RIVER MURRAY DRAINAGE INVESTIGATION

POTENTIAL EVAPORATION SITES - WAIKERIE AREA

PROGRESS REPORT NO. 1

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South Australia

DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY

ENGINEERING DIVISION

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by

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Rept.Bk.No. 76/15
G.S. No. 5692
Hydro. No. 2718
D.M. No. 1420/68

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ABSTRACT

Two potential evaporation sites have been delineated within 20 km south and southwest of Waikerie following the drilling of 31 shallow rotary holes. A further two sites were outlined between Cadell and Waikerie as a result of an inspection of geological logs of previously drilled holes. Although the groundwater mound beneath Waikerie has been shown to be continuously growing, the time required for the water level to reach a critical level has not been determined.

INTRODUCTION

This report investigates one possible way of reducing the Waikerie drainage problem which is directly affecting the salinity of the River Murray and is detrimental to the irrigation areas.

The drainage problem in the Waikerie Irrigation Area has already been fairly well documented. The latest progress report (Killick J.C. and Allen C.M., 1974) gives a detailed account. Briefly, shallow impervious soils and clays underlie at least 60-70% of the irrigation areas, creating a perched water table with the irrigation waters. Initially the problems associated with this perched water table (water logging of root zone and seepage of saline waters to the River Murray) were temporarily solved by the drilling of over 235 drainage bores through the impervious layer into the Morgan Limestone Aquifer. However, this method is gradually becoming inadequate as the following factors become more dominant:

- increasing inefficiency of drainage boreholes
- formation of groundwater mound in Morgan Limestone under the irrigation areas.

One of the possible solutions to the above problems is the implementation of a Comprehensive Drainage Scheme, whereby drainage water is pumped into evaporation basins. It has been estimated (Gutteridge, Haskins and Davey, 1970) that an evaporation basin of about 600 ha in area would be required for drainage waters from the Waikerie Irrigation Areas. The main requirement for an area to be suitable is the delineation of enough impervious material at relatively shallow depth to act as a base to such a basin.

This report deals with the results of a rotary drilling programme that was initiated to investigate the distribution of the Blanchetown clay, which could act as an impervious base. A total of 31 shallow holes were drilled within 20 km south and southwest of Waikerie (Fig. 1). The rate of rise of the groundwater mound beneath Waikerie is also discussed.

GEOLOGY AND PHYSIOGRAPHY

The history, physiography, land use and geology of the area has been previously described in previous reports (Roberts, 1965). A summary of the geology is shown in Table 1.

Of interest in the present investigation is the distribution and characteristics of the Blanchetown Clay.

TABLE 1

AGE	FORMATION	THICKNESS	LITHOLOGY
Recent		0 - 20 m	Dune sands, limy dune sands.
Pleistocene	Kunkar	0 - 2 m	Tough, massive or pebbly limestones overlying soft grey marls.
	"Bungunnia Lst."	0 - 1.5 m	Flaggy, dense, greenish limestone.
	"Blanchetown Clay"	0 -21.5 m	Blue-green and brown clay and silty clay. Underlain in places by 0-4' of greenish-yellow very clayey fine sand.
Upper Pliocene	Norwest Bend	2.5 - 6.5 m	Calcareous sands, calcareous sandstone or oyster beds.
Lower Pliocene	Loxton Sands	0 - 6 m	Cross bedded, calcareous sands.
Lower Miocene	Pata Limestone	0 -13.5 m	Variable interbedded limestones, marly limestones and sandy limestones.
	Morgan Limestone	38 m approx.	30-70' marls and marly limestones over limestones and sandy limestones.
	Finniss Clay	0 - 3.7 m	Marl
	Mannum	70 m approx.	Mainly limestones with some marly horizons.

Blanchetown Clay

The Blanchetown Clay is a thick clay of lacustrine origin. Although overall it is widely distributed the clay has been eroded in some areas by deflation. It generally occurs only a few metres below ground surface. The upper surface of the clay is very undulating whereas the lower surface tends to be almost planar. The greatest thicknesses are generally encountered under the higher sand dunes and is generally absent from topographic lows (Williams, 1974).

The unit consists of a series of impermeable dense clays and silty sandy clays, the colour ranging from brown to grey-green with intensive mottling of brown into grey-green sections. The upper section of the Blanchetown Clay is commonly sandy due to the common presence of secondary stringers of brown sands. Gypsum has been found to be associated with the clay, particularly in the vicinity of the Sunlands Irrigation Area. In some cases, the Blanchetown Clay consists mainly of gypsum with a small clay fraction - the concentration of gypsum can thus affect the permeability of the clay.

Distribution of Blanchetown Clay in the Waikerie Area - Drilling Results

The objective of the drilling programme was to outline areas that could be used as evaporation basins within 20 km of Waikerie. Potential areas would need to satisfy most of the following requirements (Williams, 1974).

(1) area to have impervious base, that is, a sufficient thickness of Blanchetown Clay.

(2) basin to be at least 600 ha in area.

(3) short distance from irrigation areas - basins to be located within 20 km of Waikerie.

(4) to minimise earthworks, the area to occur in natural depressions.

(5) minimal disruptions to local agricultural industry.

(6) aesthetic and environment requirements.

Thirty one shallow rotary holes were drilled between 8-10-74 and 17-10-74, in the Hundred of Waikerie. The geological logs are included in Appendix 1, which also contains relevant geological logs of previously drilled bores in the area. Locations of the bores are shown in Fig. 3.

A total of 4 potential areas were outlined, two as a result of recent drilling programmes (Areas 1 & 2, Fig. 2, 3) and two as a result of an inspection of geological logs of previously drilled holes (Areas 3 & 4, Fig. 2 & 4).

Area 1 : The one with the greatest potential, as far as the availability of an impervious base is concerned, occurs within 5 and 10 km southwest of the Ramco Heights Area and Waikerie respectively. Here, an area of approximately 1200 ha has been defined with a clay base of at least 3 m thick. Of further interest is the fact that the time taken for groundwater to travel from this area downgradient towards the River Murray has been estimated to be about 2 x 10^3 years (using estimated particle velocity of 11 m/year - A.F. Williams, pers. comm., Appendix 2). This is only a first approximation and a refined estimate will be eventually required.

There are, however, a number of disadvantages that have to be considered.

(a) proximity to the Blanchetown-Waikerie main road - aesthetic considerations.

(b) area is essentially flat and major earth-movement would be required to create a reasonably water tight depression.

(c) land is currently being cultivated.

Area 2 : The second site, which is over 6000 ha in area, has been outlined approximately 13 km south of Waikerie. Within this large area, the western portion (west of bores WR1-4) shows greater potential. The average thickness of clay in that portion is about 2 m. In general, the clay is sandy, thin sand lenses having been commonly intersected during the recent drilling programme. Vertical leakage could thus be significant. The time taken for groundwater to travel from this area to River Murray has been estimated (Appendix 2) to be around 3×10^3 years. Two small advantages with this site are:

(1) the site is located in a moderately secluded area, about 13 km south of Waikerie.

(2) the occurrence of interspersed dunes which could be treated to act as retaining banks.

Areas 3 and 4 were defined following the inspection of geological logs of previously drilled holes (Appendix 1). Field inspection of the two areas was not carried out.

Area 3 : A potential area of about 4000 ha was outlined within 2 km S.E. of the Cadell Irrigation Area (Fig. 2). A number of suitable evaporation sites can be selected within this large area with a minimum thickness of 1.5-2 m Blanchetown Clay. As the time of travel for groundwater to reach the River Murray has been estimated to be about 600 years (Appendix 2), the magnitude of vertical leakage would have to be accurately determined. Of further consideration is the fact that the area is more than 13 km N.W. of the Waikerie

Irrigation Area and that the Cadell Irrigation Area is already being serviced by a Comprehensive Drainage Scheme.

Area 4 :: An area of around 1600 ha has been defined north of the Sunlands Irrigation Area within a large meander of the River Murray (Fig. 4). The thickness of the Blanchetown Clay is generally greater than 2.4 m. Major disadvantages with this area are:

(1) proximity to River Murray - possibility of leakage must be thoroughly investigated.

(2) top surface of the clay is essentially domal in nature (See Cross Sections I, II, Fig. 4). Major earthmoving would thus be required.

GROUNDWATER MOUND - WAIKERIE

The groundwater mound is formed because the quantity of water passed down the drainage bores is greater than the quantity of water which can be transmitted by the aquifer in question.

A detailed discussion of the mound created over the groundwater table in the Waikerie District for the period ended June 1970 has already been given (Roberts, 1970). The monitoring of the mound has been carried out with an observation network of 16 bores, 13 of which were drilled in the deep Morgan-Mannum Limestone and 3 in the shallow aquifer. The readings from June 1966 to March 1975 are graphically summarised in Fig. 5 and the potentiometric surface as from March 1975 (except bore 20W, 18W, 26R - March 1974) is illustrated in Fig. 6.

The same trends as discussed in the previous report are apparent in the 1970-75 period. There is a continuing general increase in the level of the water table under the Waikerie, Golden and Ramco Heights Irrigation areas and, as can be seen in Figure 5, the rate of increase varies with the locality. The greatest rate occurs in Bore 1R in the Ramco Heights I.A. Bores 26R, in the eastern boundary of Golden Heights, and 2W, on the southern edge of Waikerie I.A., also have high rates of increases. In general, the greatest rate of increase occurs in the western portion of the Mound. This could be due to variations in transmissivity of the aquifer.

