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FIVE YEAR TECHNICAL REVIEW 1991-1995 BORDER (GROUNDWATER AGREEMENT) ACT, 1985

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1. INTRODUCTION

The Groundwater (Border Agreement) Act of 1985 legislated to provide a framework for the joint management of groundwater resources within a 40 km wide strip along the length of the South Australian and Victorian Border, which is referred to as the Designated Area and is shown in Figure 1.

The Border Review Committee, comprising members of the relevant water management authorities in both South Australia and Victoria, administers the Act. A Technical Working Group reporting to and directed by the Review Committee, conducts investigations of the groundwater resources within the Designated Area to provide the necessary input for groundwater resource management by the Review Committee.

An essential requirement of the Act is the regular review of various components of the Border Agreement at intervals not exceeding five years.

The first five-year management review was completed in 1991 and incorporated the results of a five-year groundwater resource assessment review for the period 1986 to 1990 (Stadter and Stewart, 1991).

For the second five-yearly management review due in 1996, a five-year technical work plan was prepared and this document presents the results of the investigations undertaken between 1991 and 1995.

In order to fulfil the requirements of the Border Agreement Act, this document also reviews the following components specified in the Act:

- the permissible annual volumes (PAVs) of groundwater extraction for the individual Zones of the Designated Area
- the permissible distance from the border within which the Border Groundwater Agreement Review Committee is responsible for review of applications for groundwater extraction
- the permissible rate of lowering of the potentiometric surface
- the permissible levels of groundwater salinity (if any) for the individual Zones of the Designated Area.

2. GROUNDWATER USE

There is a large reliance on the groundwater resources in the Designated Area due to the general absence of any significant surface water resources. Groundwater supplies are used extensively for stock, domestic and irrigation needs, and to a lesser degree, for industrial, municipal and recreational requirements.

The majority of the groundwater is sourced from the regionally extensive Tertiary Limestone Aquifer.

With the exception of groundwater extractions for stock and domestic supplies in South Australia, all other users within the Designated Area in both States are licensed and provided with an allocation to meet individual requirements. The total licensed volume of groundwater allocated in each State cannot exceed the PAV determined for each of the Zones of the Designated Area as specified under the Groundwater (Border Agreement) Act.

The PAVs and the licensed allocations for the individual Zones of the Designated Area (as at the end of June 1993) are shown in Table 1. These statistics show the relatively higher level of total allocations in South Australia compared with those in Victoria for most of the paired Zones, with the exception of Zones 2A and 2B, where the reverse occurs. Also, the allocations in South Australian Zones 4A, 5A, 6A and 7A have almost reached the PAVs set for these Zones.

It should be noted that these statistics indicate the volumes of groundwater that are allocated and this is generally not indicative of the level of groundwater use.

In both States, surveys are undertaken to assess actual usage of the licensed allocations. In South Australia, annual land use surveys are undertaken together with aerial photographic surveillance. An attempt has been made to source these records in both States in order to determine the actual volumes of groundwater being used in each State. This information is vital for the interpretation of any groundwater trends which may be evident or become evident in parts of the Designated Area.

It is apparent that whilst records are kept in both States, a greater effort is required by the responsible authorities in each State to maintain more accurate and regular data for usage of licensed allocations.

Table 2 presents the irrigation groundwater use for the South Australian Zones since 1985/86, and the known usage in Victoria for the same period of time is shown in Table 3.

TABLE 1: PERMISSIBLE ANNUAL VOLUMES AND ALLOCATIONS FOR THE INDIVIDUAL ZONES OF THE DESIGNATED AREA

ZONE	PERMISSIBLE ANNUAL VOLUME (ML)	TOTAL LICENSED ALLOCATIONS (ML PER ANNUM)*
1A	71 000	19 880
1B	71 000	886
2A	25 000	10 300
2B	25 000	13 154
3A	24 000	19 037
3B	16 500	95
4A	20 000	19 193
4B	14 000	403
5A	18 500	18 488
5B	18 500	2 308
6A	8 500	8 284
6B	6 000	810
7A	7 500	7 498
7B	7 000	436
8A	3 500	2 085
8B	3 500	215
9A	6 000	2 320
9B	6 000	192
10A	6 000	5 930
10B	6 000	8
11A	12 000	3 170
11B	12 000	–

* All Allocations As At End Of June 1993

TABLE 2 : IRRIGATION GROUNDWATER USE IN THE SOUTH AUSTRALIAN PORTION OF THE DESIGNATED AREA

ZONE	CURRENT PERMISSIBLE ANNUAL VOLUME (ML)	VOLUME OF GROUNDWATER USED (ML)								
		85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94
1A	71000	3524#	3440#	3377#	3771#	4294#	3932#	6732#	3078#	N/A
2A	25000	N/A	N/A	220*	N/A	937*	N/A	550*	N/A	N/A
3A	24000	7316	7375	8080	9589	9840	10067	10762	10621*	11298*
4A	20000	10420	9071	11139	9370	8242	8565	8201	8276	9407
5A	18500	14867	14506	12876	12335	12122	11930	11077	10436*	10415*
6A	8500	3997	3847	4461	3630	4286	3317	3082	2627*	2647*
7A	7500	4289	4451	5137	4365	3824	3602	2617	2390*	2629*
8A	3500	140	82	342	526	628	653	488	183*	183*
9A	6000	1052	431	431	425	425	425	425	416*	416*
10A	6000	N/A	296*	283*	614*	370*	625*	1120*	1216*	995*
11A	12000	N/A	171*	559*	633*	1519*	1976*	1105*	1479*	1489*

Includes extraction from the Blue Lake, irrigation data are under-estimated
* Likely to be under-estimated
N/A Data not available

