DEPARTMENT OF MINES AND ENERGY
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ANGAS-BREMER IRRIGATION AREA, MILANG GROUNDWATER BASIN, GROUNDWATER MODELLING

By

M.J. SHEARD
GEOLOGIST

GEOLOGICAL SURVEY

GROUNDWATER AND ENGINEERING SECTION

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* - Transparent overlay in pocket at rear of report.

FIGURES

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ANGAS-BREMER IRRIGATION AREA, MILANG GROUNDWATER BASIN, GROUNDWATER MODELLING

ABSTRACT

Computer modelling of the Milang groundwater basin was done to evaluate the groundwater flow systems of the basin, to test the basin hydrogeology described by Waterhouse et al. (1978), and to derive a management strategy for this area. The data from that report was modelled using the AFPM (Aquifer Flow through Porous Media) modelling package developed by Golder & Associates for the E. &. W.S. Department.

Refinements to aquifer geometry and hydraulic parameters were done in three stages, and prepumping steady state hydraulic solutions derived. Pumping rates based on estimates from Waterhouse et al. (1978) and on estimates of irrigation requirements according to mapped land use, were applied to a fourth modelling stage. Computed water levels did not show good agreement with observed water levels.

The modelling has revealed areas where further research and field tests may supply data enabling a more accurate model to be constructed. This model was unable to simulate known drawdown or compute cones of depression similar to those observed. Reasons for this include: the lack of data on aquifer permeabilities; a lack of knowledge about aquifer geometry and hydrogeology at the basin extremities, and estimates of current pumping rates possibly being too low.

INTRODUCTION

The Groundwater Modelling Package used to model the aquifer regimes in the Milang groundwater basin was developed by Golder Associates for the South Australian Government.

Waterhouse, Sinclair and Gerges (1978), in a Department of Mines and Energy report, have described the hydrogeology of the area, providing a foundation for developing a steady state hydraulic simulation of the two aquifer system.

Groundwater from the confined-semiconfined lower aquifer is used for irrigation of pasture, lucerne, and to a small extent - potatoes. Little use is made of the saline water from the unconfined upper aquifer. The model developed is capable of being used to test the system as presently understood, the system response to management strategies both present and future, and also to indicate areas where data improvement is required.

DATA

Waterhouse et al. (1978) have described in detail the hydrogeologic system close to the main Irrigation Area. Further data was obtained from Department of Mines and Energy bore records covering areas not included in that report. Information concerning recharge from the Bremer River and Lake Alexandrina was obtained from Hall (1977), and Smith (1978).

GEOLOGY

The Milang groundwater basin forms part of the southwestern extremity to the much larger Murray Basin, (Fig. 1). Sediments within the Milang groundwater basin rarely exceed 125 m in thickness and are variously, marine, fluviatile, lacustrine, and aeolian in origin.

Tertiary marine limestones, richly fossiliferous, of the Ettrick and Mannum Formations form a basal sequence up to 100 metres thick. This sequence thins westward and has been truncated by a fault that forms its western boundary. These limestones are indistinguishable except by palaeontological methods. Collectively the two limestones form the highly permeable lower confined aquifer.

The sandy and silty clays of the Pliocene Parilla Sand and Norwest Bend equivalents overly the Tertiary limestones. They act as a separating layer between the two main Milang groundwater basin aquifers.

Quaternary gravels, sands and clays - equivalent to the Blanchetown Clay, overlie the Pliocene Sediments. They form the upper unconfined aquifer which has permeabilities about an order of magnitude less than the lower aquifer.

Basin geology and hydrogeology is given in summary form in Table 1.

A more detailed description of the geology and its depositional history can be found in Waterhouse et al. (1978).

TABLE 1 SUMMARY OF HYDROGEOLOGY

Stratigraphic Unit	Age	Lithology	Hydrogeological Characteristics	Groundwater Use
Equivalent to the Blanchetown Clays and Chowilla Sand.	Quaternary	Fluviatile and lacustrine clays, sands, and silts, overlain by aeolian sands. 10-35 metres thick.	Unconfined aquifer, permeabilities range from 0.5 to 10 m/day. Salinity 1 000 to 30 000 mg/L.	little development - mainly stock supplies.
Equivalent to the Parilla Sand and Norwest Bend Fm.	Pliocene	Sands and clays inter-fingering with shelly marls. 0 to 13 metres thick.	Leaky separating layer.	Not known to be used for groundwater supplies.
Mannum Limestone Ettrick Formation Buccleuch Beds	Late Eocene to Miocene	Fossiliferous limestones with interbeds of sand and marl. Distinguished by micropalaeontology. Clayey marls and sands at base.	Confined aquifer, permeabilities range from 15 to 25 m/day. Salinity 1 500 to 10 000 mg/L.	Main groundwater source.
Kanmantoo Group	Cambrian	Schists, phyllites and metagreywackes	Poor aquifer, low permeabilities and high salinities.	Not used in the Milang Basin

Adapted from Table 1 in Waterhouse et al. (1978)

HYDROGEOLOGY

In the Milang groundwater basin there are two main aquifer systems: the lower aquifer, which is confined in the northern part of the area and supplies most of the underground water used for irrigation; and the upper aquifer which is unconfined. The upper aquifer is rarely used because of the high salinity of its water. This aquifer extends over the whole study area, (Fig. 2). It is recharged by the ephemeral, often brackish, Bremer and Angas Rivers; and by downward leakage of fresh water from Lake Alexandrina. Upper aquifer loss by downward leakage to the lower aquifer is only significant in the southern part of the area. Sands, silts, and clays equivalent to the Blanchetown Clay make up most of the upper aquifer. Overlying this material are Pleistocene dune sands on land and lacustrine silts below Lake Alexandrina.

Forming a separating layer between the upper and lower aquifers are the equivalents to the Norwest Bend Formation and Parilla Sands. This layer is a good separator in the northern part of the study area but to the south is leaky.

The lower aquifer is truncated by a fault on its western margin and covers a smaller areal extent than the upper aquifer (Fig. 2, 3). It is made up of limestones from the Mannum and Ettrick Formations. Recharge to this aquifer occurs where the confining bed is leaky, (in the southern part of the area), and along its faulted western margin.

Both the Angas and Bremer Rivers lose water to both aquifer systems near and just down stream of the faulted margin of the lower aquifer.

AQUIFER MODELLING

The aquifer modelling was done to mathematically simulate the aquifer's behaviour, by applying the groundwater flow equation to the observed hydraulic and geologic data.

The modelling technique employs a finite element approach which is described in the various manuals supplied by GOLDER ASSOCIATES (1979) as part of the Groundwater Modelling Package.

For the modelling, the groundwater system is broken up into a series of blocks or ELEMENTS which are individually described, (Fig. 4). A simplified surface map was prepared (Fig. 3), onto which the element mesh was imposed. The choice of element size and distribution is described in the next section. The modelling package formulates the necessary flow equations for each block, calculates the requested solution(s) and produces the results - usually as contour maps.

Unconfined aquifer - LAYER A

The element mesh is displayed in Figures 5 and 6 which are loose transparent overlays held in the pocket at the rear of this report. They can be overlaid on any of the other figures. Elements are restricted to quadrilateral or triangular shapes - the basal corners of which are called NODES. In this model there are 106 elements and 112 nodes in Layer A. The area modelled covers 511 km^2, 378 km^2 of which is land area and 133 km^2 is occupied by Lake Alexandrina. The irrigation area covers 200 km^2. Land use patterns, recharge sources, areas of varying permeability, and the distribution of potentiometric contours were used as criteria in forming the element mesh. Element sizes range from 0.94 km^2 to 15.6 km^2 and average about 5 km^2. The largest elements occur below Lake Alexandrina.

External boundaries to the model were selected in the following manner: the northeastern and southwestern boundaries parallel flow lines (and are thus no flow boundaries), the northwestern boundary was considered to be a no flow boundary (except for river input nodes), and the east and southeastern boundaries were positioned so that they lay beyond the suspected position of pre-pumping zero potential levels. Extrapolations from known data then had to be made in order to complete the model description. These extensions to reported data were based wherever possible on Department of Mines and Energy bore records.

Lake Alexandrina was treated as a reservoir with a leaky separator (lake muds, vertical permeability initially set at 1×10^{-3}m/day) between it and the top of the upper aquifer. Lake level is 0.75 metres above sea level, and all lake shore nodes had their potential heads set at this value.

Initial material zones were based on the sand to silt ratio map from Waterhouse et al. 1978, (Fig. 12). Five zones of differing lithology were chosen (TABLE 2), and to these, permeabilities were assigned, based on average values appropriate for these lithologies. This method was adopted as no upper aquifer testing had been carried out. The permeability of zone 1 (2.0 m/day) reflects the suggestion by Waterhouse et al. (1978) - that it is an order of magnitude less than that for the lower aquifer (15 to 20 m/day). Figure 7 displays upper aquifer material zones, (a loose overlay at the rear of the report).

TABLE 2 STAGE I MATERIAL ZONE INPUT DATA

Material Zones	Lithology	Permeability Kx m/day	Permeability Ky m/day	Rain Recharge m/day	Evapotranspiration Potential Loss m/d	Evapotranspiration Effective Depth m
1	sand/silt	2.0	2.0	8.0x10-5	2.2x10-3	2.0
2	clay	1.0x10-3	1.0x10-3	8.0x10-5	2.2x10-3	2.0
3	clay	1.0x10-3	1.0x10-3	8.0x10-5	2.2x10-3	2.0
5	fractured rock	1.0x10-4	1.0x10-4	8.0x10-5	2.2x10-3	0.5
9*	sand/silt	2.0	2.0	0.0	0.0	-

* There is no rain recharge or evapotranspiration applied to Zone 9 below Lake Alexandrina.

Each zone had rainfall recharge, and potential evapotranspiration applied. The rates derive from data in Waterhouse et al. (1978), TABLE 2. The evapotranspiration function only operates when the computed water table reaches within a pre-determined distance from the ground surface, and is fully explained in the Golder Associates (1979) manual.

River recharge was approximately simulated by linking the river nodes and inputting river flow (equivalent to actual river recharge) initially at the first upstream node (Fig. 6,7). Values of river recharge in the study area were taken from Waterhouse et al. (1978), with refinements from Hall (1977) and Smith (1978). Recharge values rather than actual river flows were used because the modelling system is not designed to cope with excess water not playing an active role in the system, TABLE 3.

TABLE 3 RIVER RECHARGE TO MODEL

River	Recharge in m^3/day	Input Node
Angas	8 200	23
Bremer	25 700	63

Contour maps of Layer A thickness and its basal elevation relative to sea level are displayed in Figures 8 and 9 respectively.

Separator between the two main aquifers

The confining bed/leaky separator zones are indicated on Figure 10 (loose overlay, rear of report). A value between $3\text{x}10^{-3}$m/day and $3\text{x}10^{-2}$m/day - from Waterhouse et al. (1978), of $1.7\text{x}10^{-2}$m/day was used in the southern part of the area. Vertical conductivity of the northern confining bed was considered by Waterhouse et al. (1978) to be zero. However, this is rarely the case in practice, and a small value of $1\text{x}10^{-4}$m/day was used in the modelling.

Lower aquifer - LAYER B

The element mesh for Layer B is similar to that of Layer A except for the western boundary. This boundary represents the Milang groundwater basin's faulted western margin as marked on Figures 2 and 3. Its horizontal mesh position has been indicated on figure 6. Layer B contains 92 elements and 105 nodes. Initially Layer B was defined as one material type with a permeability value of 25 m/day (from Waterhouse et al. (1978)).

Recharge to this layer is by downward leakage from the overlying aquifer, leakage of river water through Layer A near the faulted western margin of Layer B, and leakage of lake water.

Figures 11 and 12 are contour maps of Layer B thickness and its basal elevation.

MODELLING

STAGE I:

Potentiometric maps computed using the described input data are presented in figures 13 and 14 (upper and lower aquifers respectively).

The objective was to produce a pre-pumping potentiometric simulation that could then be used to test the effects of pumping. The results showed that modifications were required to some of the input data. Permeabilities were too low at the northwestern end of Layer A, resulting in steep potential gradients northwest of a line between nodes 5 and 91. Mounding in Layer B at its western edge, indicating high leakage from the river nodes above in Layer A, did not conform to observed water level data. Upper aquifer geometry, such as thickness and basal elevation, caused artifically high potential gradients along the northern and southwestern boundaries. Dry nodes and elements resulted, which were remedied by lowering the aquifer base at these points.

STAGE II:

To overcome the permeability problems in the upper aquifer, data from Waterhouse et al. (1978) was re-examined. Using the potentiometric map for March 1977 (which gave the steepest gradients), 19 new material zones were created, Fig. 15 (loose overlay, report rear). These zones were assigned permeabilities ranging from 1 m/day to 10 m/day. It was assumed that variations in hydraulic gradients were at least in part due to variations in hydraulic conductivity, and the hydraulic conductivity zones were allotted according to the distribution of gradients (TABLE 4).

Zone 17 was assigned a higher permeability than in Stage I and its thickness increased, to overcome an artificial numeric hydraulic instability near this area.

TABLE 4 STAGE II UPPER AQUIFER MATERIAL ZONES

Material Zones	Permeabilities Kx m/day	Permeabilities Ky m/day	Rain Recharge m/day	Evapotranspiration Potential Loss m/d	Evapotranspiration Effective Depth m
1	1.0	1.0	8.0x10-5	2.2x10-3	2
2	4.0	4.0	8.0x10-5	2.2x10-3	2
3	10.0	10.0	8.0x10-5	2.2x10-3	2
4	4.0	4.0	8.0x10-5	2.2x10-3	2
5	5.0	5.0	8.0x10-5	2.2x10-3	2
6	6.0	6.0	8.0x10-5	2.2x10-3	2
7	7.0	7.0	8.0x10-5	2.2x10-3	2
8	8.0	8.0	8.0x10-5	2.2x10-3	2
9	9.0	9.0	8.0x10-5	2.2x10-3	2
10	10.0	10.0	8.0x10-5	2.2x10-3	2
11	9.0	9.0	8.0x10-5	2.2x10-3	2
12	8.0	8.0	8.0x10-5	2.2x10-3	2
13	7.0	7.0	8.0x10-5	2.2x10-3	2
14	6.0	6.0	8.0x10-5	2.2x10-3	2
15	4.0	4.0	8.0x10-5	2.2x10-3	2
16	4.0	4.0	8.0x10-5	2.2x10-3	2
17 *	0.05	0.05	8.0x10-5	2.2x10-3	1
22 **	10.0	10.0	0.0	0.0	-
23 **	9.0	9.0	0.0	0.0	-

* Fractured rock zone = material zone 5 in Stage I
** There is no rain recharge or evapotranspiration applied to Zones 22 and 23 below Lake Alexandrina.

Changes were made to node elevations along the northern and southwestern boundaries for both aquifers, and to the faulted western margin of the lower aquifer. Here numeric instability resulted from the aquifer floor being too steep in elements 127, 128, 142, 144, 145, 168 and 169. (These lie directly below elements 21, 22, 36, 38, 39, 62 and 63 - shown in Figure 5). Further modifications to aquifer boundary conditions were required during the running of Stage II. Dry nodes resulted from increased permeabilities near the southern boundary allowing greater drainage from the upper aquifer here. Where aquifer thickness increases involved inclusion of fractured rock material with low permeability the material zone permeability was decreased accordingly. Improvements in hydraulic flow was achieved by modifying zones near the Angas River, TABLE 5.

TABLE 5 STAGE II - REVISED MATERIAL ZONES, UPPER AQUIFER

Material Zone	Original K m/d	New K m/d
3	10.0	8.0
5	5.0	3.0
14	6.0	4.0
17	0.05	0.1

The resultant contoured potential maps are displayed in figures 16 and 17, for Stage II.

STAGE III:

Waterhouse et al. (1978) indicated by their contour plans and text that Mosquito Creek may be a source of recharge to the upper aquifer. This creek flows only when the Bremer River floods - so that its overall contribution is small and represents a diversion of Bremer River water. To test the validity of this assumption, a flow equivalent to 1/11th the Bremer River recharge rate was applied through nodes 71, 84, and 96 (Fig. 18).

Swamping problems along the upper reaches of the Angas River between nodes 20 to 23, were noticed in Stage II. Element permeabilities were reduced (Table 5) in this area to raise the water table near the river, however, this resulted in elements associated with nodes 20 to 23 having surface water over their entire area. To overcome this, river recharge was distributed along additional nodes, (Fig. 18).