Although the majority of the bores show some seasonal fluctuations in their water levels, a number of bores have strong seasonal effects superimposed on the general increase. These bores, namely 18W, 19W, 22W, 31W and to a lesser extent 20W, 17W, 16W seem to be clustered around the peak of the mound in the Waikerie I.A. As mentioned in the previous report (Roberts 1970) variation in transmissivity of the limestone aquifer could account for the greater fluctuations in some bores. Unhomogeneous distribution of drainage bores could also play a part - this aspect has not as yet been investigated in the field.

The three bores drilled into the shallow aquifer (Norwest Bend Formation) generally show the same trend as the deep bores.

Of prime concern is the interaction of the ground-water mound with the Blanchetown Clay. As a great percentage of the region is underlain by this impermeable layer, the majority of the drainage bores will become inoperative when the level of the mound reaches the bottom surface of the clay. The distance between the bottom surface of the Blanchetown

Clay and the present (March 1975) static level in the observation bores that intersected clay, together with the average annual increase in the water level of each bore is given in Table 2.

TABLE 2

Bore No.	Average Annual Increase in water level (m)	Distance between clay and water level (March 1975) (metres)	Depth from top of casing to water level m
28R	.1	3.2	15.4
16W	.18	11.2	15.8
2W	.43	17 (Jan. 75)	25.2
17W	.39	15	23.5
18W	.1	12.7 (March 74)	23.3
31W	.03	2.2	13.2
1R	1.8	13.9	18.9
19W	.06	No Blanchetown	9.9
20W	.18	Clay	25.3 (Aug. 74)
21W	.13	-	26.5
22W	.31	-	
23W	.15	-	24.
25W	.1	-	14.
25AW	.32	-	26.5
26R	.43	-	23.9
27R	.35	-	16.2

The region in the vicinity of bore 1R appears to be the most critical, assuming that the water level observed in that bore is in fact a true representation of the water level in that area. In view of the complex response of the groundwater mound to the application of drainage water, it is not possible, at this stage, to safely predict the time for the mound to reach a critical level.

CONCLUSIONS AND RECOMMENDATIONS

Four areas that could further be investigated as sites for evaporation basins have been outlined within 20 km of Waikerie. At least 600 ha in each area is underlain by more than 1.5 m of Blanchetown Clay. Area I probably presents the best potential, in view of thickness of underlying clay (at least 3 m), distance from the River Murray (25 km) and small distance from the irrigation areas.

The next step in the investigation of the evaporation sites is the testing of the permeability of the Blanchetown Clay and the estimation of the magnitude of any vertical leakage through the clay. If the leakage is in fact expected to be significant, a more detailed investigation of the effects of the proposed basins on the saline groundwater inflow to the River Murray must be carried out. This would probably require testing of the aquifer(s) between sites and River. Shallow drilling, possibly with an auger should also be carried out within each area to define the best possible site for a 600 ha evaporation basin.

The continually rising water levels in the observation bores, suggest that the groundwater mound beneath the Waikerie Irrigation Area is continually growing and a stage will be eventually reached when the water level intersects the Blanchetown Clay. As the response of the mound to the application of drainage is complex, it is difficult to predict with any degree of confidence the time required for the level of the mound to reach a critical stage, bearing in mind that the higher the mound develops, the faster the drainage will disperse. A literature research will therefore be undertaken to better understand the growth and/or decay of the mound in response to deep percolation. A reappraisal of the groundwater mound problem will eventually be presented in a report in the near future.

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APPENDIX 1

GEOLOGICAL LOGS

A. Shallow Rotary holes drilled between 8.10.74 and 17.10.74. Driller D. White, logged by X. Sibenaler, air circulation.

WR1

0 - 3.5 m	Dune sands and calcrete
3.5 - 4	Calcrete (and calcreted limestone?)
4 - 6	Sandy marl
6 - 6.2	Fawn grey sandy clay, brownish at depth.

WR2

0 - 3 m	Dune sands and calcrete
3 - 3.9	Sandy marls
3.9 - 5.6	Brown sandy clays, mottled green-grey
5.6 - 8	Fine (clayey) sands (less than 10% clay)
8 - 9	Fossiliferous whitish fine sands, micaceous.

WR3

0 - 2.3 m	Fine brown sands (dune sands)
2.3 - 3.4	Calcrete
3.4 - 5.5	Brown mottled green-grey sandy clays.
5.5 - 5.8	Fine yellowish white sands.

WR4

0 - 1.5 m	Dune sands
1.5 - 2.	Calcrete
2 - 4.9	Dune sands, sandy, silty marls at depth
4.9 - 5.8	Brown, mottled green, sandy clays.

WR5

0 - 6.9 m	Red brown fine sands with calcrete
6.9 - 12	Yellowish-white fine sands, micaceous. Fossiliferous at depth.

WR6 Abandoned in wet silty sands. Less than 1 m.

WR7

0 - 3.7 m	Top soil and calcrete
3.7 - 6.5	Brown very fine clayey sands
6.5 - 12	Yellow-brown micaceous sands.

WR8

0 - 1.0 m	Top soil and calcrete
1.0 - 3.7	Sandy brown clays, mottled grey green.
3.7 - 5	Yellowish fine to coarse sands, micaceous calcareous grey green sandstone at depth.

WR9

0 - 1 m	Top soil and calcrete
1 - 4	Fawn to brown clayey, silty and sandy marls.
4 - 7	Red brown clayey silts

WR10

0 - 1 m	Top soil, calcrete and minor light brown clayey sands
1 - 3.5	Fawn, light brown silty and sandy marls
3.5 - 6	Clayey sandy silts

WR11

0 - 1.5 m	Dune sands
1.5 - 3	Calcrete
3 - 4	Off-white sandy marls
4 - 4.8	Grey green mottled brown sandy clays
4.8 - 6.2	Yellowish fine sand - micaceous

WR12

0 - 0.8 m	Calcrete (top soil)
0.8 - 3.7	Fawn sandy marls
3.7 - 5.7	Dark brown very sandy clays
5.7 - 6.7	Yellowish fine to medium fine sands - micaceous

WR13

0 - 1 m	Calcrete
1 - 2	Fawn sandy marl
2 - 2.8	Grey-green mottled brown sandy clays
2.8 - 3.7	Olive sandy clays
3.7 - 4	Greater % of sands; yellow-green sands at depth
4 - 6	Yellowish green grey fine sands

WR14

0 - 1.5 m	Top soil, calcrete and calcreted limestone
1.5 - 2	Fawn sandy marls
2 - 3.7	Greenish, mottled brown, sandy clays; browner at depth (olive-khaki).
3.7 - 5	Khaki clayey fine sands
5 - 5.8	Whitish grey very fine sands, shell fragments, at 5.5 m.

WR15

0 - 1.3 m	Top soil calcrete
1.3 - 2	Sandy marl
2 - 3.4	As above with khaki-green clayey fine sands - minor shell fragments? 2.8-3 m.
3.4 - 3.8	Brownish, mottled green, very sandy clays or clayey sands
3.8 - 5.6	Yellowish-khaki green very fine sands (silts) with abundant fossil fragments at depth.

WR16

0 - 0.1 m	Top soil and calcrete
0.1 - 1.2	As above with calcreted grey green limestone?
1.2 - 1.5	Red brown very sandy clays (clayey sands?)
1.5 - 5.13	Grey green calcareous sandstone. Shell fragments at 4.9 m.

WR17

0 - 1.5 m	Dune sands (0-0.1 m) calcrete and sands.
1.5 - 3	Light brown silty and sandy marls. 2.5 m thin layers of calcreted sandy limestone.
3 - 3.4	Calcreted sandy limestone? - grey green.
3.4 - 4	Yellow brown fine sands - (less than 10% clay)
4 - 7.6	Yellow-khaki micaceous fine to medium sands. Thin calc. sandstone. Traces of fossils at depth.

WR18

0 - 0.1 m	Sands
0.1 - 1	Calcrete
1 - 1.8	Light brown (fawn) clayey silty sandy marl.
1.8 - 2	Very sandy clays (clayey sands) mottled grey-green.
2 - 4	Khaki brown fine sands - micaceous
4 - 5.6	Whitish and yellowish fine sands to medium coarse and calcareous sandstone. Fossiliferous, micaceous.

WR19

0 - 0.8 m	Top soil and calcrete
0.8 - 2	Light brown marl
2 - 3.8	Red brown clayey sands (sandy clays?)
3.8 - 4.7	Brown sands - fine to coarse
4.7 - 5.5	Brown sandy clays or clayey sands. Thin sands.
5.5 - 7	Light brown, mottled grey green, fine sands (10% clay).
7 - 8	Red brown very sandy clays (clayey sands) with thin fine to medium coarse sands.
8 - 9	Light brown fine sands - micaceous.

WR20

0 - 1.7 m	Top soil, calcrete and minor greyish green limestone.
1.7 - 3	Fawn sandy marl.
3 - 3.9	Grey, light brown sandy clays.
3.9 - 4.5	Light brown clayey silt and sands. Minor grey green calcreted limestone?
4.5 - 5.6	Dark brown sandy clays (clayey sands) - thin sands.