TABLE 3 : GROUNDWATER USE IN THE VICTORIAN PORTION OF THE DESIGNATED AREA

ZONE	CURRENT PERMISSIBLE ANNUAL VOLUME (ML)	VOLUME OF GROUNDWATER USED (ML)								
		85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94
1B	71000	+	+	+	N/A	N/A	N/A	N/A	N/A	265
2B	25000	+	+	+	N/A	N/A	N/A	N/A	N/A	5650
3B	16500	+	+	+	N/A	N/A	N/A	N/A	N/A	41
4B	14000	+	+	+	N/A	N/A	N/A	N/A	N/A	105
5B	18500	+	+	+	N/A	N/A	N/A	N/A	530*	800*
6B	6000	+	+	+	N/A	N/A	N/A	N/A	653*	830*
7B	7000	+	+	+	N/A	N/A	N/A	N/A	N/A	N/A
8B	3500	+	+	+	N/A	N/A	N/A	N/A	N/A	N/A
9B	6000	+	+	+	N/A	N/A	N/A	N/A	N/A	N/A
10B	6000	+	+	+	N/A	N/A	N/A	N/A	N/A	N/A
11B	12000	+	+	+	N/A	N/A	N/A	N/A	N/A	N/A

\+ Before completion of monitoring network
* Likely to be under-estimated
N/A Data not available, but may reflect low allocation

3. SUMMARY OF WORK UNDERTAKEN DURING FIVE-YEAR PERIOD

An integral component of the Border Groundwater Agreement Act is a schedule of technical investigations to update and improve the understanding of hydrogeological processes within the Designated Area. Information gained from these investigations is fundamental in providing technical integrity for the development and implementation of groundwater management policies. The schedule of technical investigations also provides information for periodic review by the Border Groundwater Review Committee, as required by the Act.

The previous five-year technical and management reviews recognised some deficiencies in the hydrogeological knowledge of the Designated Area. These deficiencies formed the basis for investigations undertaken for the current five-year technical work plan, which is summarised below.

3.1 Joint Work

The objectives of the current Plan were to update information gained from previous work and to satisfy the identified data deficiencies, with the ultimate aim of reassessing the established PAVs for the individual Zones of the Designated Area with greater accuracy. Work broadly concentrated on six areas, each of which comprised several individual investigations.

- Upgrading estimates of groundwater recharge to the Tertiary Limestone Aquifer. Recharge investigations by various organisations have been carried out during the recent five year period. A review of the results of these studies and their applicability to the determination of groundwater availability within the Designated Area was conducted.

  Maps showing the distribution of soil types, depth to groundwater, vegetation and land use, and distribution of shallow aquitards for the Designated Area were compiled as the basis for re-examining the vertical recharge by rainfall and the review of the current PAVs for the individual Zones.

  The impacts of extensive softwood afforestation in the southern Zones on vertical recharge were also evaluated.

- Groundwater throughflow estimates for the Tertiary Limestone Aquifer were reassessed, including a detailed compilation of available hydraulic information.

The maps of the aerial extent and thickness of the shallow aquitards were also used to improve the understanding of the nature and degree of potential groundwater leakage between the main aquifers.

- The factors related to groundwater salinity changes for the Tertiary Limestone Aquifer were examined. An evaluation of the variability in the time series salinity data, including possible sources of error, has been conducted.

  Typical salinity trends observed within the Designated Area were documented and compared to salinity increases experienced in similar hydrogeological environments. Possible mechanisms of salt increase were reviewed and their relative significance within the Designated Area evaluated. The technical merits of various salinity management strategies were examined.

- A review of the PAVs for the Tertiary Limestone Aquifer was undertaken.

- The status of the investigations for the Tertiary Confined Sand Aquifer was documented. Less development of the Tertiary Confined Sand Aquifer has occurred because of its depth, associated higher drilling and pumping costs and the presence of suitable groundwater in the overlying limestone aquifer.

  A preliminary assessment was made of the groundwater throughflow resource of the Tertiary Confined Sand Aquifer and long term water level and chemistry monitoring programs were proposed.

- Preparation of this 1991 to 1995 five year technical report.

Work completed as part of the requirements of the Agreement but not included in this report were the preparation of two-yearly monitoring review reports and the regular inter-State transfer of monitoring data. Additionally, specific work conducted at the request of the Border Review Committee but not incorporated as part of the five year technical work plan included a review of the monitoring network, preparation of a proposal for monitoring of the Tertiary Confined Sand Aquifer, and examination of options for electrical conductivity monitoring of the Tertiary Limestone Aquifer.

In addition to these investigations, other studies within and relevant to the Designated Area have been undertaken by other organisations, particularly the CSIRO Division of Water Resources, which have involved individual members of the Technical Working Group.

Several investigations relevant to specific concerns within each State were also conducted. These are outlined below.

3.2 Victoria

Specific investigations conducted in Victoria during the five year period included:

- assessment of the effects of softwood afforestation on water levels and chemistry
- assessment of long term rainfall trends on water levels
- drilling of three bores to provide stratigraphic information in areas where hydrogeological information was sparse
- completion of outstanding reports for bores drilled and aquifer testing undertaken during the previous five year period
- preparation of completion reports for bores drilled during the current five year period

3.3 South Australia

The various investigations undertaken separately in South Australia have comprised:

- a joint investigation between the CSIRO Division of Water Resources and the SA Department of Mines and Energy to examine and assess both diffuse and point source recharge to the Tertiary Limestone Aquifer in the area of Zones 4A to 7A. This work comprised the drilling of several investigation wells at a number of sites with sampling to determine the chemical and isotopic signatures of the groundwater.
- assessment of vertical recharge rates by the SA Department of Mines and Energy in Zones 3A, 4A and 5A
- resampling of a number of wells in Zones 4A to 6A to examine the conclusion by the CSIRO Division of Water Resource that a long term increase in salinity was evident and related to the irrigation activity in the area
- drilling of a number of investigation wells in areas of softwood plantations in Zone 2A to test for the presence of atrazine in the Tertiary Limestone Aquifer
- expansion of the Tertiary Limestone Aquifer salinity monitoring network in Zones 4A to 6A due to the significant irrigation activity in these areas
- an assessment of the groundwater resources for the Blue Lake in Zone 1A, which is a major single extraction point for the Tertiary Limestone Aquifer.

