DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

REPORT BOOK NO 91/9

BORDER GROUNDWATERS AGREEMENT

FIVE YEAR GROUNDWATER RESOURCE ASSESSMENT REVIEW 1986 - 1990

REPORT TO

BORDER GROUNDWATERS AGREEMENT REVIEW COMMITTEE

by

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FIVE YEAR GROUNDWATER RESOURCE ASSESSMENT REVIEW 1986-1990

1. INTRODUCTION

In an endeavour to avoid any deleterious effects occasioned by present and future large-scale groundwater withdrawals on the availability and quality of the resource in areas close to the State Border of South Australia and Victoria, a policy to manage the groundwater resources within a 40 km wide Designated Area centred along the border in each State was developed (see Figure 1). Known as the Groundwater (Border Agreement) Act (Governments of South Australia and Victoria, 1985), it came into effect in December 1985.

The Designated Area was divided into twenty-two management Zones, comprising eleven pairs of adjoining Zones, with the State Border as their common boundary. The South Australian Zones are referred to as the "A" Zones whilst the Victorian Zones are referred to as the "B" Zones. For each Zone pair, a volume of groundwater available for extraction annually (known as the Permissible Annual Volume) was determined assuming hydrogeological homogeneity within corresponding State Zones and using an agreed formula.

The Permissible Annual Volumes were based on the groundwater resources in the Tertiary Limestone and Quaternary sediments of the Otway and Murray Basins due to the predominant usage of groundwater from this aquifer. The lower Tertiary confined aquifer groundwater resources were not considered, although it was recognised that an assessment of this resource would need to be undertaken in the future. The Groundwater (Border Agreement) Act, however, has not specified whether the Permissible Annual Volumes refer solely to the groundwater resources of the Tertiary Limestone and Quaternary aquifer system or those of both the aquifer systems described above.

With the ratification of the Groundwater (Border Agreement) Act (1985), a management committee referred to as the Border Groundwaters Agreement Review Committee was established to administer the legislative and technical matters required under the Agreement. An integral part of the Agreement requires that certain aspects of the legislation be reviewed at intervals of not more than five years, these being:

- the permissible distance from the border between South Australia and Victoria. This criterion specifies that the Border Groundwaters Agreement Review Committee must consider and approve all applications for bore construction and for extraction of water from any bore situated within a distance less than the permissible distance from the border. The current permissible distance for all Zones within the Designated Area is one kilometre.

- the permissible annual volumes of groundwater extraction for the various Zones within the Designated Area.

- the permissible rate of potentiometric surface lowering. This criterion specifies that no applications for bore construction and for extraction of water from any bore will be granted in Zones where the average annual rate of potentiometric surface lowering has exceeded the specified rate over the preceding five years. The current permissible rate of potentiometric surface lowering for all Zones within the Designated Area is 0.05 metre per annum.

- the permissible levels of salinity (if any) that may have been established in various Zones.

The first five yearly review is due in December 1990, and as a basis for that review, this report has been prepared to describe the work undertaken by the authorities in both States and to present a re-assessment of the groundwater resources based on the available new information gained from the various investigation programmes.

2. GROUNDWATER UTILISATION

In the absence of large supplies of surface water, groundwater within the Designated Area is widely used for irrigation, domestic and stock purposes and, to a lesser extent, for industrial, recreational and township supplies.

Apart from groundwater extractions for stock and domestic supplies, all other groundwater users within the Designated Area in both States are licensed and are provided with an allocation to suit their individual requirements. As an indication of groundwater use in the Designated Area, Table 1 details for each Zone the Permissible Annual Volume, the number of extraction licensees and the licensed annual volume for the 1989/90 year.

In South Australia, individual irrigation allocations are based on the irrigated crop water requirements as determined by the S.A. Department of Agriculture. In Victoria, a similar approach is used for the allocation of irrigation licences, with individual crop water requirements ranging from 3 to 12 ML per hectare being used to determine particular licensed volumes. In both States, therefore, the licensed annual allocations do not necessarily represent the actual quantity of groundwater extracted.

TABLE 1: GROUNDWATER ALLOCATION IN THE DESIGNATED AREA FOR 1989/90

ZONE	PERMISSIBLE ANNUAL VOLUME (ML.)	NUMBER OF EXTRACTION LICENSEES	LICENSED ANNUAL VOLUME (ML.)
1A 1B	71 000 71 000	126 72	8 100 2 524
2A 2B	25 000 25 000	52 111	6 700 14 616
3A 3B	24 000 16 500	129 2	16 700 317
4A 4B	20 000 14 000	93 5	14 420 306
5A 5B	18 500 18 500	115 23	18 360 4 605
6A 6B	8 500 6 000	49 7	6 380 1 692
7A 7B	7 500 7 000	62 9	7 230 560
8A 8B	3 500 3 500	15 7	2 035 1 738
9A 9B	6 000 6 000	1 3	1 050 1 737
10A 10B	6 000 6 000	14 2	5 860 181
11A 11B	12 000 12 000	17 0	4 220 0
TOTALS			
A ZONES B ZONES	202 000 185 000	673 241	91 055 28 276
DESIGNATED AREA	387 000	914	119 331

The variation in groundwater allocation with time is shown in Table 2, which presents the licensed annual volume for each Zone from June, 1987 to June, 1990. Increases in the licensed annual volume for this period are particularly evident for South Australian Zones 2A, 3A, 4A, 6A, 10A and 11A, and for Victorian Zones 5B and 6B.

TABLE 2: GROUNDWATER ALLOCATION FROM JUNE, 1987 TO JUNE, 1990

ZONE	CURRENT P.A.V. (ML.)	LICENSED ANNUAL VOLUME (ML.)			
		JUNE 1987	JUNE 1988	JUNE 1989	JUNE 1990
1A	71 000	16 110	17 020	17 930	8 100
1B	71 000	2 800	2 640	2 520	2 524
2A	25 000	4 300	5 620	7 440	6 700
2B	25 000	9 240	14 520	14 490	14 616
3A	24 000	12 270	12 960	14 460	16 700
3B	16 500	310	320	320	317
4A	20 000	13 890	13 650	13 480	14 420
4B	14 000	260	310	310	306
5A	18 500	15 940	18 060	18 150	18 360
5B	18 500	3 920	3 560	4 040	4 605
6A	8 500	5 540	5 920	5 770	6 380
6B	6 000	1 140	1 140	1 620	1 692
7A	7 500	6 770	6 800	6 800	7 230
7B	7 000	560	560	560	560
8A	3 500	1 200	1 870	1 710	2 035
8B	3 500	1 620	1 620	1 740	1 738
9A	6 000	1 050	1 050	1 050	1 050
9B	6 000	2 340	1 500	1 740	1 737
10A	6 000	3 410	4 590	4 890	5 860
10B	6 000	390	240	180	181
11A	12 000	790	1 730	3 810	4 220
11B	12 000	0	0	0	0

A more complete perspective of groundwater use in the Designated Area can be obtained by comparing the number of licensed irrigation bores with the estimated number of stock/domestic bores in Victoria (see Appendix 1). In each Zone, the number of stock/domestic bores exceeds the number of irrigation bores. Using a range in groundwater use of 1 to 5 ML per annum for each stock/domestic bore, it is evident that the volume of groundwater extracted for domestic and stock purposes in some Zones can therefore be significant when compared with current licensed allocations.

3. SUMMARY OF WORK CARRIED OUT DURING FIVE-YEAR PERIOD

It was recognised that on-going hydrogeological studies would be required within the Designated Area to improve the knowledge of groundwater occurrence and to monitor the effects of the groundwater management policies implemented in the various Zones. This information is also necessary for the periodic reviews legally required by the Groundwater (Border Agreement) Act.

In the initial five-year period (1986-1990), both States have undertaken various investigations in addition to the required groundwater monitoring.

The bulk of these investigations culminated in the preparation of a joint technical report by officers from the respective authorities in South Australia and Victoria (Stadter *et al.*, 1989). This report formed the basis for a review and subsequent increase in the Permissible Annual Volume for Zones 3A, 4A, 6A and 7A in August, 1989.

In addition to these studies, investigations relevant to the Designated Area are currently being undertaken by the Bureau of Mineral Resources and the CSIRO as part of the hydrogeological assessment of the Murray Basin.

A summary of the investigations carried out in each State are presented below.

3.1 South Australia

The investigations in South Australia have concentrated on defining the nature of the Tertiary limestone aquifer and determination of aquifer recharge rates in Zones 3A through to Zone 7A. This work enabled a re-assessment of the groundwater resources for Zone 2A to 8A to be undertaken (Stadter, 1989). Specific details of the investigation programmes are provided in the above mentioned report.

Since May, 1989 further studies have been undertaken by the CSIRO, Department of Mines and Energy and the Engineering and Water Supply Department to examine the significance of localised recharge from drainage wells, swamps and runaway holes. This work is continuing and results are not expected until late 1991.

3.2 Victoria

The emphasis of the investigative work in Victoria was the establishment of a network of bores for the purposes of monitoring water quality and aquifer pressures as required under the Agreement.

As part of the need to improve the understanding of the groundwater system, over the past year, eight wells in the Victorian network (in Zones 3B to 7B) have been used for aquifer tests to determine the bulk hydraulic conductivity of the limestone aquifer and co-efficients of storage. Separate reports on these tests have been prepared by Stewart (1990a; 1990b; 1990c; 1990d).

The data obtained from the tests will also be useful in future numerical modelling of the aquifer system.

Since late 1989, studies with the CSIRO and the Rural Water Commission have been undertaken to assess the distribution of both diffuse and point recharge within the Mallee and Wimmera regions. This work is expected to provide useful data for the Designated Area in several years time.

4. PHYSIOGRAPHY AND CLIMATE

4.1 Geomorphology

The geomorphology of the greater part of the Designated Area has evolved in the absence of fluvial processes. The environments of deposition of the sedimentary sequence have not only influenced the geometry and inter-relationship of the aquifers but, for the younger parts of the sequence, have determined many of the landforms observed today. Both Late Tertiary and Quaternary age features are to be found in the landscape of the Designated Area. Overall, the features are of low relief and the slopes of the natural surface have small gradients.

4.2 Climate

With reference to median values of rainfall data, the Designated Area experiences a variation in yearly rainfall from 280 mm in the north near the Murray River to 860 mm in the south over the Mount Gambier Coastal Plain. South and south-west of the Padthaway Ridge the rainfall tends to exceed 500 mm per year but it decreases north and north-east of the Ridge.

Mean maximum daily air temperatures tend to be higher further inland irrespective of the month of a year. In January, they range from 21°C at the coast to 32°C at Mildura, whereas for July, the coastal zone temperature is 13°C and 15°C in the north of the Designated Area.

Mean yearly evaporation, as measured using a Class A pan, varies from 1065 mm at Mount Burr to 2200 mm at Mildura. Mean monthly figures for evaporation mirror the trend of the yearly figures.

Given the above pattern in climatic conditions through the Designated Area, changes in vertical recharge and irrigated crop water requirements are therefore to be expected. It is considered that vertical recharge would reduce towards the north as a consequence of the reduction in annual rainfall and the increase in evaporation. Conversely, it is considered that irrigated crop water requirements would increase in a northerly direction.

4.3 Surface Hydrology

With the exception of the Murray and Glenelg Rivers, most of the Designated Area has a poorly developed drainage system due to the general low topographic relief, and in certain areas, the low rainfall and the presence of permeable soil and rock units. There are some ephemeral streams, such as the Tatiara, Morambro and Mosquito Creeks in the southern part of the Murray Basin, which generally terminate in swamps, lagoons or runaway holes. In some areas, these streams are known to provide an additional source of recharge to the shallow aquifer.

In some areas of poor surface drainage, sheet or overland flow towards local depressions results in the formation of semi-permanent, and in some cases permanent, swamps. Water in these depressions either infiltrates into the underlying aquifer and/or is removed by evaporation.

5. GEOLOGY

The Designated Area spans the Cainozoic sedimentary Murray Basin to the north and the Upper Cretaceous-Cainozoic sedimentary Otway Basin to the south, as shown by the geological provinces plan (see Figure 2). A synthesis of the geological and hydrogeological investigations by numerous prior workers has been made by Brown (1989) and Brown and Stephenson (in press). The geology and groundwater resources of the Otway Basin have also been compiled from the work of numerous investigators and published (Wopfner and Douglas, 1971). Published geological plans covering the entire Designated Area have been produced by the Geological Surveys in both States.

Much of the sedimentation in the two basins was contemporaneous. However, the tectonics of the basement beneath each basin differed.

It is difficult to clearly define the boundary between the two basins within the Designated Area because the basins were linked with the deposition of the sediments being contemporaneous. However, the boundary is taken to be in the general Naracoorte area.

The Otway Basin is the thicker of the two. The principal depocentre was offshore. With abundant supplies of source materials coupled with energetic environments of transport and deposition, thick accumulations of sediment resulted.

Comparatively speaking, subsidence in the Murray Basin was much less. Faulting in the pre-Tertiary rocks resulted in large blocks which were gently tilted. Tertiary-age sediments draped over these structures. Nevertheless, an area surrounding the common State borders of New South Wales, South Australia and Victoria has been identified as the principal depocentre of the Basin. Accumulation of sediment did not appear to have a significant effect on isostatic adjustment of the basement rocks.