WR21

0 - 0.2 m	Fine red - brown dune sands
0.2 - 0.7	Calcrete
0.7 - 1.7	Fawn, light brown marl
1.7 - 4	Brown khaki to yellowish very fine micaceous sands. Fossiliferous at depth. Minor calcareous sandstone.

WR22

0 - 0.7 m	Calcrete
0.7 - 1.5	Fawn sandy marl
1.5 - 2	Fine red brown sands
2 - 2.8	Green - grey, mottled brown clays
2.8 - 4	Greyish-green to brown clayey sands (very sandy clays)
4 - 4.7	Light brown sandy clays
4.7 - 10.7	Greenish grey light khaki very fine sands.
10.7 - 12	As above and calcareous sandstone and shell fragments (shells)

WR23

0 - 0.7 m	Top soil and calcrete
0.7 - 1.7	Light brown sandy marl
1.7 - 3	Dark brown, mottled grey green, sandy clays with thin sands
3 - 3.6	Mainly brown sands, thin clays
3.6 - 5.6	Fine to coarse sands, micaceous, fossiliferous at depth. Calcareous sandstone.

WR24

0 - 0.5 m	Top soil and calcrete
0.5 - 1.8	Very fine brown sands
1.8 - 4	Red brown clayey sands - Clay content increasing with depth (2.7 - 3 m very sandy clays?)
4 - 5.6	Brown, mottled grey, sands, micaceous.

WR25

0 - 3.5 m	Top soil, calcrete, fawn sandy marl.
3.5 - 5	Red brown, very sandy clays
5 - 5.6	Fine grey-green sands.

WR26

0 - 1 m	Topsoil, calcrete
1 - 1.8	Fawn brown sandy and silty marl.
1.8 - 2.1	Red brown sandy clays
2.1 - 5.6	Grey green and light brown fine sands, micaceous.

WR27

0 - 1 m	Top soil and calcrete
1 - 2	Sandy marl
2 - 2.5	Sandy clays
2.5- 4	Abundant shell fragments in grey, light green limey matrix.
4 - 5.6	Very silty yellowish fine sands.

WR28

0 - 1 m	Top soil, nodular calcrete
1 - 2	Calcrete with fawn silty and sandy marl
2 - 8	Brown, grey green clays - sandy. 4-8 m green clays becoming sandier at 7.9 m.

WR29

0 - .4 m	Dune sands
0.4 - 1	Calcrete
1 - 1.6	Fawn silty marl
1.6 - 4.5	Greenish khaki (sandy) clays - mottled brown
4.5 - 5.2	Calcareous sandstone, fossiliferous (shells) fine brown yellow sands.

WR30

0 - 0.8 m	Calcrete
0.8 - 1.1	Light brown marl
1.1 - 2.2	Dark brown to brown khaki sandy gypseous clays.
2.2 - 8.7	Sands (fine to coarse), gypsum, shell fragments (2.3 - 3.5 sands) (3.5 - 8 gypsum, sands)

WR31

0 - 0.4 m	Dune sands
0.4 - 0.6	Calcrete
0.6 - 3	Fawn marl, grey-green limestone
3 - 5.5	Green khaki clays becoming greener with depth - sandy.
5.5 - 5.7	Sandier grey - green clays (clayey sands)
5.7 - 6	Fine green - grey sands.

B. Simplified Geological Logs of Previously Drilled Bores

CADELL AREA

Bore No.

1C

0 - 1.22 m	Calcrete
1.22- 1.52	Limestone: hard, pale green
1.52- 2.74	Limestone: recrystallised, oyster fragments
2.74- 41.16	Limestone: with thin marly clays

2C

0 - 1.52 m	Calcrete with red brown sandy clay
1.52- 2.44	Clay: red, brown, shell fragments
2.44- 15.24	Limestone: sandy, with oysters and marly clay (7-12 m)

3C

0 - 1.52 m	Calcrete and greenish limestone
1.52- 3.66	Clay: brown, mottled grey-blue
3.66- 5.49	Limestone: with oyster fragments

4C

0 - 1.22 m	Calcrete
1.22- 11.9	Clay: mottled grey and reddish brown. Gypsiferous at depth.
11.9- 15.2	Limestone: with oyster fragments and bryozoal

5C

0 - 2.4 m	Calcrete
2.4 - 4.9	Clay: variegated blue-green-yellow slightly silty towards base
4.9 - 7	Sands: yellow-green, fine, micaceous with oysters
7 - 7.6	Limestone: sandy

6C

0 - 1.83 m	Sand: dune sands
1.83- 3.7	Calcrete
3.7 - 7	Clay: blue-green, becoming silty at base
7 - 8.8	Sand: white to light yellow, fine

7C

0 - 1.2 m	Sand: dune sand
1.2 - 3.7	Calcrete: hard pink calcrete with thin sands
3.7 - 4.6	Sands: orange brown, fine to medium
4.6 - 5.8	Limestone: hard, sandy

8C

0 - 4 m	Sands: red brown dune sands overlying fine fawn micaceous sands.
4 - 5.5	Calcrete
5.5 - 7.9	Sand: light brown clayey sand, and greenish yellow fine micaceous sand.

9C

0 - 7.3 m	Sand: brown to light brown, fine to medium sands. Thin shallow calcrete.
7.3 - 8.8(?)	Clays: blue-green, with calcareous material at depth.
8.8 - 10.7	Sand: greenish-yellow, fine to coarse micaceous.

10C

0 - 4.9 m	Sand: buff, fine, slightly micaceous. Thin calcrete at top.
4.9 - 5.5	Calcrete
5.5 - 7.9	Clay: blue-green
7.9 - 9.2	Sand: yellow-green, micaceous, fine.

11C

0 - 1.2 m	Calcrete
1.2 - 8.8	Clay: brown mottled green, silty. Becoming siltier with depth.
8.8 - 10.7	Sand: oyster bed in yellow grey fine sand.

12C

0 - 3.4 m	Sand: fine to coarse dune sand.
3.4 - 4.6	Calcrete
4.6 - 8.8	Clay: blue-green.
8.8 - 11	Sand: yellow green fine sand and sandstone with oyster fragments.

13C

0 - 1.8	Calcrete and sand
1.8 - 3	Limestone: hard, grey-green
3 - 7.3	Clay: blue-green
7.3 -11	Sand: yellow-green fine sands with oysters

14C

0 - 7.9 m	Sand: brown fine - medium dune sand
7.9 - 8.8	Calcrete
8.8 - 9.8	Limestone: green, calcreted at top
9.8 -14.3	Clay: blue-green

15C

0 - 5.2	Sand and calcrete
5.2 - 6.1	Limestone: green, calcreted at top
6.1 -10.7	Clay: blue-green
10.7 -12.8	Sand: yellow green, fine, micaceous, oysters at depth.

SUNLANDS AREA

2S

0 - 0.6 m	Sand: medium grained, brown
0.6 - 5.2	Clay with Sand: sandy clays with thin sands and calcrete fragments.
5.2 - 5.8	Sand: fine to medium, yellow-green. Fossil fragments.
5.8 - 6.1	Limestone: sandy, oyster fragments
6.1 - 8.5	Sand: clayey, oyster fragments, mica flakes
8.5 -10.1	Sandstone: calcareous, shell fragments
10.1-11.3	Sand and grit: fossiliferous
11.3-33.4	Clay: calcareous, sandy, fossiliferous, grey and brown. Bryozoa at depth.
33.4-51.8	Limestone: grey and fawn.

3S

0 - 1.22 m	Sand: red dune sands
1.2 - 2.7	Calcrete: minor red sand, greenish limestone 2.4-2.7 m
2.7 - 6.1	Sands: numerous oysters, slightly micaceous.

4S

0 - 3.4	Sands: red dune sands
3.4 - 4.8	Calcrete and green limestone
4.8 - 8.8	Clay, brown and green. Sandy towards base.
8.8 -13.4	Sand: yellow and white sands. Micaceous and shelly at depth.

5S

0 - 0.9 m	Sand: brown
0.9 - 2.1	Calcrete and greenish limestone
2.1 - 7	Clay: brown and green
7 -10.7	Sand: yellow-brown, fossiliferous oysters at depth

6S

0 - 8.2 m	Sand: reddish fine dune sands
8.2 - 9.5	Calcrete
9.5 -10.7	Sand
10.7-12.5	Limestone, greenish, marly
12.5-17.1	Clay: greenish and brown
17.1-18.6	Clayey sands.(?)

7S

0 - 0.9 m	Sand
0.9 - 1.8	Calcrete
1.8 - 3.4	Limestone, greenish, becoming soft and marly with depth
3.4 -21.3	Clay: greenish, brown.
21.3-24.4	Sands: clayey, yellow green at top. Yellow, micaceous at depth.

8S

0 - 3.4 m	Calcrete, minor sands
3.4 - 4	Limestone, greenish
4 - 7.6	Clay, yellow and green, silty
7.6 - 9.5	Oyster bed

9S

0 - 3.1 m	Sands, minor calcrete
3.1 - 3.7	Limestone, greenish
3.7 -10.1	Clay, green and yellow, silty. Becoming sandy at depth (9.2 m)
10.1-11.6	Sands, oysters.