4. CLIMATE AND PHYSIOGRAPHY

4.1 Climate

The Designated Area has a Mediterranean-type climate with warm, relatively dry summers and cool to cold, wet winters. The variation in rainfall and evaporation through the Designated Area is shown in Figure 2. The annual rainfall varies from in excess of 800 mm in Zone 1 to about 250 mm in the northern part of Zone 11. The annual potential evaporation increases from about 1400 mm in the south to about 2200 mm in the north.

The summer temperatures in January range from 21 °C at the coast to 32 °C at Mildura, whereas in winter, the temperatures range from about 13 °C at the coast to about 15 °C in the northern part of the Designated Area.

4.2 Physiography

There are two major geomorphic divisions within the Designated Area, the South Eastern Coastal Plain and the Murray Basin Plain, as shown in Figure 3.

The South Eastern Coastal Plain which occupies the area from Zone 1 to 4 is a low relief plain extensively developed on Tertiary limestone with dune ridges of calcarenite and interdunal flats. Surface and subsurface karst features are common in this geomorphic division.

The Murray Basin Plain is mainly an aeolian terrain developed on Tertiary sediments, characterised with east-west trending relic dunes. Between the dune fields there are clay plains which overlie limestone with karst features. The northern limit of the Designated Area is marked by the present floodplain of the Murray River.

With the exception of the Murray and Glenelg Rivers, most of the Designated Area has a poorly developed surface drainage system due to the low topographic relief. There are some ephemeral streams, such as the Tatiara, Morambo and Mosquito Creeks in the southern parts of the area. These creeks generally terminate in swamps, lagoons or runaway holes.

In some areas the poor surface drainage with 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 evaporated.

5. GEOLOGY

The Designated Area occurs within two major sedimentary basins; the Mesozoic-Cainozoic Otway Basin and the Tertiary Murray Basin. The basins are separated in South Australia by the Padthaway Ridge, a granitic basement feature, and in Victoria by the Dundas Plateau. The general geological provinces of the Designated Area are shown in Figure 4.

This section summarises the geology of each basin as it relates to the Designated Area. The stratigraphic relationship of the various geological units between and in each of the two basins is presented in Figure 5.

5.1 Murray Basin

The generalised geology of the Murray Basin comprises a series of transgressive and regressive marine sediments and terrestrial sediments. During Tertiary times these sediments were deposited upon a continually subsiding bedrock basin that has its deepest point (the central western depocentre) near Renmark in South Australia.

Sedimentation began around 60 million years ago (Ma) in the central western parts of the Basin, with deposition of fluvio-lacustrine Renmark Group sediments. These sediments include medium to coarse grained sands and weakly consolidated sandstones of the Warina Group, and overlying unconsolidated to poorly consolidated carbonaceous silts, sands and clays of the Olney Formation. The Renmark Group is characterised by an abundance of carbonised and pyritic plant remains (Brown 1989), and forms the Tertiary Confined Sand Aquifer (refer to Section 6 of this report).

Around 32 Ma, a marine transgression marked the beginning of the deposition of marginal marine sediments of the Murray Group. Initially sedimentation was confined to a restricted shallow marine platform and resulted in deposition of a green-grey, highly fossiliferous, glauconitic calcareous clay of the Ettrick Formation (Brown 1989). This clay forms a thin (20-30 m) but important confining layer to groundwater movement (see Section 6 of this report). The Ettrick Formation grades laterally into near shore deposits of the Geera Clay and Winnambool Formation.

The Ettrick Formation is overlain by a shallow marine platform limestone consisting predominantly of coarse-grained skeletal debris mixed with minor calcareous clay, micrite and quartz sand (Brown 1989). This unit forms the Tertiary Limestone Aquifer (refer to Section 6 of this report). The unit is known as the Duddo Limestone in Victoria, and has been biostratigraphically subdivided in South Australia to include the Gambier Limestone, Mannum Formation, Morgan Limestone and Patta Formation (Brown 1989).

Deposition of the Renmark Group continued in the east of the Basin as the terrestrial time equivalent of the Murray Group.

A marine regression around 10 Ma resulted in the deposition of the Geera Clay, Winnambool Formation and Upper Renmark Formation sediments over the Murray Group sediments as the sea retreated. A short period of erosion and non deposition followed the retreat of the sea in the mid Miocene. A further short lived marine transgression - regression occurred about 6 Ma (Brown 1989), with the deposition of calcareous clays and silty sands (Bookpurnong beds) at the base of this sequence. This unit forms the Upper Tertiary Aquitard over the Murray Group Limestone (see Section 6 of this report).

The final retreat of the sea occurred from approximately 4 to 2 Ma (Brown 1989), and resulted in the deposition of an extensive sheet of quartz sand (Loxton-Parilla Sands) as stranded beach ridges and strand plain deposits. Younger fluvial and estuarine sediments were deposited between, and locally cross-cut, these stranded beach ridges (Brown 1989). These sands are a composite of the Lower Pliocene Loxton Sands and Upper Pliocene Parilla Sands in South Australia and the stratigraphically equivalent Pliocene Parilla Sand in Victoria (Brown 1989), and form the Pliocene Sands Aquifer (refer to Section 6 of this report).

Uplift of the Pinnaroo Block in the late Pleistocene resulted in damming of the Murray River behind the block and the formation of a large freshwater lake (Lake Bungunnia) which existed from around 2.5 to 0.7 Ma (Brown 1989). A thin veneer of lacustrine clay was deposited at the base of the lake (Blanchetown Clay). An area of Loxton - Parilla sand not covered by the lake in the south-west of the basin was remobilised by prevailing western winds and redeposited over much of the Mallee area as the dunes of the Woorinen and Molineaux sands.