Consequently, the terrestrial deposits of quartzose sediments were thin and widespread while the predominantly calcareous marine sediments were thick and widespread.

An elevated ridge of basement rocks known as the Padthaway Ridge and comprising Ordovician granites and Cambrian meta-sediments separates the lowermost sediments of the two basinal sequences in South Australia (see Figure 2).

For a full description of the stratigraphy of the Murray and Otway Basins the reader is referred to Brown and Stephenson (in press), and Douglas and Wopfner (1971). To overcome State differences in the nomenclature of stratigraphic units, the Border Review Committee has, by consensus, adopted its own nomenclature. Figures 3 and 4 depict respectively geological cross-sections in a north-south direction and east-west direction through the Designated Area. The locations of the geological cross-sections are shown in Figure 5.

The lower Tertiary confined aquifer and the pre-Tertiary rocks are not currently included in the Management Plan due to the low level of groundwater utilisation and the limited information available at this stage. Accordingly, detailed differentiation of these rock units on the geological cross-sections has not been attempted.

The predominant lithologies in each of the Murray and Otway Basins are summarised in Table 3 below:

TABLE 3: TERTIARY AND QUATERNARY STRATIGRAPHIC UNITS OF THE MURRAY AND OTWAY BASINS

MURRAY BASIN		OTWAY BASIN	
		Quaternary	Limestone, sand and sandstone
Parilla Sand	Quartzose sand		
Bookpurnong Beds	Clay, marl		
Murray Group	Limestone, marl	Heytesbury Group	Limestone
Ettrick Formation	Marl	Nirranda Subgroup	Marl
Renmark Group	Quartzose sand, clay and lignite	Wangerrip Group	Quartzose sand, clay and lignite

Not shown on the geological cross-sections, because of difficulties with identification and correlation of some units, are the surficial geology units. A surficial geological plan has been compiled (see Figure 6) using the geological boundaries as presented on the published relevant 1:250 000 geological sheets. It is considered that the nature of the surficial deposits are important in evaluating the magnitude of diffuse recharge to the principal aquifers.

6. HYDROGEOLOGY

The Designated Area contains two main aquifer systems; the lower Tertiary sand aquifers (the Wangerrip Group of the Otway Basin and the Renmark Group of the Murray Basin) and the middle to late Tertiary Limestone aquifer (the Heytesbury Group Limestone of the Otway Basin and the Murray Group Limestone of the Murray Basin). A third more restricted late Tertiary sand aquifer (the Parilla Sand) is found in parts of the Murray Basin, in the northern part of the Designated Area and in local areas north of the Dundas Plateau in Victoria (see Figure 7). In the Otway Basin, the Quaternary sediments are also an important aquifer and are often in direct hydraulic connection with the underlying Tertiary limestone aquifer.

With few exceptions, in both the Murray Basin and Otway Basin, the groundwater in the sequences of limestone rocks represents the freshest and most economic water to produce. The alternative aquifers, both above and below the limestone, are usually less favourable sources of water but are, nevertheless, exploited in the absence of adequate supplies from the limestone.

The Management Plan to date has focused on the limestone aquifers because of their high usage and in anticipation of their possible over-exploitation. The thrust of the investigative drilling will gradually focus on the acquisition of data from the other aquifers.

The limestone aquifers have previously been termed the "unconfined aquifer", however, this term is strictly not correct due to the confined nature of the limestone in the northern part of the Designated Area. The term "Tertiary Limestone Aquifer" has therefore been adopted in this report as it is the major relevant hydrogeological unit in both basins. In certain areas within the Otway Basin, the term "Tertiary Limestone Aquifer" also includes the hydraulically continuous Quaternary limestone, sand and sandstone units. The term "confined aquifer" as referred to in this report comprises the lower Tertiary sand aquifers (the Wangerrip Group and the Renmark Group of the Otway and Murray Basins respectively).

6.1 The Aquifers and their Relationships

Those aquifers closest to surface are the quartzose Parilla Sand of the Murray Basin and the calcareous and quartzose Quaternary age units of the Otway Basin, both of which can be saturated or unsaturated, depending on location. When saturated, the water that they contain can be chemically distinct from the groundwater in the underlying limestone aquifer system at certain localities. This has been interpreted as meaning that there are locations where the sand aquifers are entities that are distinct in a hydraulic sense from the limestone aquifers and that there are other locations where the water in the sand aquifers is free to percolate downwards into the limestone. Further support for this interpretation is to be found in the observation that the potentiometric surfaces of the sand aquifers can differ from those of the limestone at common localities.

The Quaternary age aquifer system of the Otway Basin is within a sequence of limestone, sand, silt and clay units deposited under a variety of depositional environments. Consequently the changes in the lithologies may locally influence the groundwater flow regime of this aquifer.

In the northern part of the Designated Area, the basal part of the Parilla Sand is saturated and forms the uppermost aquifer. The area in which the Parilla Sand aquifer occurs is shown in Figure 7. In local areas north of the Dundas Plateau (Victorian Zones 4B to 6B), the basal part of the Parilla Sand is also saturated. Percussion drilling has revealed that for a large part of the area represented by Zones 9B to 11B the Parilla Sand is unsaturated.

Geographically, the quality of the water in the Parilla Sand varies from fresh to quite brackish, particularly east of the Designated Area from the Highland front to the Little Desert in Victoria.

From Zone 7B through to the Murray River, a low permeability unit, the Bookpurnong Beds, separates the Parilla Sand from the Murray Group limestone aquifer.

The Tertiary limestone aquifers of the two basins are generally laterally continuous and tend to thicken in the direction of the depocentres of the respective basins. The variation in thickness of the Tertiary limestone aquifer within the Designated Area is shown in Figure 7.

In the Otway Basin, the Heytesbury Group limestone is underlain by a marl of the Nirranda Subgroup; completely so in the Victorian portion of the basin and substantially so in South Australia. The marl can be as much as 50 metres thick and it acts as a confining bed.

The Ettrick Formation separates the Murray Group limestone aquifer from the underlying Renmark Group aquifer system in the Murray Basin. The Ettrick Formation rarely exceeds a thickness of 40 metres in the main part of the basin but can exceed 80 metres in thickness near the margin. Though the Ettrick Formation sediments generally act as a confining bed, parts of the more permeable Ettrick Formation are known to be capable of transmitting large quantities of water where there is a favourable hydraulic gradient (e.g. at Woolpunda near the River Murray in South Australia (Telfer, 1988)).

The Renmark Group aquifer comprises quartzose sediments and lignite of the Olney Formation and sand of the Warina Sand which is the older of the two units. The Warina Sand has been identified sub-surface near the basin margins but does not reappear in the stratigraphic sequence until as far north as Zones 10 and 11. This means that both units of the Group are in contact with the pre-Tertiary basement at different locations in the Designated Area. There is hydraulic continuity between the two units.

In the Otway Basin, sand aquifers of the Wangerrip Group underlay the Nirranda Subgroup. The sand is extensive, thick and is, generally, a high yielding aquifer.

Although water quality data from the arenaceous aquifers underlying the limestone aquifers is sparse compared to the availability of the limestone aquifer data, it appears that the water in the limestone is chemically distinct from the water in the deeper aquifers.

6.2 Characteristics of the Tertiary Limestone Aquifer

As the main thrust of the investigation to date has been towards evaluating the Tertiary limestone aquifer, most of this section of the report will be devoted to this unit.

The limestone aquifer is essentially unconfined in the Otway Basin and into the southern part of the Murray Basin where overlying units are connected hydraulically. Further north in the Murray Basin the aquifer becomes confined beneath a clay layer, the Bookpurnong Beds, which separates the Parilla Sand from the limestone, forming an aquitard.

Considerable variation in lithology and permeability occurs laterally within the aquifer. Immediately to the north of the Dundas Plateau the limestone is marly with a relatively low permeability.

To the south and west of the Dundas Plateau the aquifer becomes karstic in places with resulting very high permeabilities. Consequently well yields from these rocks are known to vary markedly over short distances depending on the presence or absence of solution features. Surface karstic expressions are known through Zones 1A to 7A in South Australia.

Although there is a lack of surface karstic features in Victoria, evidence is emerging of sub-surface solution features in Zones 2B to 4B. Enlarged voids in the limestone tend to localise and speed up the transfer of groundwater through the aquifer. If karst is developed to any significant extent the concepts of an average co-efficient of storage and hydraulic conductivity become less meaningful as descriptors of an aquifer's physical attributes. This has been manifested in some of the aquifer tests performed by Stadter (1989) and Stewart (1990a; 1990b; 1990c; 1990d).

Notwithstanding that, results from the aquifer testing programmes in South Australia indicate regional transmissivity values ranging from 200 to 4000 m^2/d, with locally high values in excess of 5000 m^2/d associated with karst features (Stadter, 1989). The more recent work carried out in Victoria confirms the high regional transmissivity values ranging from 600 to 900 m^2/d in Zones 5B to 7B and the significantly lower transmissivity (less than 200 m^2/d) in the eastern parts of Zones 3B and 4B (Stewart, 1990a and 1990b).

The regions encompassed by these distinct hydrogeological provinces are shown in Figure 8 which highlight the considerable variation in the nature of the limestone aquifer throughout the Designated Area. The spatial variation in the magnitudes of the transmissivities point to the need to base the Permissible Annual Volumes on hydrogeological criteria, rather than on a generalised formula for the whole of the Designated Area.

Assessments of the groundwater resources held in storage within the limestone aquifer have assumed a co-efficient of storage of 0.1. This value is probably unreliable given the large spatial variability of the limestone (i.e. karstic, unconfined and, in places, confined). To date, there have been insufficient long term aquifer tests to confidently determine appropriate regional values for this parameter.

Regional flow patterns are shown by the potentiometric surface contour plan for the limestone aquifer (see Figure 9). In Zones 1 and 2 the groundwater flow is in a general south or south-west direction. Within Zone 2A, the flow system is more complex with major recharge and discharge features superimposed on the regional flow pattern, and the physical characteristics of the limestone aquifer in this area are poorly understood. Between Zones 3 and 5, the groundwater flow is in a westerly direction with the direction of flow changing to the north-west and north in the Designated Area northwards of Zone 5.

6.3 Recharge to the Tertiary Limestone Aquifer

The process of groundwater recharge is evidenced by the increase in the volume of groundwater passing through the aquifer in a down-gradient flow direction. This recharge occurs via a number of mechanisms depending on the local hydrogeological conditions.

Vertical infiltration occurs where the aquifer is unconfined or semi-confined, either where it outcrops or where it is covered by permeable material. In certain areas, runaway holes and drainage wells can be a significant source of recharge and investigations are in progress to quantify this form of point recharge. The Parilla Sand (and the Quaternary Bridgewater Formation in the Otway Basin) and the Tertiary limestone outcrop extensively in the Otway Basin and in the southern part of the Murray Basin and can be directly recharged by rainfall. Elsewhere they are covered by thin Quaternary deposits, which means that vertical recharge needs to pass through a variety of lithologies.

As shown in Figure 8, vertical infiltration of rainfall is considered to occur within Zones 1A to 10A and Zones 1B to 7B in South Australia and Victoria, respectively.

In the area where the limestone aquifer is confined, lateral groundwater flow forms the main source of recharge.

To date considerable effort has been expended, principally in South Australia, in an attempt to quantify both diffuse and point recharge (Stadter, 1989 and Walker *et al.*, 1990). Joint additional studies with the CSIRO are currently in progress in both States.

The methods used to determine recharge rates have previously been outlined in an earlier report to the Border Review Committee (Stadter *et al.*, 1989) and the adopted average annual recharge from diffuse and point sources is shown in Figure 10. The indicated spatial variability is governed by a number of factors - the varying soil types (and geomorphology), differences in rainfall, varying depths to the top of the aquifer, the extent and distribution of point recharge sources (ephemeral swamps, drainage wells, runaway holes etc) and varying vegetation cover (e.g. the presence of extensive softwood plantations in the southern portion of the Designated Area were considered in the determination of the annual recharge rates).

The adopted recharge values for Victoria were determined based on the studies carried out essentially in Zones 3A to 7A. It is yet to be determined how appropriate those recharge values are for the corresponding Victorian Zones, given the changes in hydrogeological conditions and differences in vegetation cover and type. Therefore the recharge rates for Victoria must be regarded as tentative at this stage, particularly as point source recharge is considered to be less significant in Victoria.

A recent report by the CSIRO (Walker *et al.*, 1990) indicates that diffuse recharge rates range from 0 to 80 mm per annum in Zones 4A to 7A. These are less than those determined by standard hydro-geological methods as outlined above. This discrepancy may, however, be a reflection of the significance of point source recharge and the fact that the CSIRO investigations were undertaken at sites where the soils have a low permeability.

6.4 Groundwater Quality of the Tertiary Limestone Aquifer

With the establishment of the groundwater quality monitoring network in the Designated Area, there has been an improvement in the knowledge of regional changes in groundwater quality.

