the Tertiary aquifers are restricted in extent.

3. Potentiometric levels at the Honeymoon site

The four wells at the site have different potentiometric levels, and two wells 3 km to the east are also different (Figure 1 in Appendix III). Although consistent gradients are not indicated from the wells (discussed in 4. below) these variations could not occur in a continuous, unpumped aquifer without movement of the water.

4. Water levels in the test well 7034000WW00018

The three aquifers had different water levels. These were measured carefully during drilling and after completion, with consistent results. The aquifers merge into one another elsewhere in the channel (D. Brunt, Mines Administration Pty. Ltd., pers. comm., 1977).

Again this is an indication of flow in three aquifers with slightly different transmissivities.

5. Estimation of velocity of groundwater flow

Measurement of hydraulic gradients between the Honeymoon site and two wells to the east was not successful.

The difference in water levels between the three aquifers at the test site was found to be 1.4 metres. This is the same order of magnitude that might be expected of water level differences between observation wells several kilometres apart in the Frome Embayment. Any "gradients" observed may thus be unreliable, if it is not certain that the wells measured are completed with hydraulic separation of the aquifers. It is not known whether the aquifers have consistently different water levels at points distant from the test site.

The difference in water level between the two close wells 3 km east of the test site is in fact greater than the difference between the lower water level of the two and levels in wells at the test site. This is an indicator of the 2 wells unreliability as measuring points for regional hydraulic gradients in the basal sand aquifer.

There is a westerly gradient between the 3 km distant wells and the test site, but an easterly gradient at the test site, where the measurements are inherently more reliable, although with smaller differences between the measured water levels. Levels were all measured with one water level probe, and all wells were accurately levelled with respect to HC3, so they can be considered reliable indicators of easterly flow at the test site.

The hydraulic gradient data near the test site are not reliable enough to estimate flow in the aquifer system in the light of the contradictory flow directions derived from the six wells measured. If reliable estimates of flow rate are required, observation wells in the basal sand must be constructed in the palaeochannel system within 5-25 km of the test site.

An order of magnitude estimate of the maximum flow rate can be obtained by ignoring the site data and assigning a hydraulic gradient equal to the surface gradient (about 0.001, from Ker, 1966). Ker's hydraulic gradient for water in Tertiary/Quaternary aquifers north-east of the site is about 0.003, a similar figure.

Then using Darcy's Law in the form

$$\text{Velocity} = \frac{\text{Hydraulic Gradient x Hydraulic Conductivity}}{\text{Porosity}}$$

$$= \frac{0.001 \text{ x } 500}{0.3 \text{ x } 12} \text{ x } 365 \text{ m year}^{-1}$$

$= 50 \text{ m year}^{-1}$ (or 150 m year^{-1} if 0.003 is used for the hydraulic gradient)

(Hydraulic conductivity = Transmissivity/Aquifer thickness)

The real hydraulic gradient is likely to be lower than 0.001, because the channels meander, however the calculation gives a reasonable order of magnitude estimate of the natural rate of flow.

DEPARTMENT OF MINES - SOUTH AUSTRALIA
BOREHOLE LEVEL SURVEY

Date of Survey 31-8-1977
Datum AHD
Surveyor ERKELENS

AREA East of Kulkaroo H.S.

Copy to	Date
C.S.D.	

Hundred Name	Hundred No.	Sec. No.	Bore No.	Field Survey No.	Obs. Bore No.	R.L. Peg m	R.L. Ground m	R.L. Reference m	Casing above Ground m	Level Book No.	Level Book Page	Remarks	C.S.D. Ledger	C.S.D. O.B.S.	C.S.D. B.R.C.
	State Number														
[illegible]					Bore 1	120.067	120.067	120.084		483	10	T.O.C. Highest Point			
[illegible]					" 2	119.851	119.851 ~~120.142~~	120.142		"	11	"			
					HC 1	119.781	119.781	119.862		"	12	"			
					HC 2A	120.466	120.466	120.479		"	12	"			
					HC 3	119.800	119.800	119.786		"	10	[illegible] "			
					QD 14	120.816	120.816	121.164	0.348	"	12	Top of Flange.			
		ALL LEVELS TAKEN WITH RESPECT TO HC-3													
		50 x 50 mm G.L. PEGS AT ALL WELLS													

APPENDIX V

WELL CONSTRUCTION REQUIREMENTS-METHODS FOR INJECTION-EXTRACTION WELLS AT THE HONEYMOON SITE

APPENDIX V

CONTENTS

General

The only satisfactory method of completing production wells into a confined aquifer to prevent leakage of water, via the well, into or out of the aquifer, is to cement the well casing at the top of the aquifer, and to drill on into the aquifer beneath the cemented casing shoe.

In practice this is achieved by drilling an oversize hole to the top of the aquifer, setting the casing and filling the annulus with cement from the bottom up, by displacing the cement from inside the well column with a calculated volume of water. Return of cement to the surface demonstrates positively that the annulus between the casing and the wall of the hole has been filled with cement, i.e. that the cement has not been lost to the aquifer, or higher formations. The "follow-up water" which forces the cement up the annulus, is calculated to leave a few metres of cement inside the casing, to demonstrate positively that there is effective cementing at the bottom of the casing.

It is recommended that the casing be set 1 metre minimum into the aquifer to ensure that clays of the confining bed do not settle over the screen during development of the well. This is recommended for all wells but may be impractical where the orebody is at the very top of the aquifer.

This Appendix is a standard explanation of the reasons for, principles and practice of pressure cementing techniques in water wells, prepared by D.J. Stanley, a drilling engineer of the S.A. Department of Mines.

Figure 1 shows the construction recommended for the Honeymoon site.

PRESSURE CEMENTING CASING IN WATER WELLS

1. INTRODUCTION

The object of pressure cementing casing in a water well is to permanently protect our fresh water resources from contamination or from loss as the case may be.

For this discussion we are assuming a stratified geological sequence with permeable formations above the fresh water bearing aquifer. This geological phenomenon is true of the Great Artesian Basin, and many other sedimentary basins.

Comparing uncemented and cemented wells, it may be seen how loss or damage occurring in uncemented wells can be prevented by an impermeable sheaf of cement across the face of the formations:

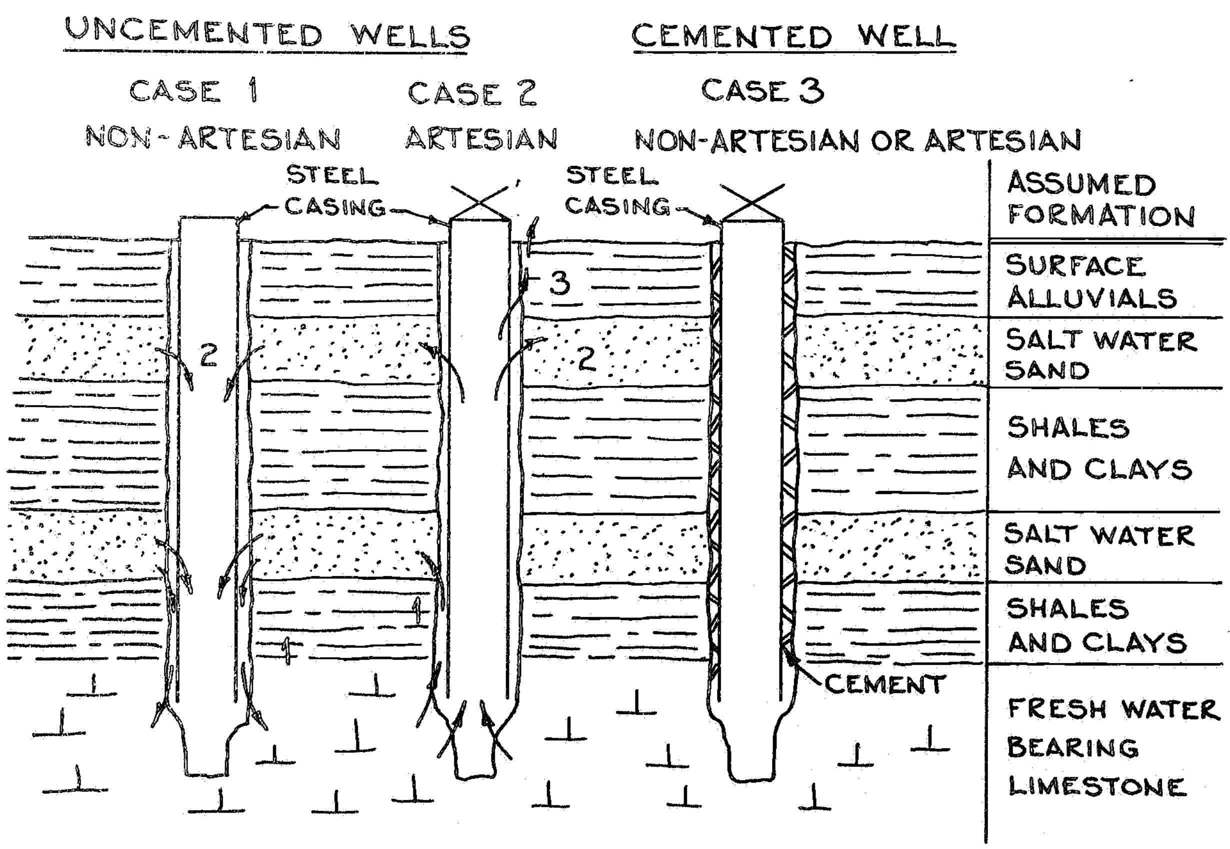


DIAGRAM 1

CASE 1

Contamination of the non artesian fresh water aquifer may occur in two ways.

1. by salt water from an upper sand leaking down behind the casing into the fresh water formation;

2. by the casing failing - getting holes in it - allowing salt water to flow into the well and drain into the fresh water bearing formation.

The displacing of fresh water out of an aquifer by the downward migration of salt water, contaminates the aquifer and will eventually pollute all producing wells in the vicinity unless corrected.

CASE 2

In an artesian well, where the fresh water is under pressure, loss of water may occur in three ways.

1. by fresh water being forced up behind the casing into a higher permeable zone, or surface, as the case may be;

2. by the casing failing and the water under pressure being lost to an upper thief zone;

3. by the casing failing and fresh water flowing at the surface out of control.

The uncontrolled flow of water results in a loss of our resources, plus a reduction in the pressure drive of the aquifer.

The remedial measures required to correct a well with fluid communication between the different zones (or surface) is both difficult and expensive. In many instances it would be cheaper to fill the whole well with cement, redrill and complete a replacement well than attempt rehabilitation of the original bore.

Since steel casing has a limited life in a well due to corrosion - it may be said that SOMETIME IN ITS LIFE EVERY UNCEMENTED WELL WILL ALLOW FLUID MIGRATION BETWEEN THE FORMATIONS OR SURFACE CAUSING CONTAMINATION, POLLUTION AND/OR LOSS OF OUR LIMITED NATURAL RESOURCE OF FRESH WATER.

The best known safeguard against this occurrence is pressure cementing.

CASE 3

The reasons for pressure cementing the casing in the water well is to form an impermeable barrier on the face of the formations, preventing the migration of fluids from one formation to another for an indefinite period of time, regardless of whether the casing is corroded or not. In the artesian well the cement around the well-head also serves as the basis upon which flow control equipment can be mounted at completion.

Pressure cementing has become standard practice in water well completions. It is a simple technique but requires increased capital, equipment and additional effort. It should also be practised on a community basis because a properly constructed well can be adversely influenced - and even ruined - by an adjoining improperly constructed well. The increased initial cost and effort, however, should be more than compensated by the resultant trouble-free operation throughout its producing life.

2. METHODS OF CASING WELLS

a. Rotary Drilling: Since casing is run in an over-sized hole, there is sufficient clearance between the casing and the formation for filling with cement. Cementing casing is standard procedure.

b. Cable Tool Drilling: There are two alternative techniques available -

i Drill an over-sized hole using drilling mud to stabilise sides and cement casing in a similar manner to the rotary technique. This method is satisfactory where the depth, water quality and quantity of the producing aquifer are known.

ii. Drill with standard cable tool techniques, using casing to stabilise the hole. This allows reliable sampling of all waters cut together with improved sand sampling for screen size determination. In order to effectively pressure cement this well a second casing string must be run inside the initial casing, the latter being withdrawn to expose the formation to the cement. For example:

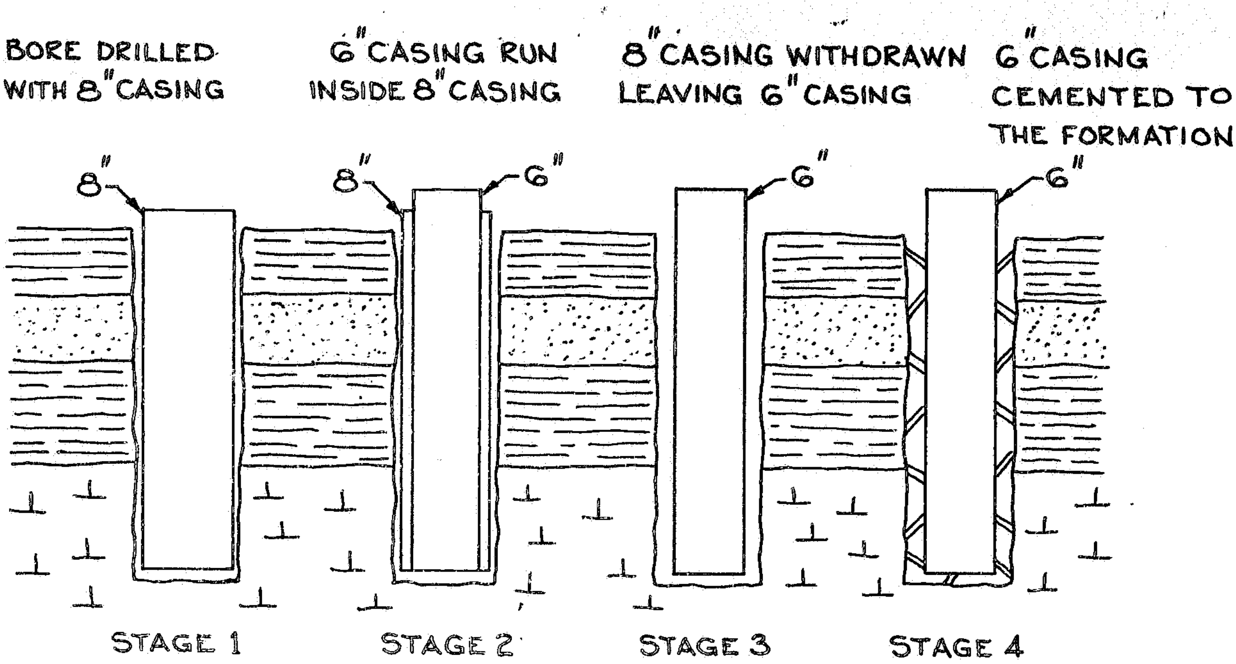


DIAGRAM 2

To prevent collapse of the formation in Stage 3 when the outside casing is withdrawn, the hole must be filled with drilling mud which exerts a hydrostatic pressure against the formation to hold it in place. (This stage is reached automatically when drilling with mud). The outside casing must be withdrawn before cementing since the bond of the cement to the formation is the only positive method of preventing migration of fluids behind the casing.

c. Deep Wells: Discussion so far has been for shallow wells to approximately 150 m. In the Great Artesian Basin the depths are up to 1 500 m, in which case multiple casing strings are required.

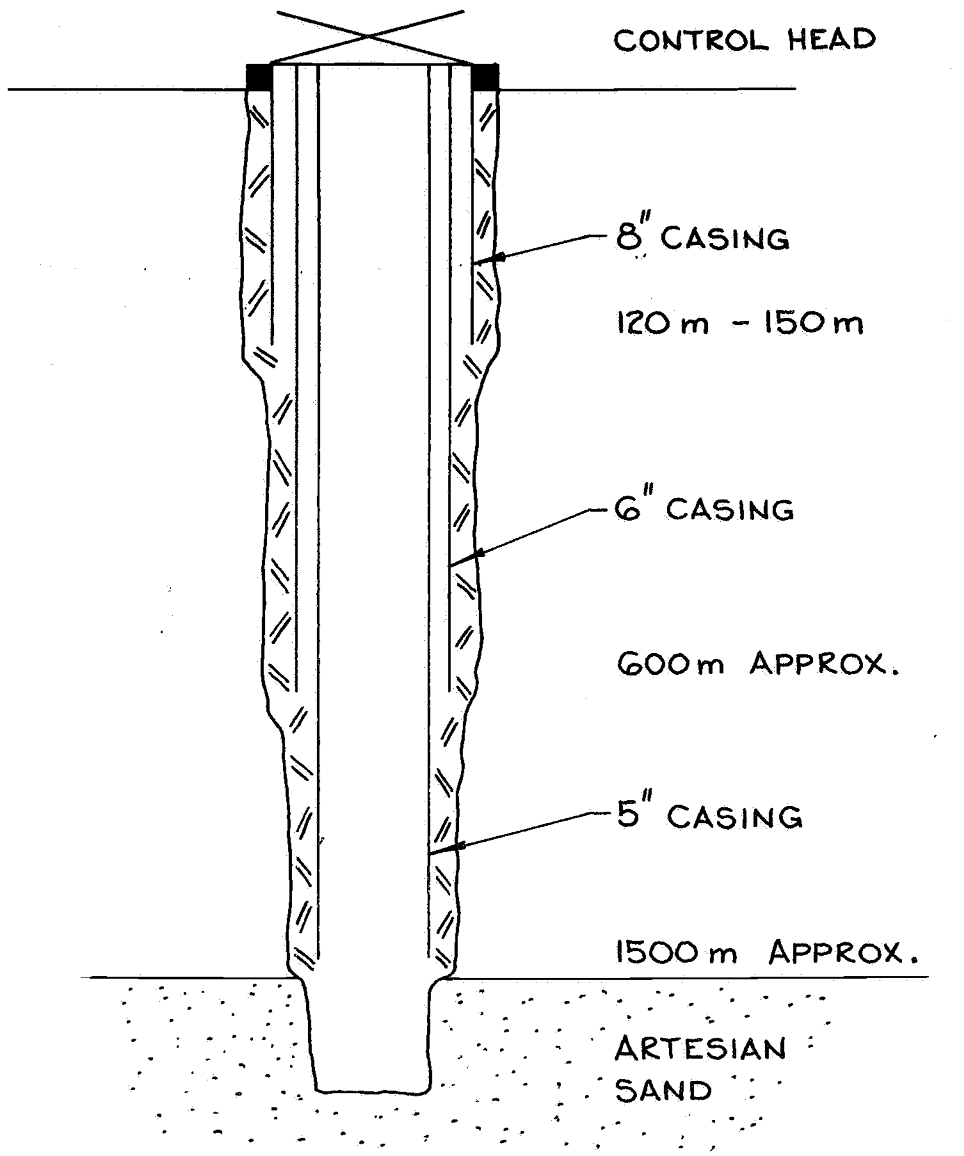


DIAGRAM 3

c. (Continued)

To achieve the advantages of a cemented well, each casing length should be cemented from its shoe (or bottom) back into the previous casing shoe, or surface as the case may be.

In practice the difficulties associated with drilling and pressure cementing a deep cable tool well, are such that this method could not economically compete with a rotary drilling machine.

3. PRESSURE CEMENTING METHODS

a. General

The technique involves loading the inside of the casing with a calculated volume of cement slurry and displacing this cement (by pumping other fluid into the casing behind it), around the bottom of the casing and up the outside:

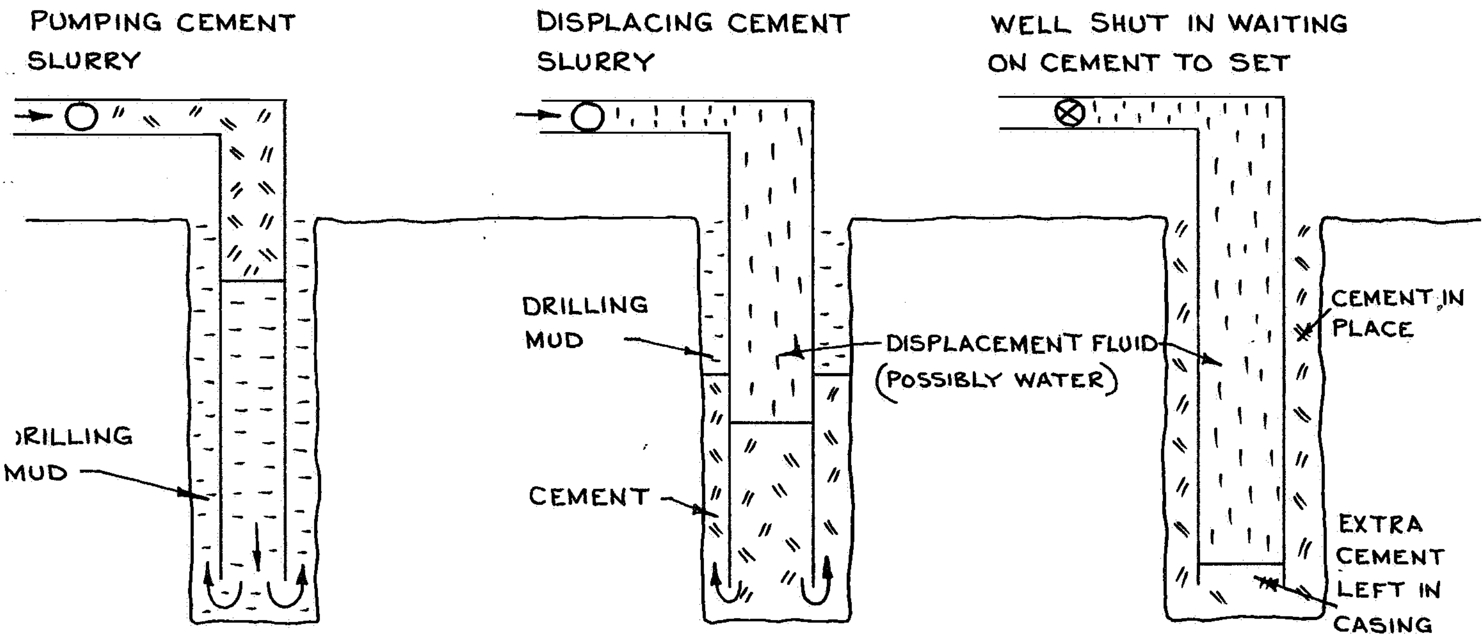


DIAGRAM 4.

The pressure cementing is a technical operation in which there are two essentials:

- Equipment must be in first-class order and designed for the operation. Pump failure could result in cement setting in the wrong place.
- Volumes of cement and fluids must be closely calculated and carefully measured.

b. <u>Practice</u>

In actual practice a number of techniques have evolved in oil well drilling and completion operations which have been adapted to meet water well drilling requirements.

The basic requirement is to ensure minimum contamination of the cement by the drilling mud - while pumping the cement into postion. This is achieved by separating the mud and cement by a drillable cementing plug and displacing the cement with water. (This is satisfactory for shallow holes, but on deeper wells the cement must be displaced by mud to prevent excessive pump pressure. The cement in this case should be separated from the mud by both top and bottom plugs).

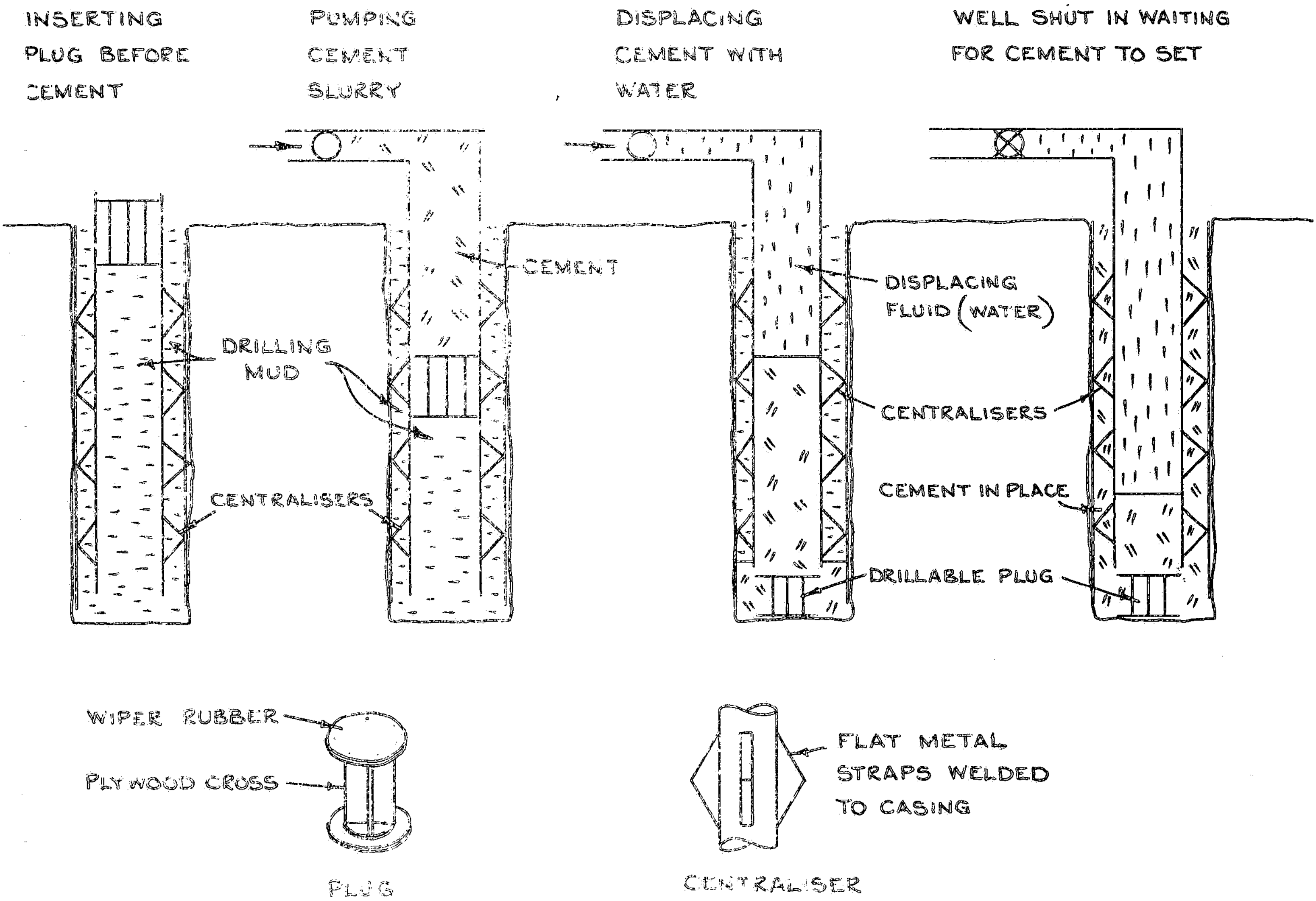


DIAGRAM 5

Using the above pressure cementing method, the calculation and measurement of the water volume displacing the cement is of critical importance. If the cement is over-displaced and water is pumped behind the casing, then the operation is <u>NOT</u> successful.

Other techniques recommended include:

- Screw casing joints tightly to ensure no joint leakage.
- The use of good drilling mud to ensure stability of the hole. The drilling mud should be as 'thin' as possible.
- Keeping the hole <u>filled</u> with mud while recovering the outside casing string to prevent hole collapse.
- Adequate circulation of mud around the casing before pumping the cement.
- The use of centralisers, placed every 20 m, on the outside of the casing to ensure an even thickness of cement.
- Moving the casing while displacing the cement to reduce the possibility of cement channelling.
- Shutting the well in under pressure to prevent the heavy cement equalising back into the casing before it sets.
- The use of ready mixed cement slurry cannot always be recommended due to screenings left in the mix. Often it is easier to mix the cement required on site.
- The use of additives to the cement to speed setting time and remove lumps.

4. LIMITATIONS OF PRESSURE CEMENTING TO SURFACE

In exceptional circumstances, cement returns to the surface cannot be obtained due to lost circulation - such as cavernous limestone - which occur above the casing shoe. If drilling in an unknown area, and these zones are not recognised, their presence will be determined when filling the hole with mud before pressure cementing. In these circumstances permanent protection of the fresh water can be gained by using plastic-coated steel pipe now available on the market.