10S

0 - 6.1 m	Sands, red and greenish-grey brown clayey sands
6.1 - 9.8	Clay, light grey, thin sands
9.8 -10.7	Gypsum

11S

0 - 1.8 m	Sands, red
1.8 - 10.1	Sands, very clayey
10.1-15.2	Sands, increasing quantities of grey clays

12S

0 - 1.2 m	Sandy soil and calcrete
1.2 - 1.8	Calcrete
1.8 - 2.4	Limestone, greenish
2.4 - 7.9	Clay: brown and green, sandy at depth, thin marls.
7.9 - 9.8	Oysters in sandy matrix.

13S

0 - 6.1 m	Dune sands
6.1 - 9.2	Dune sands with calcrete and limestone at base
9.2 -10.1	Sand: yellow clayey
10.1 -16.2	Clays: blue-green and yellow brown
16.2 -18.6	Sands: clayey, oyster fragments

14S

0 - 1.2 m	Sands: red, fine to medium
1.2 - 1.8	Calcrete and sand
1.8 - 2.4	Calcrete, clayey sand and green clay
2.4 - 4.6	Sand with oysters
4.6 - 6.1	Sand, micaceous

15S

0 - 0.6 m	Sand and calcrete
0.6 - 1.2	Calcrete
1.2 - 4.3	Clay, with gypsum
4.3 - 5.5	Sandstone and sands, with gypsum
5.5 - 7	Sand, clayey
7 - 8.5	Sand, with oysters

16S

0 - 3 m	Sands and minor calcrete
3 - 3.4	Limestone, green
3.4 -11.9	Clay, blue-green with brown
11.9 - 12.2	Sand, micaceous, clayey
12.2 -15.5	Sands

17S

0 - 0.9 m	Sand and calcrete
0.9 - 2.4	Calcrete
2.4 - 5.5	Clay, silty
5.5 -10.4	Sand
10.4 -10.7	Sand with oyster fragments

18S

0 - 2.1 m	Sand, clayey
2.1 - 3	Sand and clay
3 - 3.7	Sand, very clayey
3.7 - 6.1	Sand, with recrystallised limestone at depth

19S

0 - 6.7 m	Sand and calcrete
6.7 - 8.5	Calcrete
8.5 - 10.7	Limestone (green) and marl
10.7 - 15.2	Clay, blue-green

21S

0 - 6.1 m	Sand and calcrete
6.1 - 8.8	Clay, brown and green, thin limestone and oysters at depth
8.8 - 9.8	Oyster bed

22S

0 - 4.9 m	Sand and calcrete
4.9 - 5.5	Calcrete, green limestone and soft marl
5.5 - 11	Gypsum
11. - 13.4	Clay and gypsum
13.4 - 14.6	Clayey sand and gypsum
14.6 - 17.1	Sand, with oysters

23S

0 - 2.7 m	Sand and calcrete
2.7 - 4	Calcrete and limestone
4 - 4.9	Clay, blue-green and yellow
4.9 - 7.6	Sand and oyster bed

24S

0 - 0.9 m	Calcrete
0.9 - 1.5	Green limestone and marl
1.5 - 2.4	Gypseous clay
2.4 - 5.5	Gypsum
5.5 - 5.8	Sand
5.8 - 7.3	Gypsum
7.3 - 9.5	Clayey sand, gypseous
9.5 - 11	Sand, micaceous

25S

0 - 1.2 m	Sand and calcrete
1.2 - 1.8	Green limestone
1.8 - 3	Clay, grey green and brown
3 - 4.3	Sand, clayey
4.3 - 6	Limestone

26S

0 - 7.9 m	Sand and calcrete
7.9 - 9.8	Marl and sand
9.8 - 10.4	Sandy marl and green sandy clay

27S

0 - 5.5 m	Sand
5.5 - 8.2	Calcrete and marly sand
8.2 -11.3	Clay, blue-green

28S

0 - 3.7 m	Sand
3.7 - 6.1	Sand and marl
6.1 - 11.3	Clay, brown and blue-green

RAMCO AND GOLDEN HEIGHTS IRRIGATION AREAS

Bore No.

1R

0 - 2.1 m	Soil and calcrete, minor sands
2.1 - 4.9	Clay, green-grey. Oysters in basal 15 cm
4.9 - 7.3	Oyster beds, sand
7.3 - 11.	Sands, micaceous, calcareous, oysters
11 - 24.4	Limestone
24.4 - 44.2	Marly clays and marls
44.2 - 76.2	Limestone and marls

2R

0 - 2 m	Sands: brown and fawn, fine-medium
2 - 4	Calcrete and greenish limestone
4 - 5	Clay, sandy and silty, grey green and red
5 - 8.2	Clay, green, gypseous
8.2 - 8.5	Sands, fine, calcareous
8.5 - 15	Clay, green, gypseous
15 - 16	Sands, green, yellow, clayey
16 - 18.6	Sands, gypseous

4R

0 - 3.4 m	Sands
3.4 - 5.2	Calcareous sand and calcrete
5.2 - 6.1	Limestone
6.1 - 7.6	Limestone and sands
7.6 - 8.5	Sands
8.5 - 10.1	Limestone

5R

0 - 0.6 m	Pink hard kunkar
0.6 - 1.2	Brownish hard sandy kunkar
1.2 - 1.8	Fine and medium brown sand
1.8 - 2.7	Green and brown fresh water limestone passing down into grey marl.
2.7 - 4.8	Variegated blue-green clay
4.8 - 6	Yellowish green sandy clay with fine shell fragments.
6 - 8.5	Fawn and light fine sands and sandy limestones with oyster fragments.

6R

0 - 20.1 m	Sands with calcrete at top

7R

0 - 12.5 m	Sands, calcareous, clayey in parts, calcrete
12.5- 13.1	Green clay and sand
13.1- 14.6	Limestone
14.6- 16.8	Sand, clayey, oyster shells
16.8- 20.1	Limestone

9R

0 - 3. m	Sands and calcrete
3 - 3.7	Calcrete and green limestone
3.7 - 6.7	Clay, silty
6.7 - 8.2	Limestone

10R

0 - 16.2 m	Sands and calcrete
16.2- 17.1	Green limestone
17.1- 29.3	Clay, silty
29.3- 30.5	Sand, clayey
30.5- 32.6	Clay
32.6- 33.2	No samples

12R

0 - 9.8	Sands and calcrete
9.8 - 11.3	Green limestone and marl
11.3- 14.6	Clay
14.6- 17.1	Sandstone

13R

0 - 5.5 m	Sand and calcrete
5.5 - 8.5	Calcareous sand and sandstone
8.5 - 10.4	Sand, very clayey, calcareous

14R

0 - 0.6 m	Fawn limey sand
0.6 - 1.2	Pink nodular kunkar - hard
1.2 - 2.7	Fine fawn kunkar (hard) and fine sand
2.7 - 3.3	Pink hard rubbly kunkar
3.3 - 4.5	Variegated blue-green-brown clay with limey nodules
4.5 - 10	Mainly brown clays
10. - 11.2	Brown clay with green marly layers
11.2- 14.5	Brown and green-grey clays
14.5- 19.4	Grey-green clays with light grey layers
19.4- 20.3	Mainly fawn fine sands
20.3- 22.4	Very clayey fawn and light brown sands with shell fragments.
22.4- 24	Limey sands somewhat less clayey - shell fragments.

15R

0 - 2.4 m	Fawn soft kunkar and sand
2.4 - 6	Brown fine to coarse sand becoming finer downwards
6 - 7	Pink kunkar and greenish kunkarised fresh water limestone
7 - 9.4	Marly clay - light greenish grey
9.4 - 22	Brown clay
22 - 27	Yellow-green clay
27 - 31	Blue-green clay
31 - 32	Oyster bed

16R

0 - 2.7 m	Soil, sands and calcrete
2.7 - 3.4	Limestone, green
3.4 - 4.6	Clay, brown and green
4.6 - 6.1	Sand, very clayey
6.1 - 7.6	Sand, clayey

17R

0 - 9.1 m	Sand and calcrete
9.1 - 10.7	Green clay

18R

0 - 17.1 m	Sand and calcrete
17 - 18.	Marl
18 - 19.8	Clay

19R

0 - 19.8 m	Sands and calcrete
19.8- 22.3	Marls and fine sand
22.3- 24.4	Clay

20R

0 - 7.3 m	Sands and calcrete
7.3 - 8.8	Green limestone and marl
8.8 - 11.	Clay, green and red

21R

0 - 8.8 m	Sands and calcrete, marl at depth
8.8 - 9.1	Clay, marly

22R

0 - 1.8 m	Sand and calcrete
1.8 - 3	Sand with oyster fragments
3 - 5.8	Sandy limestone and clayey sand

23R

0 - 1.8 m	Soil, calcrete and sand
1.8 - 4.9	Clayey fine sand with oyster fragments

24R

0 - 0.9 m	Soil, calcrete and sand
0.9 - 3.9	Limestone and limey sand, oysters.