The distribution of groundwater salinity through the Designated Area, as shown in Figure 11, highlights a number of important features, these being:

- the variation from a low salinity groundwater (about 400 mg/L) in the south to a very saline groundwater (about 25 000 mg/L) in the north.

- the change in groundwater salinity from about 2 000 mg/L in the Victorian Zones 3B and 4B to about 1 000 mg/L or less in the corresponding South Australian Zones. This is attributed to the direct vertical recharge received by the aquifer.

- the improvement in groundwater salinity (to less than 1000 mg/L) beneath the Big Desert in Victoria and in the corresponding area across the Border in South Australia. Such a change in groundwater salinity is due to either an increase in direct recharge to the aquifer or from upward leakage from underlying aquifers. Further studies are required to determine the reason for this regional salinity change.

Although full chemical analysis results are available for the monitoring network for the last three years, there has been no detailed review of the hydrochemistry of the aquifer. This study should be undertaken to improve the understanding of recharge to the aquifer and the degree of groundwater leakage between the various aquifers.

7. GROUNDWATER MONITORING

As mentioned previously, monitoring of groundwater levels and quality is an important requirement under the Border Groundwaters Agreement.

The responsible authorities in both States (the S.A. Department of Mines and Energy and the Victorian Rural Water Commission) have undertaken this monitoring on a quarterly basis, generally in the months of March, June, September and December of each year. The monitoring programme is synchronized between the respective authorities and is usually carried out over a common fortnightly period.

At the present time, each State is responsible for the storage of their respective monitoring information on separate computer data bases. Mutually compatible computer data files are exchanged between the respective authorities.

Since 1987, annual reports have been prepared for the Border Review Committee to present the results of the groundwater monitoring (Ingram *et al.*, 1988 and 1989; Stadter *et al.*, in preparation).

7.1 Groundwater Level Monitoring

The network of observation wells used to monitor groundwater levels in the Designated Area is shown in Figure 12.

The monitoring record for a number of wells, particularly in the southern part of the Designated Area and in South Australia, spans a period of about 20 years. For the observation wells that have been specifically constructed or added to the network in the last few years, the monitoring record is obviously much shorter and the determination of any longer term trends in groundwater levels is not yet possible.

An examination of the available monitoring records has shown the following:

- The seasonal fluctuations in groundwater levels range from less than 0.5 metres to about 2 metres. The larger seasonal fluctuations can be attributed to higher rates of vertical recharge.

- The groundwater levels in several monitoring wells in parts of Zones 1 and 2 have shown a gradual decline over the last 10 to 20 years. This decline is apparent in both the Tertiary Limestone and in Victoria the underlying confined (Dilwyn Formation) aquifers. In South Australia, a decline exceeding 0.1 metre per year in the Tertiary limestone aquifer can be correlated with the area of extensive softwood plantations east and southeast of Mount Gambier. In Victoria, the decline in potentiometric head in the confined aquifer could possibly be caused by groundwater extraction from this aquifer in an area outside the Designated Area at Portland, but this needs to be verified. This rate of potentiometric surface lowering, observed over at least the last 5 years, exceeds the rate of 0.05 metre per annum as specified in the Groundwater (Border Agreement) Act. Hydrographs for selected monitoring wells which highlight this trend, the locations of which are shown in Figure 12, are presented in Figures 13 and 14.

- The effect of softwood afforestation on groundwater levels in the southern part of the Designated Area can readily be seen by the rise in groundwater levels observed in a number of monitoring wells in an area of Zone 2A where the pine forests were extensively destroyed in the 1983 bushfire. Groundwater levels in some wells have risen by up to 3 metres. Hydro-graphs for several of these wells are shown in Figure 15, with the locations shown in Figure 12.

- The groundwater levels in a number of monitoring wells in South Australian Zones 6A to 8A and Victorian Zone 10B have shown a rise in groundwater levels which is attributed to an increase in vertical recharge resulting from the clearance of native vegetation. Hydrographs for several monitoring wells exhibiting this trend are shown in Figures 14 and 16 and the locations of the wells are shown in Figure 12.

The monitoring of groundwater levels at the current three monthly frequency needs to be continued to further examine the trends evident in some areas of the Designated Area and to provide a sufficient data base to assess vertical recharge to the aquifer.

7.2 Groundwater Quality Monitoring

The network of observation wells used to monitor groundwater quality in the Designated Area is shown in Figure 17.

Groundwater samples (which are generally obtained by pumping) are tested quarterly for conductivity, and from 1988 to 1990, samples collected during the March monitoring period have also been analysed for the following parameters:

Bicarbonate	Iron
Chloride	Nitrate and Nitrite
Sulphate	Phosphorus
Calcium	Silica
Magnesium	pH
Sodium	Hardness
Potassium	Alkalinity

The results for the full chemical analysis sampling are tabled in Ingram *et al.* (1988; 1989) and Stadter *et al.* (in preparation).

The monitoring record for most wells is relatively short, generally covering a time span of less than five years. Examination of the salinity monitoring data has shown the following:

- for most observation wells there is no discernible salinity change
- a small number of monitoring wells in Zones 3A to 8A suggest a possible increase in groundwater salinity with time, but it is stressed that the short length of monitoring period needs to be considered in the interpretation of these results. Graphs of salinity versus time for a few of these wells are shown in Figure 18, and the locations of the wells are shown in Figure 17.

In order to establish an adequate long term data base of groundwater quality, the current three monthly monitoring of groundwater salinity needs to be continued. However, the frequency of the full chemical analysis sampling programme should be changed from annually to once every three years, with samples being collected during the March monitoring period. It is considered that this frequency should be adequate to determine longer term trends in groundwater quality, and this has been the case for the Padthaway irrigation area (west of Zone 6A) where full chemical analysis data has been obtained over the last nine years.

8. MODELLING

Several attempts have been made to model the Tertiary Limestone aquifer system in the Designated Area since 1988.

8.1 Hydraulic Modelling

Oakes *et al.* (1989) established a preliminary hydraulic model for Zones 4 to 8 to examine the relationship between recharge and aquifer transmissivity for the Tertiary Limestone aquifer and to provide a focus for additional investigations. The lack of data for these two parameters, particularly in Victoria, highlighted the need to obtain additional information.

A computer strip model was established by the E. & W.S. Department through Zone 5 and reasonable calibration of the potentiometric surface was achieved (A. Telfer, pers. comm.) using the general range of aquifer transmissivity values and recharge rates determined by Stadter (1989).

8.2 Salinity Modelling

Dudding (1990) utilised three separate models to define a basic framework and to outline any data deficiencies for the assessment of the impact of recycling irrigation water on the groundwater salinity.

It is considered that sufficient data particularly in terms of establishing a reliable water balance are not yet available to confidently model at the required scale the behaviour of the Tertiary limestone aquifer in terms of changes in groundwater salinity.

Such salinity modelling would be useful to establish the time scale for expected longer term groundwater quality changes associated with irrigation developments.

Salinity modelling in regions in South Australia, close to the Designated Area, where groundwater salinity problems have developed would be useful to determine the reliability of particular salinity models.

9. ASSESSMENT OF GROUNDWATER RESOURCES

It is generally accepted that the sustainable groundwater resource in a particular area is largely dependant on the magnitude of the recharge to the aquifer. This recharge is in the form of lateral groundwater throughflow, whether the aquifer is confined or unconfined, and can also include vertical recharge where the aquifer is unconfined or semi-confined.

The proportion of lateral groundwater throughflow which forms part of the Permissible Annual Volume for some of the Zones of the Designated Area needs to be carefully considered. Groundwater flow is essentially from east to west (except Zone 1 and 2). Where the limestone aquifer is unconfined in the Designated Area, there is an addition to throughflow from vertical recharge. The current approach to management attributes the vertical recharge in the Designated Area as part of each State's entitlement. Furthermore, throughflow and also vertical recharge need to be examined in relation to the minimum rates required to maintain groundwater quality.

The initial re-assessment of the upper limits of permitted annual groundwater extraction for most Zones within the Designated Area, as summarised in the 1989 joint technical report (Stadter *et al.*, 1989), was based on the above considerations.

As the additional investigations carried out since that time have not significantly altered our understanding of the groundwater system and the results of the on-going recharge studies are not yet available, the results of the above assessment are still considered to be essentially valid and those results are briefly outlined below.

9.1 Resource Assessment in South Australia

In line with the current management policy to minimise adverse salinity impacts by ensuring adequate groundwater throughflow across the Zones of the Designated Area, the assessment of groundwater availability within Zones 2A to 8A inclusive was based entirely on the vertical recharge to the aquifer, using the adopted average annual recharge rates.

The results of this assessment are presented in Table 4.

TABLE 4: CURRENT PERMISSIBLE ANNUAL VOLUMES AND ESTIMATED VOLUMES OF ANNUAL VERTICAL RECHARGE FOR SOUTH AUSTRALIAN ZONES

ZONE	CURRENT PERMISSIBLE ANNUAL VOLUME (ML)	VOLUME OF ANNUAL VERTICAL RECHARGE (ML)	ANNUAL VERTICAL RECHARGE (mm)
1A	71 000	67 500*	100*
2A	25 000	27 100	75
3A	24 000	31 700	75
4A	20 000	26 400	50
5A	18 500	16 600	30
6A	8 500	11 100	20
7A	7 500	8 300	15
8A	3 500	6 700	12
9A	6 000	270*	0.2*
10A	6 000	105*	0.1*
11A	12 000	210*	0.1*

* Value used for original basis of Permissible Annual Volume

Due to the priority of investigations in the above mentioned Zones, no re-assessments were made for Zones 1A, 9A 10A and 11A.

9.2 Resource Assessment in Victoria

Although a broad general re-assessment of groundwater availability in Victoria was carried out in 1989, at this point of time it is proposed not to undertake a more detailed re-assessment until the results of current research provide better estimates of vertical recharge rates.

More recent studies in Victoria suggest at this stage that the transmissivity at the eastern boundary of the Designated Area in the southern part of the Murray Basin is lower than previously thought, but further assessment of this data is required.

Therefore it is considered that the previous results (Stadter *et al.*, 1989) should be used for the purposes of this five yearly review as presented in Table 5 below.

TABLE 5: RESOURCE ASSESSMENT FOR VICTORIAN ZONES

ZONE	CURRENT PERMISSIBLE ANNUAL VOLUME (ML)	ESTIMATED VOLUME OF ANNUAL THROUGHFLOW AT EASTERN BOUNDARY OF ZONE (ML/YR)	VOLUME OF ANNUAL VERTICAL RECHARGE (ML)	ANNUAL VERTICAL RECHARGE (mm)
1B	71 000	N/D	67 500*	100*
2B	25 000	N/D	22 300*	42*
3B	16 500	2 440	24 300	50
4B	14 000	1 200	15 900	30
5B	18 500	8 100	11 100	20
6B	6 000	5 000	11 100	20
7B	7 000	3 370	3 340^	12^
8B	3 500	2 940	820^	12^
9B	6 000	N/D	$	0
10B	6 000	N/D	$	0
11B	12 000	N/D	$	0

N/D Not determined
* Value used for original basis of Permissible Annual Volume
^ Vertical recharge only determined for area where aquifer is not confined
$ No vertical recharge is assumed as the aquifer is confined

10. CONCLUSIONS

From the review of the studies carried out within the Designated Area during the period from 1986 to 1990, it is concluded that:

(1) The investigations by the respective authorities in both States have increased the understanding of groundwater occurrence within the Designated Area, particularly for the Tertiary limestone aquifer.

The majority of this work was carried out within Zones 4, 5, 6, 7 and 8 of the Designated Area and comprised stratigraphic drilling and aquifer testing programmes, assessment of aquifer recharge rates, groundwater modelling, and monitoring of groundwater levels and quality **(SECTIONS 3, 6, 7 AND 8)**. A re-assessment was made in 1989 of the groundwater resources focussing on South Australian Zones 2A to 8A, and this resulted in an increase in the Permissible Annual Volume for Zones 3A, 4A, 6A and 7A **(SECTION 9)**.

It is evident, however, that further investigations need to be undertaken in both States in order to complete the re-assessment of the groundwater resources for the remainder of the Zones of the Designated Area, and to model the longer term effects of various groundwater management options. It is considered that sufficient data is not yet available, particularly quantitative aquifer recharge rates, to confidently model at the required scale the behaviour of the Tertiary Limestone aquifer.

Preliminary data from more recent studies in Victoria suggests that the transmissivity at the eastern boundary of the Designated Area is lower than previously thought. However, this work is still in progress and, at this stage, it is considered that the previously adopted transmissivity values should be used.

(2) The nature of the aquifer varies considerably throughout the Designated Area with respect to hydraulic conductivity, thickness,and whether it is confined, unconfined or semi-confined **(SECTION 6)**.

(3) The available groundwater resource of the Tertiary Limestone aquifer is made up of vertical recharge and part of the groundwater throughflow **(SECTION 9)**. Where the aquifer is confined it is assumed there is essentially little or no vertical recharge, but it will be necessary to quantify leakage to the Limestone aquifer in the future. The volume of throughflow is dependent on aquifer thickness, hydraulic conductivity and hydraulic gradient. As these characteristics vary throughout the Designated Area, then clearly the available resource varies correspondingly. It is therefore essential to

determine the groundwater availability for each Zone in relation to the appropriate governing hydrogeological parameters.