5.2 Otway Basin

The Otway Basin is an east-west trough-like geomorphic depression containing a thick sequence of Mesozoic and Cainozoic sedimentary and volcanic rocks (see Figure 4).

A number of subdivisions or embayments can be recognised in the Otway Basin. These embayments are relatively distinct onshore, but offshore appear to lose their significance forming an unbroken shelf, co-extensive with the present continental shelf (Ludbrook, 1971).

This overview will concentrate on sedimentation and volcanism in the Gambier Embayment. The Gambier Embayment is separated from the Murray Basin by the Padthaway Ridge in the north and is bounded by the Dundas Plateau in the east (refer to Figure 4).

During the early Cretaceous, a lithologically monotonous unit consisting of mudstone, sandstones and shales with minor basalts and pyroclastics was deposited in a non-marine, shallow water environment. These deposits are known collectively as the Otway Group and include the fluvial sands and clays of the Pretty Hill Sandstone, and the fluvio-lacustrine shales and minor sands, and volcanogenic deposits of the Eumeralla Formation. The Otway Group outcrops over an area of approximately 1100 km^2 in the Merino-Casterton-Coleraine area, occupying a region known as the Dundas Plateau (see Figure 4).

An unconformity marks the boundary between the Otway Group and the overlying Sherbrook Formation. This unit is a complex regressive-transgressive sequence comprised chiefly of quartzose sand and clay, and includes the Timboon Sand, Parette, Flaxman and Waarre Formations of the Sherbrook Group (Love et al, 1992).

Sedimentation continued into the Tertiary in a prograding fluviatile deltaic environment, with deposition of gravels, sands and clays of the Dilwyn Formation and minor sand and clay horizons of the Mepunga Formation. These units are time equivalents of the Renmark Group in the Murray Basin. Off-shore the Dilwyn Formation reaches a maximum recorded thickness of 800 m and gradually thins northwards to the basement highs of the Padthaway Ridge and the Dundas Plateau (Love et al 1992). The Dilwyn Formation forms the Tertiary Confined Sand Aquifer (see Section 6 of this report).

The Dilwyn Formation is overlain by glauconitic and fossiliferous marls and clays of the Narrawaturk Marl and clay of the Mepunga Formation. These units form an important aquitard (referred to as the Lower Tertiary Aquitard, see Section 6 of this report) which is the time equivalent of the Ettrick Marl of the Murray Basin, and has a thickness of 20 to 40 m, becoming thinner against the Padthaway Ridge.

The Lower Tertiary Aquitard is conformably overlain by the Gambier Limestone which is equivalent to the Murray Group Limestone of the Murray Basin. The Gambier Limestone has a thin marl member at the base, which grades upwards to highly fossiliferous, often recrystallised limestone (Ludbrook 1971). The Gambier Limestone forms the Tertiary Limestone Aquifer (see Section 6 of this report).

During the Pleistocene, the Gambier Limestone was subjected to erosion and consequently over most of the Gambier Embayment the Miocene part of the limestone has been removed and replaced by a cover of Quaternary calcareous sands, mostly of the Bridgewater Formation (Ludbrook 1971) and limestone of the Padthaway Formation.

6. HYDROGEOLOGY

6.1 General

The Otway Basin and the Murray Basin contain a number of different aquifers and aquitards. The hydrostratigraphic relationship of these units is shown in Figure 5.

In the Otway Basin, the sedimentary sequence is generally wedge shaped from north to south. It is thinnest in the north where sediments abut the basement Padthaway Ridge, increasing in thickness up to 1000 m near the coast and over 5000 m off-shore.

In the Murray Basin, the sedimentary succession is relatively thin, attaining a maximum thickness of around 600 metres in the central western depocentre under Renmark in South Australia. In the south-west, the Murray Basin succession is connected to the Cainozoic sediments of the Otway Basin, but thins over the Padthaway Ridge (Brown and Stephenson, 1991).

Three major aquifer systems occur within the Designated Area:

- the Tertiary Confined Sand Aquifer of the Wangerrip Group in the Otway Basin and of the Renmark Group in the Murray Basin
- the Tertiary Limestone Aquifer which comprises the Heytesburry Group in the Otway Basin and the Murray Group in the Murray Basin. In the Otway Basin, the Quaternary sediments are commonly in direct hydraulic contact with the Tertiary limestone and form part of the Tertiary Limestone Aquifer.
- a more restricted late Tertiary aquifer within the Pliocene sands is also found in parts of the Murray Basin in the northern part of the Designated Area and in local areas north of the Dundas Plateau (see Figure 6), referred to as the Pliocene Sands Aquifer. This aquifer comprises only the saturated portion of the Pliocene sands, which are regionally more widespread than the extent of the aquifer.

6.2 Hydrogeological Provinces of the Designated Area

The Designated Area has been divided into three hydrogeological provinces as shown in Figure 6 to reflect the variation in hydrogeological conditions of the Tertiary Limestone Aquifer.

The area south of the Kanawinka Fault is identified as Province 1, which is characterised by the occurrence of the Quaternary limestone formations (Bridgewater and Padthaway Formations) which together with the Gambier Limestone comprise the Tertiary Limestone Aquifer.

Province 2 is the area north of the Kanawinka Fault, where the Tertiary Limestone Aquifer is unconfined and mainly comprises either the Gambier Limestone or the Duddo Limestone. In parts of Zones 3B and 4B in this Province (see Figure 6), the Pliocene Sands Aquifer directly overlies the Tertiary Limestone Aquifer. The Shepparton and Woorinen Formations act as aquitards in parts of this province.

Province 3 is the area where the Tertiary Limestone Aquifer is confined by the Bookpurnong Formation which is referred to as the Upper Tertiary Aquitard.

6.3 Hydrostratigraphic Units Of The Designated Area

The various hydrostratigraphic units found within the Designated Area, as shown in Figure 5, are described below.