Waterhouse et al. (1978) suggest that the lower aquifer permeabilities decrease in the northwestern part of the study area. To obtain a more detailed picture, data from all the known irrigation wells (almost 200) were examined. Following the rule of thumb that tested output on completion, in gallons/hour, is approximately equal to transmissivity in gallons/day-Foot, (J. Forth, E. & W.S., pers. com.) and metricating this, a map of approximate permeability was drawn up. Three distinct zones were apparent - ranging in permeability from 15 m/day in the north, to 25 m/day where the present day cone of depression due to pumping exists. These zones were incorporated into the existing mesh, (Fig. 20 - loose overlay, report rear).

Final steady-state non pumping results for both aquifers are shown in Figures 18, 19 and 21. The depth to water table map (Fig. 19), portrays the Bremer River flowing to approximately node 54 - indicated by the zero depth to water line.

Groundwater levels were not routinely measured before the onset of large scale groundwater usage. Hence, the contoured results for Stage III cannot be compared with observed data. Only after applying pumping (as it is thought to be distributed) can a computed result be obtained which can be compared to observational data and a check in the modelling accuracy be made.

STAGE IV:

Pumping applied to Stage III results

To test the model, known pumping was applied to the results of Stage III. Waterhouse et al. (1978) calculated an approximate withdrawal rate of $25 \times 10^6 m^3$/year, for the Irrigation Area. However, pumping rates for individual bores were not known and distribution of pumping was based on the land use map (Fig. 15 in Waterhouse et al. (1978)). By overlaying the element mesh on the land use map, element extraction rates were calculated (in metres/day for each element area), and applied as negative distributed inflows to the elements of the lower layer. To ensure that a crop is adequately irrigated, more water than necessary is applied. The reasons for this include evaporative losses from sprinklers, and the need to flush residual salts from the soil. Experience in other irrigation areas indicates that over application amounts to 20% of applied water. Thus by implication the remaining 80% of applied water is used by the irrigated crop and/or evaporated, and so is lost from the system. Hence, of the $25 \times 10^6 m^3$/year removed from the lower aquifer as pumpage, 80% was treated in the model as loss to the system, and 20% was returned to the upper layer as recharge. This recharge was applied to Layer A elements directly overlying those Layer B elements with applied pumping.

The results are shown in figures 22, 24 and 25. Figures 22 and 25 can be directly compared with Figures 23 and 26 (from Waterhouse et al. (1978)), showing observed potentiometric levels.

Apparent Problems

1. There appears to be insufficient extraction from the lower aquifer because the observed cones of depression are not matched by the modelling results, (Fig. 25, 26).

2. The irrigated areas shown on the land use map in Waterhouse et al. (1978) do not correspond well with the number and distribution of known irrigation wells. Nor do they correspond well with the observed cones of depression, and hence high extraction rates. For example; land overlying the cone of depression covers an area of 50 km^2, of which 8.5 km^2 is irrigated. In this area the lower aquifer permeability is high and there are almost 70 known irrigation bores. To the north east near the Langhorne Creek township, where a smaller cone of depression occurs, there are almost 70 known irrigation bores in an area of 60 km^2 of which 15 km^2 is irrigated. This area overlies a low permeability zone in the lower aquifer. These facts indicate a weakness in the land use map as presented. It is likely that irrigated pasture is more significant than previously estimated. This type of irrigation probably ceases in mid summer - as elevated temperatures increase evaporation and hence the salt content of marginal groundwater (more than 2 500 mg/L), reducing the advantages of irrigation. Land use maps have to date been based on aerial photography taken in late summer, taking advantage of contrasts between irrigated and non-irrigated lands. This photography may not be recording early summer groundwater use, hence the apparent discrepancy in area irrigated and rates pumped.

3. Downward leakage by groundwater from the upper to the lower aquifer is more significant than the permeability values from Waterhouse et al. (1978) would suggest. Pumping from the lower aquifer in the model did not produce significant drawdown in the upper aquifer. Observed superimposed cones of depression occur suggesting significant hydraulic coupling between the two aquifers in the southern portion of the Basin. Hence, vertical permeabilities of the separating layer in this area measured by Waterhouse et el. (1978) may reflect local values rather than a general value.

Abstraction measurement

During 1978 bore flow meters were installed at 10 bores on a voluntary basis. Monthly flows have been recorded from these meters beginning in September 1978. One of these bores was used for only two months, and two others have been used for less than six months. The areal distribution is not ideal and the number of meters too small for the readings to be directly applicable to the whole area.

CONCLUSIONS

The results of the groundwater modelling using available data from the Angas-Bremer Irrigation Area, are not in accord with observed water levels. Apparent from; graphic data presented in Waterhouse et al. (1978), and also the modelled hydraulic behaviour, is the singular aquifer response exhibited by both aquifers in the southern part of the area. Superimposed cones of depression, and similar response times observed for both aquifers imply a significantly larger vertical conductivity for the separating layer than indicated by pump testing to date. Some reasons for the differences between observed data and modelling results are:

1. pumping rates may be larger than present estimates, and the methods employed to calibrate groundwater use (summer aerial photography and metering of 10 wells), may be inadequate.

2. too little is known about;

   (a) boundary conditions applying to the Basin away from the central irrigation zone,

   (b) the influence of Lake Alexandrina on the system,

   (c) the aquifer geometry below the Lake,

   (d) actual permeabilities for both aquifers,

and (e) vertical hydraulic interaction between the upper and lower aquifers.

RECOMMENDATIONS

Should perhaps be supported ?

1. A better estimate of underground water usage may be obtained by correlating pumpage and metered electricity consumption for the 10 metered bores. Then if permission can be obtained to access the well owners' electricity accounts, applying this correlation to other irrigators electricity accounts, a correlation between water pumped and electricity consumed should be made. According to E.T.S.A. Accounts Branch, most

bore motors operate on a tariff rating not used by many other appliances, this tariff can be separated from the main users on a semi-regional basis. Hence, a correlation between electricity consumed and water pumped for the irrigation area may be obtainable to within ±10%.

2. An examination of aerial photography taken in early summer of the area, and comparing this with the later season photography in current use, may serve to identify irrigated pasture which at present is not identified. This could be tied in with recommendation 1. — ? should be recommended.

3. Rather than relying on meter installation on a volunteer basis, which to date has resulted in a random and sparse coverage, a more representative network should be planned. There are approximately 200 irrigation bores at present, and to obtain a reasonable sample up to 40 to 50 bores might have to be metered. This is a costly exercise at approximately $300 per meter - including installation and should not be undertaken until the need for better data has been justified. Results from such a program over a two year period in combination with recommendation 2 may give adequate information on water consumption. cost possibly outweighs advantages.

4. Further aquifer tests on both aquifers and their separating layer may be required. Some of these can be made using existing Dept. of Mines. bores and also well constructed private bores. More information about the basin margins is required that would necessitate drilling test holes. North of Mosquito Creek, west of the upper reaches to the Angas

River, and the floor to Lake Alexandrina are likely areas for more drilling. Such an exercise would be costly and should not be carried out until the need can be justified.

Malcolm J. Sheard

<u>MALCOLM J. SHEARD</u>

<u>GEOLOGIST</u>

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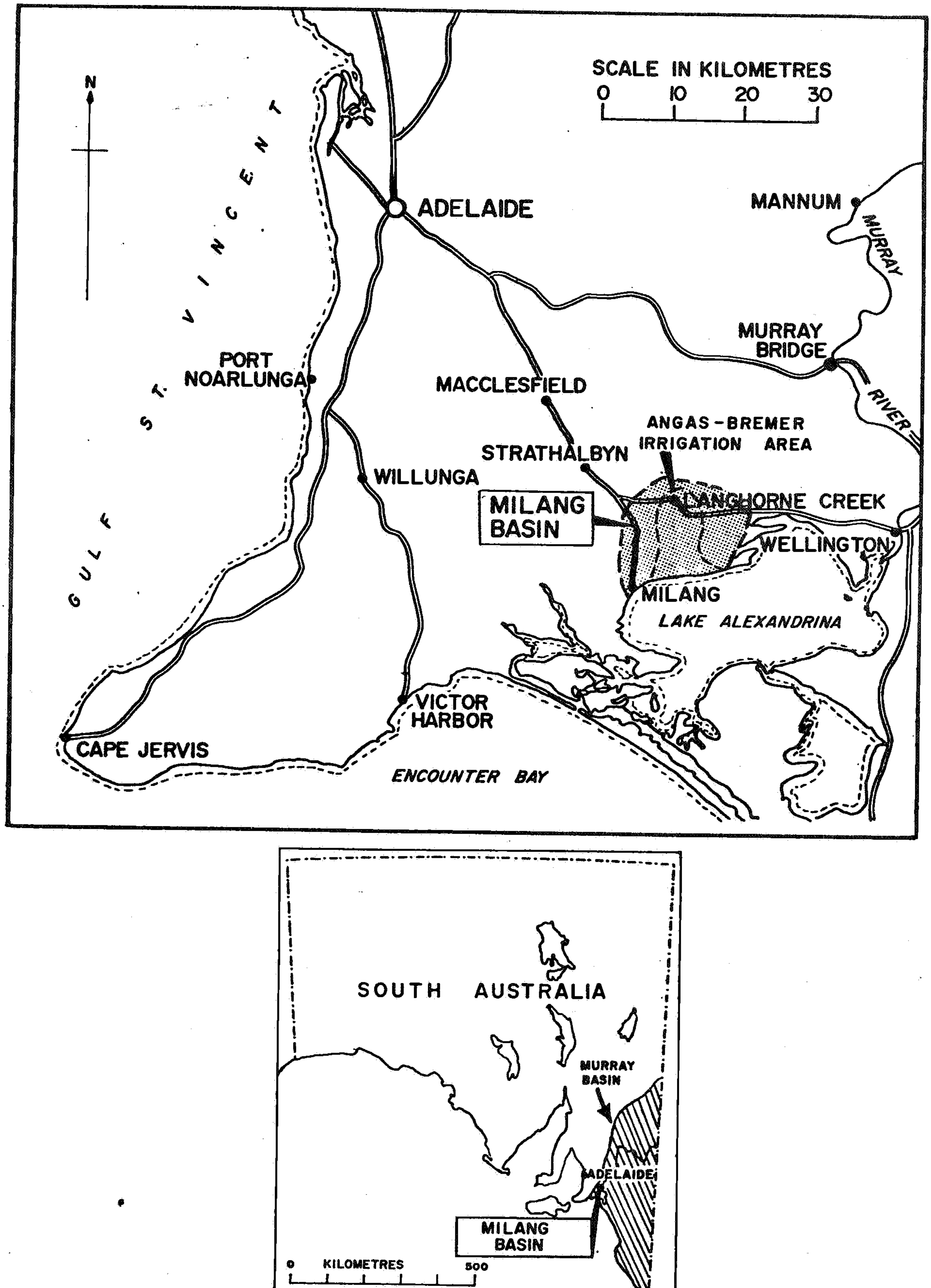
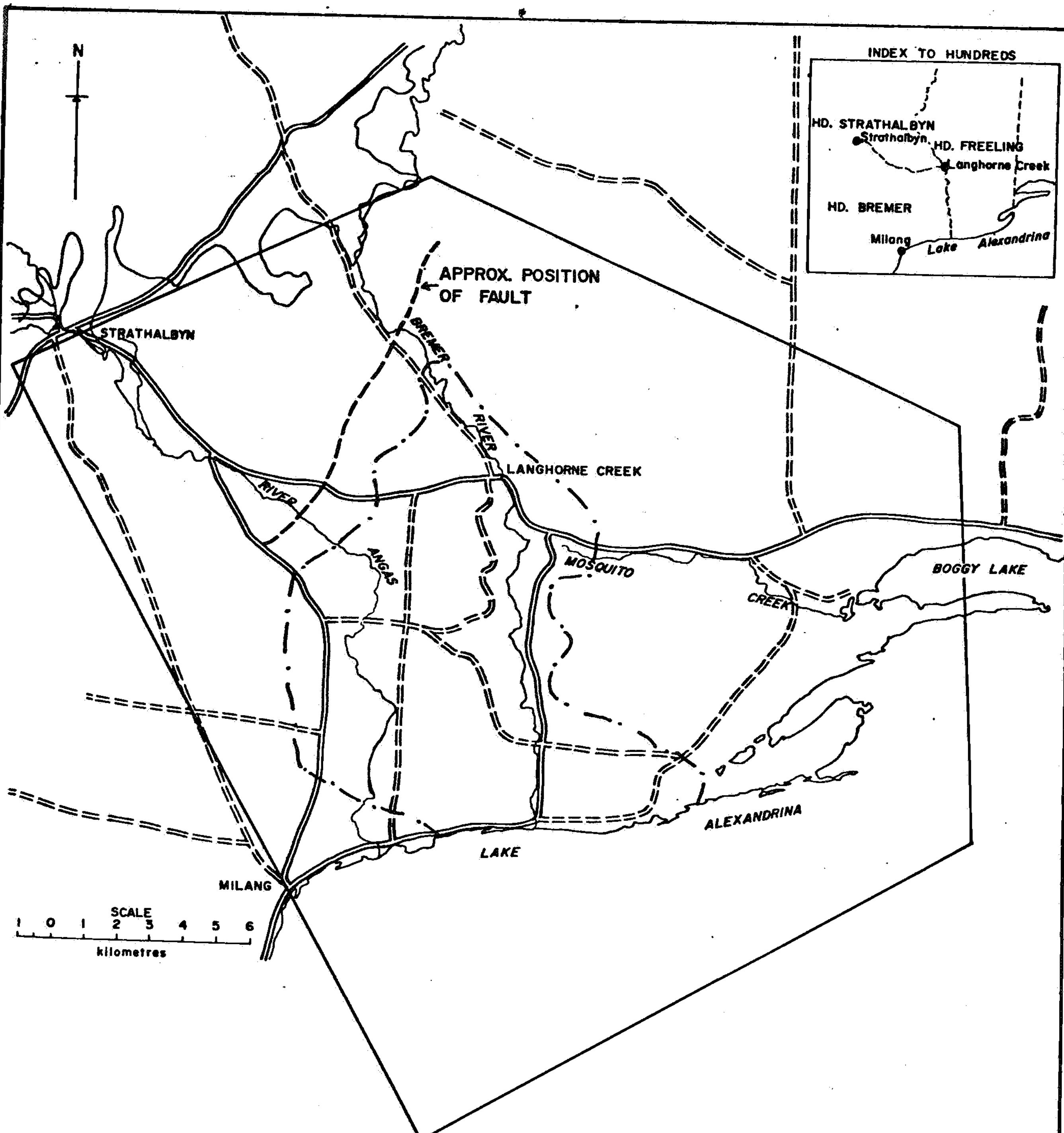


FIG.1

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE: AS ABOVE
COMPILED: M.J. SHEARD	ANGAS - BREMER IRRIGATION AREA TWO AQUIFER MODEL	DATE: SEPT. 1979
DRN: E.C. CKD:	REGIONAL LOCALITY PLAN	PLAN NUMBER S 14263



Boundary to area modelled.

Approximate boundary to main Angas–Bremer Irrigation Area (after Waterhouse et al. 1978).