(4) The relevant groundwater throughflow that should be used for apportionment in determining the groundwater availability for the various Zones should be the groundwater entering the Designated Area and not that at the State Border. This is because the addition to the groundwater throughflow in the Victorian Zones arising from the excess of vertical recharge over extraction should remain as part of Victoria's entitlement.

(5) Future assessment needs to take into account the minimum volumes of vertical recharge and groundwater throughflow required to maintain water quality in the aquifer. The Permissible Annual Volumes in either or both States may need to be revised in the future should unacceptable levels of groundwater quality deterioration become manifest.

(6) The groundwater level monitoring at a three monthly frequency through the Designated Area has provided necessary information to assess seasonal fluctuations and longer term trends in groundwater level elevations **(SECTION 7.1)**. The monitoring record for some wells, however, is relatively short and further monitoring at the same frequency is required to verify longer term trends. The additional water level data is also required to quantify aquifer recharge rates.

(7) The available groundwater level monitoring data has shown that longer term changes in groundwater levels are evident in some Zones **(SECTION 7.1)**.

A decline in groundwater levels in both the Tertiary Limestone aquifer and the lower Tertiary confined aquifer is evident in parts of Zones 1 and 2. The potentiometric surface lowering in the Tertiary Limestone aquifer can be correlated with the areas of extensive softwood plantations, and it is considered that this decline is due to the reduction in vertical recharge to the Limestone aquifer beneath the forested areas. The rate of potentiometric surface lowering in these areas has over at least the last five years exceeded the rate of 0.05 metre per annum specified as the permissible rate of potentiometric surface lowering in the Groundwater (Border Agreement) Act.

The cause and extent of the decline in the potentiometric surface of the lower Tertiary confined aquifer is less obvious, and may possibly be due to the groundwater extraction from this aquifer outside the Designated Area in Victoria at Portland.

A rise in groundwater levels in the Tertiary limestone aquifer in South Australian Zones 6A to 8A is attributed to an increase in vertical recharge following the clearance of native vegetation, whereas the rise in Victorian Zone 10B (where the aquifer is confined) is likely due to a regional response to clearing of native vegetation.

(8) The monitoring of groundwater salinity at a three monthly frequency over the last five years through the Designated Area has provided the necessary data to show the variability in groundwater salinity through the area, but the period of monitoring is too short to predict any longer term trends **(SECTION 7.2)**. An adequate data base to define any groundwater salinity trends will require the continuation of monitoring for the next five to ten years.

The annual full chemical analysis sampling has established an initial water quality data base which will allow a review of the hydrochemistry of the Tertiary Limestone aquifer, and with which any future water quality changes can be compared. Given the expected slow change in groundwater quality with time, the annual frequency of this sampling could be expanded to three-yearly.

(9) Given the variability in groundwater salinity within the Zones of the Designated Area, the definition of a permissible level of groundwater salinity would be difficult. The establishment of a permissible level of salinity hence seems inappropriate. The rate of change in groundwater salinity is a preferred indicator of the effectiveness of groundwater management policies.

(10) Within the one kilometre permissible distance from the State Border, no known problems have arisen in relation to either demand for or actual groundwater extraction in either South Australia or Victoria. The potential for these problems to arise, however, still exists.

11. RECOMMENDATIONS

11.1 It is recommended that the following specific investigations be undertaken:

(1) determination of vertical recharge for the Victorian portion of the groundwater system and similar studies in the more sandy areas within the Designated Area in South Australia, and review the current approaches to recharge assessment in light of their applicability to the understanding of recharge to the regional groundwater system.

(2) a compilation of all data relevant to an assessment of transmissivity of the Tertiary limestone aquifer in the vicinity of the eastern boundary of the Designated Area be completed.

(3) a detailed review of the hydrochemistry of the Tertiary Limestone aquifer using the available full chemical analysis data to improve the understanding of its recharge and the degree of groundwater leakage between the various aquifers.

(4) assessment of the impact of softwood afforestation, groundwater extraction from the lower Tertiary confined aquifer outside the Designated Area in the Otway Basin and other possible factors on the groundwater resources.

(5) re-assessment of the groundwater resources in Zones 1, 2, 3, 9, 10 and 11.

(6) assessment of the vertical groundwater leakage to and from the Tertiary limestone aquifer.

(7) when sufficient data is available, salinity modelling of the Tertiary Limestone aquifer to predict longer term groundwater salinity changes in response to various possible management options.

(8) studies to quantify usage for stock and domestic purposes to gain a more complete perspective of groundwater use.

11.2 It is also recommended that the following on-going investigations be continued:

(1) the study being largely undertaken by the CSIRO to quantify point source recharge in particular South Australian Zones of the Designated Area.

(2) continuation of the current monitoring programme with the exception of decreasing the frequency of the full chemical analysis sampling from annually to three-yearly.

11.3 It is also recommended that the Border Review Committee consider the following:

(1) The Permissible Annual Volumes (P.A.V.'s) be determined taking into account the different hydrogeological conditions throughout the Designated Area.

(2) Clarification whether the P.A.V.'s refer to the total groundwater system or a particular defined aquifer.

(3) The exceedance of the permissible rate of potentiometric surface lowering in parts of Zones 1 and 2.

(4) Amendments to the Groundwater (Border Agreement) Act to enable the implementation of a policy to use an annual groundwater salinity change, in a similar manner to the use of a specified rate of potentiometric surface lowering, to assess the impacts of groundwater extraction in preference to the concept of using permissible levels of salinity as presently defined in the Agreement.

(5) The maintenance of the present policy regarding the one kilometre permissible distance from the State Border in either South Australia or Victoria.

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APPENDIX 1

NUMBER OF IRRIGATION AND STOCK/DOMESTIC BORES IN THE VICTORIAN PORTION OF THE DESIGNATED AREA AND COMPARISON OF LICENSED ANNUAL ALLOCATIONS TO ESTIMATED STOCK/DOMESTIC WATER USE

VICTORIAN ZONE	NUMBER OF IRRIGATION BORES	NUMBER OF STOCK/ DOMESTIC BORES	LICENSED ANNUAL VOLUME (ML)	ESTIMATED STOCK/ DOMESTIC USAGE (ML)	
				1 ML/ ANNUM/ BORE	5 ML/ ANNUM/ BORE
1B	72	354	2 524	354	1 770
2B	111	193	14 616	193	965
3B	2	88	317	88	440
4B	5	75	306	75	375
5B	23	155	4 605	155	775
6B	7	46	1 692	46	230
7B	9	70	560	70	350
8B	7	107	1 738	107	535
9B	3	25	1 737	25	125
10B	2	146	181	146	730
11B	-	10	0	10	50