WAIKERIE IRRIGATION AREA

Bore

1W

Depth 55.7 m No clay

2W

0 - 6.1 m	Sand and calcrete
6.1 - 7.6	Calcrete clay and limestone
7.6 - 14.6	Sandstone and sand
14.6- 16.5	Limestone
16.5- 17.7	Clay, calcareous
17.7- 25.9	Marl
25.9-154.9	Limestone and marl
154.9-173.8	Sands
173.8-196.6	Clay
196.6-213.4	Sands
213.4-234.7	Clay

3W

Depth 6.4 m No clay

4W

0 - 0.9 m	Calcrete
0.9 - 2.1	Green limestone
2.1 - 3.	Clay
3 - 6.1	Sandstone

5W

Depth 10.4 m No clay

6 W

Depth 4.6 m No clay

7W

0 - 4.3 m	Sandy soil, calcrete and sand
4.3 - 4.6	Green limestone
4.6 - 7.6	Clay - sandy
7.6 - 10.7	Sand, with oysters at depth

8W

Depth 6.7 m No clay

9W

0 - 3.7 m	Sand and calcrete
3.7 - 4.6	Calcreted green limestone and marl
4.6 - 5.5	Clay, minor sand
5.5 - 6.7	Sand, very clayey
6.7 - 10.1	Sand, clayey, shell fragments at depth

10W

Depth 32.3 m No clay

11W

0 - 0.9 m	Soil and calcrete
0.9 - 1.8	Green limestone and marl
1.8 - 4	Clay
4 - 6.4	Sands, clayey

12W

Depth 7 m No clay

APPENDIX 2

Estimation of groundwater flow velocity

In the regions considered, groundwater flow is generally in a westerly direction towards the Rivery Murray. The particle velocity can be calculated by using the relationship

$$v = \frac{1}{E} Ki$$

where v = particle velocity

E = porosity of water bearing material 0.2 (arbitrary value, variable)

K = Hydraulic Conductivity = 10 m/day (from aquifer testing, variable)

i = gradient of potentiometric surface 1 in 1650 (greatest gradient)

From the above parameter approximations, the groundwater flow velocity has been estimated to be around 11 m/year.

Area 1

Distance from this area to the River Murray along flow lines is approximately 23 km.

$\therefore$ Time required to travel that distance is approximately 2×10^3 years.

Area 2

Distance to River Murray - 35 km

$\therefore$ Time of travel 3×10^3 years

Area 3

Distance to River Murray along flow lines - 6.5 km

$\therefore$ Time of travel 0.600×10^3 years.

Note: These estimations can only be regarded as first approximations. A more refined approach will eventually be required.

APPENDIX 3

SUMMARY OF WATER DELIVERED TO IRRIGATION AREAS

WAIKERIE IRRIGATION AREAS

Year	Rainfall in inches	Area Under Irrigation (acres)	Quantity Delivered in Acre /feet	in inches/ft
1964/65	11.24	3925	15900	48.6
1965/66	8.5	3925	17000	51.9
1966/67	6.6	3925	17600	53.8
1967/68	9.4	4150	16600	48
1968/69	10.5	4150	15400	44.5
1969/70	7.5	4150	16700	48.3
1970/71	12.4	4150	15900	45.9
1971/72	8.5	4150	17720	51
1972/73	13.3	4150	17700	51
1973/74	23.2	4200	11300	32

GOLDEN HEIGHTS/RAMCO IRRIGATION AREAS

1968/69	10.5	550	1850	40.4
1969/70	7.5	550	2100	45.8
1970/71	12.4	550	1801	39
1971/72	8.5	560	2016	43
1972/73	13.3	560	2100	45
1973/74	23.2	560	1306	28

Note the lesser application of water in the Golden Heights/Ramco I.A. where a springling system is used as compared to channel system in Waikerie I.A.

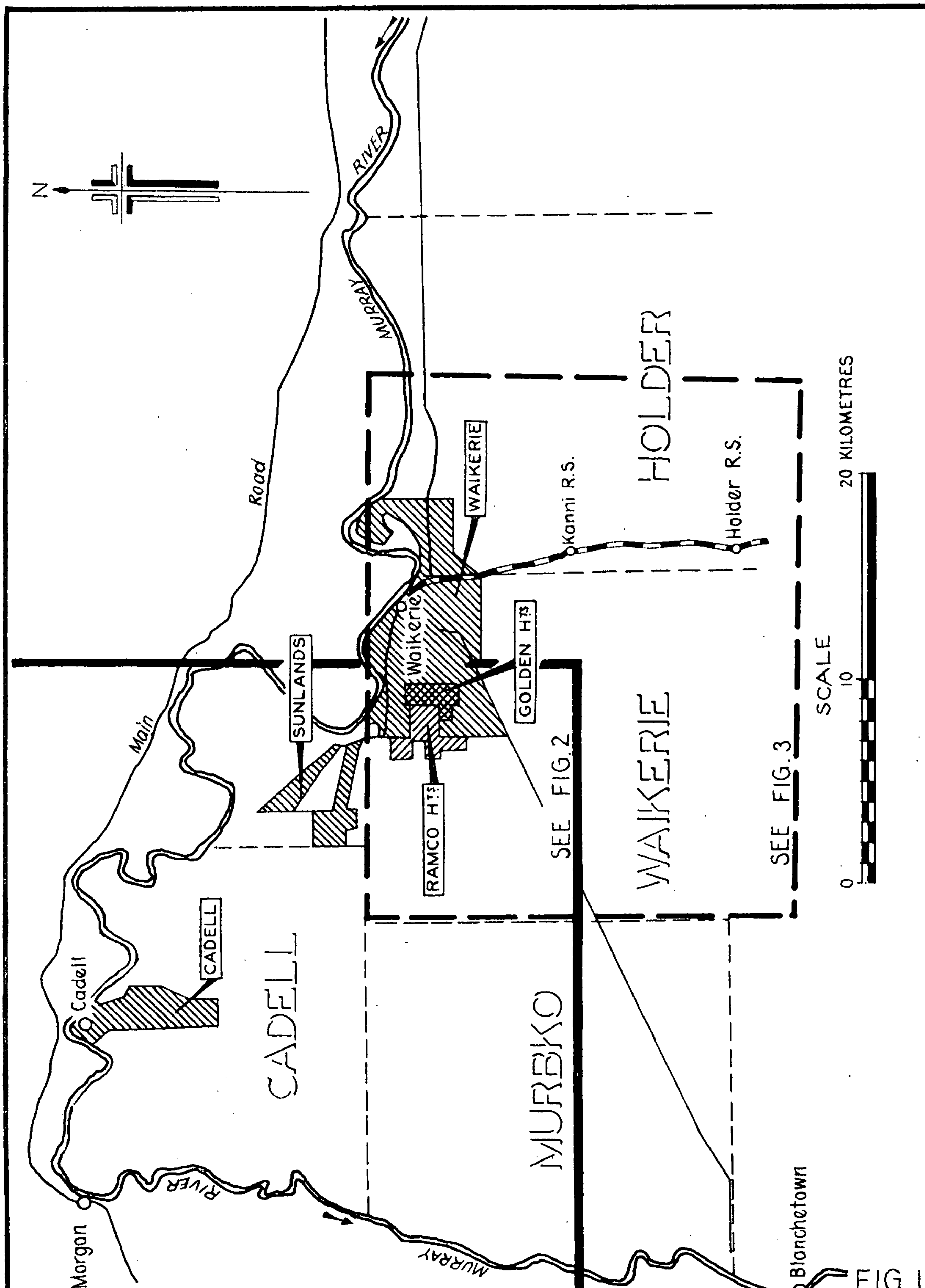
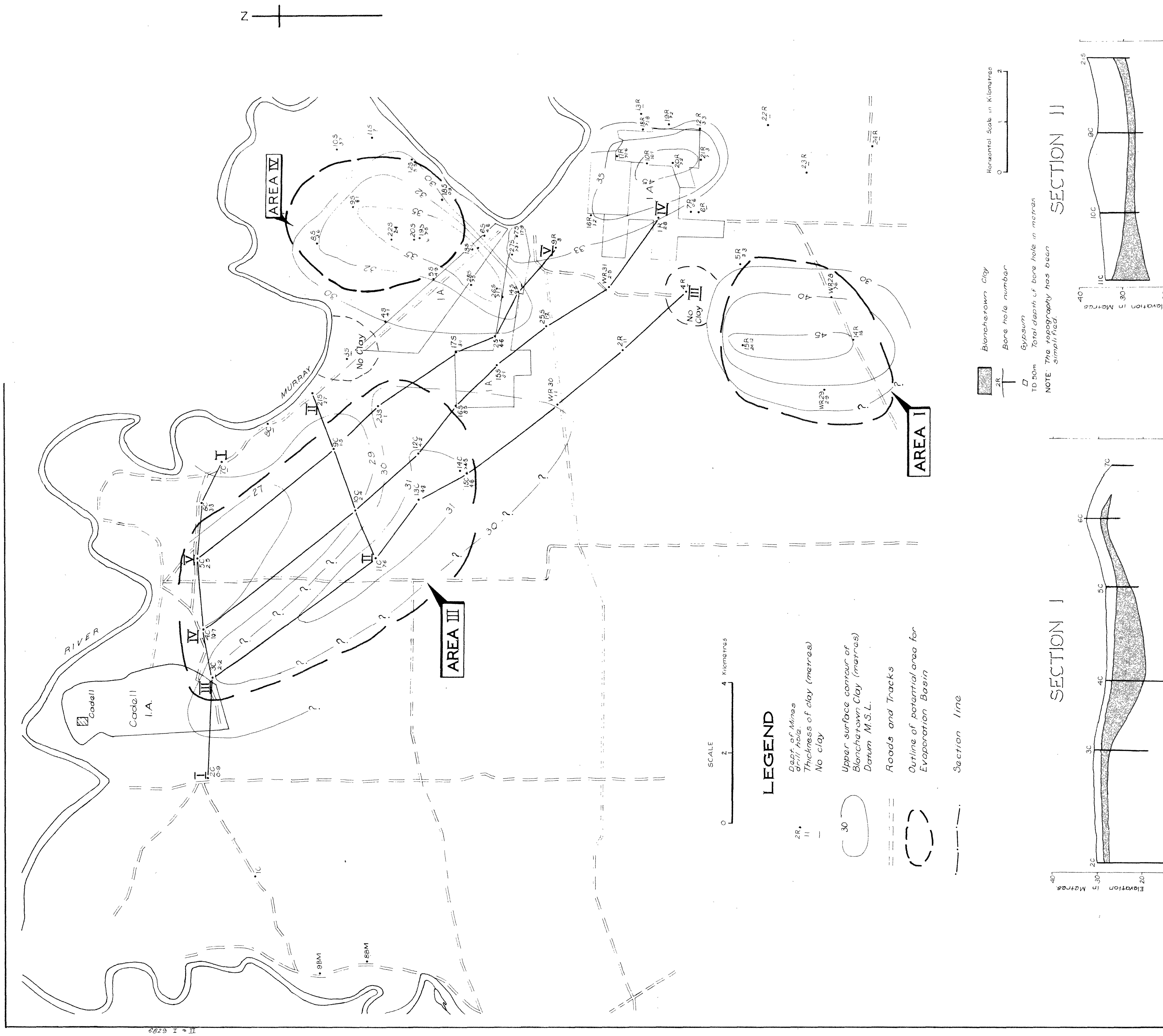