FIG. 2

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE: 1:177,000
COMPILED M.J. Sheard	ANGAS – BREMER IRRIGATION AREA TWO AQUIFER MODEL LOCALITY PLAN	DATE: Sept. 3, 1979
DRN E.C. CKD:		PLAN NUMBER S 14264

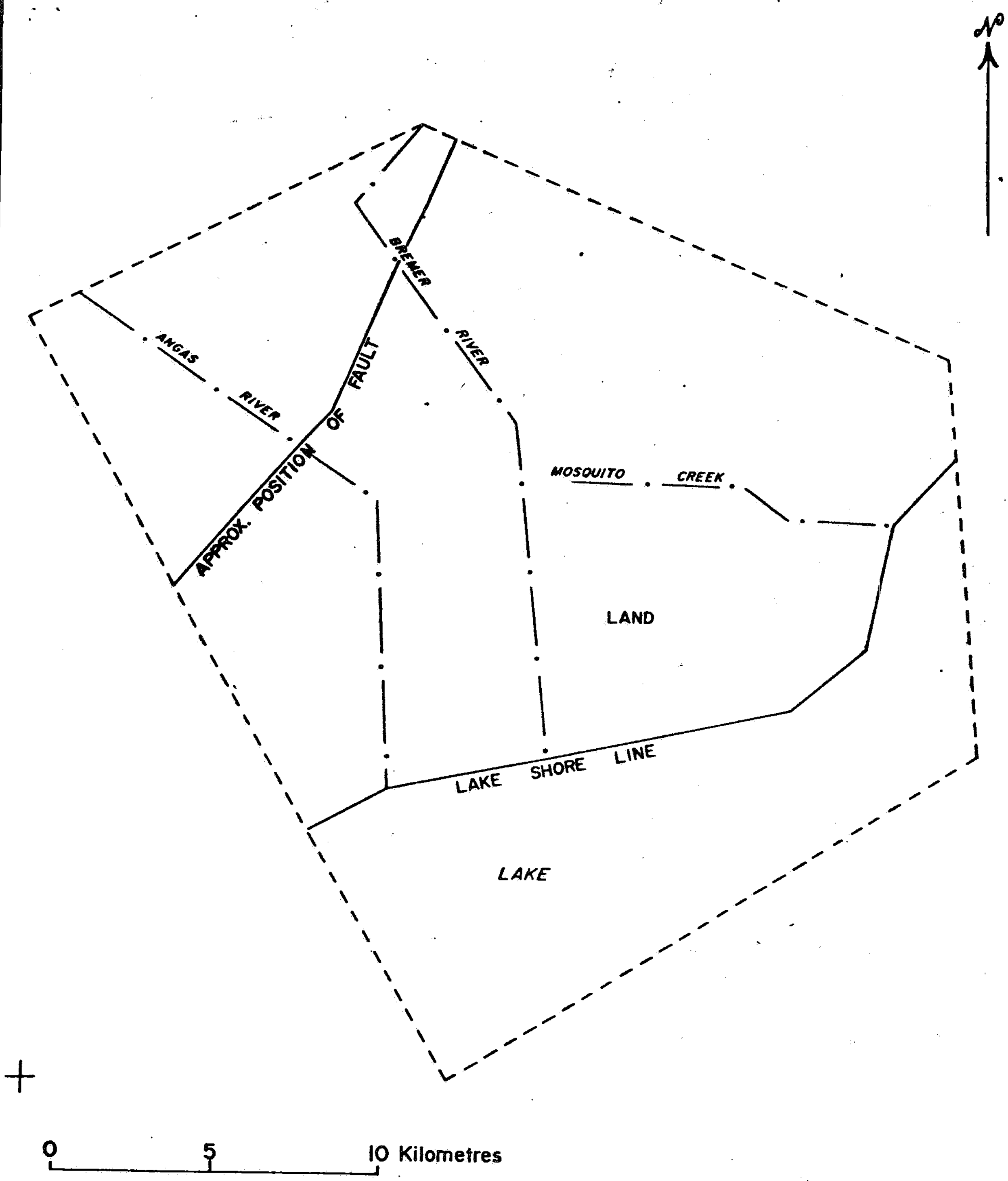


FIG. 3

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M.J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL LOCALITY PLAN SIMPLIFIED FOR MODELLING PURPOSES	DATE SEPT. 1979
DRN E.C. / CKD		PLAN NUMBER S 14265

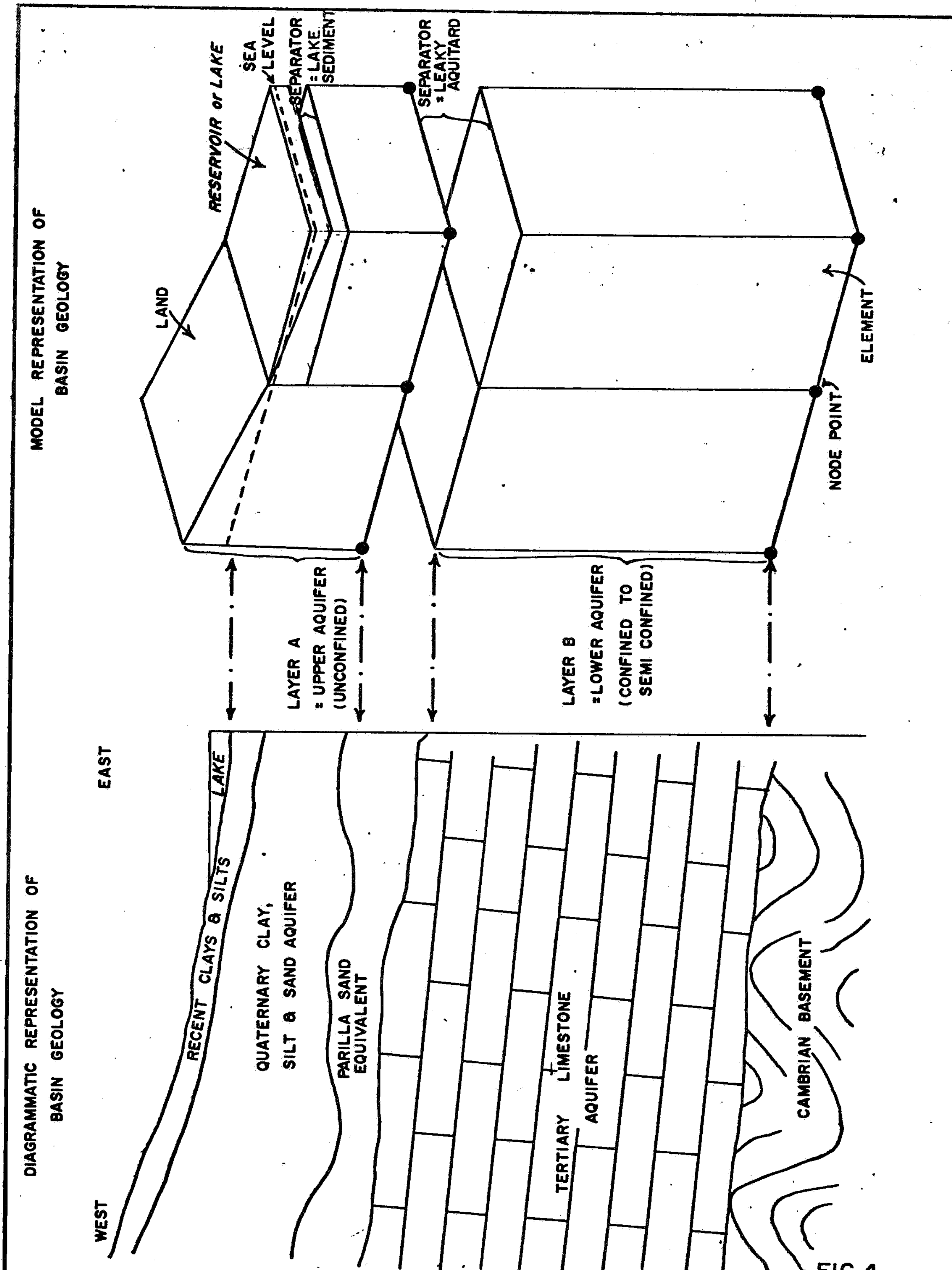


FIG. 4

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE:
COMPILED: M.J. Sheard	ANGAS – BREMER IRRIGATION AREA TWO AQUIFER MODEL RELATIONSHIP BETWEEN GEOLOGY AND MODEL	DATE: SEPT. 5, 1979
DRN: E.C. CKD:		PLAN NUMBER S 14266

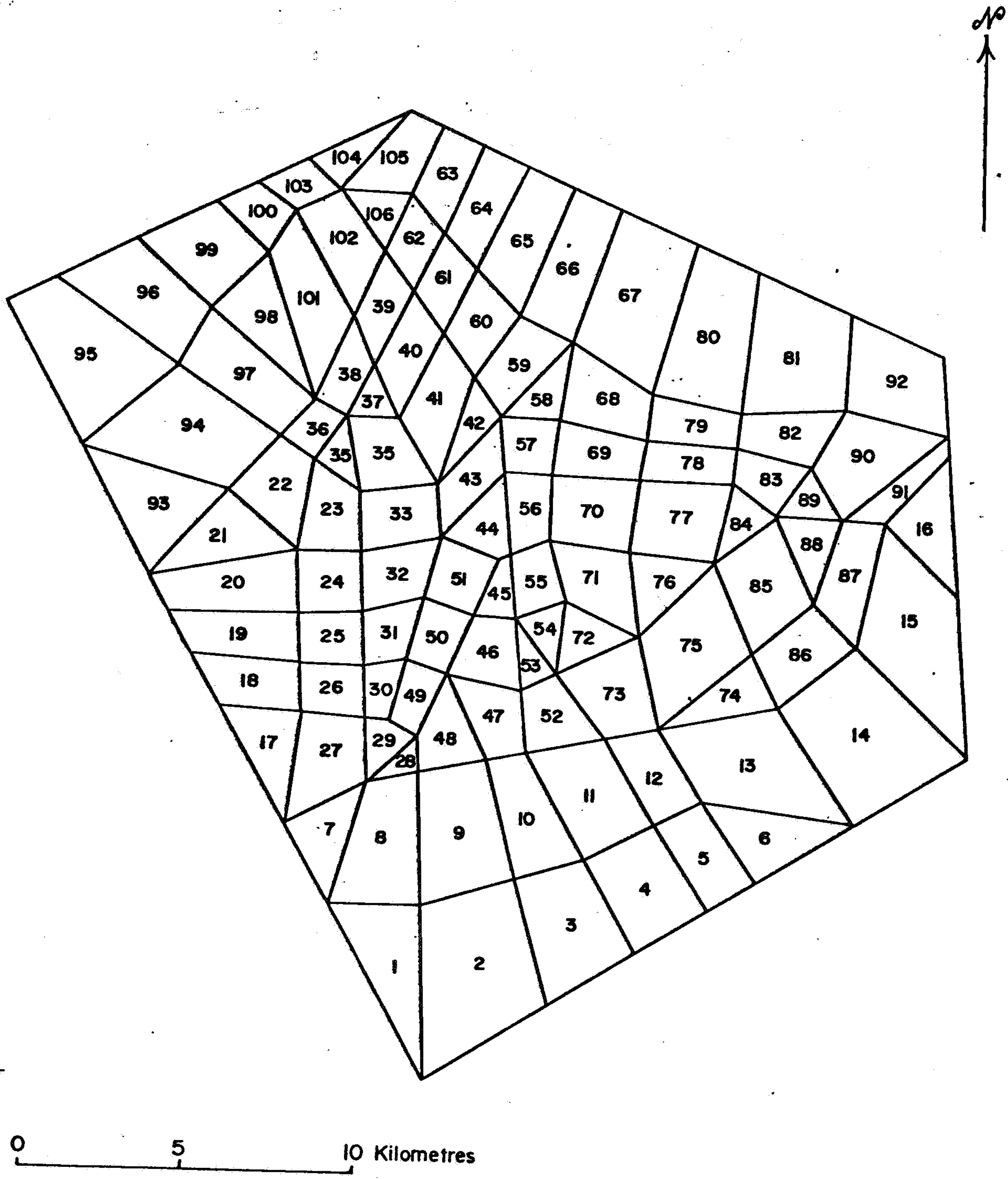


FIG. 5

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M.J. Sheard	ANGAS–BREMER IRRIGATION AREA TWO AQUIFER MODEL	DATE SEPT. 1979
DRN E.C. | CKD	MODEL MESH, ELEMENTS, LAYER "A"	PLAN NUMBER S 14267

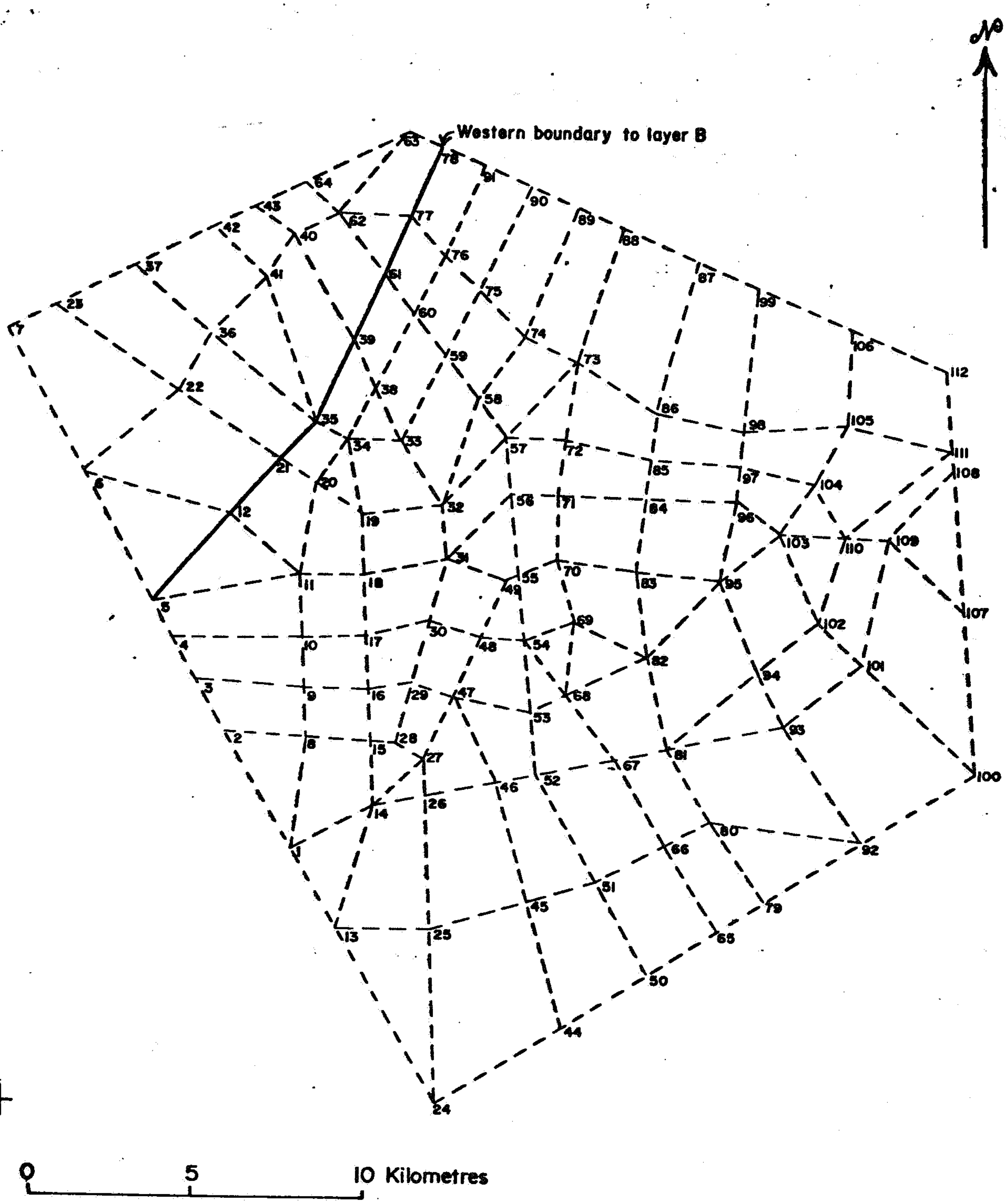


FIG. 6

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE: 1: 180,000
COMPILED M. J. Sheard	ANGAS - BREMER IRRIGATION AREA TWO AQUIFER MODEL MODEL MESH, NODES, LAYER "A"	DATE: SEPT. 1979
DRN E.C.	CKD:		PLAN NUMBER S 14268