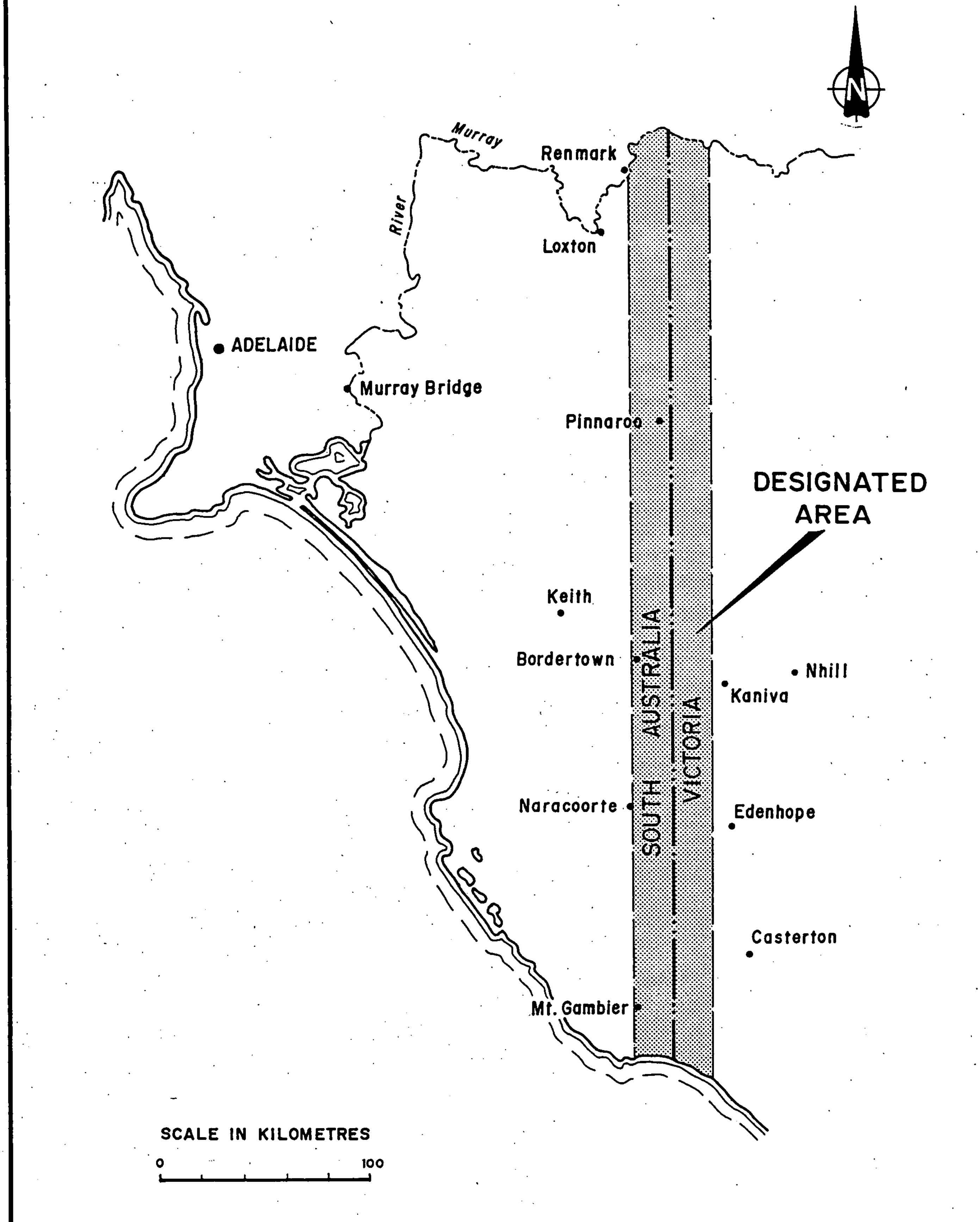


Figure......1

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION

LOCATION OF DESIGNATED AREA

COMPILED M.H.S.	C.D.O.	14·9·89 DATE	
DRAWN R.H.	SCALE As shown		
DATE July 1989	PLAN NUMBER		
CHECKED	S20870		

4197

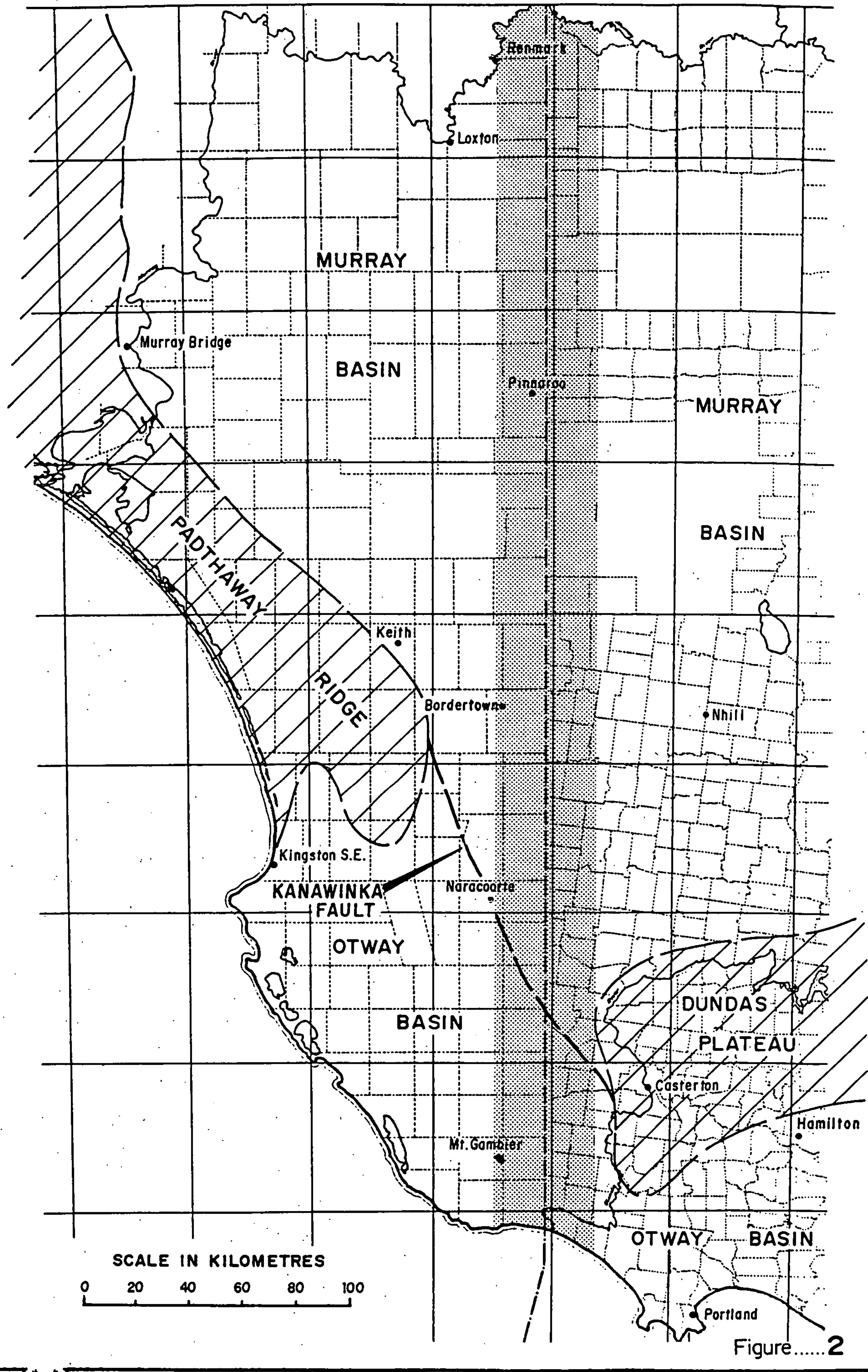


Figure......2

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION

GEOLOGICAL PROVINCES OF THE DESIGNATED AREA

COMPILED M.H.S.	C.D.O.	DATE 14-9-89	
DRAWN R.H.	SCALE As shown		
DATE June 1989	PLAN NUMBER S20871		
CHECKED			

4197

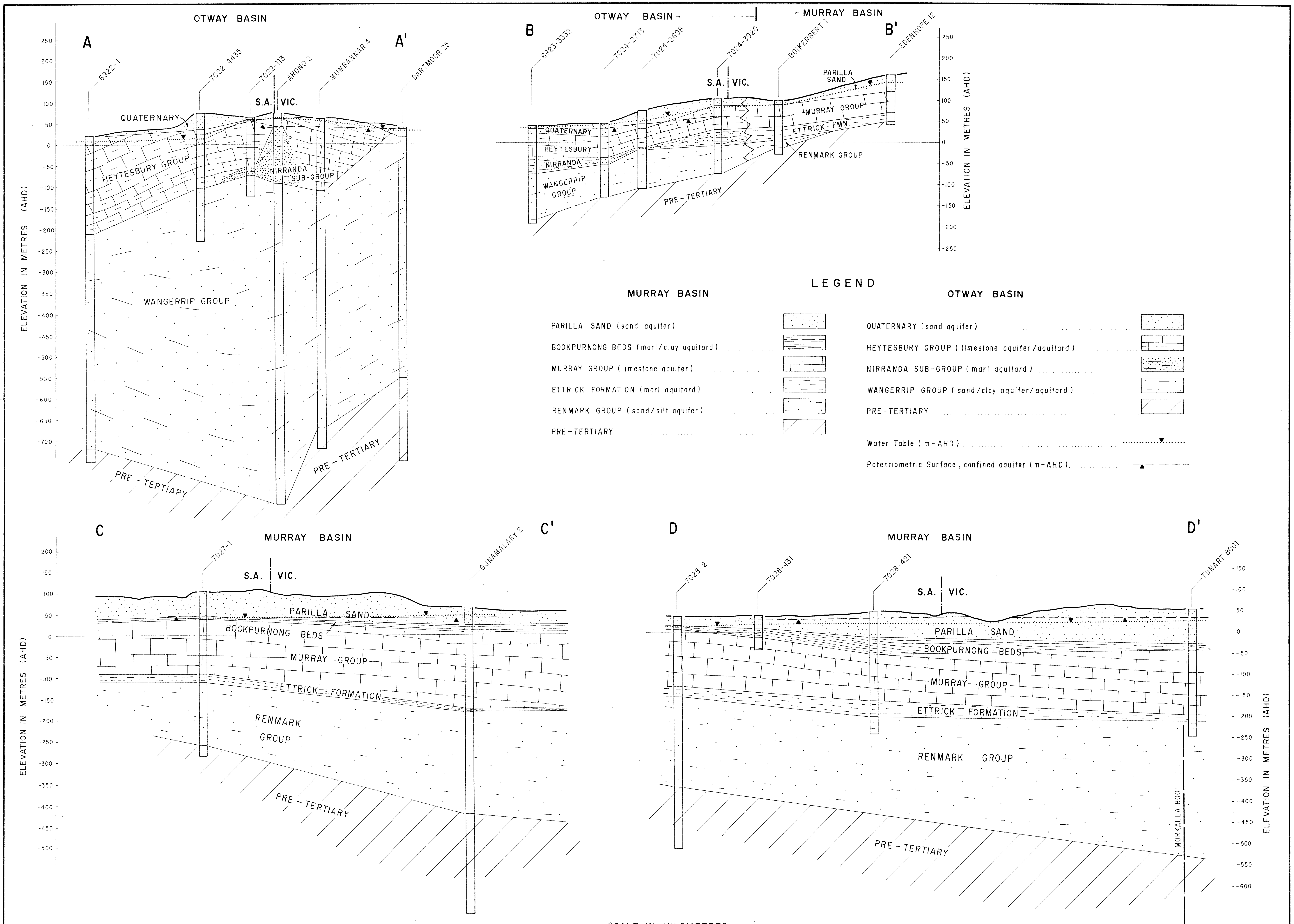
Figure.....3

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

SOUTH AUSTRALIA / VICTORIA STATE BORDER
HYDROGEOLOGICAL INVESTIGATION

NORTH – SOUTH
GEOLOGICAL SECTIONS

COMPILED	
DRAWN	B Donovan
	October 1990
CHECKED	
C.G.G.	DATE
SCALE	1:500 000
PLAN NUMBER	90-795



SCALE IN KILOMETRES

0 5 10 20 30

For location of section, see figure 3 (Plan No. 90-795)

Figure 4

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED G.S., S.R.B. M.H.S.	7 11 89 CDO DATE
S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION	DRAWN R.H.	SCALE As shown
EAST - WEST GEOLOGICAL SECTIONS	DATE Oct 1987 CHECKED	PLAN NUMBER 87-790

4197

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

SA/VIC STATE BORDER HYDROGEOLOGICAL INVESTIGATION

LOCATION OF GEOLOGICAL SECTIONS

Figure 5

Scale 1:500 000

Drawn R. Bird, April 1987

87-783

BORDER ZONE - SURFICIAL GEOLOGY

SYMBOL	ADOPTED FORMATION NAME	ALTERNATIVE NAME	LITHOLOGY	DEPOSITIONAL ENVIRONMENT	INFILTRATION POTENTIAL
Qa	Coonambidgal Formation		Clays overlying sands	Alluvial	Low
Qdm	Molineaux Sand	Lowan Sand	Yellow-grey deep sand	Aeolian	High to very high
Ql	Un-named		Laminated clays and silty clays	Lacustrine	Low to medium
Qly	Yamba Formation		Gypsiferous clays	Lacustrine, evaporitic Groundwater discharge area	Low
Qdw	Woorinen Formation		Red-brown sands & sandy clays often containing calcretes. (Bakara & Ripon Calcretes)	Aeolian dunes and swales	Medium
Qrs	Un-named	Shepparton Formation	Sands and silts	Swamp & lagoonal deposits of the red-gum plains	Low to medium
Qcl	Padthaway Formation		Sands, silts & clays overlying freshwater limestone	Interdunal swamps and lagoons	Very high north of Zone 2A. High elsewhere
Qpb	Bridgewater Formation		Calcarenite	Coastal beach & aeolian dunes	Very high
TQv	'Newer Volcanics'		Basaltic lava, scoria tuff and ash	Volcanic (sub-aerial)	Low to medium
Tps	Parilla Sands	Pliocene Sands	Sands with minor clay. Locally capped with ferruginous duricrust	Strand plain-shallow marine, beach and estuarine	High
Tml	Murray Group limestone	Gambier Limestone	Fossiliferous calcarenite	Shallow marine platform	Very high

Figure....6

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

SOUTH AUSTRALIA / VICTORIA STATE BORDER HYDROGEOLOGICAL INVESTIGATION

BORDER ZONE SURFICIAL GEOLOGY

COMPILED XPS, SRB
DRAWN RH.
DATE April 1989
CHECKED
C.D.O DATE
SCALE As shown
PLAN NUMBER 89--107

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

SA/VIC STATE BORDER HYDROGEOLOGICAL INVESTIGATION

TERTIARY LIMESTONE AQUIFER ISOPACH & OCCURRENCE OF PARILLA SAND AQUIFER

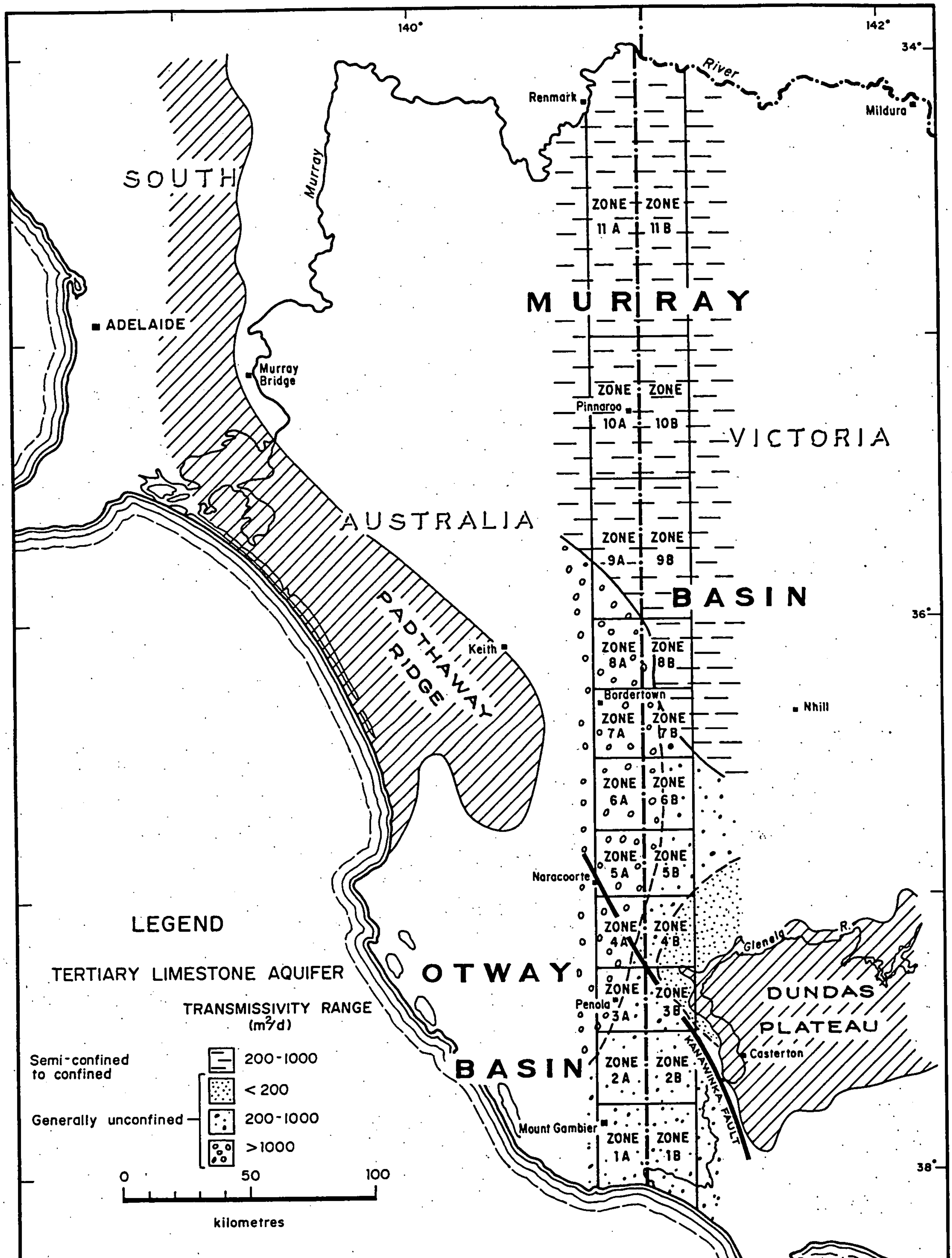
Compiled F. Stadter
Drawn B. Dobson
Date Dec. 1990
Scale 1:500 000
Plan Number 90-832

Figure 7

LEGEND

—100— Contour of Tertiary Limestone Aquifer Thickness (metres)