FIG. 1

DEPARTMENT OF MINES — SOUTH AUSTRALIA

HYDROGEOLOGY SECTION	**Drn.** X.S.	RIVER MURRAY DRAINAGE INVESTIGATION	**SCALE:** 1: 253 440
	Tcd. T.E.		S 11415
	Ckd.	LOCALITY PLAN	6829 + 6929
	Exd.		**DATE:** March 1975

500-2.69 665



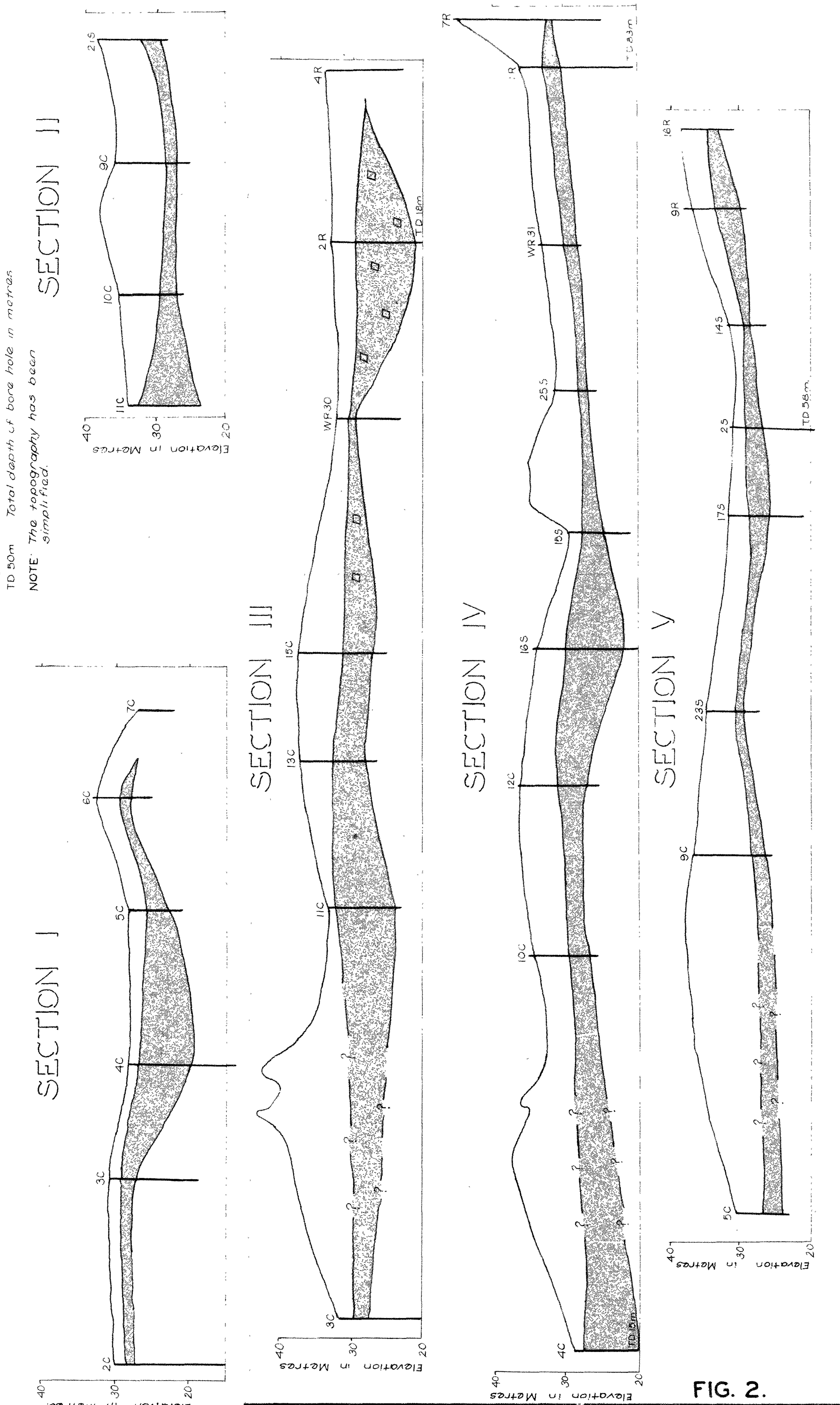


FIG. 2.

DEPARTMENT OF MINES – SOUTH AUSTRALIA

RIVER MURRAY DRAINAGE INVESTIGATION

BLANCHETOWN CLAY – CADELL AREA

POTENTIAL EVAPORATION BASINS & CROSS SECTIONS

HYDROGEOLOGY SECTION	Compiled X.S.	Scale : As shown
		Date :
	Drn. G.J.T	Drg. No. 75–390
Director of Mines	Ckd.	

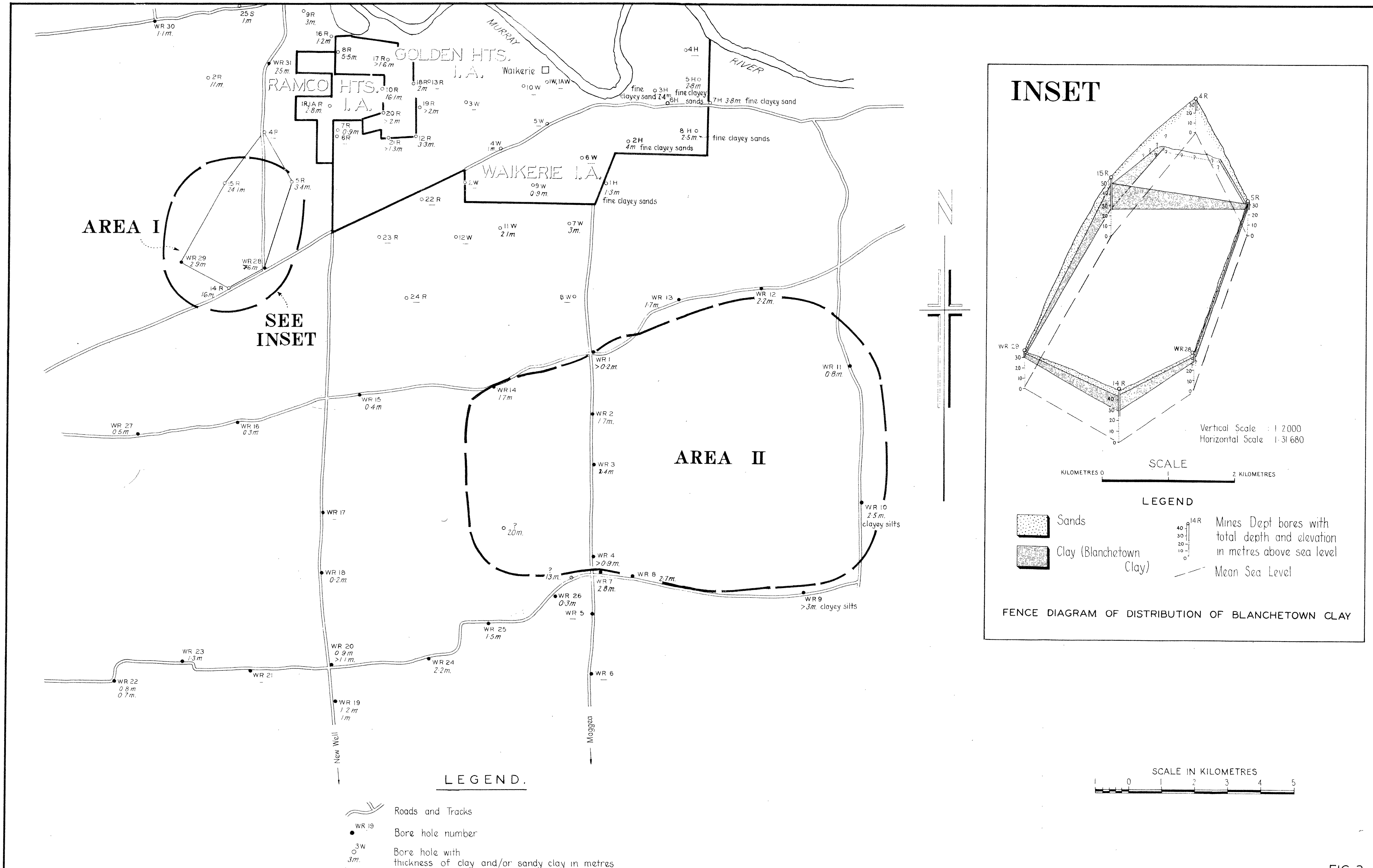
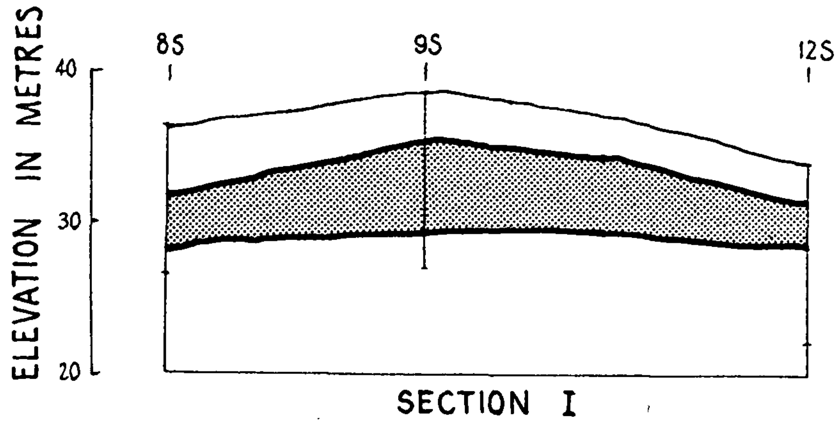