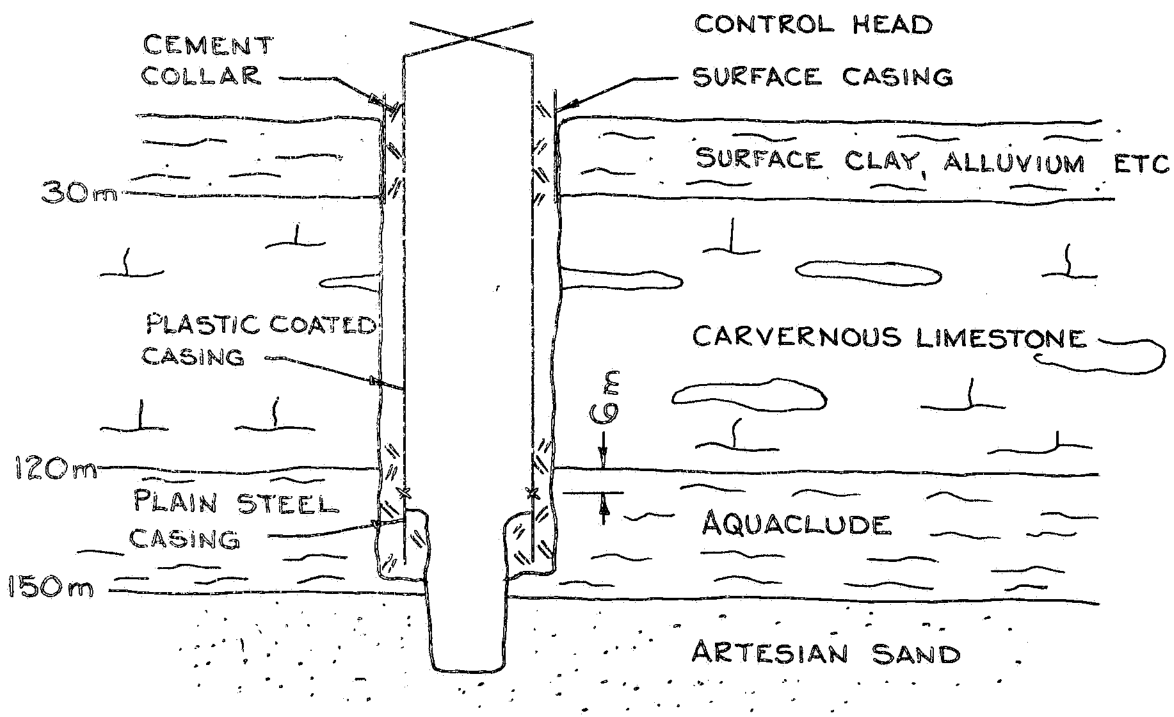


DIAGRAM G

In the above circumstances, the inert plastic coating protects the steel casing from external corrosion.

The drilling procedure would be:

- Drill and case the unconsolidated surface formations.
- Drill open hole below the surface casing through the limestone, which stands open, into the aquaclude.
- Run combined string of steel casing and plastic-coated steel casing. The top of the plain steel casing is to be below the top of the aquaclude.
- Pressure cement around the outside of the casing - with sufficient cement volume to fill annulus to surface.

The actual specification and drilling procedure must vary, dependent on depths, water pressures, temperature, type of formation, type of screen and the type of drilling equipment. Each specification must be adapted to suit the particular circumstances.

5. CONCLUSIONS

(1) All water bores, in a stratified geological section, should be completed in such a manner as to permanently prevent fluid migration between formations (or surface) which result in contamination, pollution and/or loss of our fresh water resources.

(2) Pressure cementing is the best available method of achieving this permanent protection when using steel casing.

(3) Due to the variables involved it is impossible to define a standard specification for well construction.

(4) Pressure cementing is a technical operation which requires the correct equipment and full understanding of the problems involved.

D. STANLEY
DRILLING & MECHANICAL BRANCH
S.A. DEPARTMENT OF MINES

25/5/76

APPENDIX OF PRACTICAL INFORMATION

1. PRESSURE CEMENTING REQUIREMENTS

A. Subsurface Equipment:

- Drillable Plug
- Centralisers.

B. Surface Equipment:

- Cementing Head.
- 2" H.P. valve for shutting well in under pressure while waiting on cement to set.
- Pressure hose from pump to cementing head with union connections.
- Pump - a positive displacement slurry (mud) pump capable of pumping over 50 gallons per minute at 500 p.s.i.
- Pump suction to reach cement slurry container, mud pit and water.
- Tanks of sufficient capacity for mixing mud, mixing cement if necessary, and measuring displacement fluid.
- Mud mixing hopper.

C. Other Requirements:

- Drilling mud additives.
- Cement.
- Waste Pit, for collecting the mud and cement displaced from the hole.

2. PRESSURE CEMENTING PROCEDURE (Assuming initial hole is drilled and cased):

(1) Place centraliser on bottom joint and spaced 20 m intervals on the casing.

(2) Run the casing. (Fill casing with mud; recover outside casing if necessary). Keep well full of mud at all times.

(3) Attach cementing head and circulate mud around casing and prepare to cement.

(4) Remove cementing head and place in drillable plug.

(5) Replace head; pump in required quantity of cement.

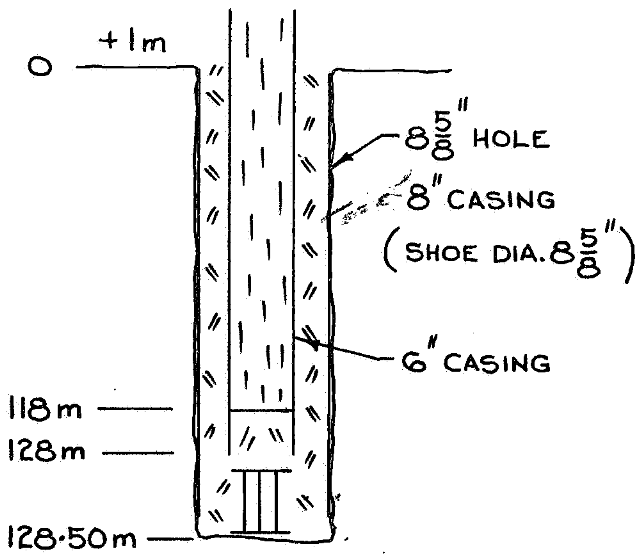
(6) Displace cement with water. If possible the casing to be moved while displacing cement.

(7) While displacing cement the mud returns should be run into pits to prevent spreading around the location. Shut in casing at pumping pressure.

(8) Wait on cement 48 hours; actual time will depend on accelerating additives and can be adjusted from setting time of surface cement samples.

(9) Bleea off casing pressure, remove cementing head, drill out cement and complete as required.