Area where Parilla Sand is an aquifer



S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION

HYDROGEOLOGICAL PROVINCES FOR THE TERTIARY LIMESTONE AQUIFER OF THE DESIGNATED AREA

Figure.....8
S 21860

SADME

4197


DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA
S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION
TERTIARY LIMESTONE AQUIFER
POTENTIOMETRIC CONTOURS – MARCH 1990
COMPILED F. Stadter
DRAWN B. Donovan
DATE Dec. 1990
CHECKED
C.D.O. DATE 23.1.91
SCALE 1:500 000
PLAN NUMBER 90-893
Figure.....9
SCALE IN KILOMETRES
10 0 10 20 30
LEGEND
100 Tertiary Limestone Aquifer Potentiometric Contour (m)
SOUTH AUSTRALIA
VICTORIA
RENMARK
LOXTON
PINNAROO
KEITH
BORDERTOWN
NARACOORTE
MT. GAMBIER
NHILL
CASTERTON
PORTLAND
Murray River
Glenelg River
ZONE 11A
ZONE 11B
ZONE 10A
ZONE 10B
ZONE 9A
ZONE 9B
ZONE 8A
ZONE 8B
ZONE 7A
ZONE 7B
ZONE 6A
ZONE 6B
ZONE 5A
ZONE 5B
ZONE 4A
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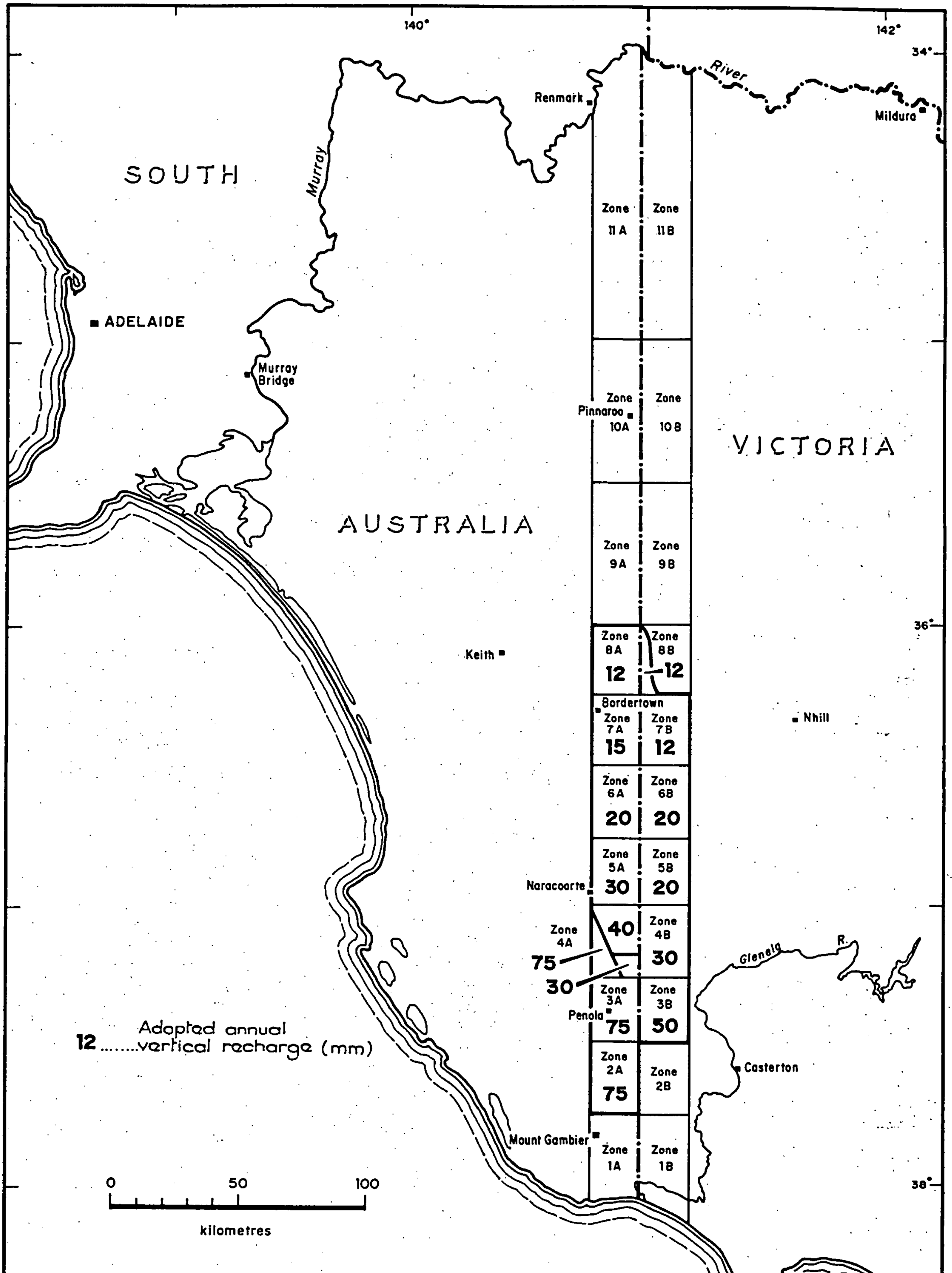
ZONE 1B
35°
36°
37°
38°



S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION

ADOPTED ANNUAL VERTICAL RECHARGE RATES FOR PORTIONS OF THE DESIGNATED AREA

Figure.....10

SADME

S 21861

4187

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION

TERTIARY LIMESTONE AQUIFER GROUNDWATER SALINITY - MARCH 1990

COMPILED	F. Stadter	SCALE	1:500 000
DRAWN	B. Donovan	PLAN NUMBER	90-894
DATE	Dec. 1990		
CHECKED			

Figure....11

SCALE IN KILOMETRES

10 0 10 20 30

LEGEND

—— 2000 —— Tertiary Limestone Aquifer Salinity Contour (mg/L)
(salinity based on summation of cations/anions from march 1990 Full Chemical Analysis)

SCALE IN KILOMETRES

10 0 10 20 30

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

SA/VIC STATE BORDER HYDROGEOLOGICAL INVESTIGATION

LOCATION OF GROUNDWATER LEVEL MONITORING WELLS

COMPILED	F. Stadter
DRAWN	B. Dewyer
DATE	Dec. 1990
SCALE	1:500 000

Figure 12

90-895

LEGEND

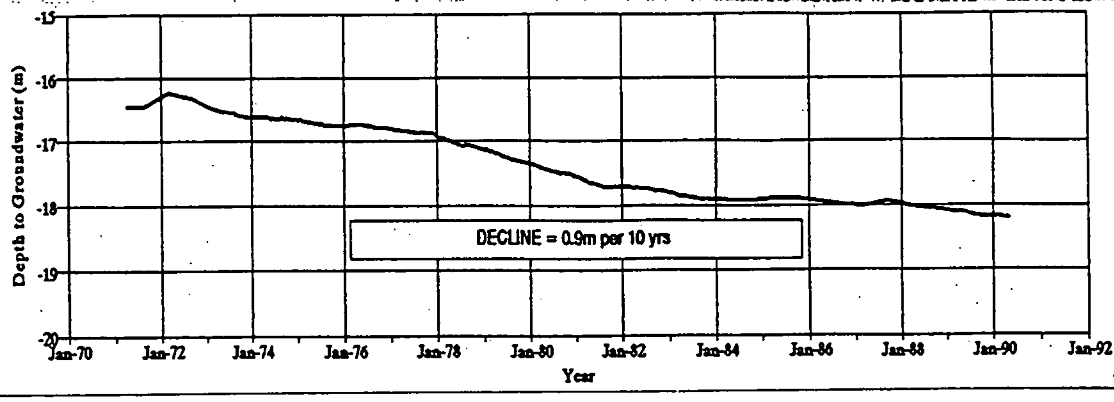
Government observation well and number .... • 39

Privately owned observation well and number ...... o 2

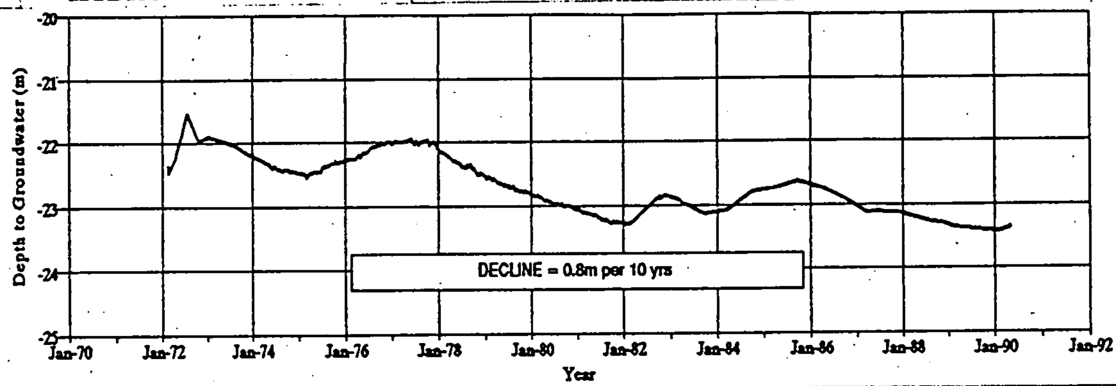
Well constructed in Dilwyn (confined) Formation ..... △

Observation well with hydrograph .... ▭2 (See plans S 21862 - S21865 / Figs. 13 to 16)

HYDROGRAPH - CAR 19



HYDROGRAPH - GAM 29



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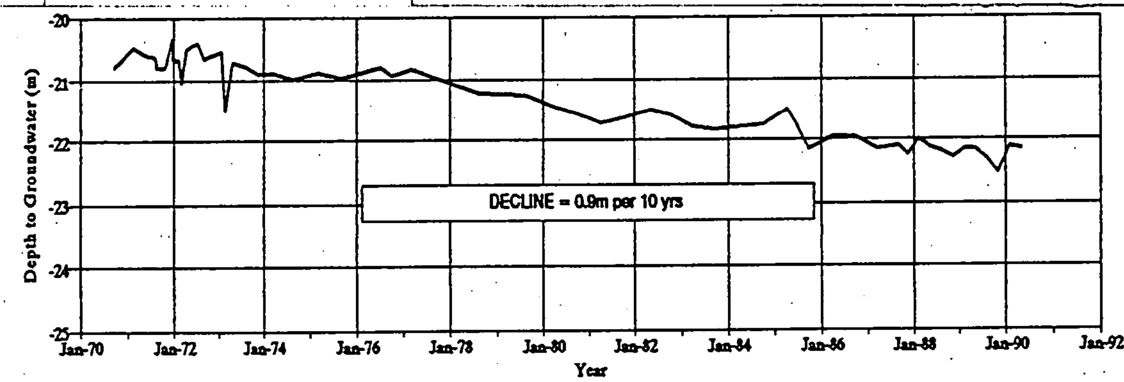


HYDROGRAPH - GAM 81

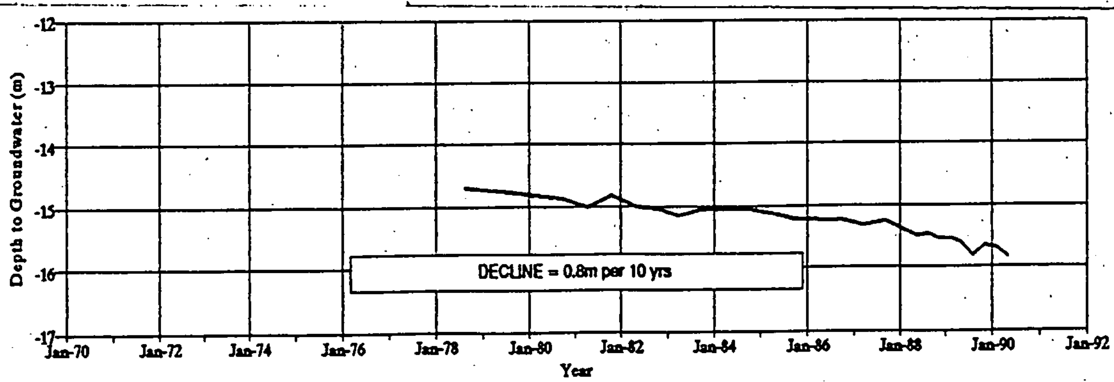


Figure.....13

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION

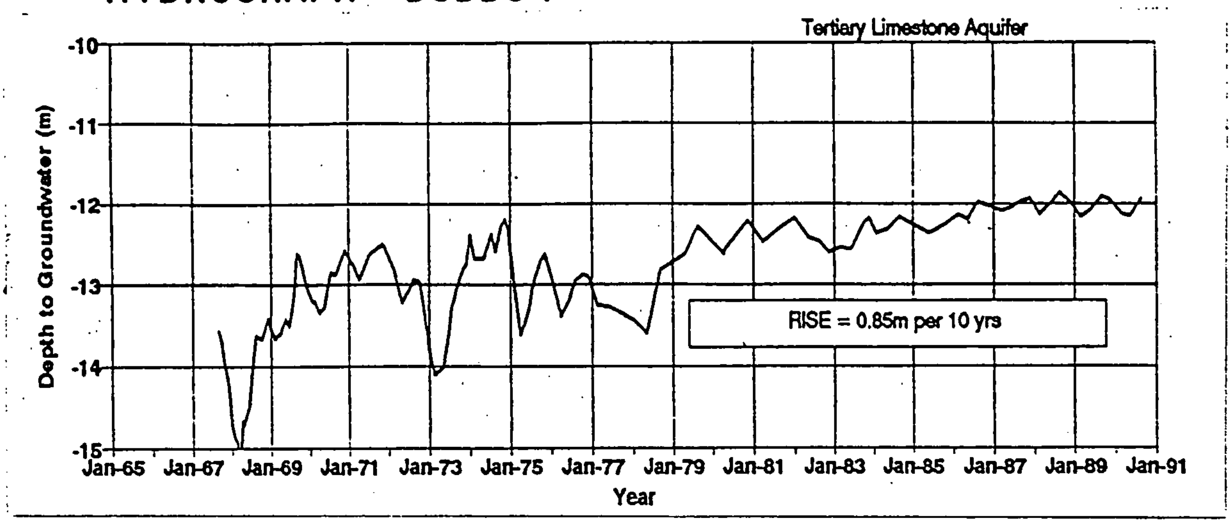
Observation Wells - CAR 19, GAM 29, GAM 55 and GAM 81

