T.I.O.

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

RECORD

No. 1976/10

TITLE: YULE RIVER GROUNDWATER REASSESSMENT

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YULE RIVER GROUNDWATER REASSESSMENT

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by

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SUMMARY

This report is a reassessment of the groundwater potential of the Yule River alluvial aquifers.

Estimates have been based on geological logs, a single controlled pumping test and a flow net analysis.

An abstraction rate of 21 000 m^3/d, equivalent to the estimated groundwater throughflow, could be safely maintained for one year after river flow, without further recharge, provided that pumping was spread over the entire area. If this rate of abstraction is continued into a second or third year of zero river flow there will be some mining of the aquifer and migration of brackish water from the interfluves towards production areas.

It is shown that previous estimates have been conservative due to their being based on poor pumping test data. Controlled pumping tests with at least three observation bores are required to determine accurate values for transmissivity. Two areas in particular (Site G and Section (C)-(D)) have been recommended for these tests.

Several conclusions and recommendations have been made and should be considered.

INTRODUCTION

Increasing industrial development at Port Hedland has led to a continual rise in water consumption. The present town water demand from the Yule River alluvium, 67 km southwest of Port Hedland, is about 350 000 cubic metres per month. Before the De Grey River alluvium and Canning Basin sediments are exploited the Yule River alluvium should be pumped at its maximum safe limit.

As a result of recent drilling the Department of Public Works has requested that a reassessment be made of the Yule River alluvium groundwater potential so that additional production bores can be linked into the scheme.

PREVIOUS WORK

The first groundwater resource assessment was made by Whincup (1967). Hydraulic properties of the aquifer were calculated from pumping tests and a production rate of 3 640 m^3/d was estimated providing that the average recharge cycle of 3.5 years continued.

A second assessment was made by Forth (1972). From pumping tests an average transmissivity of 150 m^3/d/m was estimated and applied to a flow net analysis from which it was concluded:

1. A production rate of 8 600 m^3/d can be maintained if the production is spread over the entire area.
2. A production rate of 11 300 m^3/d may be possible but cannot be determined with certainty.
3. Because the aquifers were recharged in 1971 a production rate of 18 000 m^3/d for 12 months in 1972-73 should be possible providing production is spread over a wide area.

RECENT DRILLING

During 1973 a Mayhew 15W rotary rig was used to drill 22 boreholes through the alluvium on the east side of the Yule River. Some terminated in weathered bedrock. Borehole details have been taken from drillers' logs and are given in Table 1.

Strata samples were collected at 3-m intervals and was geologically logged (G.S.W.A. records).

The bores were all tested for periods of up to 48 hours but the bore at Site D was the only one control tested using three observation bores.

GEOLOGY

The regional geology is shown on the Roebourne 1:250 000 Geological Sheet and described in the Explanatory Notes (Ryan, 1966). More detailed descriptions of the Yule River area are given in Whincup (1967) and Forth (1972).

Exploratory drilling has shown that the alluvium varies in thickness between 27 and 50 metres. The individual beds are discontinuous, and consist of lensing beds of sand, silt, clay, gravel and mixtures of these. Lithological logs from recent production-bore construction (Plate 1) confirm this variability and the difficulty of making correlations between bores.

The sediments upstream of Site E towards Site A (Plate 5) are generally more sandy and less silty than those downstream towards Site H (Plate 1). The amount of calcareous material (kankar, limestone, calcrete) is highly variable and cannot be correlated from bore to bore.

Table 1: Details of New Production Bores

Site and number	Reduced levels casing m	Reduced water level 30/10/74 1/11/74 m	Total depth m	Casing m	Screens or slots between m	Pumping-test Duration hours	Pumping-test Rate m^3/d	Pumping-test Draw-down m
A 2/73	25.348	16.068	50.9	22.8	22.2-27.2	8	491	10.46
B 5/73	25.181	16.421	45.7	46.8	13.7-45.7	8	1702	16.61
C 7/73			43.6	43.6	12.8-43.3	8	1407	19.16
D 10/73	21.962	14.612	43.6	43.6	16.6-43.6	48	2058	12.95
10m OBS						48		3.33
30m OBS						48		2.82
100m OBS						48		1.98
E 12/73	21.158	13.513	50.3	49.8	26.8-49.7	8	2793	1.98
F 16/73	18.889	12.484	48.2	43.4	41.7-48.2	8	2793	4.26
G 18/73	16.585	11.765	45.7	45.7	17.1-45.7	8	2520	19.50
H 19/73	15.594	10.839	41.2	41.2	14.3-41.2	8	1800	23.16
J 22/73	21.046	11.886	43.6	43.6	16.2-43.6	8	2406	19.2
K 21/73	17.005	10.565	29.0	29.0	12.2-29.0	8	371	14.93
L 17/73	18.194	12.424	48.2	48.2		8	2793	6.09
M 20/73	18.382	10.877	43.6	43.6	16.5-43.6			
N 13/73	21.590	14.400	45.7	45.4	21.9-45.1	8	1978	21.94
O 15/73	19.925	11.560	48.2	47.9	15.5-47.9	8	1768	19.20
P 11/73	23.379	15.749	43.6	43.6	15.2-43.6	8	1735	24.68
Q 14/73	22.272	12.422	48.2	48.2	16.0-48.2	8	1560	8.83
R 9/73	24.558	17.173	43.6	43.3	16.6-43.3	8	1339	17.37
S 6/73	23.819	14.059	40.2	40.2	13.1-40.1	8	2406	15.08
T 8/73	26.113	18.183	47.9	39.9	10.7-39.6	8	2673	6.40
U 4/73	23.879	14.809	34.8	30.2	29.1-34.1	8	2793	10.97
V 1/73	26.853	18.713	26.8	23.4	23.3-26.7	8	545	11.81
W 3/73	24.407	14.827	29.9	29.9	12.1-29.9	8	1145	11.58

The samples collected from rotary drilling are often not representative as they are contaminated with cuttings from higher in the sequence. For this reason the strip logs shown in Plate 1 may not be accurate.

A study of the drillers' logs (G.S.W.A. record) shows that there is, in most cases, a bed of silty clay below the water table, and this probably forms a confining or partially confining bed to the underlying aquifer.

HYDROLOGY

RAINFALL

The average annual rainfall of about 300 mm is unreliable and mainly falls during cyclonic storms between January and March. Annual totals of more than 700 mm have been recorded. During the winter months the climate is mainly warm and dry although winter rains sometimes occur.

RIVER FLOWS

It has been estimated that the average frequency with which the Yule River flows is once every 3.5 years (Whincup, 1967) and on most occasions only for a duration of about 5 days. Between 1952 and 1963 no flows were recorded so that the maximum interval between flows could be 11 years.

INFILTRATION AND EVAPOTRANSPIRATION

Very little recharge takes place as direct infiltration in the interfluvial areas where there are large claypans and most of the surface soils are rich in clay and silt. When recharge does occur in these areas it is due to exceptionally high rainfalls and probably varies from place to place because of the nature of the soil surface. Most of the recharge to the alluvial aquifer takes place when the river is in flood, but rainfall of sufficient intensity may provide some minor direct recharge through river-bed sands. In either instance downward percolation through these sands is thought to be quite rapid.

Along the river banks, where there is a dense cover of trees, evapotranspiration losses could be quite high.