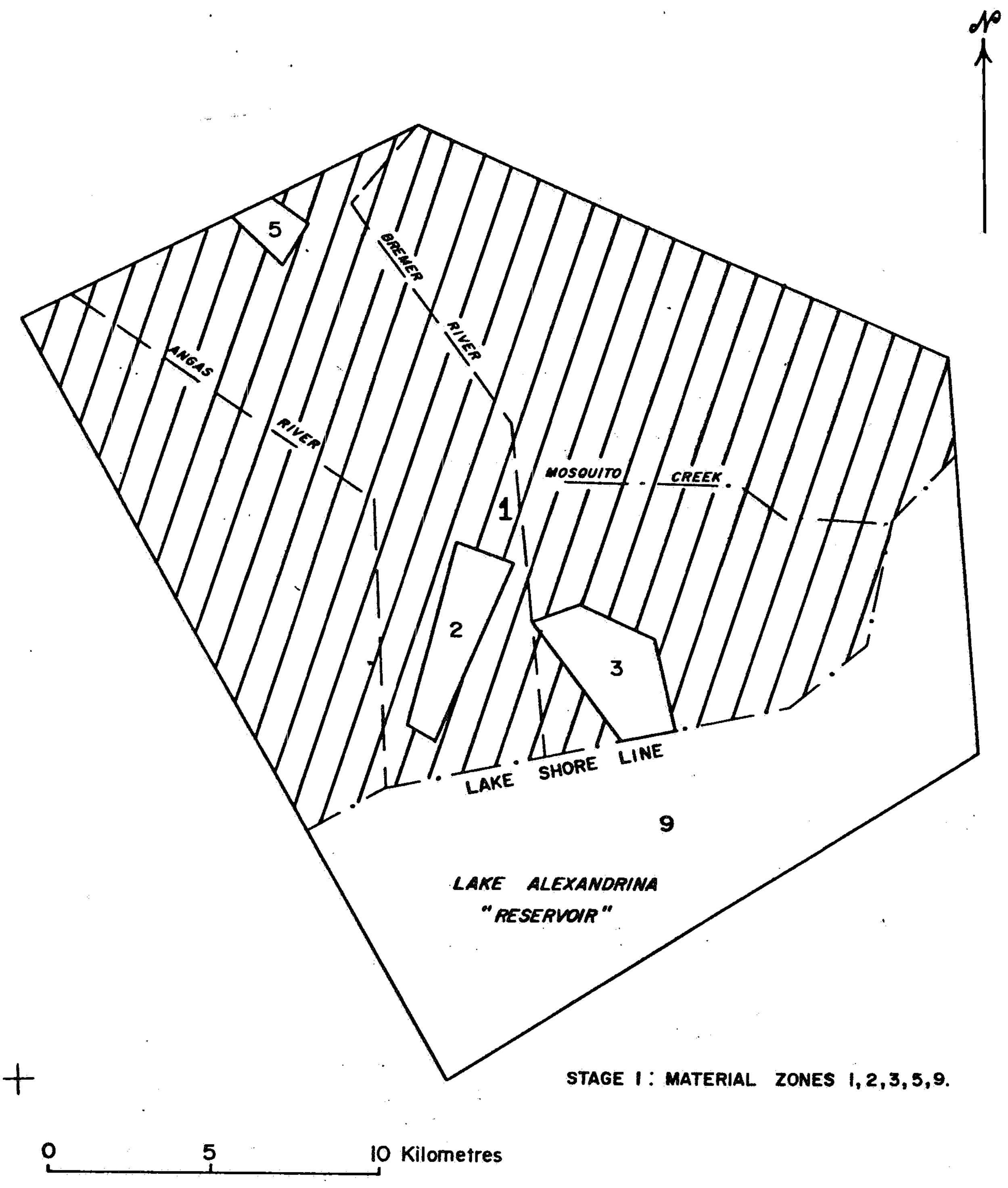


FIG. 7

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M. J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE I – MATERIALS, LAYER "A"	DATE SEPT. 1979
DRN E.C. CKD		PLAN NUMBER S 14269

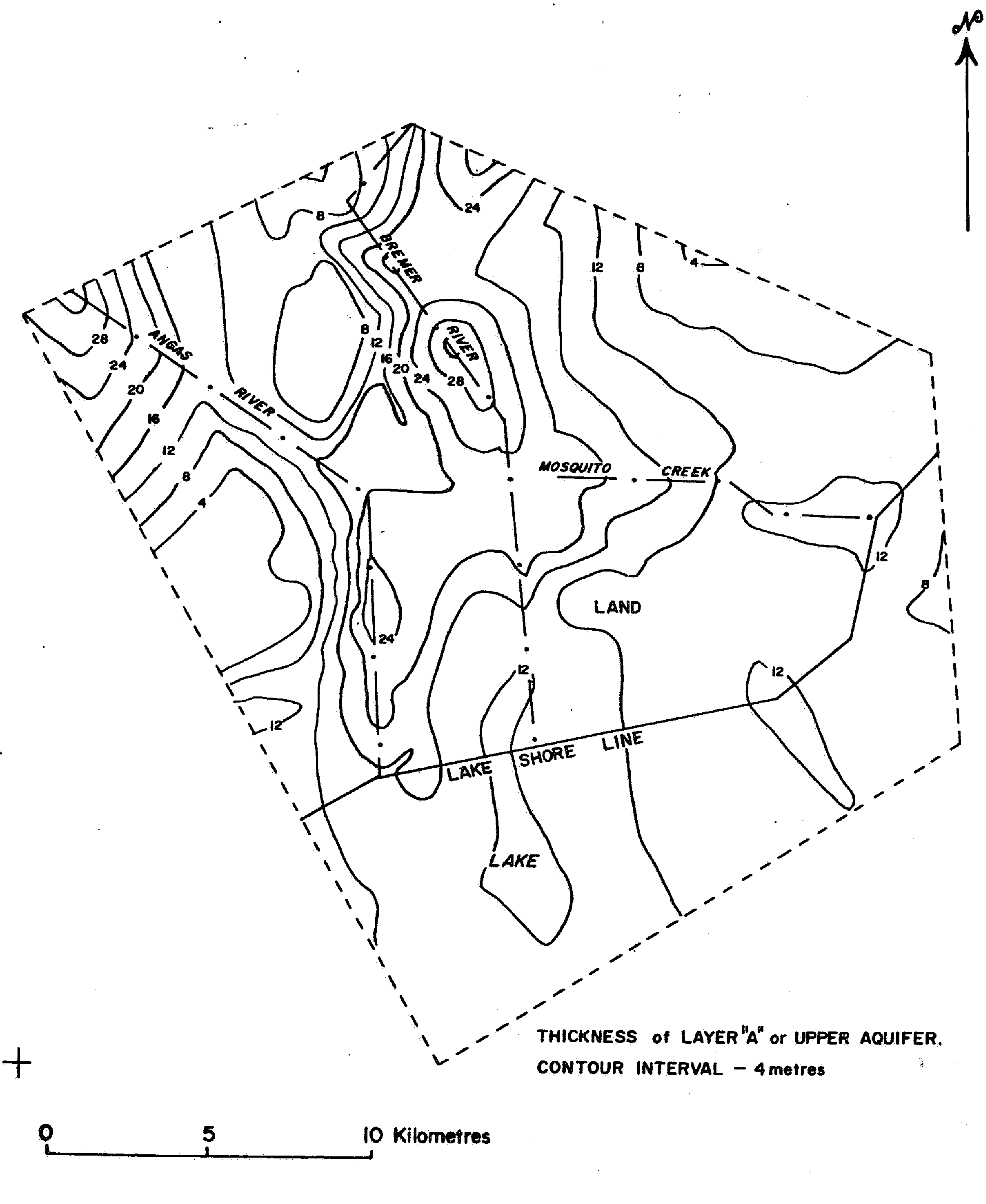


FIG. 8

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M.J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL THICKNESS OF LAYER "A"	DATE SEPT. 1979
DRN E.C. | CKD		PLAN NUMBER S 14270

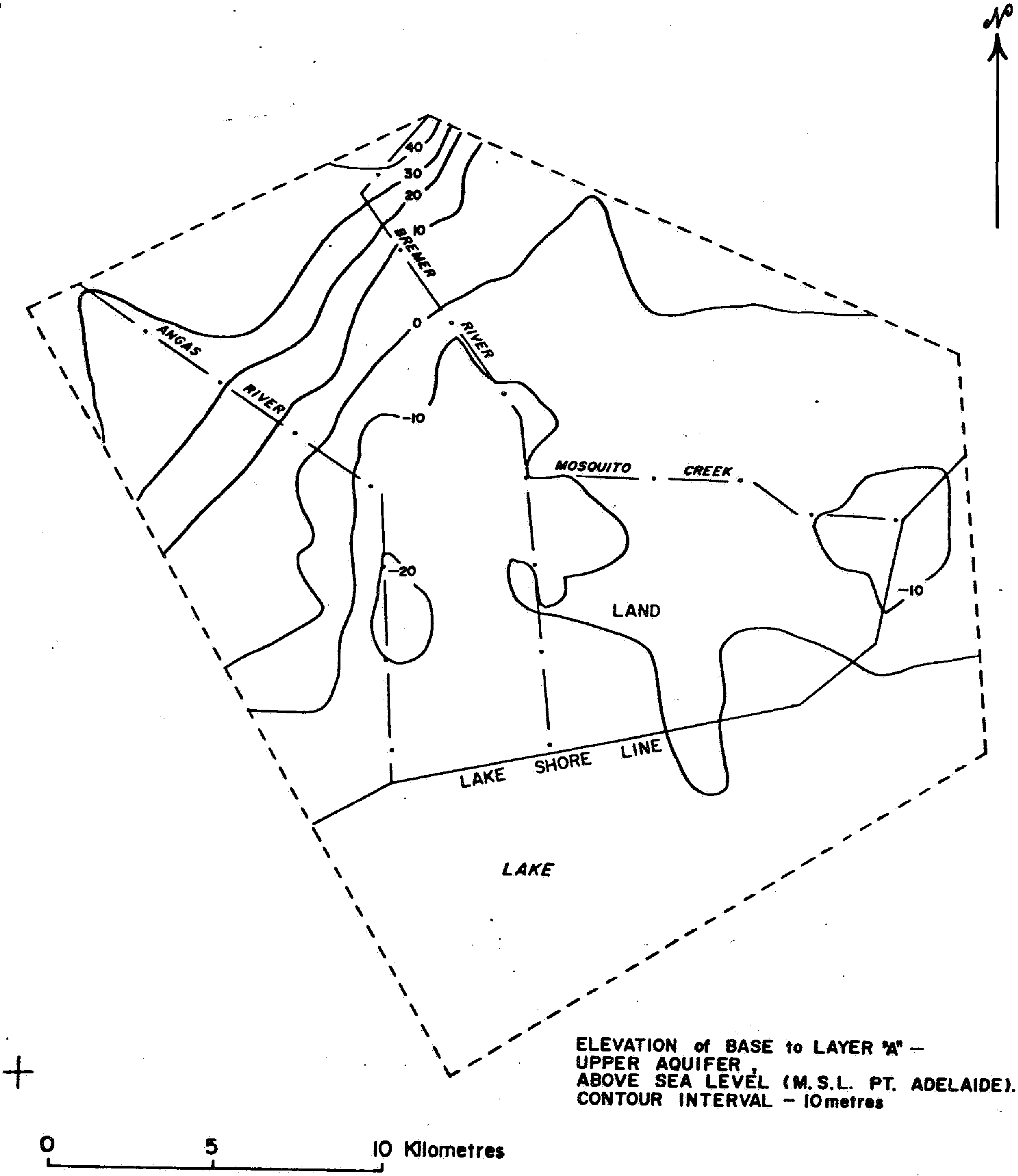


FIG. 9

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M. J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL ELEVATION OF LAYER "A" BASE	DATE SEPT. 1979
DRN E.C. / CKD		PLAN NUMBER S 14271

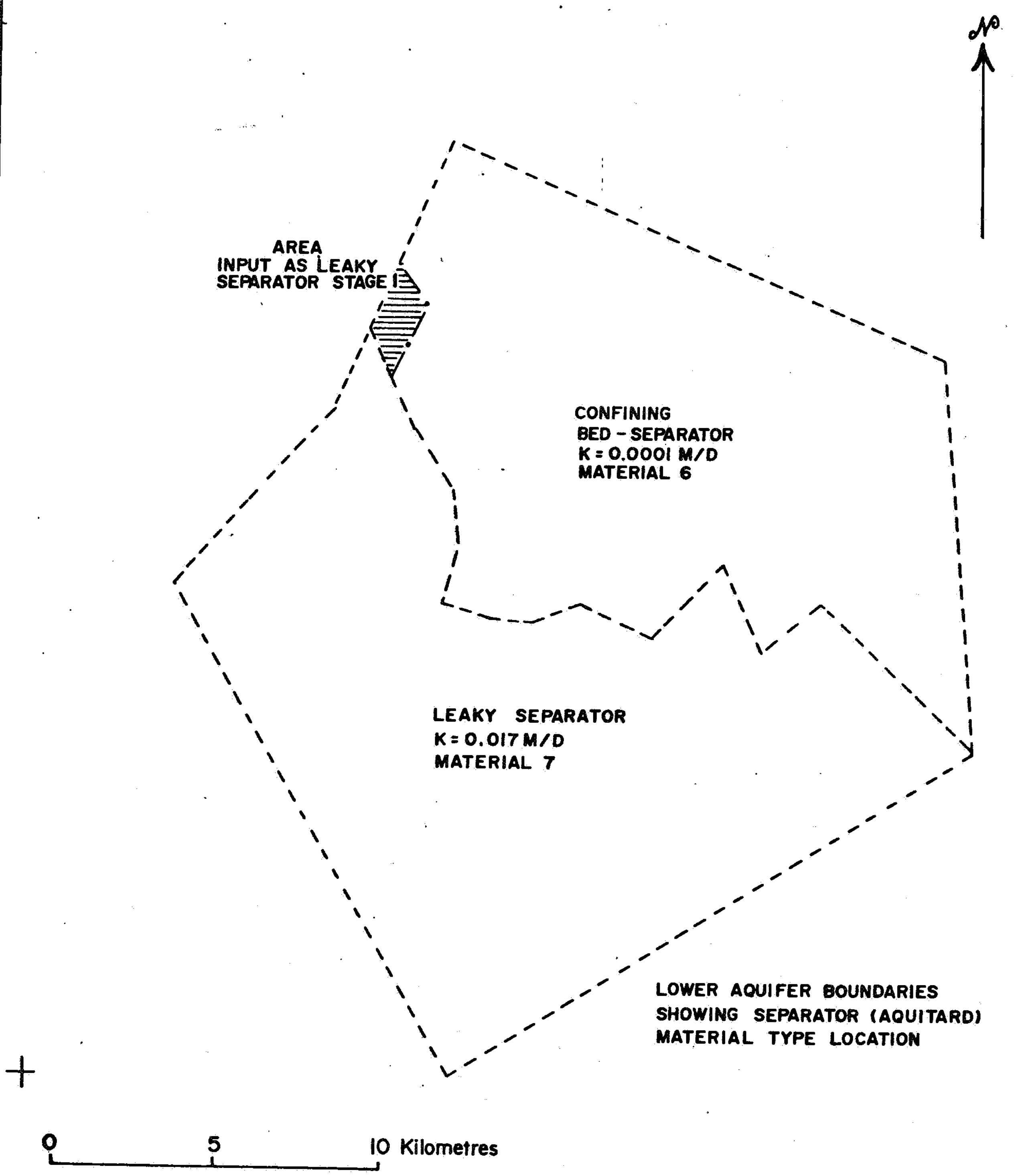
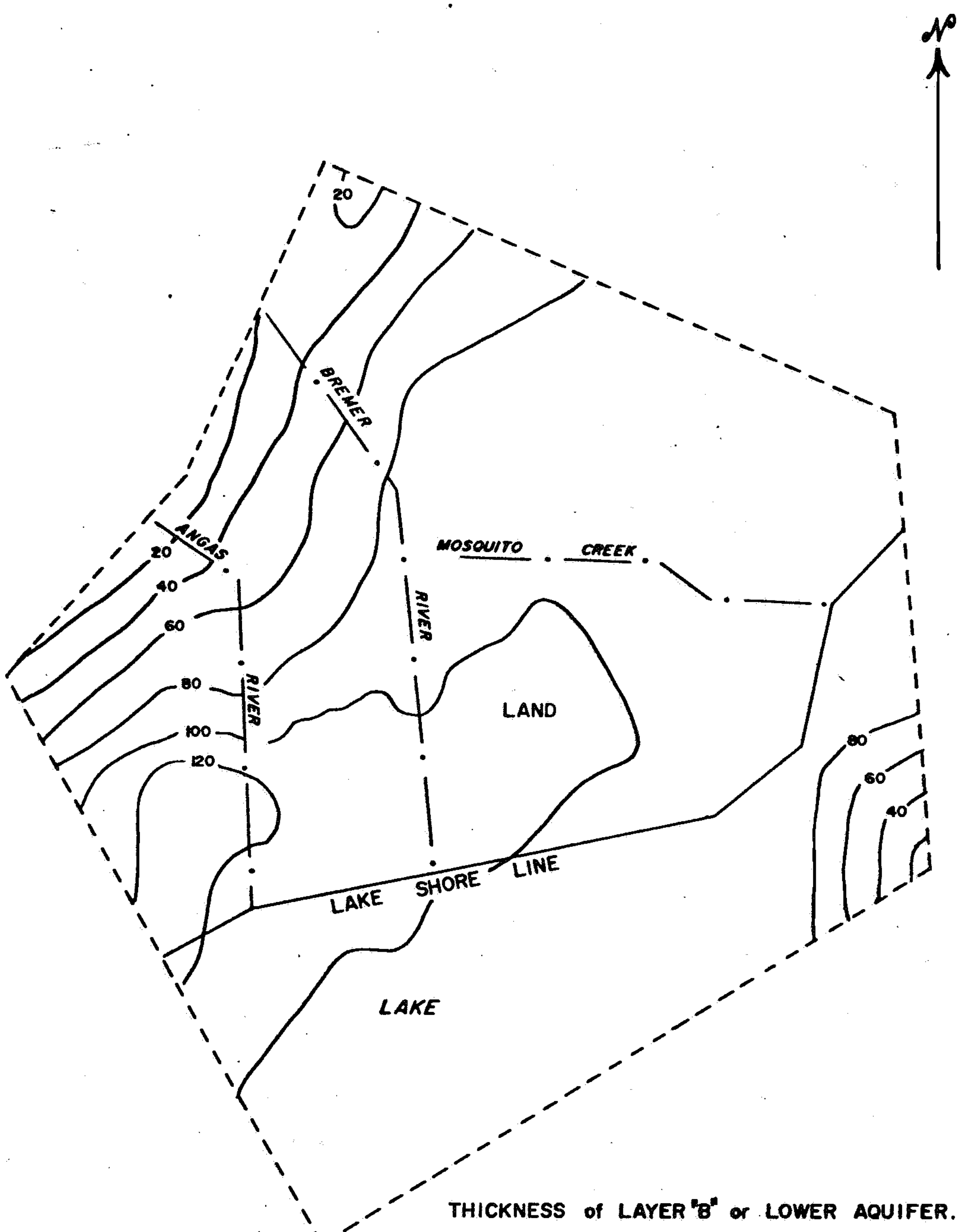