3. <u>SAMPLE CALCULATIONS</u>



<u>Assume</u>:

- Depth of hole 128.5 m.
- Drilled with 8" casing, the outside shoe diameter being 8-5/8".
- Cement 6" casing at depth of 128 m.
- Require minimum 10 m cement inside casing, to be drilled out after setting.
- Use cement slurry of 24 litres of water per sack of cement.

a. MUD REQUIRED

To calculate the capacity of the hole, refer Page 6 8-5/8" hole (assume next size up at 8¾") has a capacity of 38.794 litres/m. Since depth is 128.50 m, then the total volume is:

128.50 x 38.794 = 4985 litres

This ignores the displacement of mud by the 6" steel casing. However, this extra volume is required in the surface pits for the pump suction while circulating.

b. MUD MIX

A number of different types of drilling muds are available on the market which will stabilise the hole prior to cementing. These muds can be modified to meet various drilling conditions and quality of make up water. The mud should be kept as 'thin' as possible to assist circulation and decrease the possibility of cement channelling on the outside of the casing.

c. CEMENT REQUIRED

(The lightest cement slurry recommended for use is 27 litres (6 gallons) of water per sack of cement).

Assuming slurry mix of 24 litres of water per sack of cement, then quantity required is:

- 128.5 m between 6" casing and 8-5/8" hole (assuming 8¾" hole) holds 0.558 sacks of cement per metre (from table on Page 8 for 24 litres per sack mix).

128.50 x 0.558 = 72 sacks.

- 10 m of cement is to be left in the 6" casing to be drilled out, plus 0.50 m from casing shoe to full depth. 6" casing holds 0.436 sacks cement per metre (24 litres per sack mix on Page).

  Thus 10.50 x .436 = 5 sacks.

Thus cement required is 77 sacks (i.e. 72 sacks + 5 sacks) to which must be added allowance for loss, out of gauge hole, cement left in tanks, pumps etc.

To the theoretical quantity of cement required add 10% or 5 sacks cement whichever is greater.

Thus quantity of cement required is:

77 + 8 = 85 sacks.

Thus the required cement mixture is 85 sacks of cement mixed with 2040 litres of water.

(The Cement Tables attached are based on the fact that each sack of cement has an absolute volume of 12.8 litres. Thus a mixture of 24 litres of water and one sack of cement has a slurry volume of 36.8 litres etc.).

d. DISPLACING VOLUME

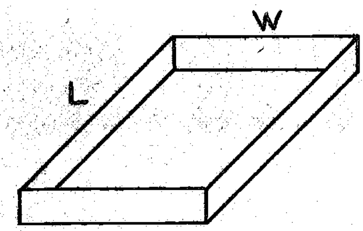
Total length of casing above the required top of the cement is 118 m + 1 m at surface = 119 m (6" casing holds 16.033 litres for every metre).

Displacing volume = 119 x 16.033 = 1908 litres. Provided the pump and lines to the cementing head are full of fluid, pumping in 1908 litres of follow-on fluid should displace the top of cement to 118 m.

Pumping rate should be as fast as possible.

e. TANK CALIBRATION

(1) Assuming a rectangular tank, the volume in litres per centimetre of depth can be determined from the following:



L x W x 0.001 = litres per cm depth where L and W are in cms. Thus if the inside length (L) is 150 cm and the inside width (W) is 102 cm, then the volume per cm is:

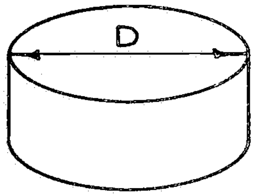
L = 150 cm

W = 102 cm

Then 150 x 102 x 0.001 = 15.3 litres/cm of depth.

Each tank should be measured and marked on the side with the volume per cm of depth.

(2) Assuming a round tank, the volume in litres per centimetre can be determined approximately from the following:



D x D x .000786 litres per cm where D is the inside diameter of the tank in cm. (Take the average of a number of readings to determine the average diameter, thus allowing for tank distortion). Thus if the inside diameter of the tank is 120 cm (i.e. 1 m 20 cm) then

120 x 120 x .000786 = 11.3 litres/cm of depth.

f. <u>MEASURING DISPLACEMENT VOLUME</u>

In our example 1908 litres are required from the rectangular tank which holds 15.3 litres per cm. In other words, the number of cms of fluid to be pumped down after the cement are:

$$\frac{1908}{15.3} = 124.7 \text{ cms (or 1.247 m) of fluid from tank.}$$

(N.B. Allowances may have to be made from pump and hose volumes).

4. CAPACITY OF HOLE

ize of ole Inches	Litres per m	CEMENT (SACKS PER METRE) 18 l/sack	21 l/sack	24 l/sack	27 l/sack	30 l/sack
2	2.027	.066	.060	.055	.051	.047
2-1/8	2.287	.074	.068	.062	.057	.053
2-1/4	2.564	.083	.076	.070	.064	.060
2-3/8	2.869	.093	.085	.078	.072	.067
2-1/2	3.167	.103	.094	.086	.080	.074
2-5/8	3.491	.113	.103	.095	.088	.082
2-3/4	3.831	.124	.113	.104	.096	.089
2-7/8	4.188	.136	.124	.114	.105	.098
3	4.560	.148	.135	.124	.115	.106
3-1/8	4.948	.161	.146	.134	.124	.116
3-1/4	5.351	.174	.158	.145	.134	.125
3-3/8	5.771	.187	.171	.157	.145	.135
3-1/2	6.207	.202	.184	.169	.156	.145
3-5/8	6.658	.216	.197	.181	.167	.156
3-3/4	7.125	.231	.211	.194	.179	.166
3-7/8	7.608	.247	.225	.207	.191	.178
4	8.107	.263	.240	.220	.204	.189
4-1/4	9.152	.297	.271	.249	.230	.214
4-1/2	10.261	.333	.304	.279	.258	.240
4-3/4	11.432	.371	.338	.311	.287	.267
5	12.667	.411	.375	.344	.318	.296
5-1/4	13.965	.453	.413	.379	.351	.326
5-1/2	15.328	.498	.453	.416	.385	.358
5-3/4	16.752	.544	.496	.455	.421	.391
6	18.241	.592	.540	.496	.458	.426
6-1/4	19.792	.642	.586	.538	.497	.462
6-1/2	21.408	.695	.633	.582	.538	.500
6-3/4	23.086	.750	.683	.627	.580	.539
7	24.828	.806	.735	.675	.624	.580
7-1/4	26.633	.865	.788	.724	.669	.622
7-1/2	28.502	.925	.843	.774	.716	.666
7-3/4	30.433	.988	.900	.827	.765	.711