HYDROGEOLOGY

AQUIFER

The aquifers which occur in the river alluvium have a wide range in thickness. The thickest section in the new production bores is at Site E where 50 m of clayey, silty and in places gravelly sand were drilled. Calcareous rock fragments (?kankar) are common in the cuttings but may be a contaminant rather than in situ.

From the drillers' logs a silty clay bed appears in most of the bores and, as indicated by the controlled pumping test on Site D, acts as a confining bed to the aquifer.

The calcareous material (?kankar) described in the lithological logs seems to have developed under two sets of geological conditions.

1. At or below the water table.
2. At the top of the weathered bedrock.

None of the kankar zones have been separately tested.

Kankar near the water table

Essentially it is a calcareous, weakly cemented alluvium. The calcareous cement is often concentrated at or near the water table, possibly as the result of water levels fluctuating during alternating wet and dry seasons but may also be found some depth below the water table.

Kankar at the top of weathered bedrock

This kankar is found at depth and at the top of the weathered bedrock, particularly if granitic. The greatest drilled thickness is about 20 m in borehole.T from which the cuttings appear to contain some intergranular porosity.

ALLUVIAL TROUGH

Drilling of the recent production bores failed to improve Forth's 1972 model of the alluvial trough (Plate 2, Bedrock Contours) because most of the bores terminated above the base of the alluvium. The model shows the axis of the trough almost coincident with the present river course and that the trough gradually deepens towards the north.

HYDROCHEMISTRY

The isohalsine map (Plate 2) gives a regional picture of the groundwater salinity. There is a wide range of salinities, the less saline water generally occurring close to the present river course.

Previous investigations have recognized that the salinity not only varies laterally but also with depth, the shallowest water sometimes being more saline than that at depth. The shallow, more saline water could be the result of one or more of the following causes:

1. the flushing downward of cyclic salt;
2. the dissolving of salts formed by oxidation at the capillary fringe; and
3. concentration of salts by selective absorption by trees.

Throughout the area the quality of the groundwater is well within the range suitable for stock consumption. Near the river it is suitable for town supply.

In most alluvial aquifers the salinity of the groundwater generally increases with increasing distance from recharge source. In this area the Yule River is the main source of recharge although some minor recharge may take place by direct downward percolation of rain especially after heavy rains.

The induction of brackish water from the interfluvial aquifers is a continual problem especially if high production pumping rates are adopted. A knowledge of flow characteristics and ionic concentrations is helpful in designing a pumping scheme and evaluating the possibility of salt-water encroachment.

PUMPING TESTS

Pumping test data

Bore Name	:	Yule River Site D No.10/73
Date	:	23rd February, 1974
Total Depth	:	43.6 m
Slotted Casing	:	16.6 m to 43.6 m
Observation Bores	:	3 observation bores (10 m, 30 m, 100 m)
Duration of Test	:	48 hours
Pumping Rate	:	2 058 m^3/d
Drawdowns	:	Pumping bore 12.95 m
		10 m OBS 3.33 m
		30 m OBS 2.82 m
		100 m OBS 1.98 m
Test Sheets	:	Available from G.S.W.A.

General

Previous aquifer evaluations have been conservative so that later production rates have been safely maintained at more than twice the initially predicted 'safe yield'.

The disparity between estimated safe rates of abstraction and actual pumping rates is due to:

1. the lack of information on the nature of the hydraulic connection between saturated river-bed sands and the adjacent alluvial aquifer;
2. the poor pumping-test design; and
3. the misinterpretation of poor pumping-test data.

Most of the tests were carried out without the control of observation bores. It is noticeable that the transmissivities obtained from the pumping bores is much smaller than those obtained from the observation bores. This is because the drawdowns measured in the pumping bores have been exaggerated due to turbulent flow at the screens causing well losses. The observation bores do not have this problem and drawdowns measured are representative of the aquifer.

In this reassessment only one pumping test, that at Site D, is considered valid and all others are neglected. At Site D a 48-hour constant-rate discharge test was carried out on Bore No.10/73 on 23rd February, 1974 and water-level drawdowns were measured in three observation bores 10 m, 30 m and 100 m distant from the pumping bore. A $^t/r^2$ versus drawdown log-log plot was matched to the Theis Non Leaky Artesian Type Curve (Plate 3). A transmissivity of 550 $m^3/d/m$ and storage coefficient of 2.0×10^{-4} was calculated indicating that the aquifer is confined. This value for transmissivity was verified by matching time versus drawdown log-log plots for each of the observation bores with Delayed Yield Type Curves (Plate 4).

Analysis of the pumping bore is not valid because a plot of time versus drawdown (Plate 4) shows that the value for transmissivity is far too small. Similarly all other non-controlled pumping-tests give values for transmissivity that are too low.

GROUNDWATER MOVEMENT

The direction of groundwater movement is perpendicular to the potentiometric contours.

Potentiometric surface

Water-level measurements obtained between 30th October and 1st November, 1974 were used to draw the contour maps of the potentiometric surface. This time was chosen because water levels were relatively stable following a period without river flow. It was also similar to that used by Forth (Plate 2).

The potentiometric map (Plate 5) indicates:-

1. The aquifers on the northeast side of the river are being recharged directly from the river.

2. The aquifers southwest of the river are being recharged by groundwater throughflow from the southeast and are thus less directly replenished from the river than those on the northeast, except for a narrow strip along the river bank.

3. Abstraction from the present production field is apparently distorting the contours and producing poorly defined cones of depletion. This may partly be because most of the measured water levels were taken before pumped bores recovered. The possibility of subsequent deterioration of water quality by inducing inflow of more saline water from the interfluves should be closely monitored.

4. The groundwater gradient on the northeastern side of the river is about 2.5 m per 1 000 m in a northeasterly direction and fairly uniform. The groundwater gradient on the southwestern side is about 1.1 m per 1 000 m in a northwesterly direction.

5. The uniformity of the groundwater gradient towards the northeast indicates either that:

   (a) transmissivity and groundwater throughflow are both constant, or

   (b) both transmissivity and throughflow vary.

The only possible losses to throughflow are from vertical downward leakage or evapotranspiration from trees. Since there is negligible vertical leakage and minimal evapotranspiration near Site D the throughflow must remain fairly constant and therefore the transmissivity must also be fairly constant. This means that (a) above is probably applicable to the area surrounding Site D.

6. Towards the northern end of the area the groundwater gradient flattens which means that either the transmissivity or the throughflow vary or possibly both. From the lithological logs it appears as though the transmissivity decreases in which case the throughflow will also decrease. This reduction in transmissivity appears to start between Sites E and F which also closely corresponds to the area where the gradient begins to flatten.

7. The section (A)-(B) between the 14 m and 16 m potentiometric contours has a uniformly constant gradient of about 2.5 m per 1 000 m, and because the

lithologies of the bores are similar it is assumed that both the throughflow and transmissivity remain constant.

Flow net analysis (New production area)

Flow net analysis is based on the flow equation described by Darcy's Law:

$$Q = TiL$$

where Q = flow rate

T = transmissivity

i = hydraulic gradient

L = width of section or distance between bounding flow lines.

With the limited data available it was not possible to construct a meaningful flow net for the entire area because of the variations in Q, T and i mentioned in the preceding section.