FIG. 10

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1: 180,000
COMPILED M. J. Sheard	ANGAS - BREMER IRRIGATION AREA TWO AQUIFER MODEL SEPARATOR MATERIALS PLAN	DATE SEPT. 1979
DRN E.C. | CKD		PLAN NUMBER S 14272

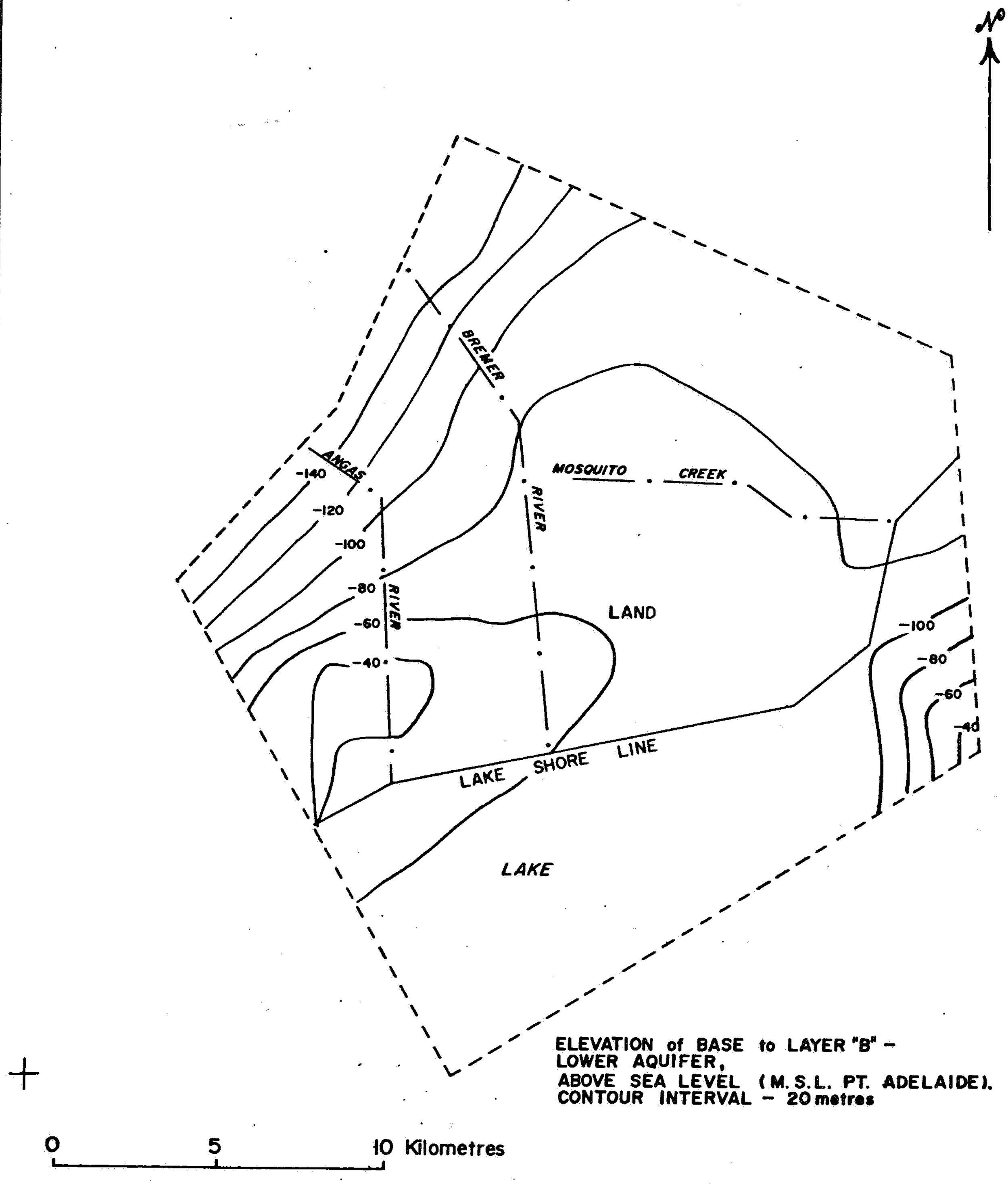


THICKNESS of LAYER "B" or LOWER AQUIFER.
CONTOUR INTERVAL – 20 metres

0 5 10 Kilometres

FIG. 11

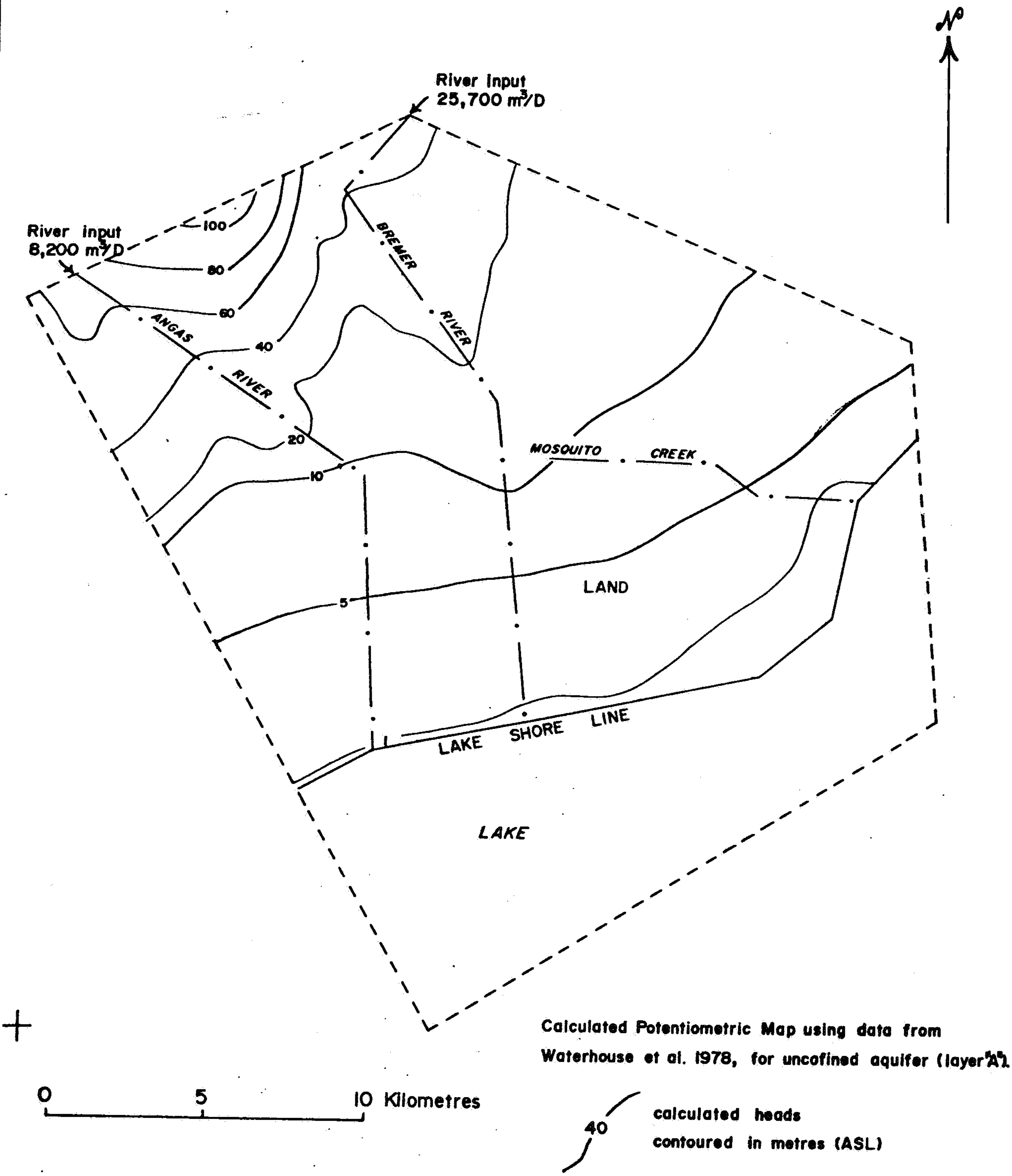
	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED: M. J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL THICKNESS OF LAYER "B"	DATE: SEPT. 1979
DRN: E.C. CKD:		PLAN NUMBER S 14273



ELEVATION of BASE to LAYER "B" – LOWER AQUIFER,
ABOVE SEA LEVEL (M.S.L. PT. ADELAIDE).
CONTOUR INTERVAL – 20 metres

FIG. 12

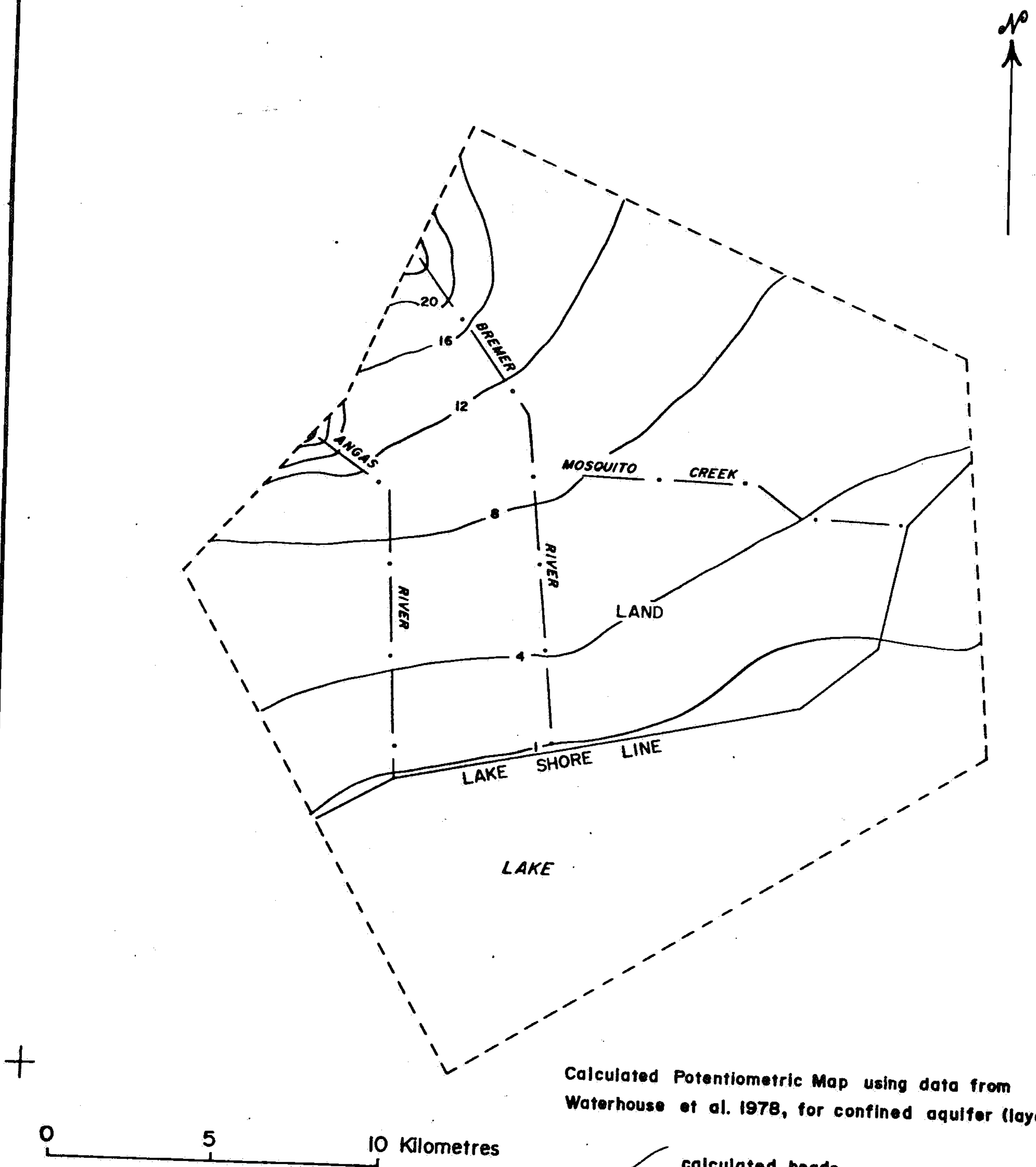
	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M. J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL ELEVATION OF LAYER "B" BASE	DATE SEPT. 1979
DRN E.C. CKD:		PLAN NUMBER S 14274



Calculated Potentiometric Map using data from Waterhouse et al. 1978, for uncofined aquifer (layer "A").