TERTIARY LIMESTONE AQUIFER HYDROGRAPHS

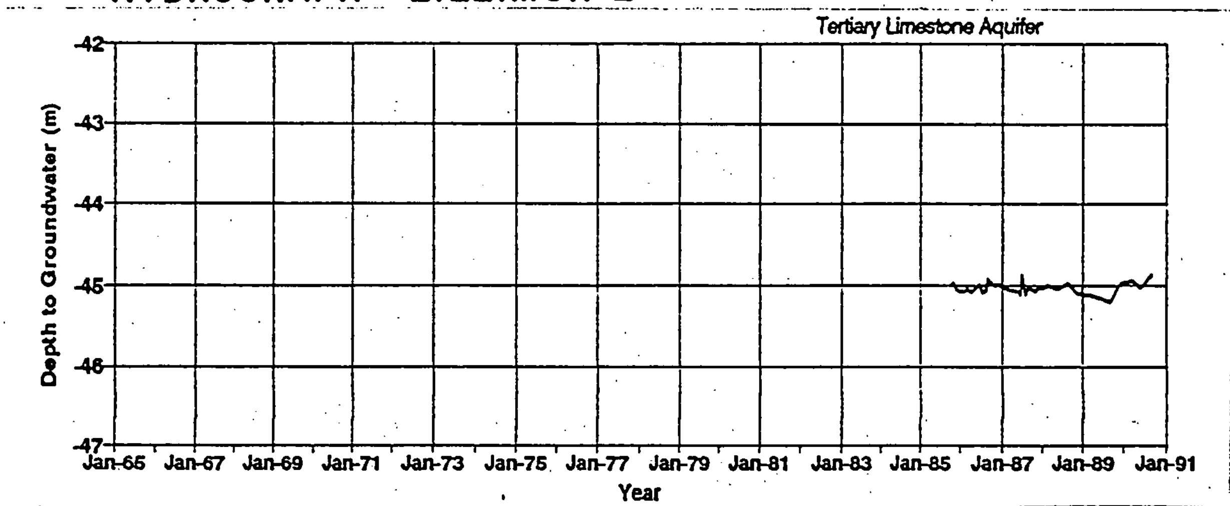
COMPILED G.A.M.	C.D.O. DATE 25.1.91
DRAWN G.A.M.	SCALE ——
DATE Oct. '90	PLAN NUMBER
CHECKED	S 21862

4197

HYDROGRAPH - DUDDO 1



HYDROGRAPH - LILLIMUR 2



HYDROGRAPH - WARRAIN 6

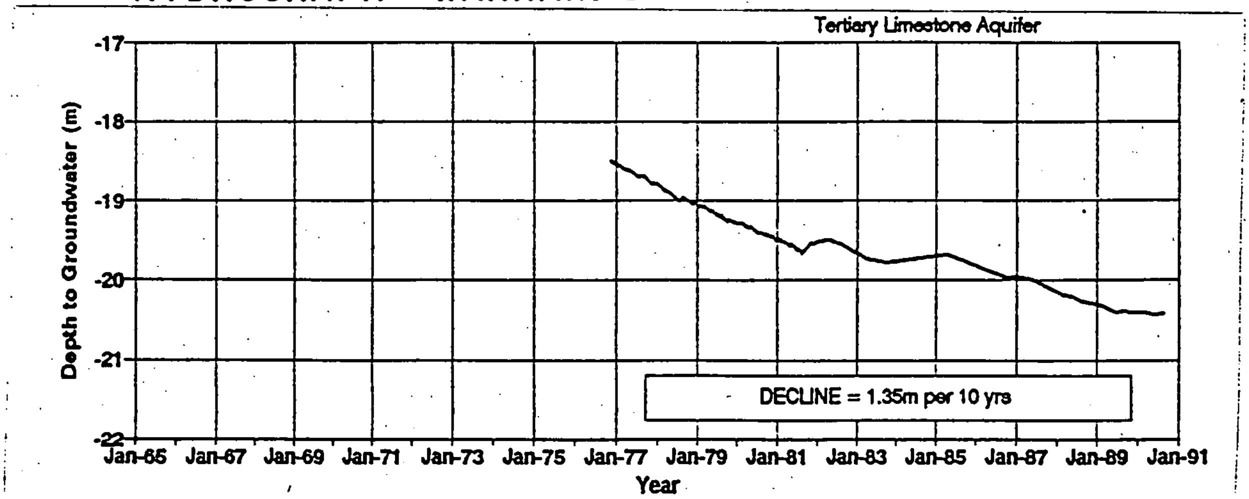


Figure 14

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION
Observation Wells - DUDDO 1, LILLIMUR 2 & WARRAIN 6
TERTIARY LIMESTONE AQUIFER HYDROGRAPHS

COMPILED G.A.M.	C.D.O. 23·1·91 DATE
DRAWN G.A.M.	SCALE
DATE Oct '90	PLAN NUMBER
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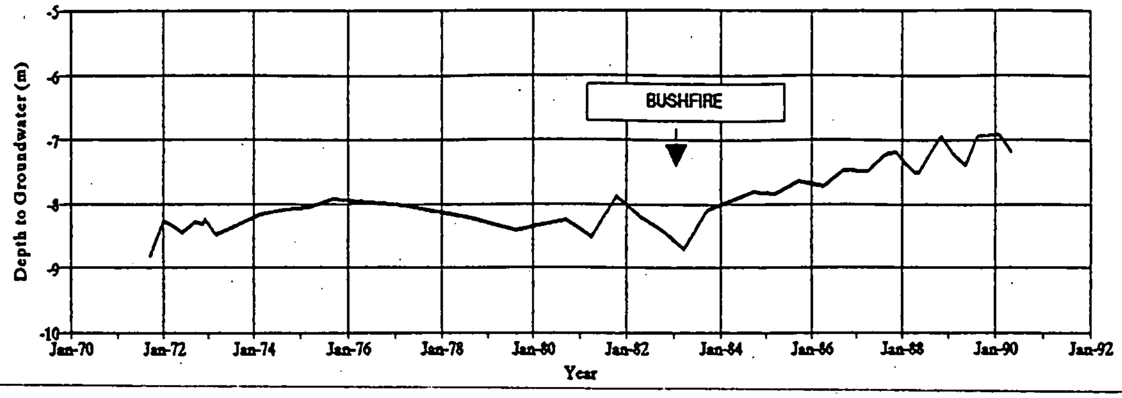
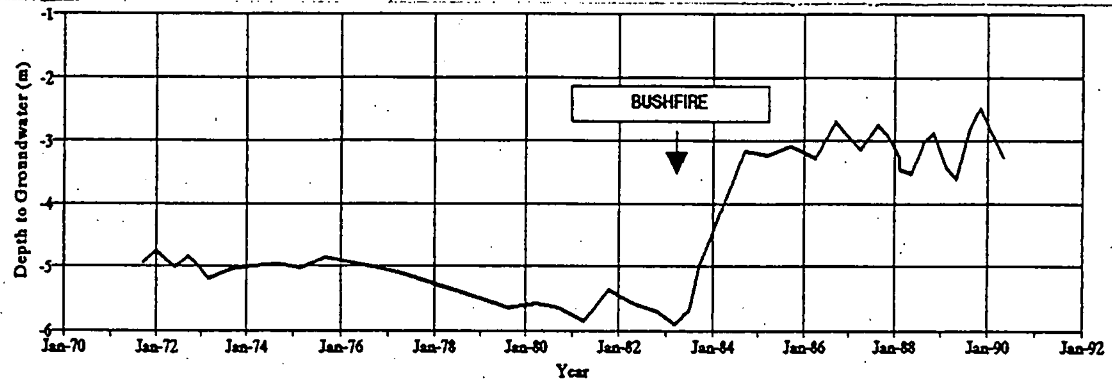
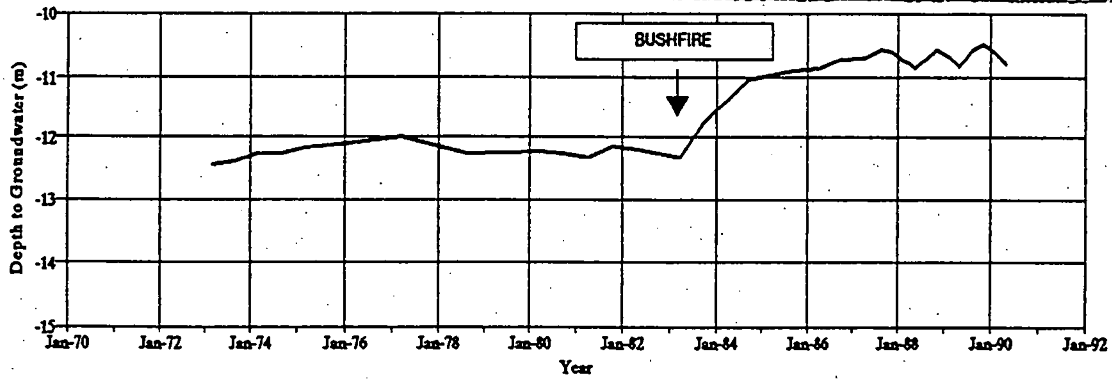
HYDROGRAPH - NAN 4



HYDROGRAPH - NAN 9



HYDROGRAPH - NAN 12



HYDROGRAPH - NAN 19

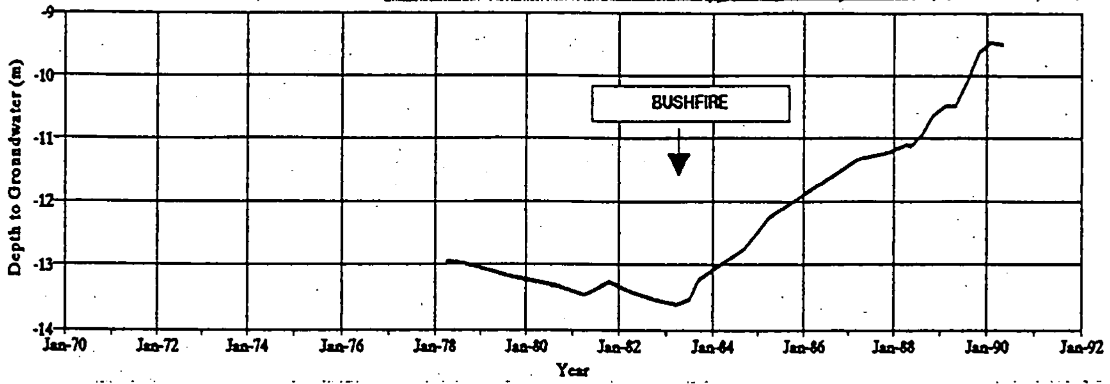


Figure.....15

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION

Observation Wells – NAN 4, 9, 12 and 19

TERTIARY LIMESTONE AQUIFER HYDROGRAPHS

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DRAWN G.A.M.	SCALE		
DATE Oct '90	PLAN NUMBER		
CHECKED	S 21864		