For the section (A)-(B) the hydraulic gradient is constant and Q and T are assumed constant. A unit cell of the flow net was constructed about Site D so that the distance between the bounding flow lines is 800 m, the distance between the potentiometric contours is 800 m, and the gradient is given by 2/800. The transmissivity as determined from the pumping test is 550 $m^3/d/m$.

$$\text{From } Q = TiL$$

$$\therefore Q = 550 \times \frac{-2}{800} \times 800 \ m^3/d$$

$$= 1\ 100 \ m^3/d \text{ per unit cell.}$$

There are 10 similar unit cells in section (A)-(B).

$$\therefore \text{Total } Q = 1\ 100 \times 10 \ m^3/d$$

$$= 11\ 000 \ m^3/d \approx 2\ 420\ 000 \text{ gpd.}$$

Although this throughflow only represents a small section of the total area it is more than three times Whincup's estimate of the entire area and considerably larger than Forth's estimate.

Total availability of groundwater from underflow

Recent production figures show that 350 000 m^3 per month (12 500 m^3/d) are being pumped from the present production field. Although water-level monitoring data are not ideal there is some evidence of local depletion so that the abstraction rate somewhat exceeds the groundwater flow through the 6 000 metre section. The pre-disturbance flow may be estimated by assuming the transmissivity to be the same as determined at Site D and that the gradient was originally the same as measured at section (A)-(B). The throughflow (Q) is then given by $Q = 550 \times \frac{2}{800} \times 6\,000$

$= 8\,250 \text{ m}^3\text{/day}.$

The new field investigated in this report is downstream of the present production field and, as shown by the potentiometric map, is independently recharged by the river. Therefore, the amount of groundwater available from the two bore fields is given by:

Old field	8 250 m^3/d	(based on production rates)
New field	11 000 m^3/d	(based on pumping-test)
	19 250 m^3/d	

Without controlled pumping-tests similar to that conducted at Site D only tentative and conservative estimates of groundwater throughflow can be made for sections (C)-(D) and (E)-(F) (Plate 5).

For Section (C)-(D):

Assume T = 150 m^3/d/m (Forth, 1972)

Average gradient = 2/2100

Length CD = 3 200 m

From Q = TiL

$$Q = 150 \times \frac{2}{2100} \times 3200 \text{ m}^3\text{/d}$$

$$= 457 \text{ m}^3\text{/d}$$

For Section (E)-(F):

Assume T = 150 m^3/d/m (Forth, 1972)

Average gradient = 2/1200

Length EF = 4200 m

From Q = TiL

$$Q = 150 \times \frac{2}{1200} \times 4200 \text{ m}^3\text{/d}$$

$$= 1050 \text{ m}^3\text{/d}$$

∴ Grand Total for Yule River aquifers is:

Old production field	8 250 m^3/d
New production field Section AB	11 000
Section (C)-(D) (conservative)	457
Section (E)-(F) (conservative)	1 050
Grand Total	20 757

i.e. 21 000 m^3/d

This total of 21 000 m^3/d or 4.6 million gallons per day is considered a realistic figure providing the aquifer is annually recharged and bores are correctly located so that all of the throughflow can be tapped. It is about six times that estimated by Whincup (1967) and considerably larger than Forth's estimate (1972).

GROUNDWATER IN STORAGE

Forth (1972) assumed a specific yield of 0.15 for the alluvial aquifers and calculated, using Plate 6, that there is 574×10^6 m^3 of potable groundwater in storage but that only a portion of this amount is available for withdrawal if the water quality standards are to be maintained at less than 1 000 ppm Total Dissolved Solids

He concluded: "To prevent migration of the 1 000 ppm isohalsine toward the production area, a hydraulic gradient away from that area must be maintained. Therefore the water that is held in storage at elevations greater than water with more than 1 000 ppm TDS is that which can be withdrawn from storage safely". He calculated this volume to be 9.09×10^6 m^3 but emphasized that pumping would have to be spread over the entire area. This means that, without recharge, the aquifer can be safely pumped at 25 000 m^3/d for about one year before salt water from the interfluves is induced to flow towards the production areas.

Assuming a specific yield of 0.15, an average saturated thickness of 10 m and an area of 60 km^2 there is 90×10^6 m^3 of potable groundwater between the production area (shown cross-hatched on Plate 6) and the eastern 1 000 ppm TDS isohalsine. This is equivalent to 10 years supply, without recharge, at a pumping rate of 25 000 m^3/d; or 6 years if a specific yield of 0.1 is assumed, after which time the salt-water interface will have migrated to the northeastern boundary of the cross-hatched area. The aquifer should, therefore, be able to sustain the supply through a 6 to 10 year drought without damage to the system providing the migration direction of the salt-water interface is reversed back towards its place of origin when recharge occurs.

Without river recharge a pumping rate of 25 000 m^3/d could be maintained for about 60 years if the entire storage of 574×10^6 m^3 is abstracted.

Before a realistically safe withdrawal rate can be determined the following must be known:

1. Frequency of river flows.
2. Duration of river flows.
3. Rate of aquifer recharge.
4. Relationship between river flows and recharge.
5. Rate of salt-water encroachment under abstraction conditions.

To meet these requirements a comprehensive monitoring system would need to be established.

A reduction of water levels near the river is desirable as this should induce additional recharge during river flow events.

AREAS SUITABLE FOR PRODUCTION

Areas of thick saturated alluvium with low salinity groundwater are suggested for production and are shown as cross-hatched areas on Plate 6.

The object of any borefield is to efficiently utilize all of the available groundwater throughflow. To accomplish this the borefields need to be correctly orientated with respect to flow direction.

The present production field (Plate 5) is probably pumping at or just above its maximum safe yield as indicated by the displacement of the potentiometric contours. The new production bores (A to W) are situated in an undisturbed part of the aquifer and are therefore capable of producing water without influencing water levels in the present field. Because the direction of groundwater flow is normal to the potentiometric contours it follows that, to trap all throughflow, a line of bores should be placed parallel to the contours as shown by sections (A)-(B), (E)-(F) and (C)-(D).

From a very successful controlled pumping-test at Site D it has been established that a total production rate of 11 000 m^3/d from bores along section (A)-(B) can be maintained without recharge for at least 12 months. An estimate of production rates for sections (C)-(D) and (E)-(F) totalling 1 507 m^3/d is based on an unreliable and probably conservative transmissivity value of 150 $m^3/d/m$. This value for transmissivity should be checked for each of the sections by control pump-testing for at least 48 hours and observing water-level drawdowns in three observation bores similar to the test at Site D.

The spacing of bores along section (C)-(D) or any other parallel section west of the river can only be determined after successful pumping tests have been carried out for that area.

CONCLUSIONS

Because of the lack of necessary data this reassessment is not complete; but an attempt has been made to update the previous assessments by more accurately defining the hydrogeological framework and the groundwater hydraulics of the alluvial aquifers.

1. Correlation between bores is not possible because of the lensing nature of the beds and the random mixing of clay, silt, sand and gravel.

2. The sediments upstream of Site E towards A are less silty than those downstream of E.

3. Rotary drill samples may not be representative.

4. A confining bed at about the 14-m level has been recognized.

5. River flows have not been accurately recorded and a frequency of once in 3.5 years estimated.

6. Most of the recharge takes place during river flows.

7. The salinity of the groundwater increases with increasing distance from the river.

8. The incursion of brackish water from the interfluves into the production areas is possible if high pumping rates are maintained.