6.3.1 Hydraulic Basement

In the Otway Basin the hydraulic basement comprises metamorphic and igneous rocks of the Cambro-Ordivician Kanmantoo Group. These rocks form the basement highs of the Padthaway Ridge and the Dundas Plateau.

6.3.2 Cretaceous Aquifer / Aquitard System

A Cretaceous aquifer/aquitard system exists in the Otway Basin and is comprised of the early Cretaceous Otway Group sediments and the late Cretaceous Sherbrook Group. These Cretaceous units thin against the Padthaway Ridge and have no important time equivalents in the Murray Basin. They are generally very saline and are often too deep for economic utilisation; as such they will not be further discussed.

6.3.3 Tertiary Confined Sand Aquifer

In the Otway Basin, the Tertiary Confined Sand Aquifer contains a series of unconsolidated sand and gravel aquifers with inter-bedded clay confining beds of the Dilwyn and Mepunga Formations. Hydraulic data is sparse, however, and available data indicate that the variation is not as large as that for the Tertiary Limestone Aquifer. Transmissivity estimates range from 200 to 1600 m^2/day.

The potentiometric contours for the Tertiary Confined Sand Aquifer as determined in March 1994 are shown in Figure 7.

Within the Otway Basin, groundwater movement is in a westerly and southerly direction towards the sea. Features of the potentiometric surface are the steep gradient zones which correspond to the Kanawinka Fault in the north-east and the Tartwaup Fault in the southern section of the Basin. A groundwater divide, coinciding with the Gambier Axis, occurs to the north of Mt Gambier and extends towards the eastern margin of the Basin. Both the Tertiary Confined Sand and Tertiary Limestone Aquifers are close to the surface at this point, and it is considered that a potential for preferred recharge to the confined aquifer exists in this area.

In the Murray Basin, the Tertiary Confined Sand Aquifer is not currently regarded as an important groundwater resource because better quality water is available in the overlying Tertiary Limestone Aquifer. Consequently, hydraulic data for this aquifer is sparse. The potentiometry of the aquifer (see Figure 7) is similar to that of the Tertiary Limestone Aquifer, showing similar lateral movement of groundwater across the State Border from Victoria to South Australia.

Groundwater salinity is generally less than 1500 mg/L throughout most of the Designated Area, apart from an area in the northern region of Zone 11 where groundwater salinities exceed 10 000 mg/L.

6.3.4 *Lower Tertiary Aquitard*

The Tertiary Confined Sand Aquifer is separated from the Tertiary Limestone Aquifer by an almost continuous layer of marl (Narrawaturk Marl in the Otway Basin and Ettrick Marl in the Murray Basin).

Barnett (1983) has identified sandier areas of the Ettrick Marl that may allow greater vertical connection between the Tertiary Confined Sand Aquifer and the overlying Tertiary Limestone Aquifer in the Murray Basin, but such areas have not been mapped.

6.3.5 *Tertiary Limestone Aquifer*

The Tertiary Limestone Aquifer is a calcareous marine deposit ranging in texture from a clayey marl to a karstic, cavernous limestone.

North of Zones 8A and 4B (as shown in Figure 6), the Tertiary Limestone Aquifer is confined beneath the Bookpurnong Beds and the Winnambool Formation.

The potentiometric surface for the Tertiary Limestone Aquifer for March 1994 (as shown in Figure 8) indicates lateral groundwater flow across the State Border from Victoria for most of the Designated Area. The direction of flow varies from north-westerly in the north, to westerly and then southerly (being almost parallel to the border) in the southern part of the Designated Area.

Recharge to the aquifer, where unconfined, is predominantly by vertical recharge from rainfall. Recharge to the confined portion of the aquifer is predominantly by lateral throughflow from recharge areas in the southern Wimmera. Diffuse recharge by rainfall may provide a small contribution to the confined portion of the limestone aquifer.

Groundwater salinity varies from less than 1000 EC units in the south and increases along flow lines to the northwest, and rapidly increases in the north of the Designated Area to over 30 000 EC units.

The distribution of groundwater salinity for the aquifer as determined in March 1993 is shown in Figure 9. The rapid increase in salinity in the north may coincide with upward leakage of saline waters from the deeper, saline Tertiary Confined Sand Aquifer (Evans & Kellett 1989).

In the Otway Basin, the Tertiary Limestone Aquifer is karstic with a dual porosity. The primary porosity of the aquifer is a mixture of framework porosity impaired by the cementing of carbonate skeletons and inter-particle porosity formed within the unconsolidated carbonate sands. The primary porosity acts primarily as a porous medium. A secondary porosity has occurred along structurally weak zones as a result of dissolution of the rock matrix by meteoric water. This forms conduits for preferred flow with the hydraulic characteristics of a fractured rock medium. The karstic nature of the aquifer is reflected in the wide range in transmissivities determined from aquifer pumping tests, which vary from 200 to greater than 10,000 m^2/day in karstic areas (Love et al, 1992). The distribution of sites with assessed transmissivity data for the aquifer is shown in Figure 10.

As mentioned previously, the Tertiary Limestone Aquifer can also include (where present) the Quaternary Bridgewater and Padthaway Formations within Hydrogeological Province 1. There are also some areas such as in Zones 3B and 4B where the saturated portion of the Pliocene sands is also in direct hydraulic connection with the Tertiary Limestone Aquifer.

6.3.6 *Upper Tertiary Aquitard*

Within Hydrogeological Province 3, the Tertiary Limestone Aquifer is confined by the Upper Tertiary Aquitard and separates this aquifer from the overlying Pliocene Sands Aquifer. The nature and distribution of this aquitard are discussed more fully in Section 7.3.3 of this report.

6.3.7 *Pliocene Sands Aquifer*

The Pliocene Sands Aquifer is generally unconfined, and includes only the Loxton/Parilla Sands (see Section 5 of this report). The sands are saturated only in the northern and most easterly parts of the Designated Area; and in the west the watertable falls below the base of the sands as the Tertiary Limestone Aquifer becomes unconfined. Groundwater flow in the Pliocene Sands Aquifer is generally towards the central western depocentre near Renmark in South Australia.