FIG. 13

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M. J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE I - COMPUTED POTENTIALS FOR LAYER "A"	DATE SEPT. 1979
DRN E.C. / CKD		PLAN NUMBER S 14275

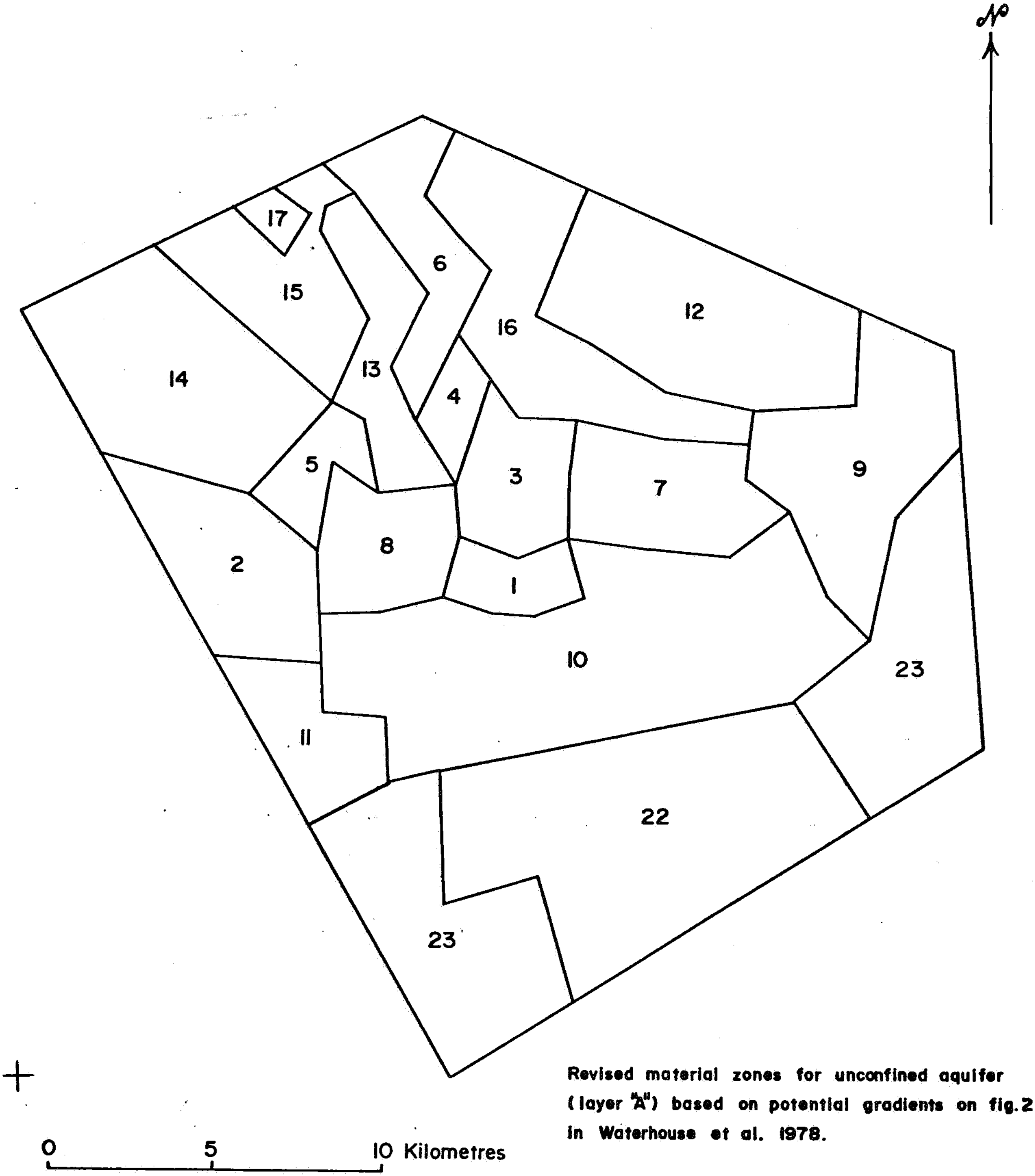


Calculated Potentiometric Map using data from Waterhouse et al. 1978, for confined aquifer (layer "B")

16 calculated heads contoured in metres (ASL)

FIG. 14

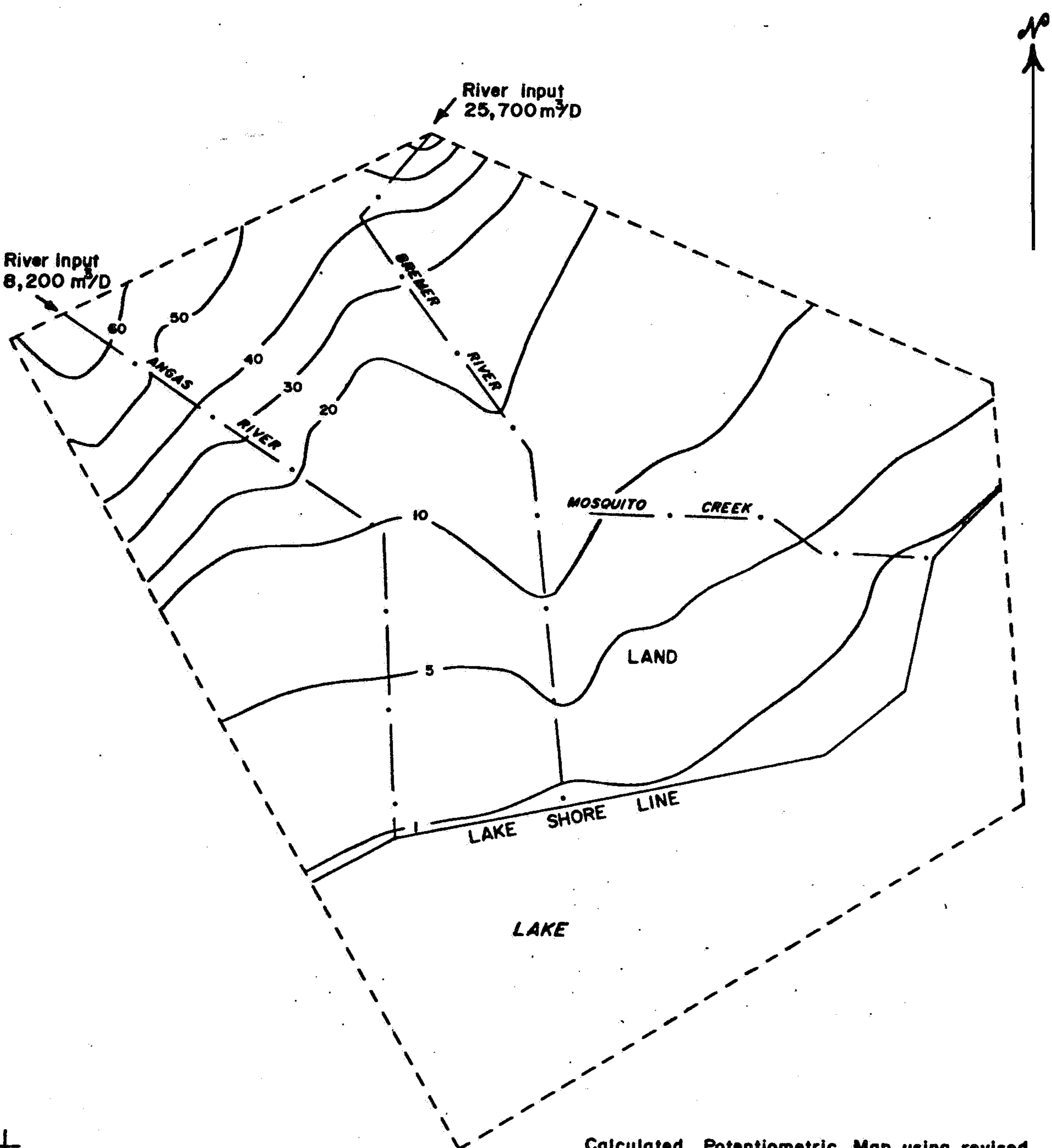
COMPILED M. J. Sheard	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
DRN E.C. CKD	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE I - COMPUTED POTENTIALS FOR LAYER "B"	DATE SEPT. 1979
		PLAN NUMBER S 14276



Revised material zones for unconfined aquifer (layer "A") based on potential gradients on fig. 21 in Waterhouse et al. 1978.

FIG. 15

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M.J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE II - NEW MATERIALS FOR LAYER "A"	DATE SEPT. 1979
DRN E.C. CKD		PLAN NUMBER S 14277



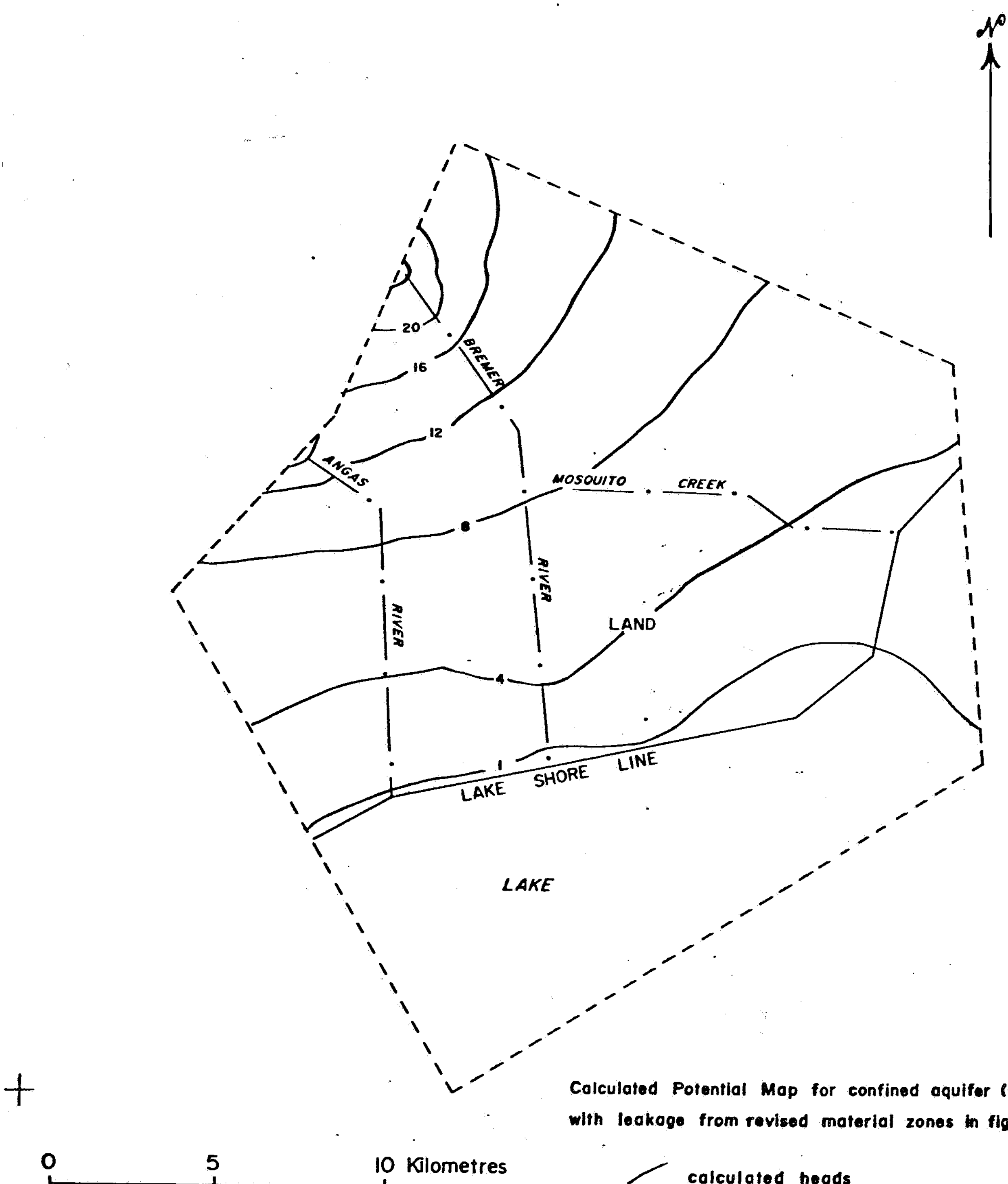
Calculated Potentiometric Map using revised material zones for unconfined aquifer (layer "A").

0 5 10 Kilometres

40 calculated heads contoured in metres (ASL)

FIG. 16

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED: M. J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE II - COMPUTED POTENTIALS FOR LAYER "A"	DATE: SEPT. 1979
DRN: E.C. CKD:		PLAN NUMBER S 14278

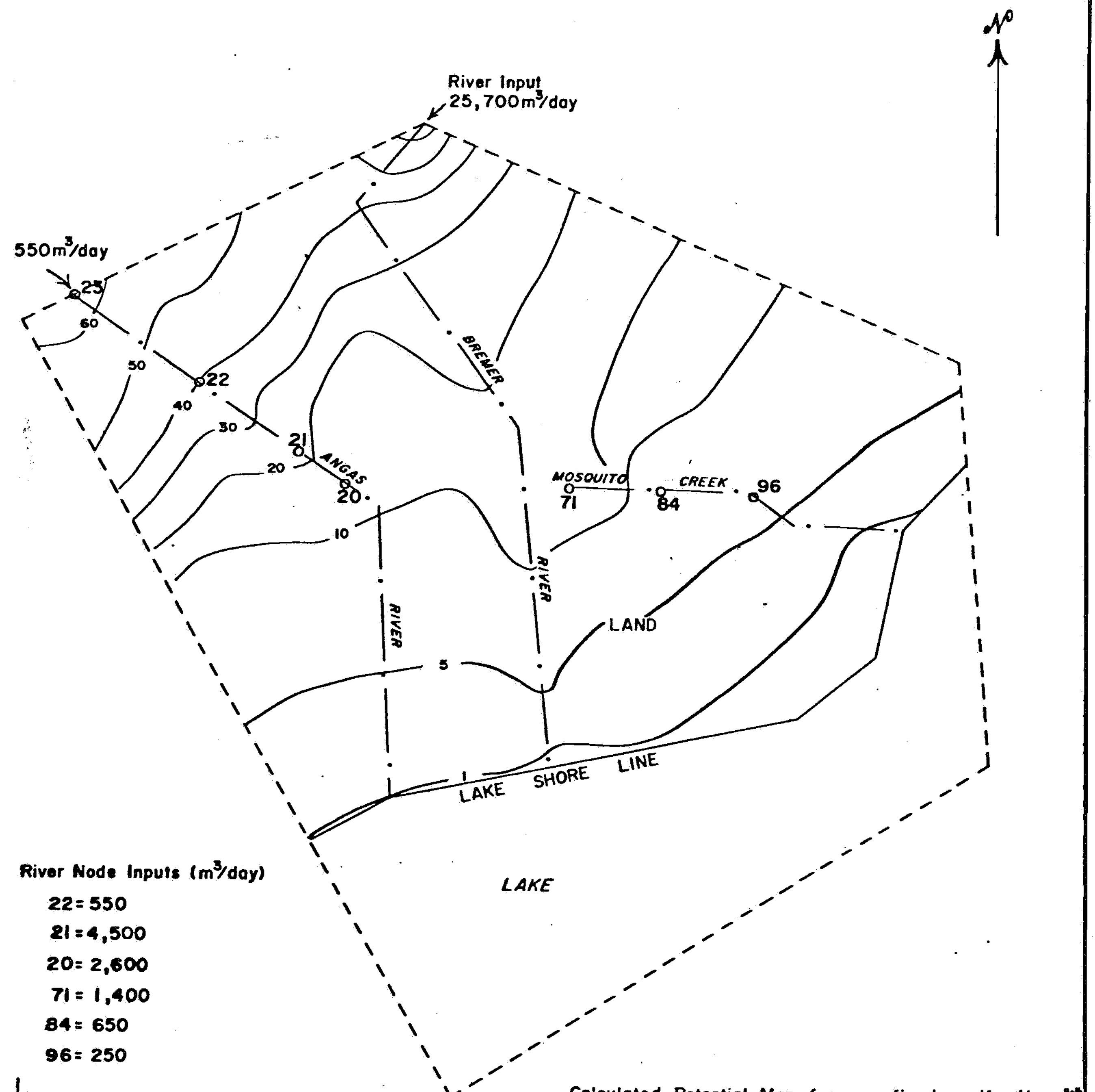


Calculated Potential Map for confined aquifer (layer 'B') with leakage from revised material zones in figure 15)

calculated heads contoured in metres (ASL)

FIG. 17

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M.J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE II - COMPUTED POTENTIALS FOR LAYER "B"	DATE SEPT. 1979
DRN E.C. | CKD		PLAN NUMBER S 14279



Calculated Potential Map for unconfined aquifer (layer "A") with revised Angas River input, and Mosquito Creek input.