9. Transmissivities from controlled pumping tests, as at Site D (550 $m^3/d/m$), can be accurately determined. Transmissivities determined from pumping bores are considered invalid.

10. Previous aquifer evaluations are conservative because incorrect values for transmissivity have been used.

11. The present production field is abstracting 12 500 m^3/d which may somewhat exceed the safe yield but this is dependent on the frequency of river flow.

12. The new production field should not influence water levels in the present production field.

13. Groundwater flow through section (A)-(B) is about 11 000 m^3/d and alone is substantially greater than previous estimates made for the entire area.

14. The estimates of throughflow for sections (C)-(D) and (E)-(F) (457 m^3/d and 1 050 m^3/d) are conservative because transmissivity values have not been accurately defined.

15. Total groundwater throughflow for November 1974 is 21 000 m^3/d and could be conservative depending on reassessment of flows through sections (C)-(D) and (E)-(F).

16. 21 000 m^3/d should be available for pumping providing annual recharge events occur and production is spread over the entire area.

17. Some controlled mining may be acceptable but the deterioration of groundwater quality by the incursion of brackish water from the interfluves needs close monitoring especially in the event of long periods without river flow.

18. Approximately 9.09 x 10^6 m^3 of low salinity groundwater can be pumped from the entire area before the salt water interface starts to migrate towards the production areas. This is equivalent to 25 000 m^3/d for 12 months.

19. The east-side aquifers (present production area and new production area) can probably maintain a production rate of 25 000 m^3/d for 6 to 10 years without river flow, but in doing so the eastern salt-water interface will be forced to migrate westward to about the boundary of the suggested production area.

20. A deliberate lowering of the water table near the river should induce additional recharge during river flows.

21. Three areas near section lines (A)-(B), (C)-(D) and (E)-(F) have been recommended for production.

RECOMMENDATIONS

Before the Yule River groundwater system can be more completely defined additional work is required.

1. As the quantity of water flowing through a section of the aquifer is directly proportional to the hydraulic gradient it is very important to establish the water-table configuration, especially near the river.

Piezometer bores spaced at about 2-km intervals within the river-bed sands are suggested for construction so that groundwater gradients away from the river can be measured, especially during and immediately after river flows.

2. To assist in the assessment of water resources and management, controlled pumping tests should be carried out over the whole area so that true coefficients of hydraulic conductivity and storage may be calculated. This applies particularly at Site G and along section line (C)-(D). Both pumping and observation bores should be fully penetrating and thoroughly developed. Step-drawdown tests should be conducted before the final pumping test to determine bore efficiencies and the desired pumping rate for the constant rate test.

3. Production bores should be set out as described under Areas Suitable for Production.

4. The possibility of salt-water encroachment should be considered and water samples from the pumping fields should be frequently tested for dissolved solids.

5. Some dewatering is recommended as this should make space for additional recharge. A close monitoring programme is essential.

6. Water-level measurements continue to be taken on all bores.

7. A staff gauge should be installed in the Yule River and read daily during periods of river flow.

8. When water is pumped from the alluvium, a precise record should be kept of the quantity extracted from each source.

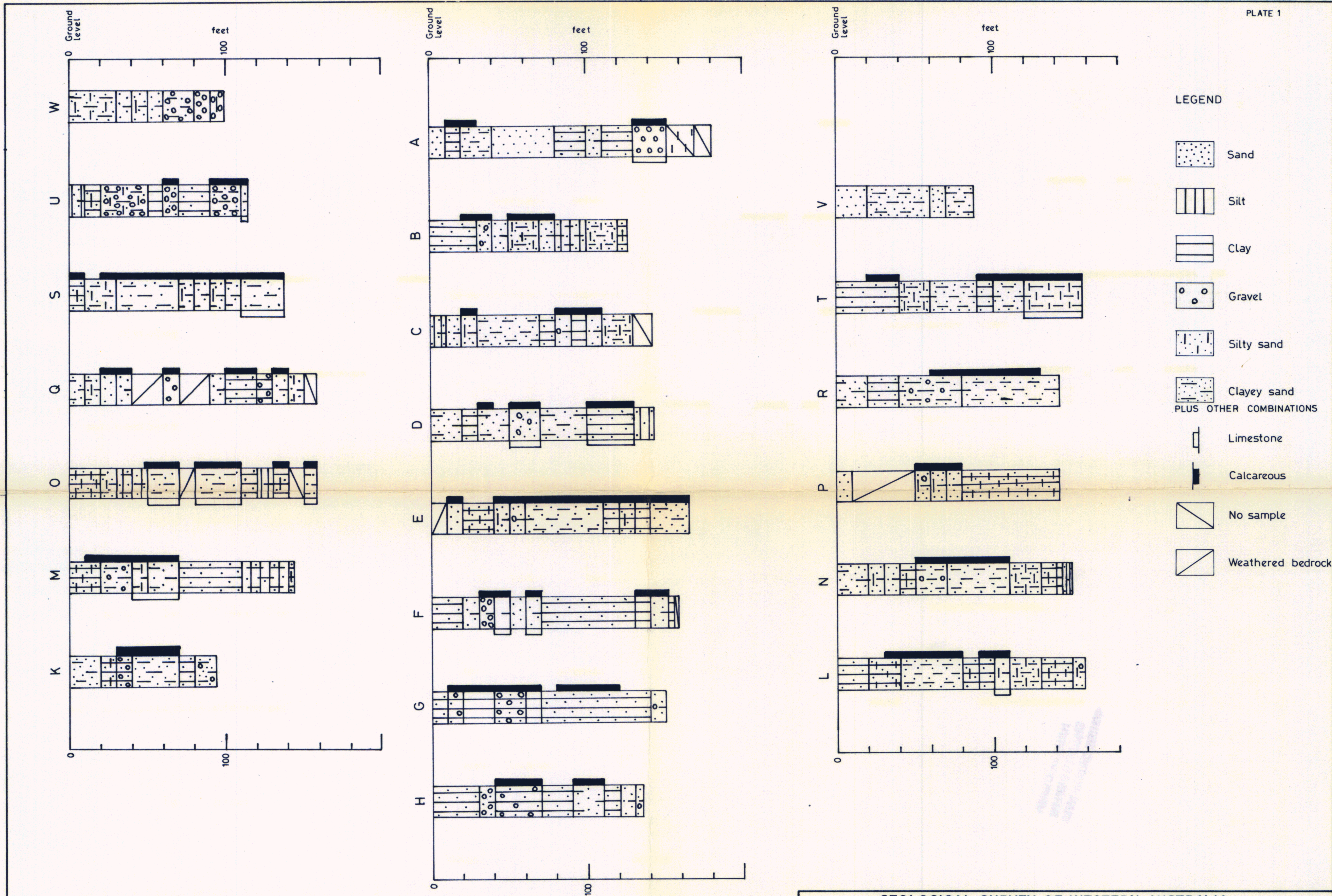
REFERENCES

Forth, J.R., 1972, A reappraisal of the Yule River area: Port Hedland town water supply: West. Australia Geol. Survey Report 2.

Ryan, G.R., 1966, Explanatory notes Roebourne, W.A. 1:250 000 Sheet: Australia Bur. Mineral Resources.

Whincup, P., 1967, Hydrogeology of the Yule River area, Port Hedland town water supply: West. Australia Geol. Survey Rec.1967/3 (unpublished).