FIG. 3

DEPARTMENT OF MINES – SOUTH AUSTRALIA

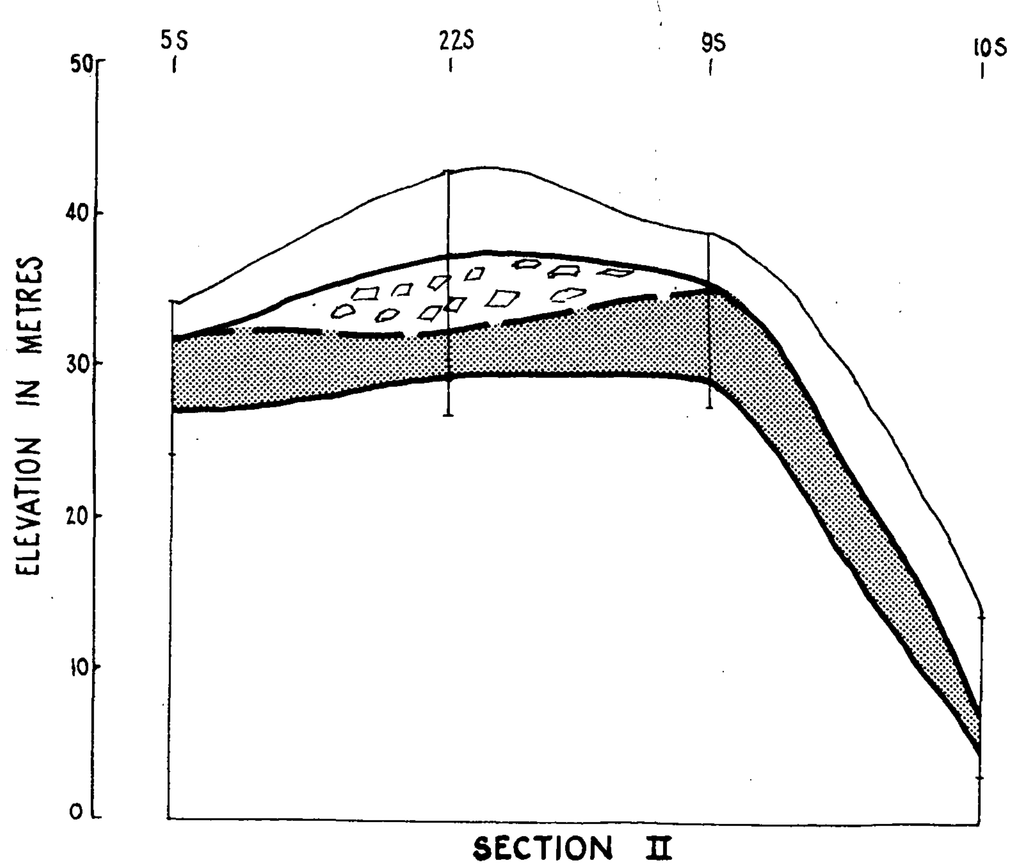
RIVER MURRAY DRAINAGE INVESTIGATION
BLANCHETOWN CLAY – WAIKERIE AREA
POTENTIAL EVAPORATION BASINS

HYDROGEOLOGY SECTION	Compiled X.S.	Scale: 1:63 360	Date: March 1975
Director of Mines	Drn. T.E. Ckd.	Drg. No. 75-395	6829+6929



■ Blanchetown Clay
.22S Borehole Number
Gypsum

HORIZONTAL SCALE
0 2 4 Kms.