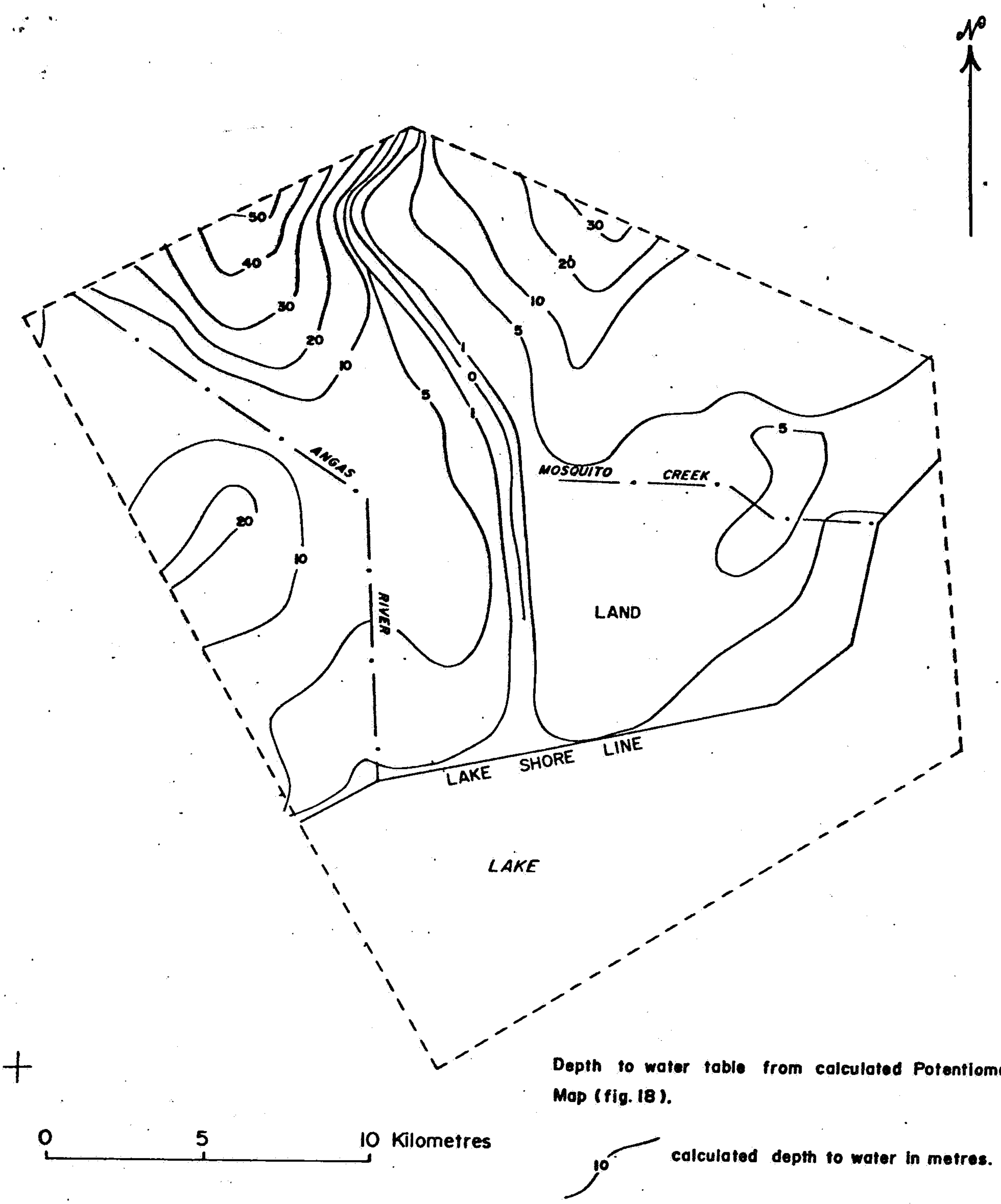
0 5 10 Kilometres

20 — calculated heads contoured in metres (ASL)

22 o — node with node numbers

FIG. 18

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M.J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE III - COMPUTED POTENTIALS FOR LAYER "A"	DATE SEPT. 1979
DRN E.C. | CKD		PLAN NUMBER S 14280

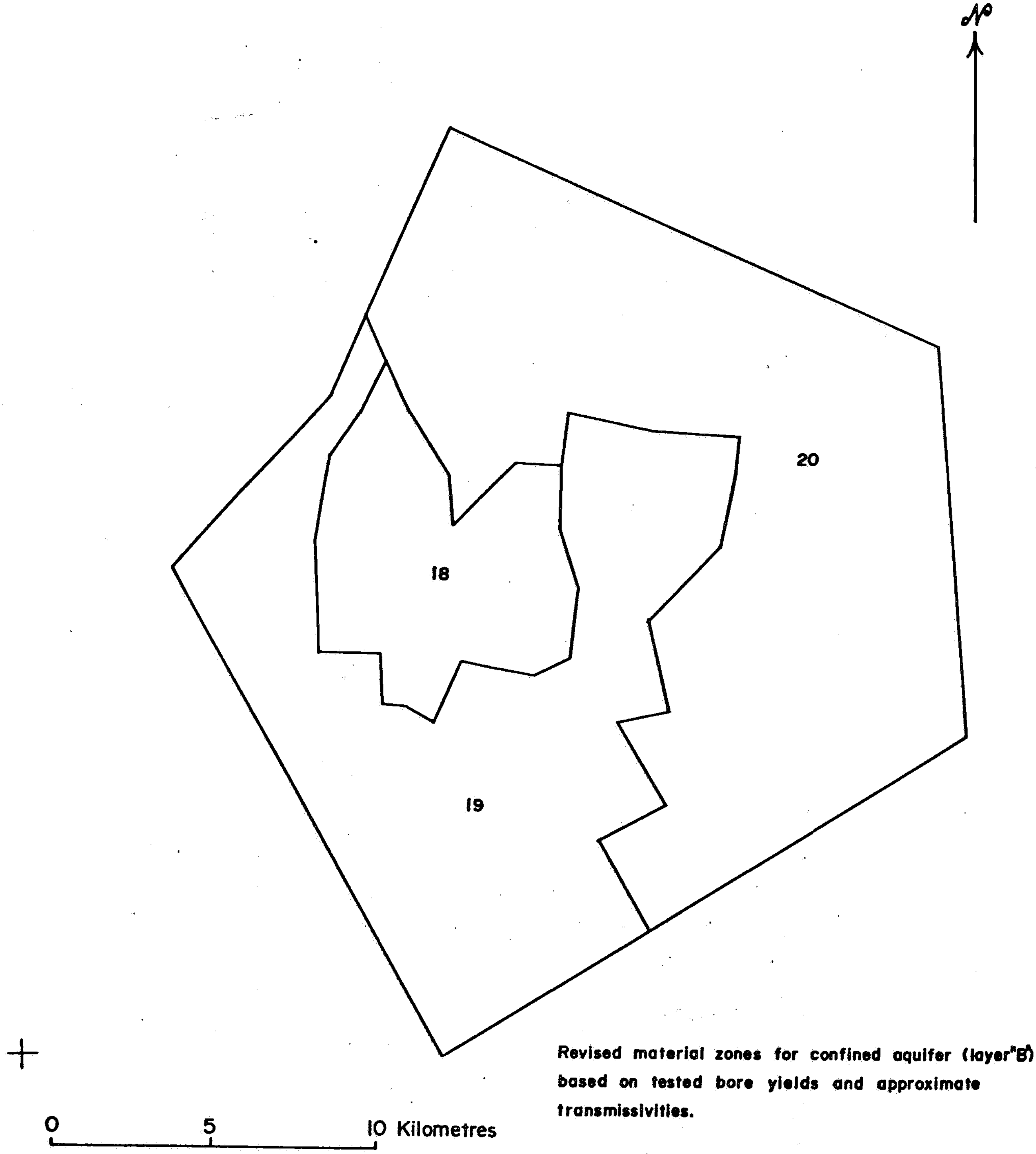


Depth to water table from calculated Potentiometric Map (fig. 18).

calculated depth to water in metres.

FIG. 19

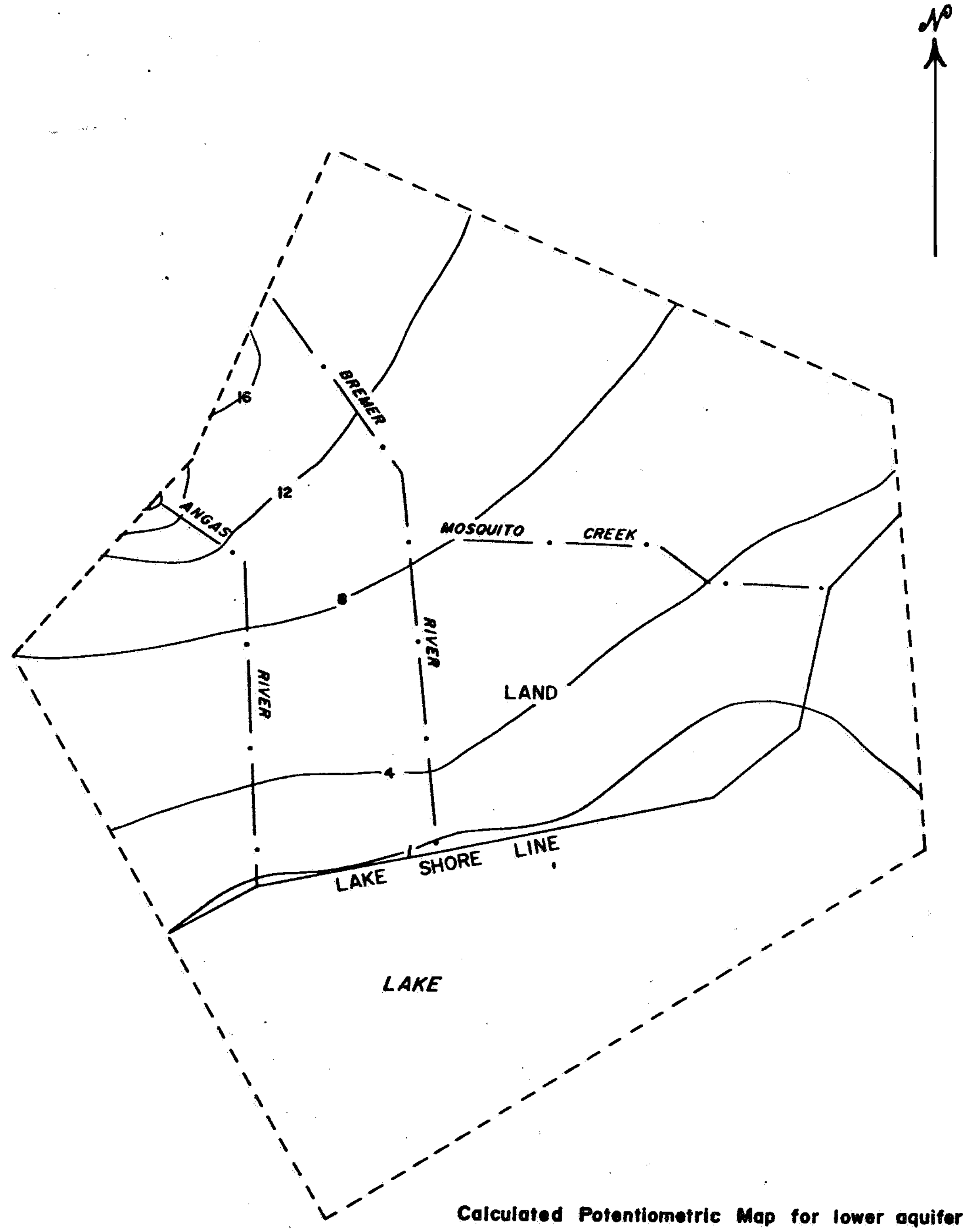
	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M.J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE III - COMPUTED DEPTH TO WATER TABLE, LAYER "A"	DATE SEPT. 1979
DRN E.C. | CKD		PLAN NUMBER S 14281



Revised material zones for confined aquifer (layer "B") based on tested bore yields and approximate transmissivities.

FIG. 20

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M. J. Sheard	ANGAS–BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE III – NEW MATERIALS FOR LAYER "B"	DATE SEPT. 1979
DRN E.C. CKD		PLAN NUMBER S 14282

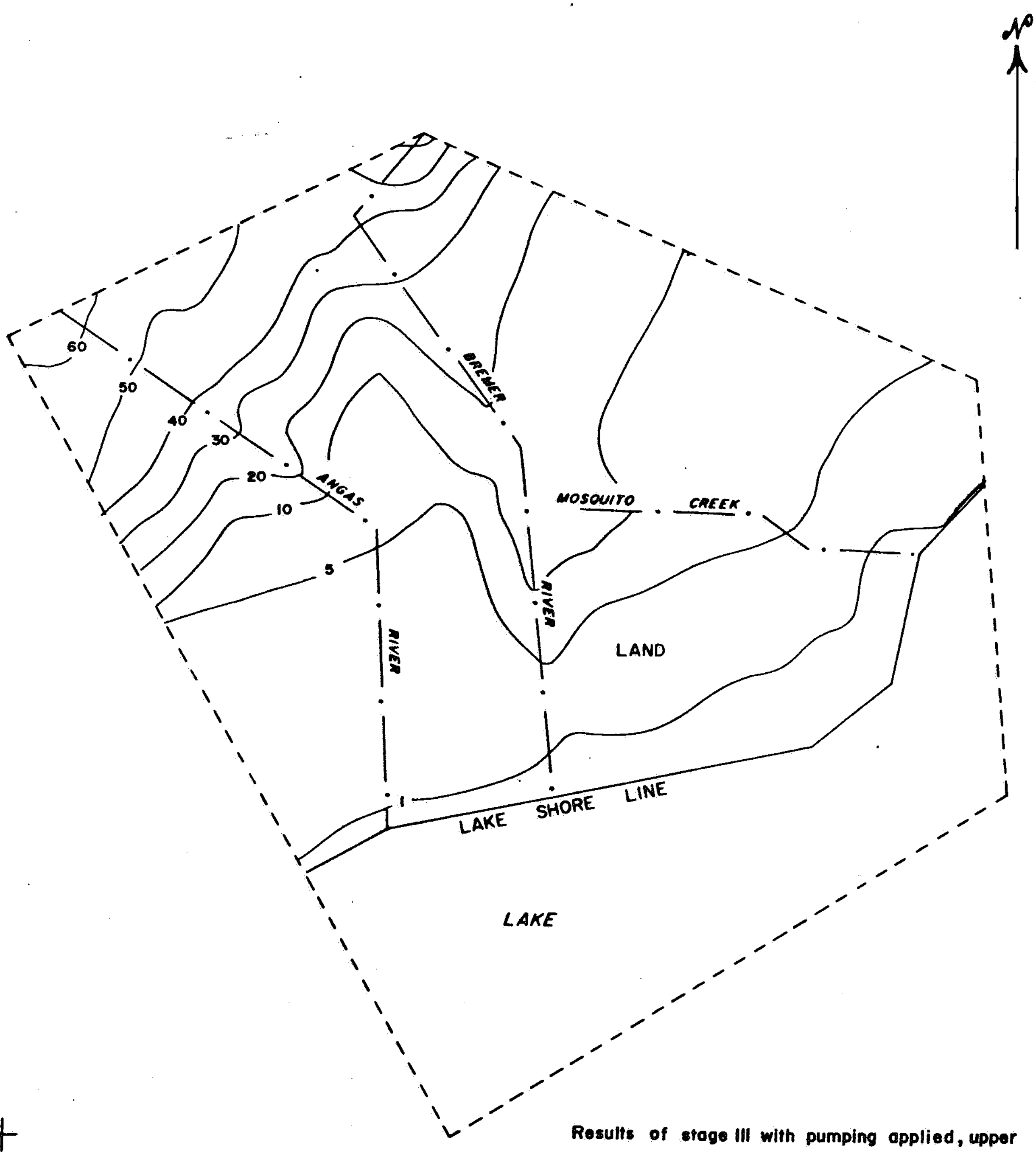


Calculated Potentiometric Map for lower aquifer (layer "B") with revised material zones.