PLATE 1



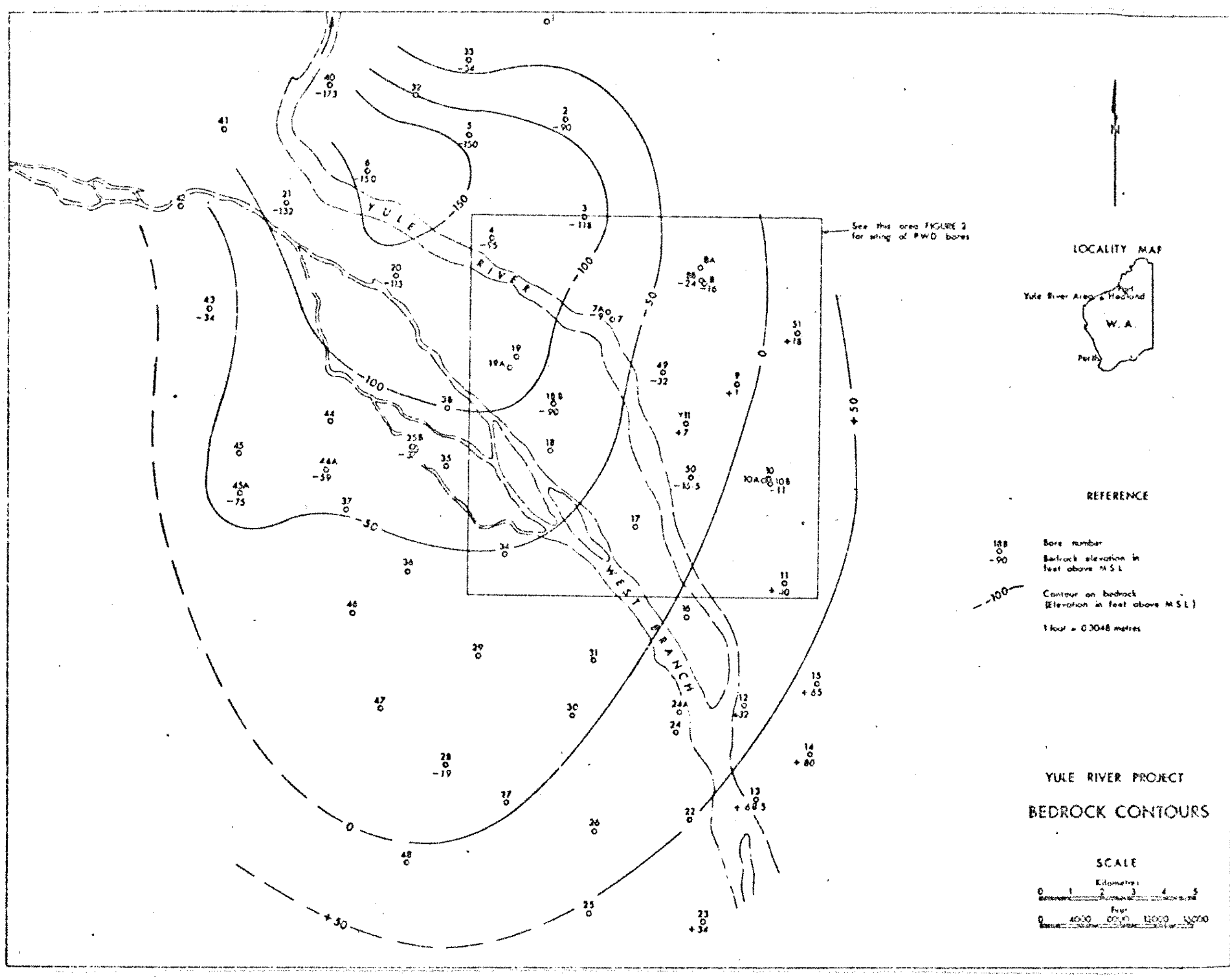
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

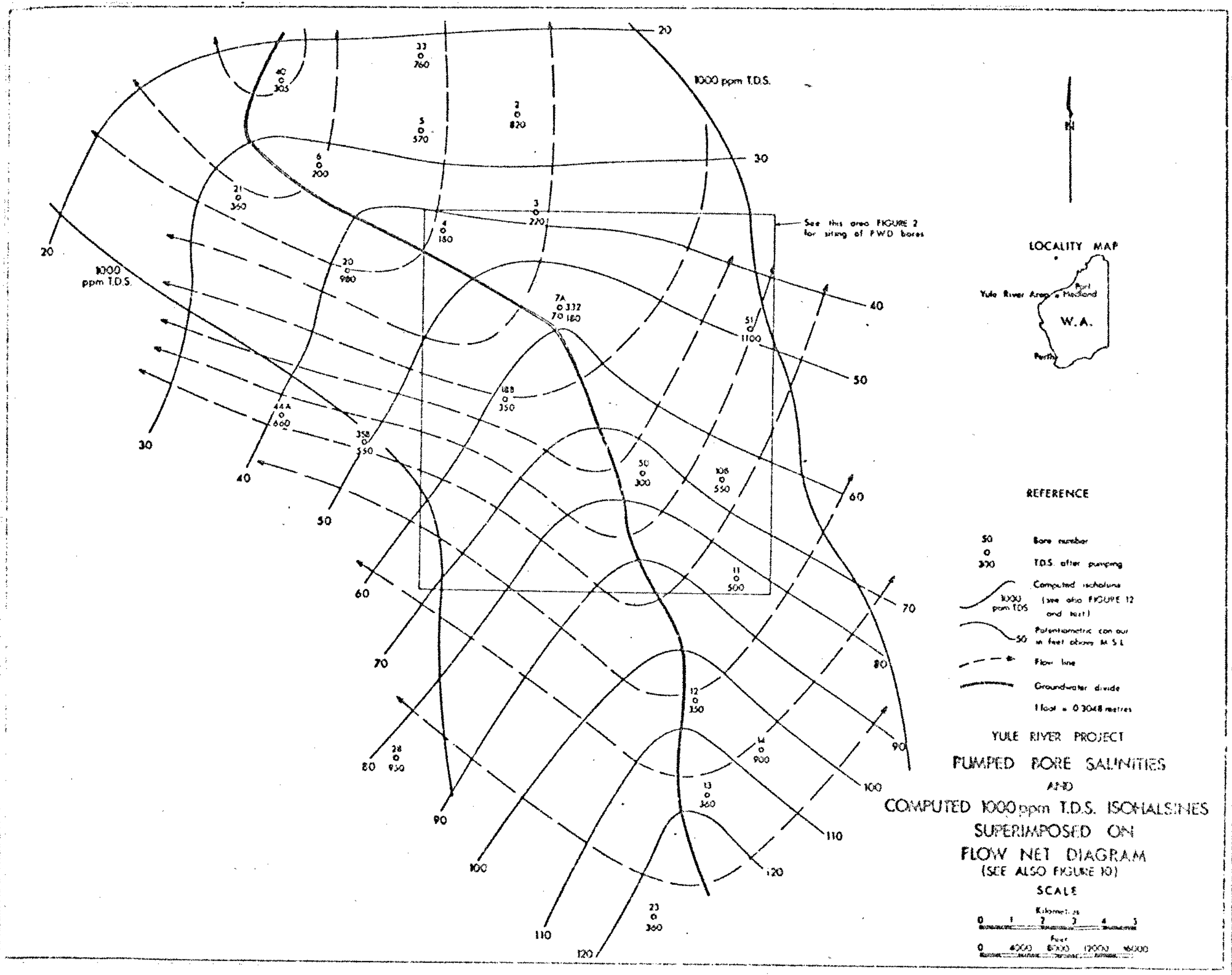
Compiled	W.A.D.	YULE RIVER REASSESSMENT LITHOLOGICAL STRIP LOGS NEW PRODUCTION BORES	SCALE
Drawn	W.A.D.		
Checked			15922
Approved		To accompany Hydrology Report No. 1396 by W.A. Davidson and Rec. 1976/10	