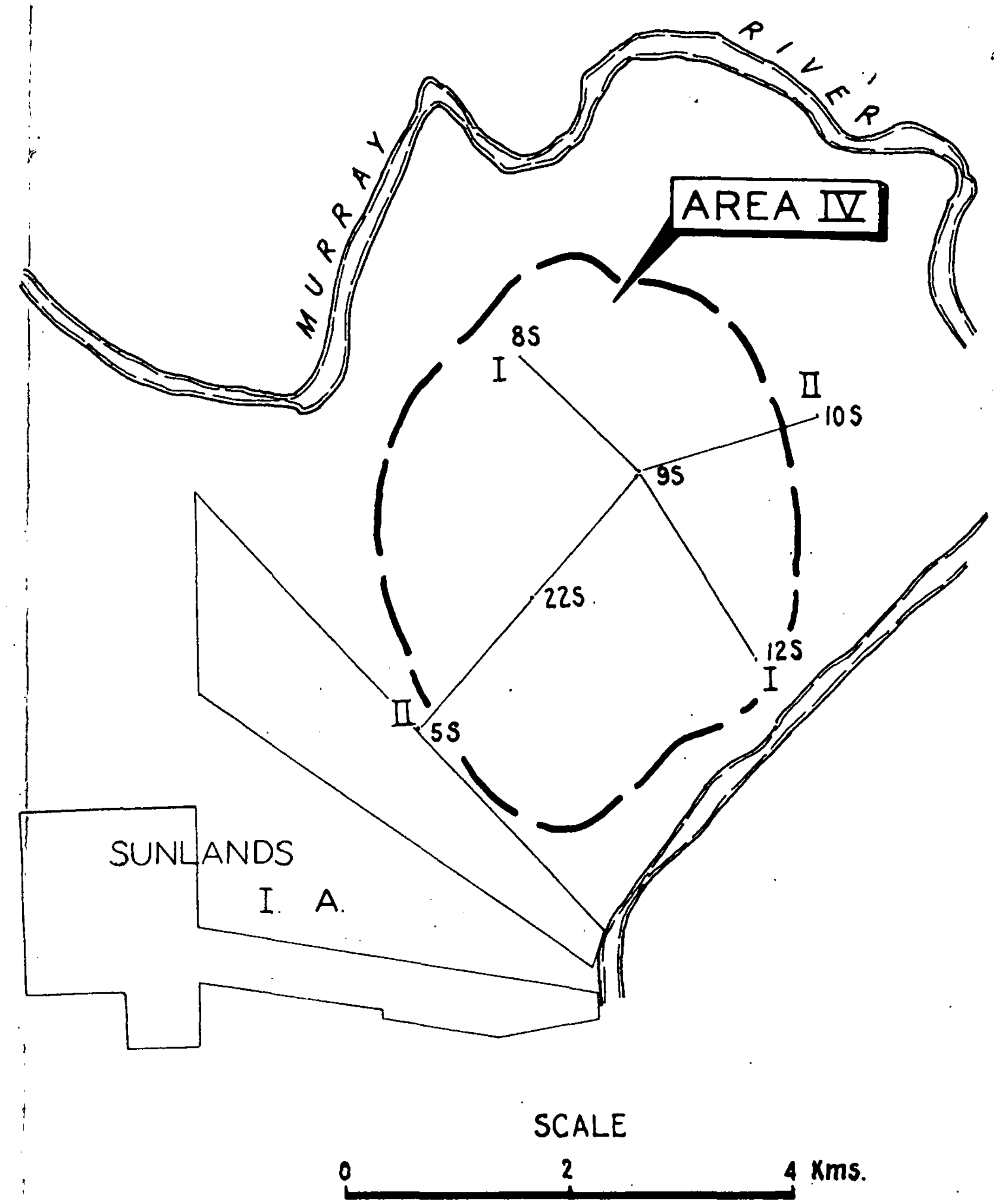


FIG. 4

DEPARTMENT OF MINES — SOUTH AUSTRALIA

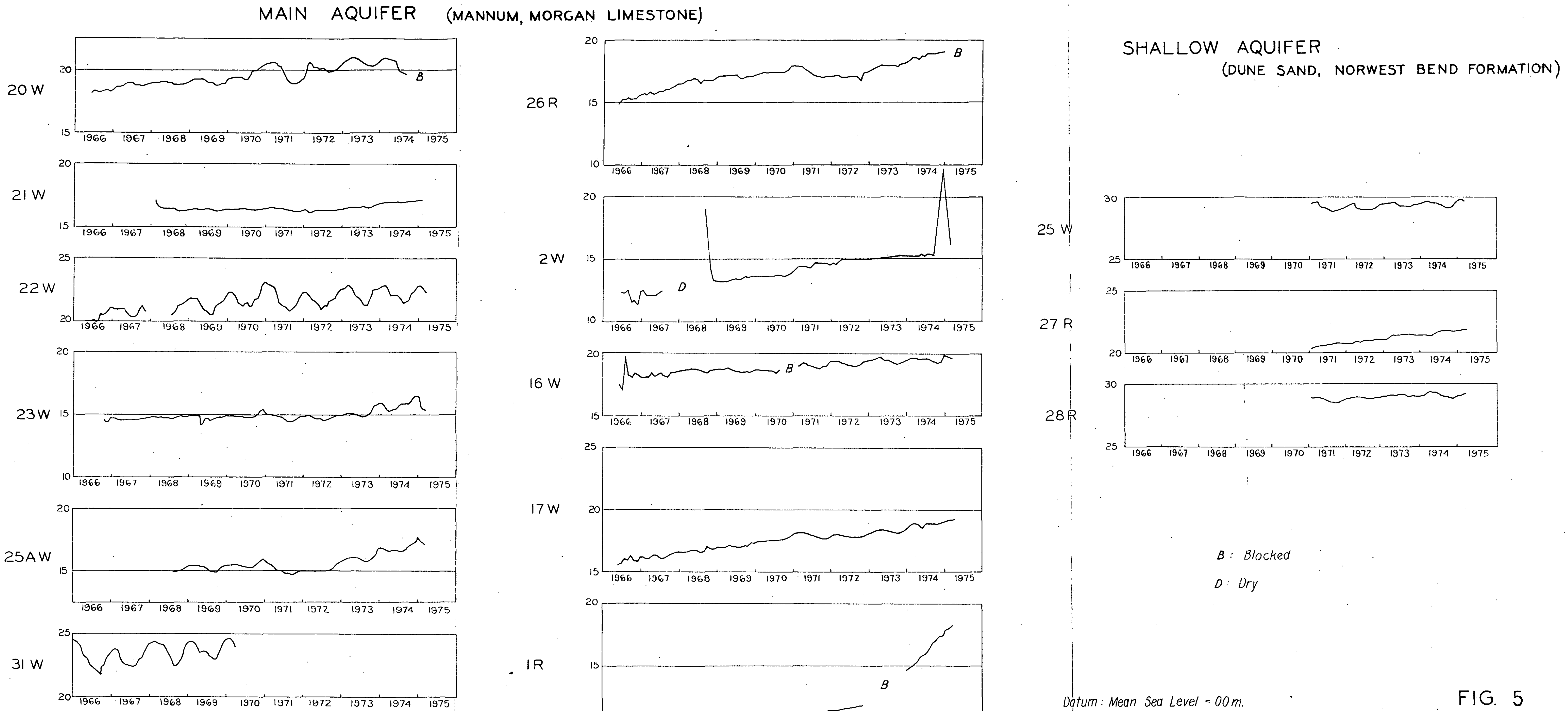
RIVER MURRAY DRAINAGE INVESTIGATION

AREA IV

GEOLOGICAL SECTIONS SHOWING BLANCHETOWN CLAY

		Drn. X.S.	SCALE: As Shown
		Tcd. T.E.	76-100
		Ckd.	
Director of Mines		Exd.	DATE: 11 February 1976

6829 + 6929



Datum : Mean Sea Level = 00 m.

FIG. 5

DEPARTMENT OF MINES – SOUTH AUSTRALIA		Scale: 1: 250
Compiled X. S.	RIVER MURRAY DRAINAGE INVESTIGATION SUMMARY OF WATER LEVELS	Date: 9 July 1975
Drn. T. E. Ckd.	JULY 1966 THROUGH TO MARCH 1975	Drg. No. 75-668

6829-I + 6929-III

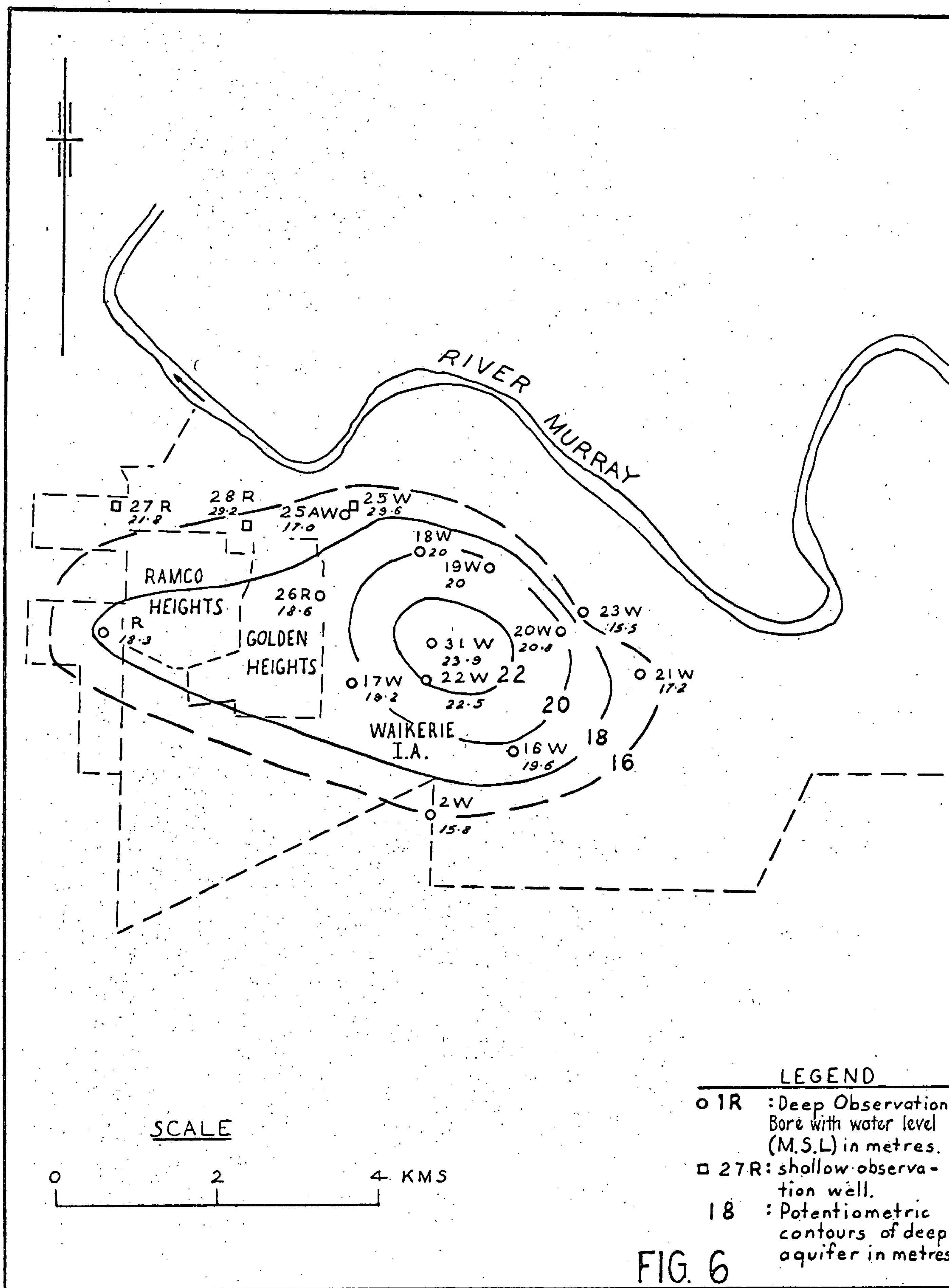


FIG. 6

	DEPARTMENT OF MINES — SOUTH AUSTRALIA	Scale 1:63,360
Compiled:	RIVER MURRAY DRAINAGE INVESTIGATION WAIKERIE AREA POTENTIOMETRIC CONTOURS AS AT MARCH 1975	Date: 27/5/75
Drn. P.D. | Ckd.		Drg. No. S11510

750—8.74 F332 O

6829