Regional groundwater salinity varies between 30,000 and 40,000 mg/L, but can be as high as 300,000 mg/L beneath refluxing groundwater discharge lakes (Evans & Kellett, 1989).

6.3.8 *Quaternary Aquitard*

The term Quaternary Aquitard has been adopted for the low permeability sediments of Quaternary age overlying the Pliocene Sands Aquifer in the Murray Basin, including the Lowan Sands, Yamba Formation, Woorinen Formation, Blanchetown clay and Shepparton Formation. The nature and distribution of this aquitard are discussed more fully in Section 7.3.3 of this report.

7. RECHARGE TO THE TERTIARY LIMESTONE AQUIFER

7.1 General

Virtually all groundwater is ultimately derived, directly or indirectly, from precipitation. In more detail, however, the main components of recharge to the Tertiary Limestone Aquifer of the Zones of the Designated Area are:

- infiltration of part of the total precipitation received at the ground surface
- influent seepage through the banks and beds of surface water bodies
- groundwater leakage from overlying or underlying adjacent aquifers
- "point source" recharge from the discharge of surface water down either naturally occurring features such as runaway holes or especially drilled drainage bores.
- lateral groundwater inflow, generally at the eastern edge of the Designated Area.

The proportion of the precipitation that infiltrates the Tertiary Limestone Aquifer (or other near-surface aquifers) generally depends upon the seasonality and magnitude of the precipitation, the topography, the nature of vegetation cover and land use, and the type and structure of the soil through which the recharging water percolates.

7.2 Previous Investigations

Several investigations of vertical recharge have been conducted by different organisations in various parts of the Designated Area. Collectively, the results have shown some variation in the magnitude of the vertical recharge rates assessed by these different agencies.

A meeting of representatives from these various organisations was held at Renmark in 1992 to discuss the different methodologies of vertical recharge assessment used and the respective results. A summary of the recharge rates determined by each organisation for specific Zones of the Designated Area, together with the generally agreed recharge rate(s) for each Zone, is presented in Table 4. It was also agreed that the magnitude of the vertical recharge depends largely on:

- the type of soil and its textural properties
- the type of land use and vegetation cover.

TABLE 4 : VERTICAL RECHARGE RATES FOR THE TERTIARY LIMESTONE AQUIFER FROM PREVIOUS INVESTIGATIONS

ZONE	RECHARGE RATE (mm/year)			AGREED RECHARGE RATE (mm/year)	COMMENT
	HYDROTECHNOLOGY	MESA	CSIRO *		
1A 1B	80			100 80	
2A 2B	65			75 65	
3A 3B	30	75 - 100		100 30	
4A 4B	30	75 30	2 - 11	75 35 35	Western part of zone Eastern part of zone, less in area of softwood forest
5A 5B	10	20 - 40		10	
6A 6B	30	20 - 60	10 - 60	20 - 60 30 - 40	Subject to soil type and vegetation cover Sandy soils 60% of Zone, uncleared
7A 7B	10	15	5 2	70 10 10	Sandy soils 25% of Zone Clay soils 75% of Zone Uncleared
8A 8B	?	12		12 12	
9A 9B	20			<1 20 (?)	For 75% of area, Tertiary Limestone Aquifer is confined and vertical recharge occurs to the Pliocene Sands Aquifer
10A 10B	10			<1 10 (?)	Vertical recharge occurs to the Pliocene Sands Aquifer Vertical recharge occurs to the Pliocene Sands Aquifer
11A 11B	7			<1 7 (?)	Vertical recharge occurs to the Pliocene Sands Aquifer Vertical recharge occurs to the Pliocene Sands Aquifer

* Walker et al (1990); Herczeg and Leaney (1993)

7.3 Vertical Recharge To The Tertiary Limestone Aquifer

As the PAVs for Zones 1 to 8 are solely based on the component of vertical recharge to the Tertiary Limestone Aquifer, it is obvious that this parameter needs to be properly assessed. A significant part of the 1991 to 1995 technical work plan investigations was therefore focussed on the assessment of the vertical recharge rates, as described in the following sections.

A number of inter-related components as mentioned previously determine the magnitude of vertical recharge to the Tertiary Limestone Aquifer. These are summarised below in context of the Designated Area.

7.3.1 Land Use and Vegetation

A land use and vegetation map, Figure 11, has been compiled for the Designated Area. The Victorian data were compiled from digital land use information supplied by the Department of Conservation and Natural Resources. The South Australian data were compiled from available 1992 aerial photography (Zones 1A to 8A), published topographic maps (Zones 9A to 11A), and irrigation land use survey records provided by the Department of Environment and Natural Resources (only for Zones 1A to 8A).

Four main categories of land use have been identified in the Designated Area, these being as shown in Figure 11, native vegetation, pine plantations, irrigated agricultural land and a remaining "other" category which essentially includes agricultural land used for broad acre cropping and dryland pasture.

Large tracts of native vegetation are located in the northern part of the Designated Area. About 95% of Zone 11B is covered by native vegetation, mallee scrub and heath associated with easterly trending dunes of the Sunset Country. In contrast, approximately only 20% of Zone 11A is native mallee vegetation found in the Billiat Conservation Park with the dominant land use in the remaining part of this Zone being wheat cultivation and grazing. Only minor areas of irrigated agriculture are found along the northern edge of Zone 11 on the Murray River floodplain, with the water being sourced from the River.

About 20% and 40% respectively of Zones 10A and 10B are covered by native vegetation, located on the northern and southern margins of the Zones. Agricultural cereal cropping and grazing centred along the Ouyen Highway are the dominant land uses, with some irrigation activity occurring in Zone 10A.