49981/5/69-200-0

PLATE 1

PLATE 2





GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Compiled J.R.F.	YULE RIVER GROUNDWATER REASSESSMENT FROM G.S.W.A. REPORT SERIES Nº 2 1972	SCALE
Drawn J.R.F		
Checked		15923
Approved	To accompany HYDROLOGY REPORT Nº 1396 BY W.A. DAVIDSON and Rec. 1976/10	

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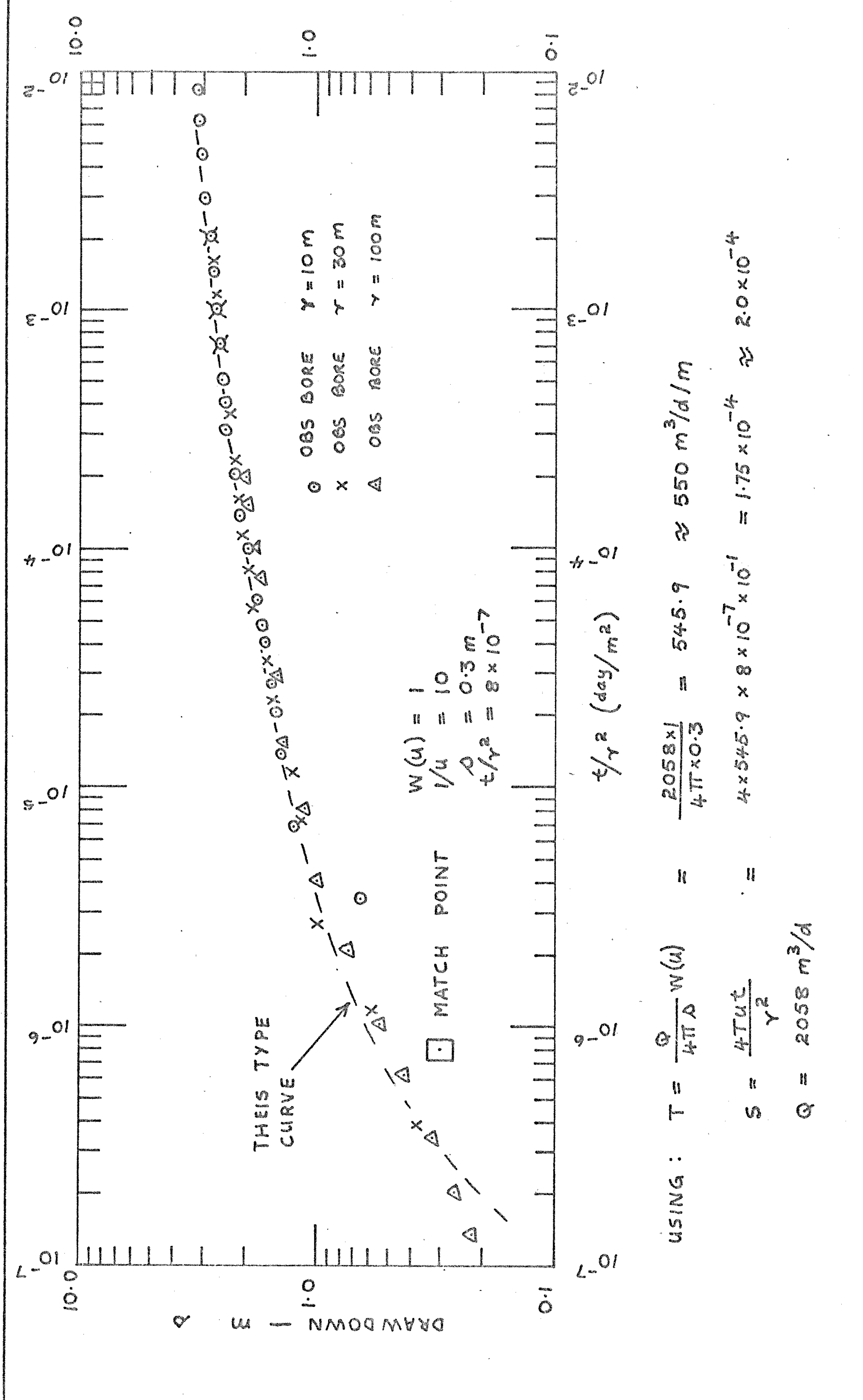
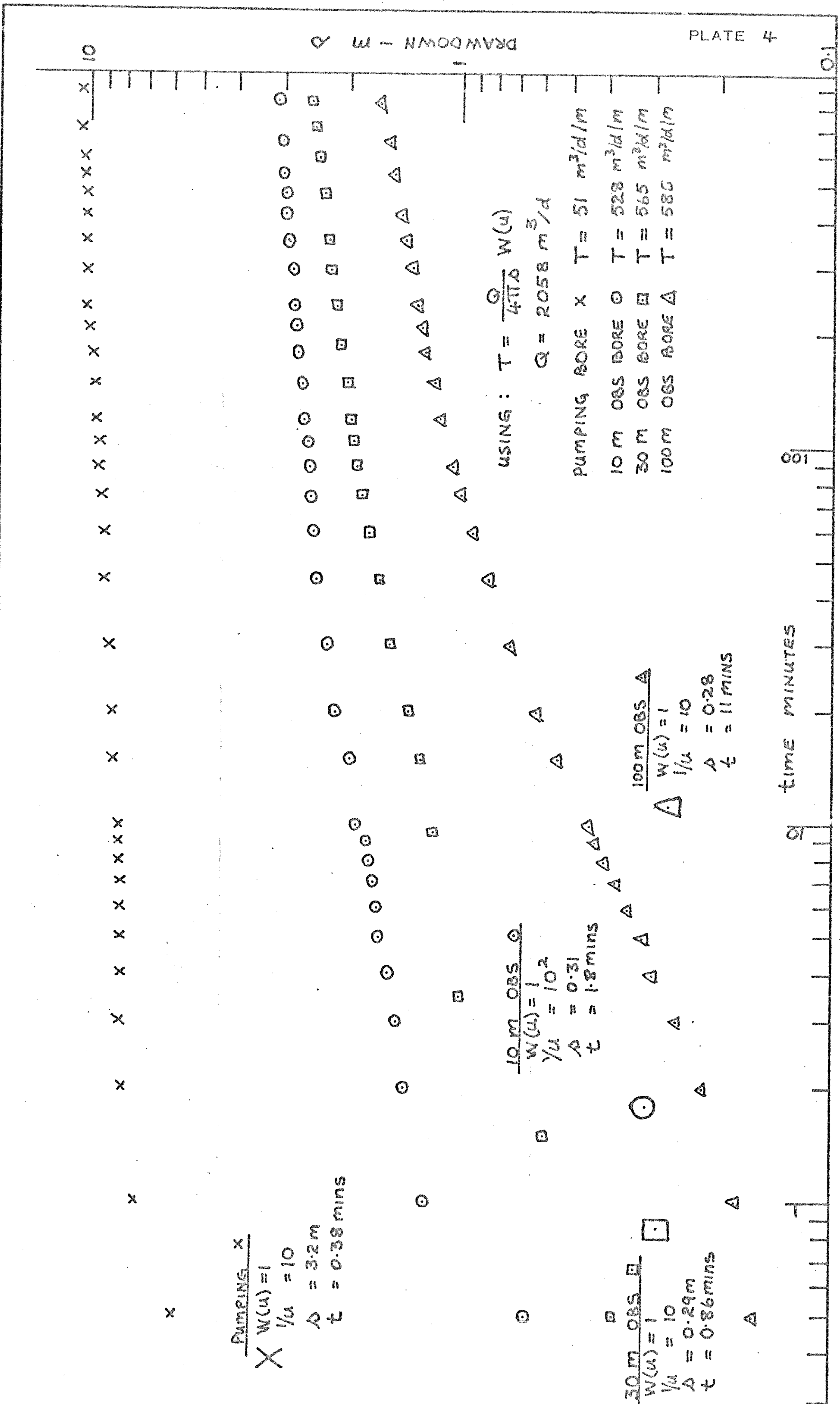
PLATE 3