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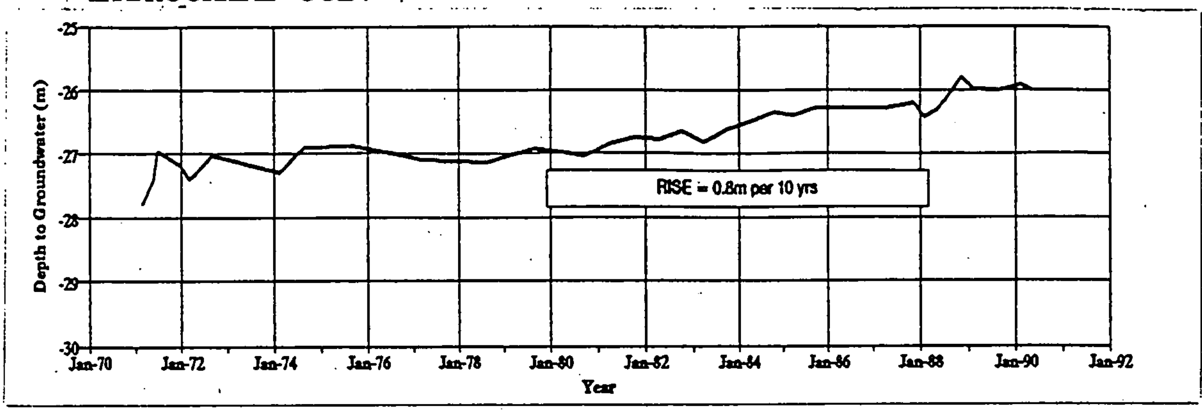
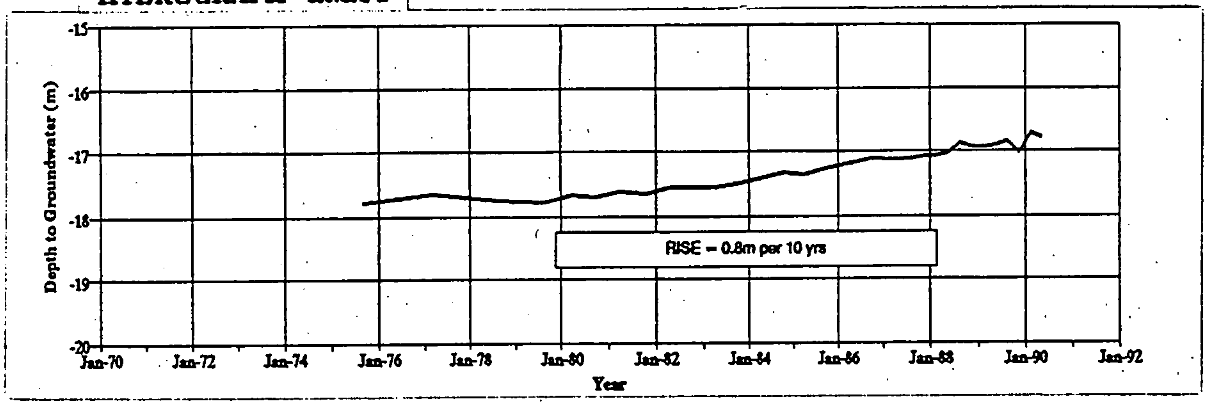
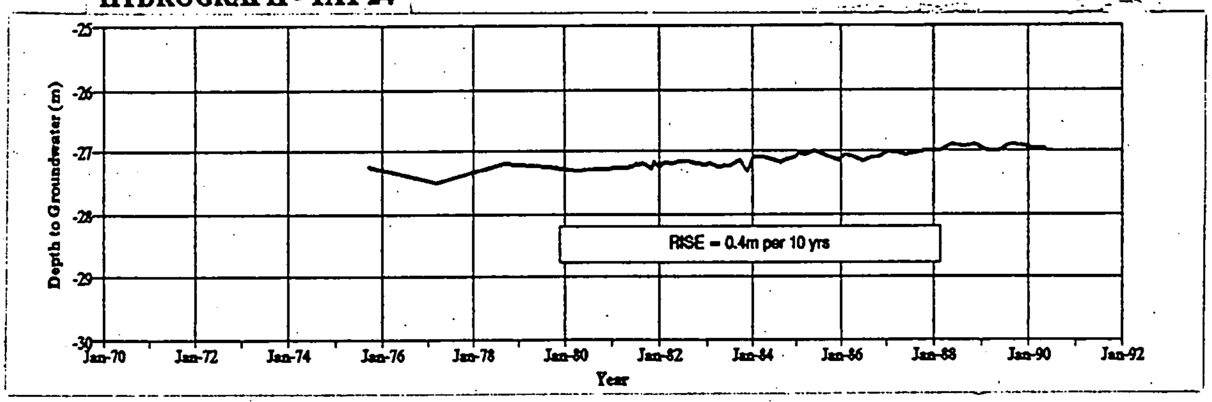
HYDROGRAPH - GGL 7



HYDROGRAPH - BMA 8



HYDROGRAPH - TAT 24



HYDROGRAPH - SEN 9

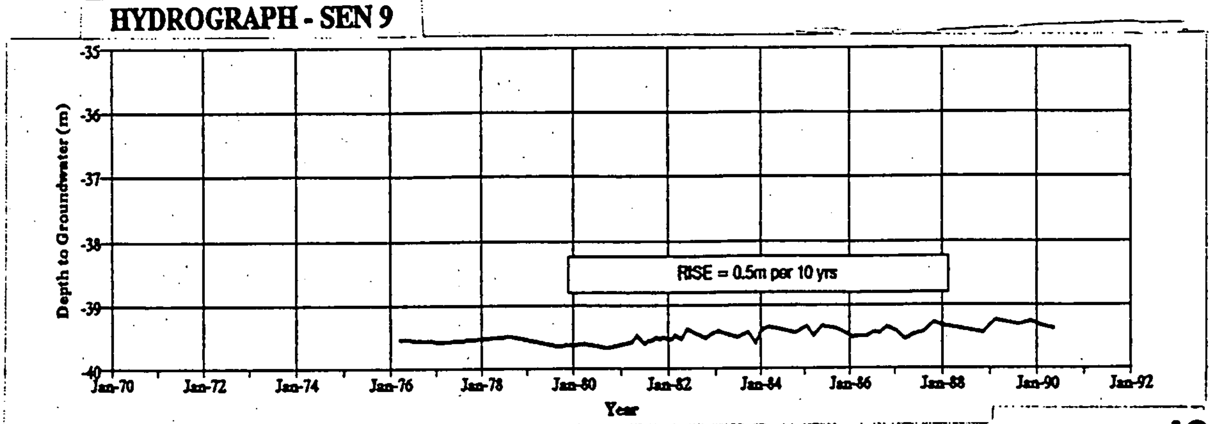


Figure..... 16

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION

Observation Wells - GGL 7, BMA 8, TAT 24 and SEN 9

TERTIARY LIMESTONE AQUIFER HYDROGRAPHS

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DRAWN G.A.M.	SCALE ——
DATE Oct '90	PLAN NUMBER
CHECKED	S 21865

4197

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

SA/VIC STATE BORDER HYDROGEOLOGICAL INVESTIGATION

LOCATION OF GROUNDWATER QUALITY MONITORING WELLS

COMPILED F. Stadter	DATE 28/1/91	Figure 17
DRAWN B. Donovan	SCALE 1:500 000	
DATE Dec. 1990	PLAN NUMBER	90-896
CHECKED		

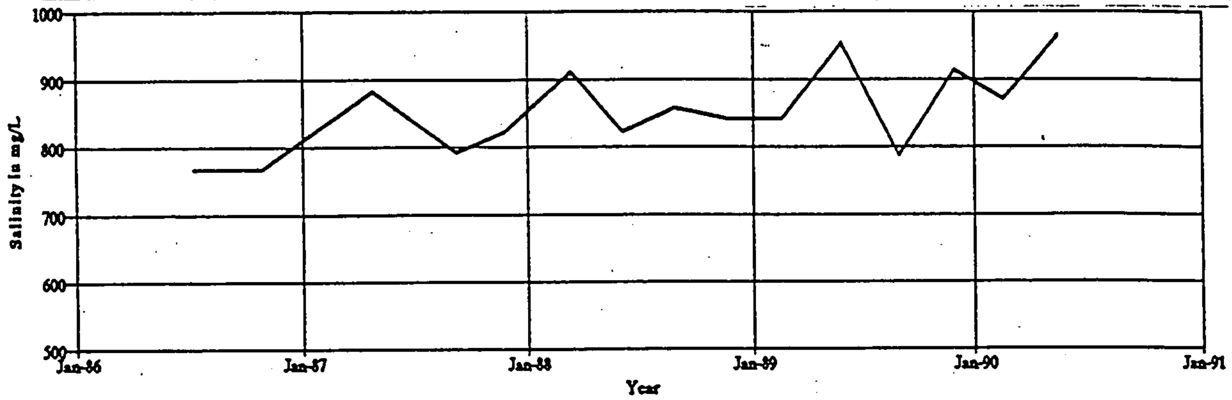
LEGEND

Government observation well and number .... • 7

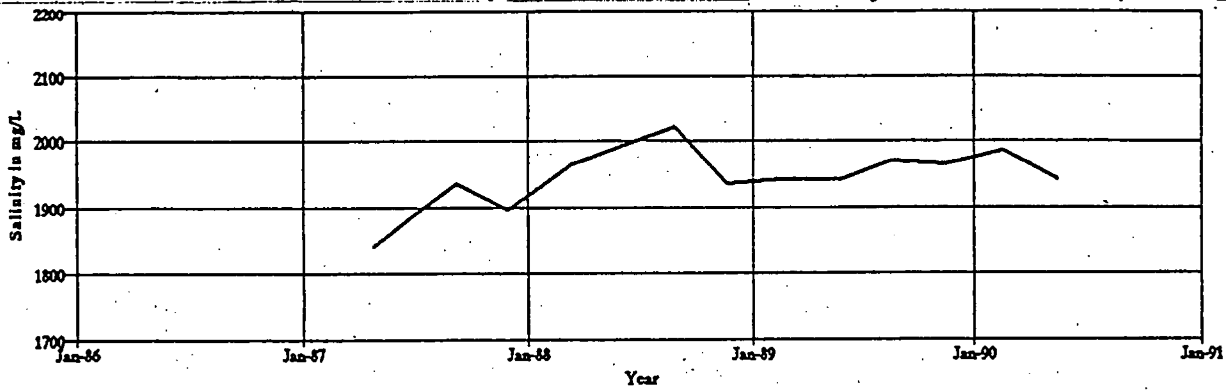
Privately owned observation well and number ..... ○ 23

Observation well with salinity graph .... ○ 83
(See plan S 27866, Fig.18)

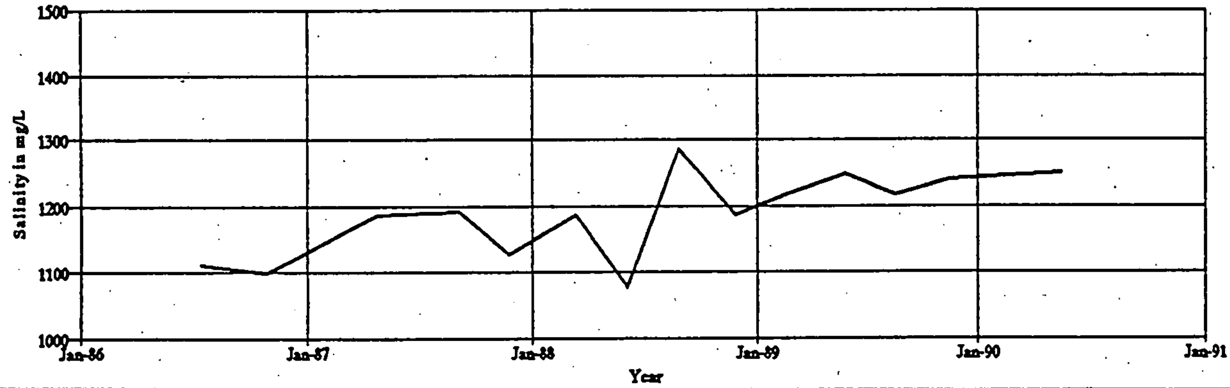
OBSERVATION WELL - CMM 83 Tertiary Limestone Aquifer



OBSERVATION WELL - BIN 26 Tertiary Limestone Aquifer



OBSERVATION WELL - BMA 13



OBSERVATION WELL - SEN 17 Tertiary Limestone Aquifer

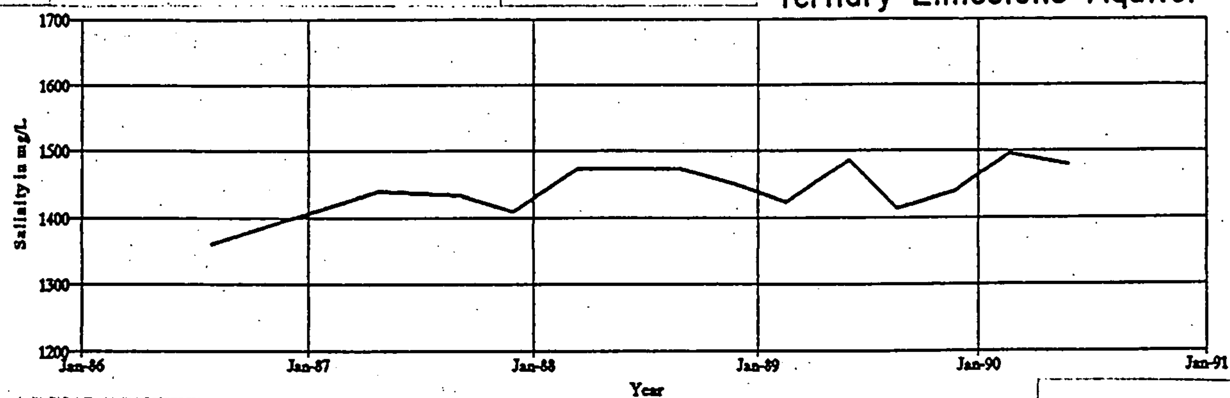


Figure.....18

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

S.A./VIC. STATE BORDER HYDROGEOLOGICAL INVESTIGATION

Observation Wells - CMM 83, BIN 26, BMA 13 and SEN 17

SALINITY v TIME

COMPILED G.A.M.	C.D.O.	DATE 23·1·91
DRAWN G.A.M.	SCALE	
DATE Oct. '90	PLAN NUMBER S 21866	
CHECKED		

4197