In Zone 9, native vegetation consisting of mallee scrub and heath associated with aeolian sand sheets and dunes found in the Ngarkat Conservation Park and Big Desert National Park is the dominant land use, comprising about 50% of Zone 9A and 80% of Zone 9B. The remaining land is used for cropping and grazing, with some irrigation in Zone 9A.

Land use on the northern plains of Zones 7 and 8 is almost exclusively grazing and cereal cropping with only small areas of irrigated land in Zone 7A. Similarly in Zone 6, agricultural cropping land dominates with the occurrence of native vegetation increasing to approximately 10% in Zone 6A and 60% in Zone 6B, with the latter being the heath and woodlands of the Little Desert National Park.

In Zone 5A, grazing rather than cropping is the dominant land use and a greater area of irrigated agriculture of mainly pasture, seed crops and vegetable production is present, constituting around 10% of the Zone. The irrigated areas do not extend into Zone 5B which is almost exclusively grazing agricultural use with only small scattered areas of native vegetation.

Land use patterns in the southern Zones are more varied with all the four land use categories being represented, compared to the northern Zones which tend to be dominated by one or two major land uses.

The Comaum Forest pine plantation located on the southern part of the northwest to southeast trending Naracoorte Range covers about 10% of Zone 4A. A similar total area of native vegetation is also located in small patches in Conservation Parks and bordering these pine plantations. Grazing is the dominant land use over the whole of Zone 4A, and irrigated agriculture with viticulture, pasture, seed crops and vegetable production comprising about 10% of this Zone. Land use in Zone 4B is predominantly dryland grazing with areas of native vegetation comprising about 10% of the Zone.

Pine plantations of the Penola Forest span Zones 2A and 3A, comprising about 40% and 30% of these Zones respectively. Only small areas of remnant vegetation bordering the pine forests are present. Irrigated viticulture in the Penola Coonawarra area and pasture production comprises about 10% of the land use in Zone 3A. The dominant land use in Zones 3A and 3B is grazing. Pine forests in Zone 3B cover a smaller area relative to Zone 3A, and native vegetation found in the Roseneath State Forest covers relatively more, around 50% of Zone 3B.

Similar land use patterns are evident in the southern Zones with around 40% of Zones 1A and 2A covered by pinus radiata plantations of the Myora, Caroline and Penola Forests, and only small areas of native vegetation being present. Grazing on improved pastures occurs in about 50% of Zones 1 and 2 and irrigated vegetable production is restricted to small areas totalling around 5% of Zones 1A and 2A. Pine plantations cover about 10% of Zones 1B and 2B being a smaller area relative to South Australia. Native vegetation of the Lower Glenelg River National Park and Drajurk State Forest covers around 30% of Zones 1B and 2B.

In summary, land use in the Designated Area can be broadly categorised as :

- large tracts of native vegetation and broad acre cropping and grazing are the dominant land uses in the northern Zones 9, 10 and 11, with some irrigation land use in Zones 9A and 10A.
- agricultural cropping and dryland grazing is by far the dominant land use in the central Zones 5 to 8, with increasing proportions of irrigated land being found to the south mainly in South Australia.
- mixed land uses are evident in Zones 1 to 4 with grazing being dominant and pine plantations covering substantial areas especially in South Australia. Native vegetation also covers significant areas, mainly in Victoria, whilst areas of irrigated agriculture mainly occur in South Australia.

7.3.2 *Soil Associations*

Given the strong relationship between the magnitude of vertical recharge and the type of soil and its properties, an attempt was made to compile a plan showing the distribution of soil types throughout the Designated Area.

Figure 12 shows the different soil associations for part of the Designated Area and was compiled using available soil maps. These maps essentially cover Zones 1 to 8 (Blackburn - 1953, 1955, 1959, 1959, and 1964; Gibbons and Downes,1964), with no suitable maps being available for the remaining part of the Designated Area. A soil association represents a distinctive soil type or group of soils which occur in a specific geomorphic setting.

The major soil types, their occurrence and depth are described below. The soil profiles generally refer to the lithology of the top 1.5 m of the geological sequence. However, different horizons occurring below 1.5 m are also described as these can bear a relationship to the soil profiles, with this data being retrieved from available bore hole logs.

Duplex Soils

There are two types of duplex soil types which have a marked textural contrast between the surface soil horizon and the subsoil horizon. These are the *solonetzic* soils and the *solodic* soils.

For the *solonetzic* soil profile, there is a 0.2 to 0.4m thick sand layer which overlies columnar, yellow and grey mottled clay with significant amounts of lime (in the form of calcium carbonate nodules).

The *solodic* soils are similar to *solonetzic* soils in many aspects. The upper sand layer is generally thicker than that of the *solonetzic* soils and the subsoil is compact clay with very little lime. In some cases, there is an ironstone gravel layer in between the upper sand layer and the clay subsoil.

There are five major soil associations, D1 to D5 as shown in Figure 12, where duplex soils are dominant.

- The D1 soil association topographically occupies the Naracoorte plateau, extending eastward from the Naracoorte Ranges into Victoria, mainly within parts of Zones 4A, 4B, 5A, 5B and 6A. For association D1, approximately 90% of the area is covered with duplex soils, mainly *solonetzic* in South Australia, and mainly *solodic* in Victoria.

  The *solonetzic* soil profile generally overlies either calcareous or clayey horizons, whereas the *solodic* soil profile overlies clayey and sandy horizons. Depth to the Tertiary limestone increases eastward from 2 to 10 m.

- The D2 soil association occupies a swampy plain with low sandy and limestone rises, mainly in Zones 1B, 2A, 2B and 3A. The density of swamps is significantly higher on the Victorian side of the border in comparison to South Australian.

  The duplex soils are mainly *solodic* and cover 70% of the area with the duplex soil profile overlying different clay horizons. Depth to the Quaternary limestone formations ranges from 2 to 5 m.

The soil types show considerable spatial variation from clay soils in swampy areas to duplex soils in the plains with some *terra rossa* soils, and sand soils in low rises.