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Compiled W.A.D	YULE RIVER SITE D PUMPING TEST	SCALE
Drawn W.A.D	t/r^2 VS DRAWDOWN FOR 3 OBS. BORES	
Checked		15924
Approved	To accompany HYROLOGY REPORT Nº 1396 BY W.A. DAVIDSON and Rec. 1976/10	

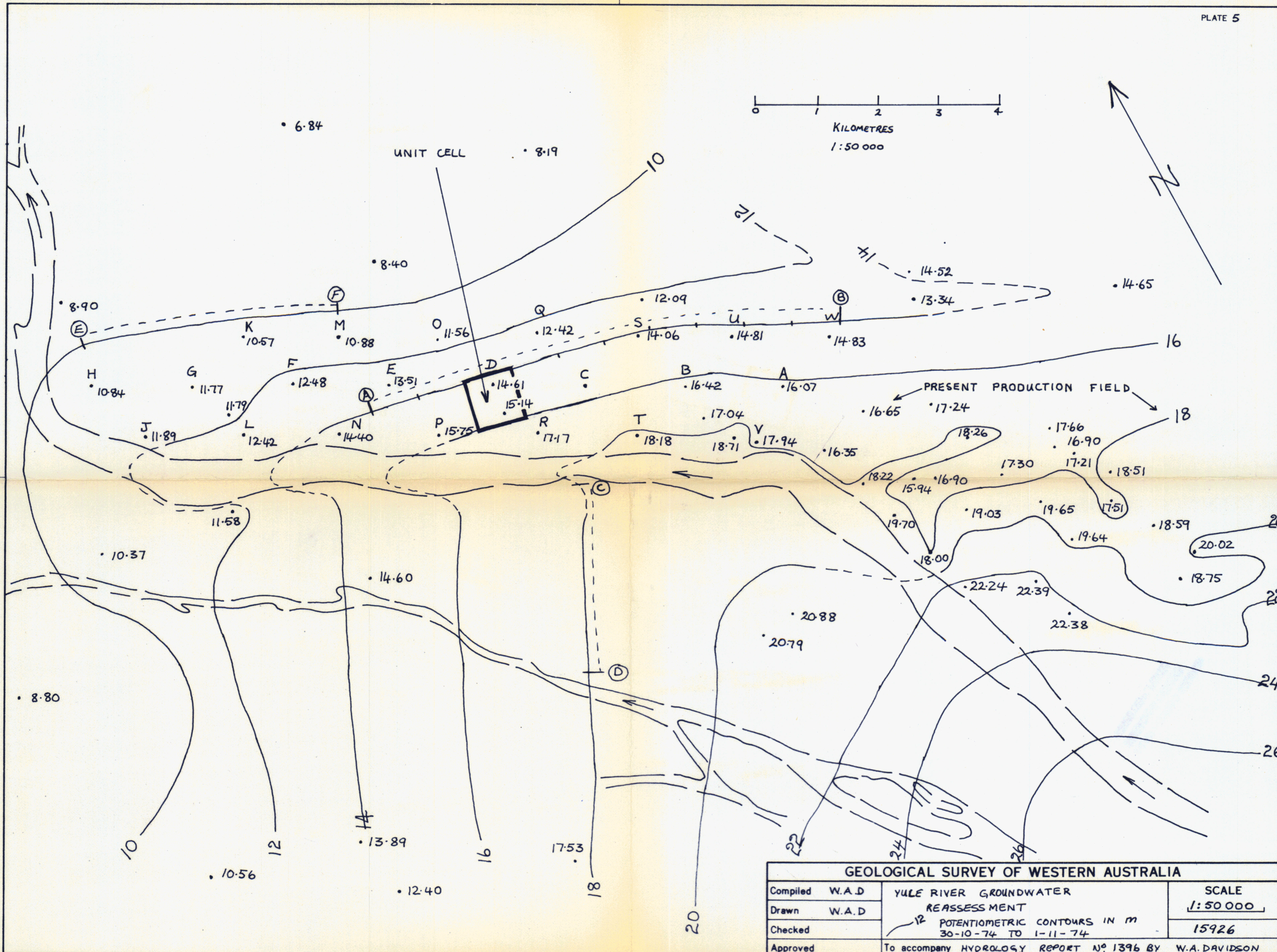
93576/11/71-2M-O/CR



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Compiled	W.A.D.	YULE RIVER SITE D PUMPING TEST TIME VS DRAWDOWN	SCALE
Drawn	W.A.D.		
Checked			15925
Approved		To accompany HYDROLOGY REPORT Nº 1396 BY W.A. DAVIDSON	