Size of Hole Inches	Litres per m	CEMENT (SACKS PER METRE) 18 l/sack	21 L/sack	24 l/sack	27 l/sack	30 l/sack
8	32.429	1.053	.959	.881	.815	.758
8-1/4	34.486	1.120	1.020	.937	.866	.806
8-1/2	36.609	1.189	1.083	.995	.920	.855
8-3/4	38.794	1.259	1.148	1.054	.975	.906
9	41.043	1.332	1.214	1.115	1.031	.959
9-1/4	43.354	1.408	1.283	1.178	1.089	1.013
9-1/2	45.730	1.485	1.353	1.243	1.149	1.068
9-3/4	48.167	1.564	1.425	1.309	1.210	1.125
10	50.670	1.645	1.499	1.377	1.273	1.184
10-1/4	53.234	1.728	1.575	1.446	1.337	1.244
10-1/2	55.863	1.814	1.653	1.518	1.404	1.305
10-3/4	58.555	1.901	1.732	1.591	1.471	1.368
11	61.311	1.991	1.814	1.666	1.540	1.432
11-1/4	64.128	2.082	1.897	1.743	1.611	1.498
11-1/2	67.011	2.176	1.982	1.821	1.684	1.566
11-3/4	69.955	2.271	2.070	1.901	1.758	1.634
12	72.965	2.369	2.159	1.983	1.833	1.705
12-1/4	76.036	2.469	2.249	2.066	1.910	1.776
12-1/2	79.172	2.570	2.342	2.151	1.989	1.850
12-3/4	82.370	2.674	2.437	2.238	2.070	1.924
13	85.632	2.780	2.533	2.327	2.152	2.001
13-1/4	88.957	2.888	2.632	2.417	2.235	2.078
13-1/2	92.346	2.998	2.732	2.509	2.320	2.158
13-3/4	95.797	3.110	2.834	2.603	2.407	2.238
14	99.313	3.224	2.938	2.699	2.495	2.320
14-1/4	102.891	3.341	3.044	2.796	2.585	2.404
14-1/2	106.533	3.459	3.152	2.895	2.677	2.489
14-3/4	110.238	3.573	3.261	2.996	2.771	2.576
15	114.007	3.701	3.373	3.098	2.864	2.664
15-1/4	117.839	3.826	3.486	3.202	2.961	2.753
15-1/2	121.734	3.952	3.601	3.308	3.059	2.844
15-3/4	125.692	4.081	3.719	3.416	3.158	2.937
16	129.715	4.211	3.838	3.525	3.259	3.031
16-1/4	133.799	4.344	3.958	3.636	3.362	3.126
16-1/2	137.949	4.479	4.081	3.749	3.466	3.223
16-3/4	142.160	4.616	4.206	3.863	3.572	3.321

Size of Hole Inches	Litres per m	CEMENT (SACKS PER METRES)				
		18 l/sack	21 l/sack	24 l/sack	27 l/sack	30 l/sack
17	146.436	4.754	4.332	3.979	3.679	3.421
17-1/4	150.774	4.895	4.461	4.097	3.788	3.523
17-1/2	155.177	5.038	4.591	4.217	3.899	3.626
17-3/4	159.641	5.183	4.723	4.338	4.011	3.730
18	164.171	5.330	4.857	4.461	4.125	3.836
18-1/4	168.762	5.479	4.993	4.586	4.240	3.943
18-1/2	173.418	5.630	5.131	4.712	4.357	4.052
18-3/4	178.136	5.784	5.270	4.841	4.476	4.162
19	182.918	5.939	5.412	4.970	4.596	4.274
19-1/4	187.763	6.096	5.555	5.102	4.718	4.387
19-1/2	192.672	6.256	5.700	5.236	4.841	4.502
19-3/4	197.644	6.417	5.847	5.371	4.966	4.618
20	202.680	6.580	5.996	5.508	5.092	4.735

5. CAPACITY OF CASING

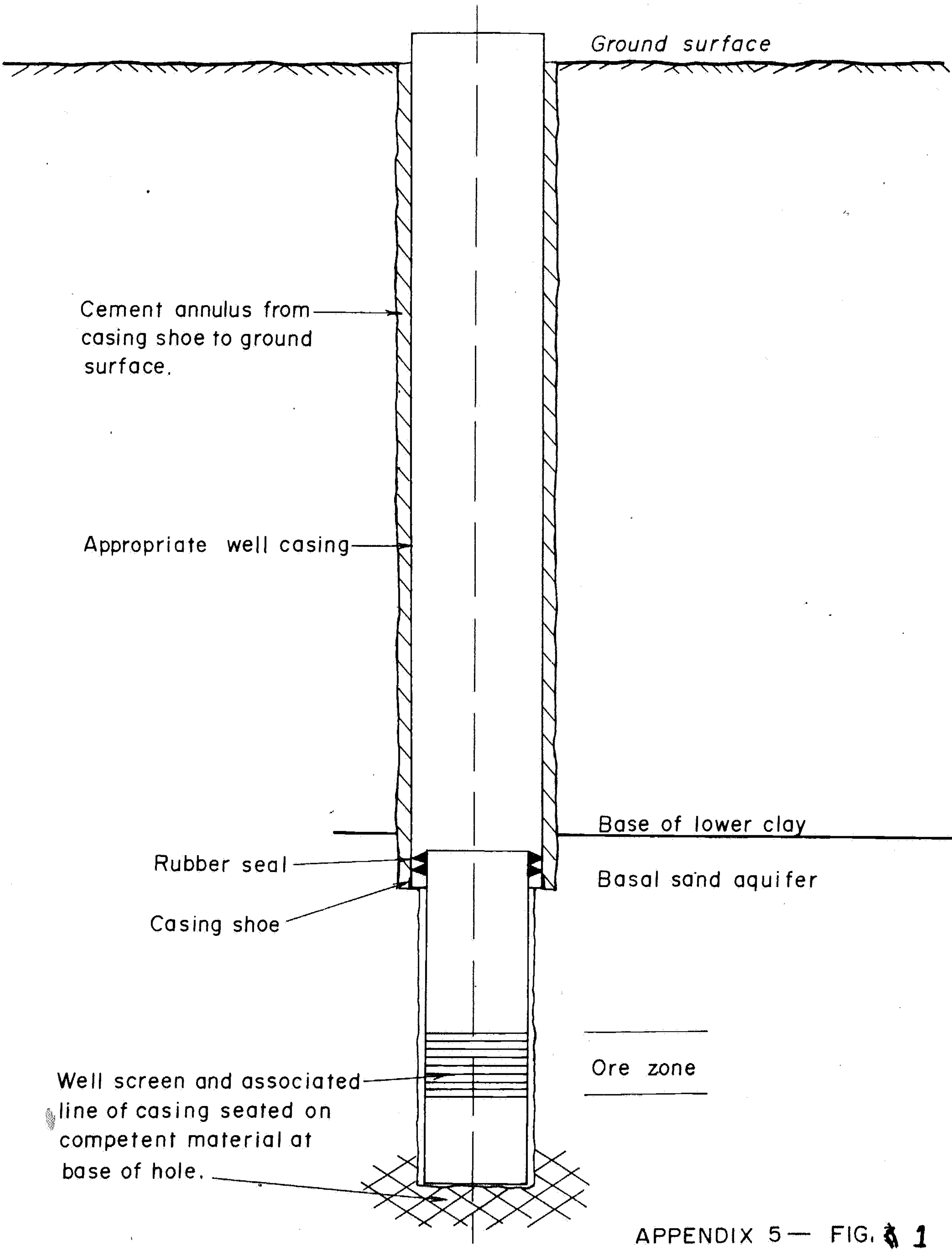
Outside Diameter Ins.	Outside Diameter mms	Wall Thickness Ins.	Wall Thickness mms	Capacity l/metre	CEMENT (SACKS PER METRE) 18 l/sack	21 l/sack	24 l/sack	27 l/sack	30 l/sack
4	101.6	.1875	4.76	6.658	.216	.197	.181	.167	.156
5	127	.1875	4.76	10.840	.352	.321	.295	.272	.253
5	127	.25	6.35	10.261	.333	.303	.279	.258	.240
5-1/2	139.7	.212	5.38	13.056	.424	.386	.355	.328	.305
6	152.4	.1875	4.76	16.033	.520	.474	.436	.403	.375
6-1/2	165.1	.211	5.36	18.719	.608	.554	.509	.457	.437
6-5/8	168.3	.219	5.56	19.396	.630	.574	.527	.487	.453
6-5/8	168.3	.25	6.35	19.009	.617	.562	.516	.478	.444
8	203.2	.281	7.14	28.033	.910	.829	.762	.704	.655
8	203.2	.25	6.35	28.502	.925	.843	.774	.716	.666
8-5/8	219.1	.25	6.35	33.450	1.086	.990	.909	.840	.782
10	254	.344	8.74	43.938	1.427	1.300	1.194	1.104	1.027
10-3/4	273.1	.25	6.35	53.236	1.728	1.575	1.447	1.338	1.244