8 — calculated heads contoured in metres (ASL)

FIG. 21

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M. J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE III – COMPUTED POTENTIALS FOR LAYER "B"	DATE SEPT. 1979
DRN E.C. / CKD		PLAN NUMBER S 14283



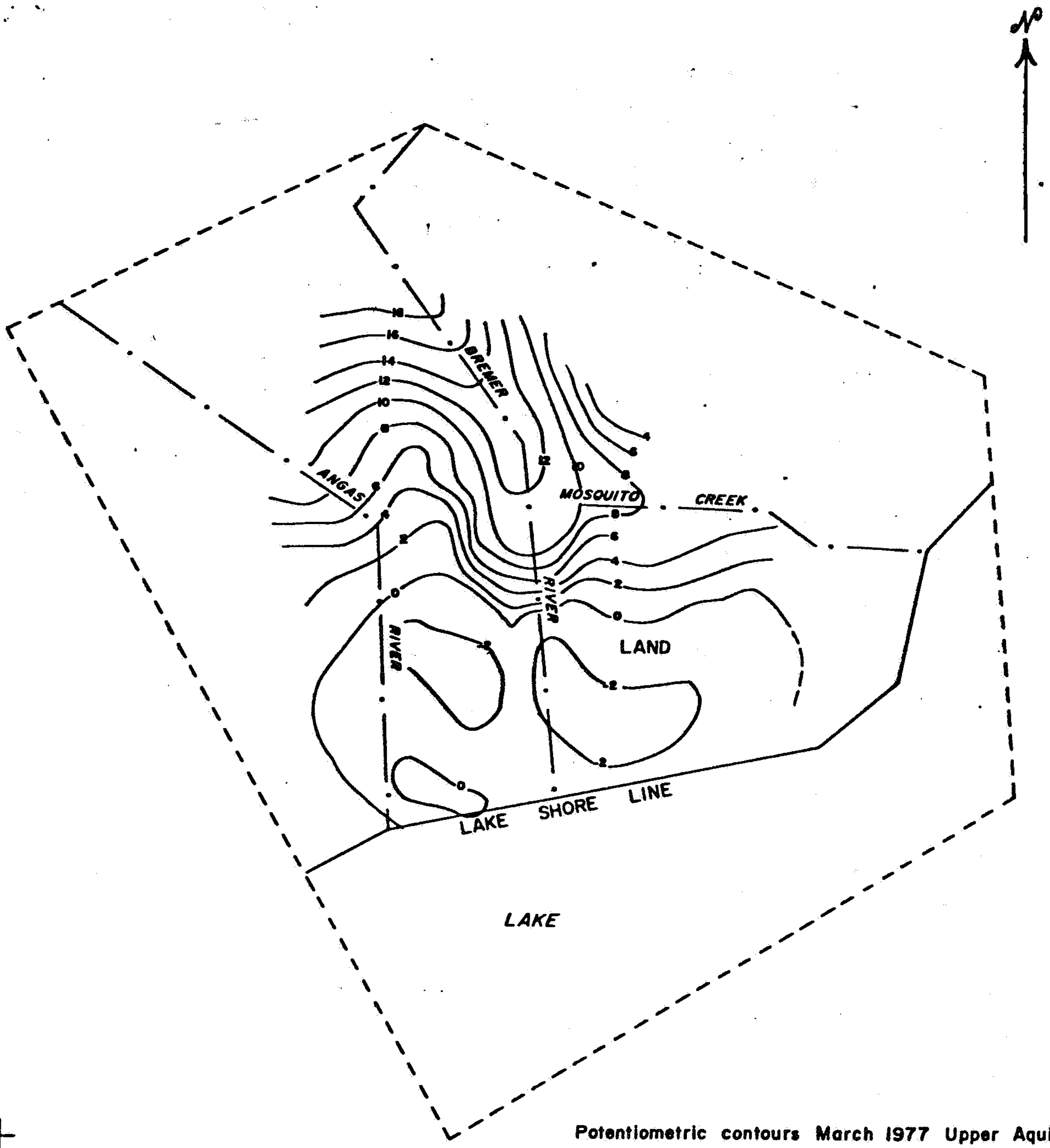
Results of stage III with pumping applied, upper aquifer (layer "A") with 20% pumped water from lower aquifer (layer "B") set as recharge.

0 5 10 Kilometres

20 calculated heads contoured in metres (ASL)

FIG. 22

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M.J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE IV - COMPUTED POTENTIALS FOR LAYER "A"	DATE SEPT. 1979
DRN E.C.	CKD		PLAN NUMBER S 14284



Potentiometric contours March 1977 Upper Aquifer after Waterhouse et al. 1978.

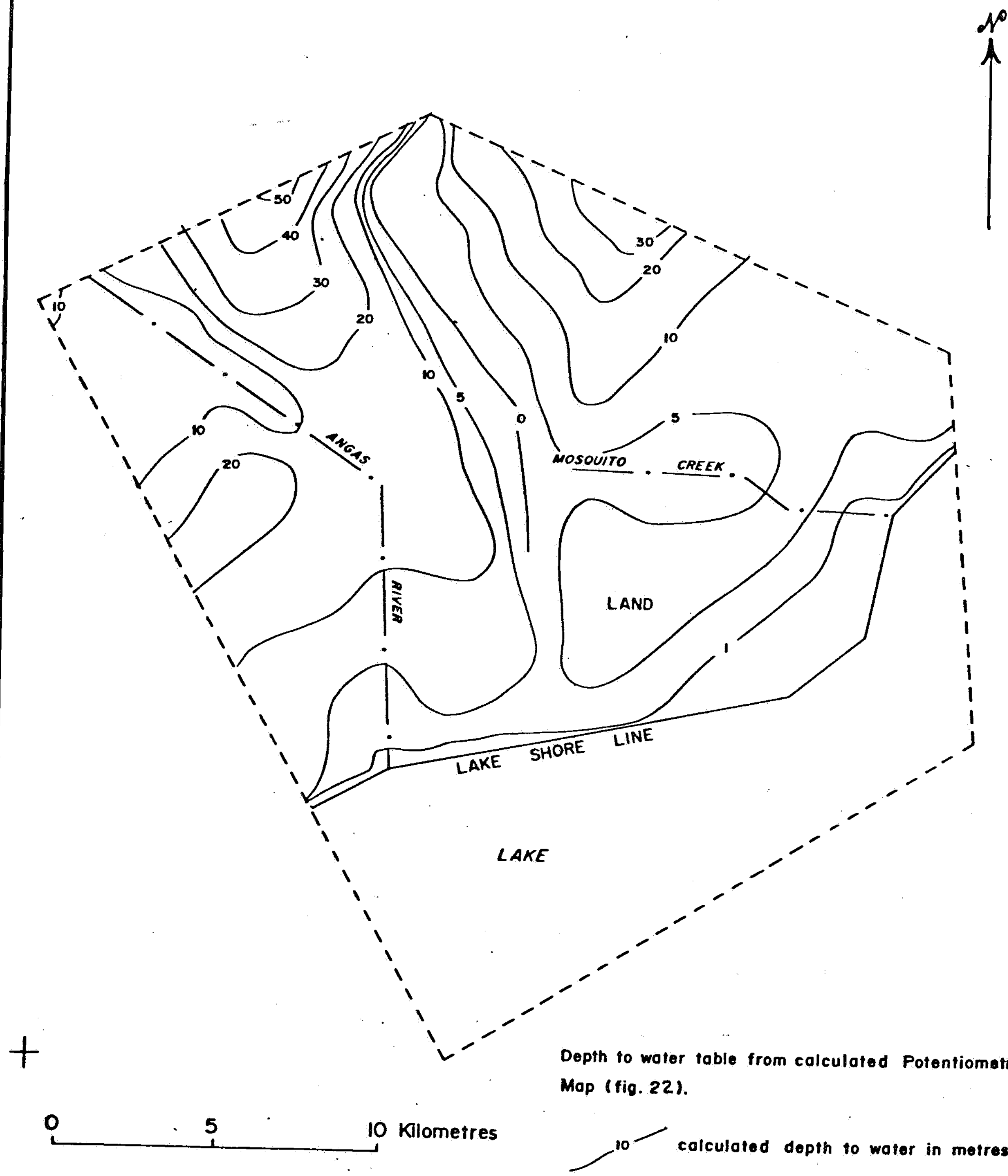
0 5 10 Kilometres

Contour of potentiometric surface
Datum: M.S.L. Pt. Adelaide

FIG. 23

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M. J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL OBSERVED POTENTIOMETRIC SURFACE UPPER AQUIFER	DATE SEPT. 1979
DRN E.C. / CKD		PLAN NUMBER S 14285

1572

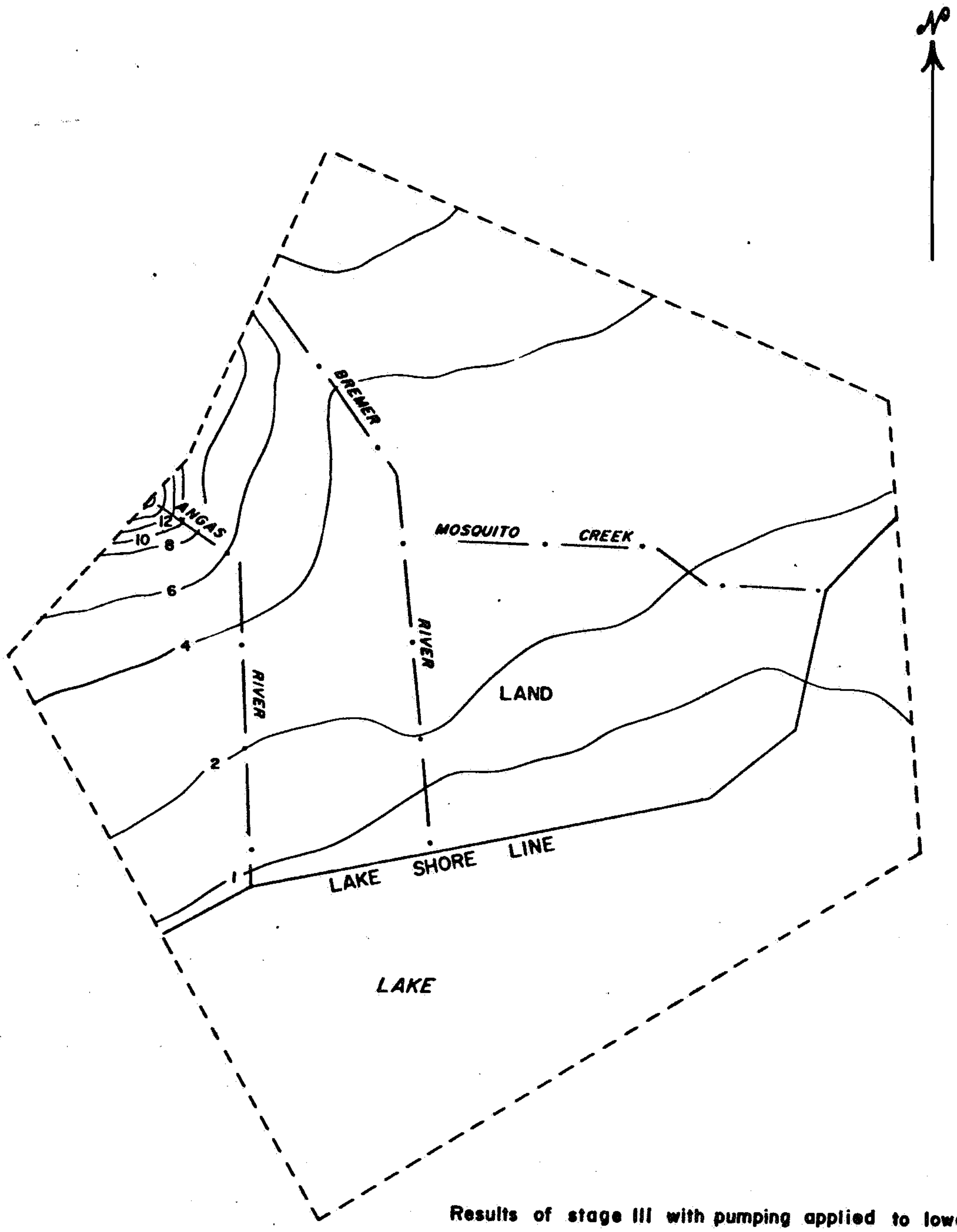


Depth to water table from calculated Potentiometric Map (fig. 22).

10 calculated depth to water in metres

FIG. 24

		DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED M.J. Sheard		ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE IV - COMPUTED DEPTH TO WATER TABLE, LAYER "A"	DATE SEPT. 1979
DRN E.C.	CKD		PLAN NUMBER S 14286



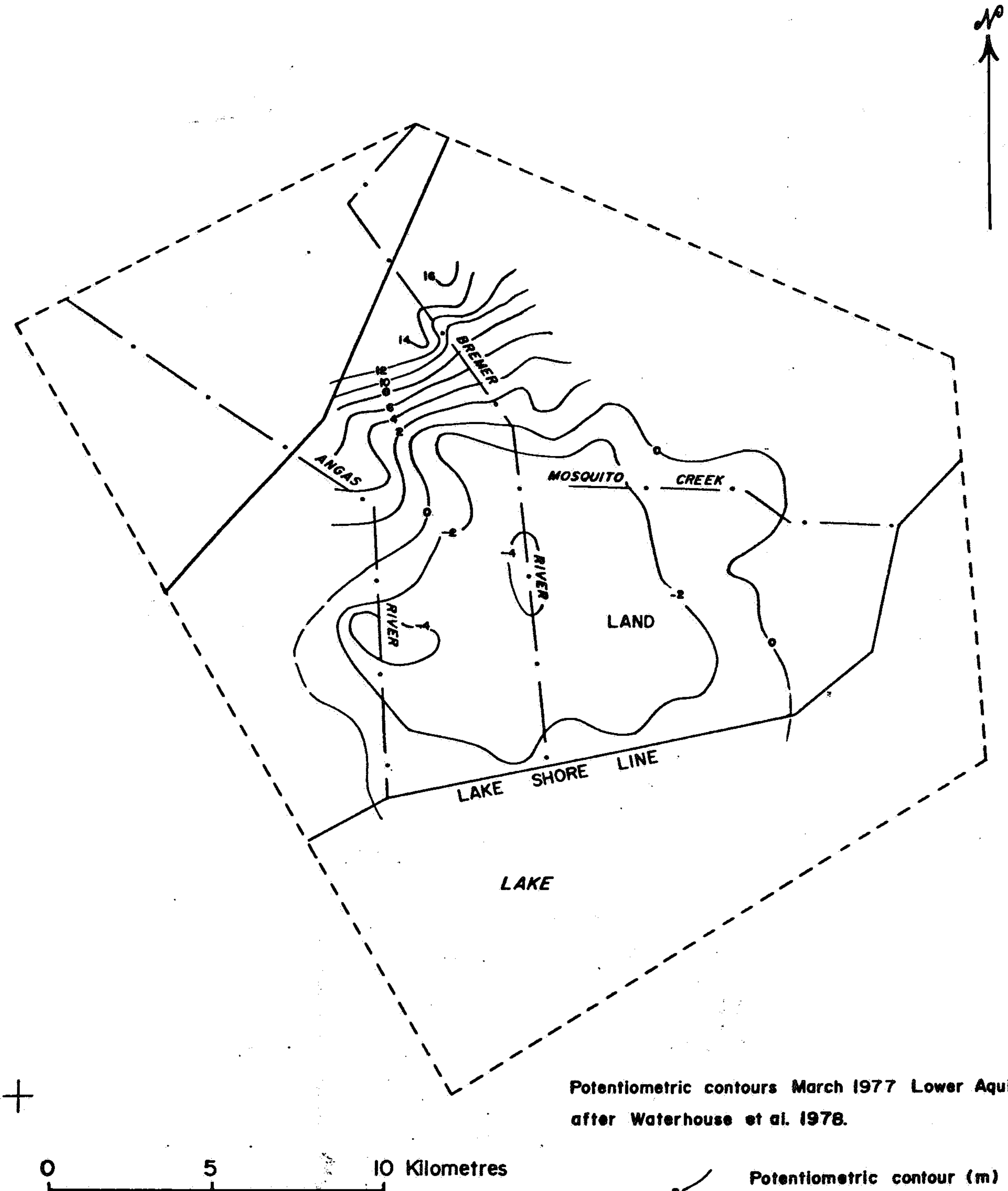
Results of stage III with pumping applied to lower aquifer (layer "B").

0 5 10 Kilometres

8 calculated heads contoured in metres (ASL).

FIG. 25

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED: M.J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL STAGE IV - COMPUTED POTENTIALS FOR LAYER "B"	DATE SEPT. 1979
DRN. E.C. CKD:		PLAN NUMBER S 14287



Potentiometric contours March 1977 Lower Aquifer after Waterhouse et al. 1978.

Potentiometric contour (m)
Datum: M.S.L. Pt. Adelaide

FIG. 26

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE 1:180,000
COMPILED: M.J. Sheard	ANGAS-BREMER IRRIGATION AREA TWO AQUIFER MODEL OBSERVED POTENTIOMETRIC SURFACE LOWER AQUIFER	DATE: SEPT. 1979
DRN: E.C. CKD:		PLAN NUMBER S 14288