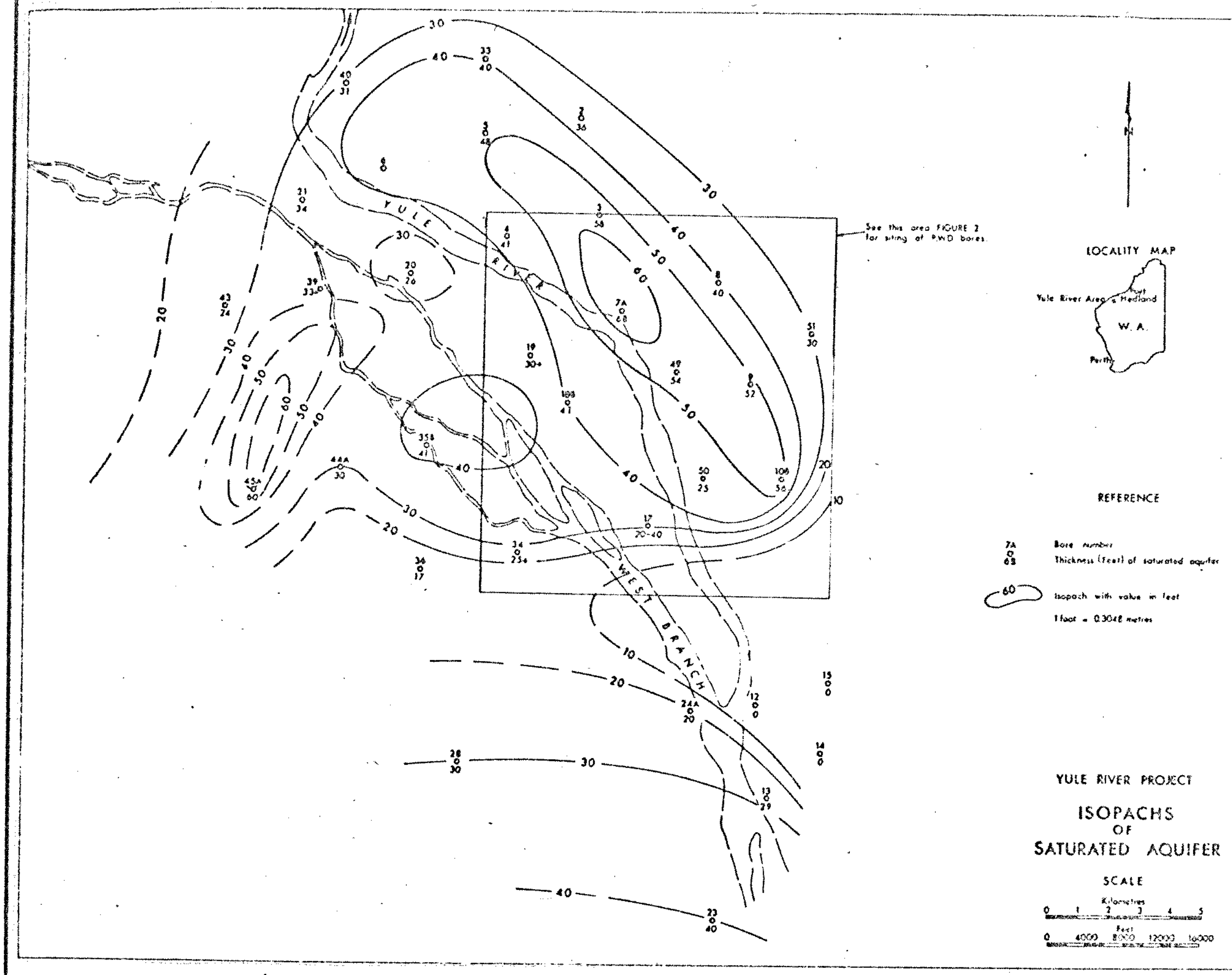
93576/11/71-2M-O/CR

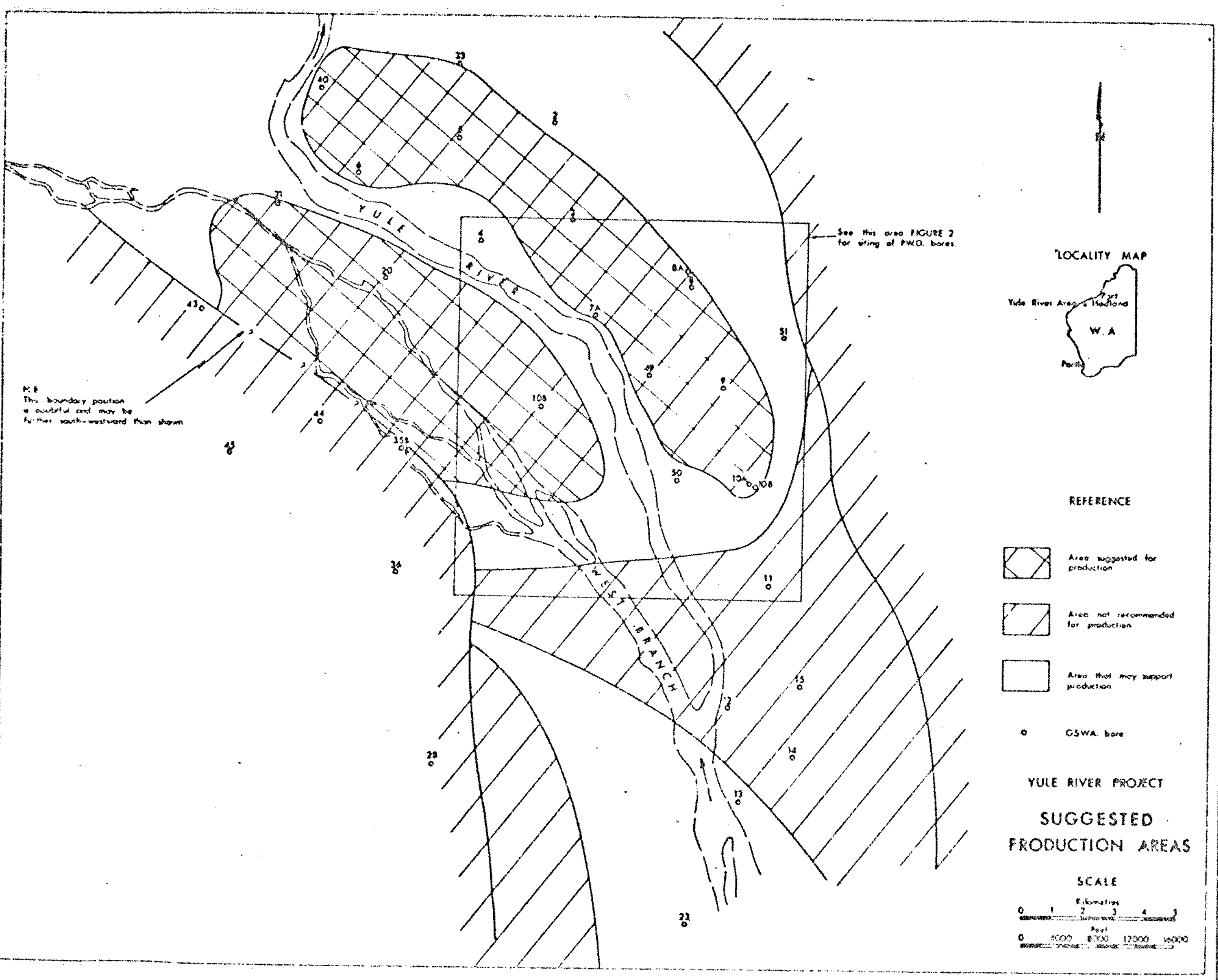


GEOLOGICAL SURVEY OF WESTERN AUSTRALIA		
Compiled W.A.D	YULE RIVER GROUNDWATER REASSESSMENT	SCALE 1:50 000
Drawn W.A.D	12 POTENTIOMETRIC CONTOURS IN m 30-10-74 TO 1-11-74	15926
Checked		
Approved	To accompany HYDROLOGY REPORT Nº 1396 BY W.A. DAVIDSON and Rec. 1976/10	

49981/5/69-200-0

PLATE 6





GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Compiled J.R.F.	YULE RIVER GROUNDWATER REASSESSMENT	SCALE
Drawn J.R.F.		
Checked	FROM G.S.W.A. REPORT SERIES Nº 2 1972	15927
Approved	To accompany HYDROLOGY REPORT Nº 1396 BY W.A. DAVIDSON	