6. VOLUME BETWEEN CASING AND HOLE

Size of Casing O.D.	Size of Hole Inches	Litres per m	CEMENT (SACKS PER METRE) 18 l/sack	21 l/sack	24 l/sack	27 l/sack	30 l/sack
	5	4.564	.148	.135	.124	.115	.107
	5-1/4	5.860	.190	.173	.159	.147	.137
	5-1/2	7.219	.234	.214	.196	.181	.169
	5-3/4	8.651	.281	.256	.235	.217	.202
4" (101.6mm)	6	10.142	.329	.300	.275	.255	.237
	6-1/4	11.692	.380	.346	.318	.294	.273
	6-1/2	13.306	.432	.394	.361	.334	.311
	6-3/4	14.974	.486	.443	.407	.372	.350
	7	16.702	.542	.494	.454	.420	.390
	6	5.578	.181	.165	.152	.140	.130
	6-1/4	7.128	.231	.211	.194	.179	.166
	6-1/2	8.742	.284	.259	.237	.220	.204
	6-3/4	10.442	.339	.309	.284	.262	.244
5" (127 mm)	7	12.156	.395	.360	.330	.305	.284
	7-1/4	13.961	.453	.413	.379	.351	.326
	7-1/2	15.838	.514	.468	.430	.398	.370
	7-3/4	17.761	.577	.525	.483	.446	.415
	8	19.761	.642	.585	.537	.496	.462
	6	2.914	.095	.086	.079	.073	.068
	6-1/4	4.465	.145	.132	.121	.112	.104
	6-1/2	6.080	.197	.180	.165	.153	.142
	6-3/4	7.758	.252	.230	.211	.195	.181
5-1/2" (139.4mm)	7	9.501	.308	.281	.258	.239	.222
	7-1/4	11.305	.367	.334	.307	.284	.264
	7-1/2	13.187	.428	.390	.358	.331	.308
	7-3/4	15.105	.490	.447	.410	.379	.353
	8	17.101	.555	.506	.465	.430	.400

Size of Casing O.D.	Size of Hole Inches	Litres per m	CEMENT (SACKS PER METRE) 18 l/sack	21 l/sack	24 l/sack	27 l/sack	30 l/sack
	7	6.592	.214	.195	.179	.166	.154
	7-1/4	8.396	.272	.248	.228	.211	.196
	7-1/2	10.260	.333	.303	.279	.258	.240
	7-3/4	12.201	.396	.361	.331	.306	.285
6" (152.4mm)	8	14.184	.460	.420	.385	.356	.331
	8-1/4	16.243	.527	.481	.441	.408	.380
	8-1/2	18.375	.596	.544	.499	.462	.429
	8-3/4	20.552	.667	.608	.558	.516	.480
	9	22.803	.740	.675	.620	.573	.533
	7	3.420	.111	.101	.093	.086	.080
	7-1/4	5.225	.170	.155	.142	.131	.122
	7-1/2	7.094	.230	.210	.193	.178	.166
	7-3/4	9.025	.293	.267	.245	.227	.211
6-1/2" (165.1mm)	8	11.021	.358	.326	.299	.277	.257
	8-1/4	13.078	.425	.387	.355	.329	.306
	8-1/2	15.201	.494	.450	.413	.382	.355
	8-3/4	17.385	.564	.514	.472	.437	.406
	9	19.634	.637	.581	.533	.493	.459
	7	2.589	.084	.077	.070	.065	.060
	7-1/4	4.394	.143	.130	.119	.110	.103
	7-1/2	6.263	.203	.185	.170	.157	.146
	7-3/4	8.194	.266	.242	.223	.206	.191
6-5/8" (168.3mm)	8	10.190	.331	.301	.277	.256	.238
	8-1/4	12.248	.398	.362	.333	.308	.286
	8-1/2	14.370	.466	.425	.390	.361	.336
	8-3/4	16.555	.537	.490	.450	.416	.387
	9	18.804	.610	.556	.511	.472	.439

Size of Casing O.D.	Size of Hole Inches	Litres per m	CEMENT (SACKS PER METRE) 18 l/sack	21 l/sack	24 l/sack	27 l/sack	30 l/sack
	9	8.619	.280	.255	.234	.216	.201
	9-1/4	10.933	.355	.323	.297	.275	.255
	9-1/2	13.306	.432	.392	.362	.334	.311
	9-3/4	15.734	.511	.465	.428	.395	.368
8"	10	18.238	.592	.540	.496	.458	.426
(203.2mm)	10-1/4	20.807	.676	.616	.565	.523	.486
	10-1/2	23.430	.761	.693	.637	.589	.547
	10-3/4	26.130	.848	.773	.710	.656	.610
	11	28.876	.937	.854	.785	.726	.675
	11	10.633	.345	.315	.289	.267	.248
	11-1/4	13.452	.437	.398	.365	.338	.314
	11-1/2	16.347	.531	.484	.444	.411	.382
	11-3/4	19.284	.626	.570	.524	.484	.451
10"	12	22.298	.734	.660	.606	.560	.521
(254 mm)	12-1/4	25.371	.824	.751	.689	.637	.593
	12-1/2	28.503	.925	.843	.774	.716	.666
	12-3/4	31.695	1.029	.938	.861	.796	.740
	13	34.959	1.135	1.034	.950	.878	.817
	11	2.756	.089	.081	.075	.069	.064
	11-1/4	5.574	.181	.165	.151	.140	.130
	11-1/2	8.456	.274	.250	.230	.212	.198
	11-3/4	11.401	.307	.337	.310	.286	.266
10-3/4"	12	14.410	.468	.426	.392	.362	.337
(273.1mm)	12-1/4	18.264	.593	.540	.496	.459	.427
	12-1/2	19.375	.629	.573	.526	.487	.453
	12-3/4	23.815	.773	.705	.647	.598	.556
	13	27.077	.879	.801	.736	.680	.633



APPENDIX 5 — FIG. 1

	DEPARTMENT OF MINES — SOUTH AUSTRALIA	SCALE. *Digrammatic*
COMPILED: J. W	SOUTHERN FROME EMBAYMENT GROUNDWATER ASSESSMENT RECOMMENDED WELL CONSTRUCTION	DATE: 9/11/77
DRN: P.D. CKD.		PLAN NUMBER: S 13149