- The D3 soil association is located in an area characterised by a plain with east-west ridges and dune systems, mainly occurring in Zone 8 with relatively small areas in Zone 5. While the ridges and dunes comprise mainly sand soils, duplex soils dominate in the plain areas.

  Duplex soils, mainly of the *solonetzic* type cover approximately 60% of the area. In Zone 8A, the duplex soil profile and underlying clays directly overlie the Pliocene sands, which generally occur at a depth ranging from 4 to 12 m.

- The D4 soil association occupies the slopes and valley floors of the Tatiara Creek system in Zone 7A. This duplex soil is mainly a brown *solonetzic* type in the slopes becoming grey in the valley floors. The duplex soils and underlying clays extend to a depth of 6 m.

- The D5 soil association is a relatively small area in Zone 1A comprising a sand plain with low rises of limestone. The duplex soils are mainly *solodic* soils and comprise in excess of 90% of the association, with some *terra rossa* soils developed on low rises of limestone. The shallow clay profile of *solodic* soils directly overlies limestone.

Clay Soils

There are two main types of clay soils found in the mapped area - a grey soil of heavy texture with grey to black clays with lime nodules extending to considerable depth, and a *rendzina* soil comprising a relatively thin black to dark grey clay ranging in thickness from 0.3 to 0.4 m and overlying marls or limestone.

There are three major clay soil associations occurring in the area, C1, C2 and C3, as shown in Figure 12.

- For soil association C1, grey clay is the dominant soil type and accounts for 60% of this soil association. Duplex soils, mainly of the *solonetzic* type, also occur in C1.

Large areas of Zone 7, and some parts of Zones 5B, 6A and 6B, comprise association C1. In Zone 7A, grey clay soils occur on a thick clay which extends to a depth of 6 to 8 m which in turn overlies the Pliocene sands. In Zone 6A, the thickness of the grey clay soil profile and underlying clay layer ranges from 6 to 10 m.

- Soil association C2 is mainly found in Zones 3A and 4A. The dominant soil type, which comprises about 90% of the association, is a relatively thin black or dark grey clay which overlies Quaternary limestone or marl formations. The thickness of the clay layer is generally about 0.4 m.

- The C3 soil association is limited to the southern swampy areas close to the coast in parts of Zone 1. For the C3 soil association, *peat* occurs with the clay (*rendzina*) soils. The *peat* layer attains a thickness of up to 3 m and generally overlies shelly sand near the coast or clay further inland.

Sand Soils

There are two types of sand soils, *podsols* and *humus podsols*. The *podsols* are primarily thick quartz sand, with the colour of the sand layers changing from white near the surface to brown and yellow at depth, indicating a degree of leaching. The *humus podsols* are similar to *podsols* except that there is a dark brown to black, hard and compact layer in the deeper horizons. This layer, sometimes referred to as "coffee rock", generally occurs at a depth of between 0.6 and 1.4 m.

Five major soil associations, S1 to S5 as shown in Figure 12, are identified where sand soils are dominant. Apart from these soil associations, significant parts of association D3 are also covered with sand soils.

- Topographically soil association S1 is located in a plain with east-west sand ridges and dunes within parts of Zones 6 and 7. The sand soils comprise about 60% of the association and are mainly *podsols* with some duplex soils occurring in the lower lying parts of the landscape. These sand soils have three different types of underlying horizons, either thick sandy clay, thick sand and clay, or thick sand which extends into the Pliocene sands (generally occurring in the more elevated dunes). The depth to the Tertiary limestone ranges from 22 to 32 m.

- Soil association S2 is mainly found in Zones 3B, 4A and 5A occupying the Naracoorte dune ranges system, where *podsols* and *humus podsols* occur with duplex and *terra rossa* soils. The sand soils are developed on deep sands and sandy clays which extend to a maximum depth of 10 m and overlie calcarenite.

  Duplex soils, mainly of the *solonetzic* type, and *humus podsols* occur in the low lying parts of the dune ranges. The sand soils comprise approximately 65% of association S2.

- Soil association S3 occupies the sandy plains and low dunes of the Naracoorte plateau occurring in Zones 3B and 4B. The sand soils and underlying horizons are developed on the Tertiary formations. The sand soils account for about 65% of this association.

- Soil association S4 is found within Zones 1B, 2A, 2B, 3A and 3B occupying an undulating sand plain with parallel trending NNW to SSE swamps. The density of swamp distribution is high in Victoria compared to that in South Australia. *Podsols* and *humus podsols* form a major part of the soil association, with some *solodic* soils. The sand soils are developed on sand or sandy clay horizons which overlie Quaternary limestone formations. The depth to these limestone formations varies from 2 to 6 m. The sand soils cover approximately 60% of the area.

- Soil association S5 occurs in Zone 1 in an area of calcarenite dune ridges similar to that of association S1. The soils comprise thick quartz sand in the dune ranges, with small patches of *terra rossa* soil developed on calcarenite. *Podsols* occur on the higher parts of the dunes and *humus podsols* occupy the lower parts of the dune ridges. The maximum thickness of the sand soils and the underlying sand/clay horizons above the calcarenite is about 10 m. The S5 association comprises approximately 90% of sand soils.

Terra Rossa Soils

The *terra rossa* soil is a red or reddish-brown sandy clay which always overlies limestone, with a general thickness of about 0.5 m. Often associated with the *terra rossa* soil is the *red-brown earth* soil type, which has a thicker developed soil profile with marked variations in texture ranging from a red brown loamy surface layer to a red brown clayey subsoil.

The *terra rossa* soils mainly occur in Zone 1 as the T1 and T2 soil associations (see Figure 12). For both of these soil associations, *terra rossa* soil is mainly developed on calcarenite ridges. For association T2, the *terra rossa* soil is closely associated with *peat* in swampy areas near the coast. Other occurrences of the *terra rossa* soils are in Zones 2A, 3A, 4A and 5A.

Other Soil Types

The V1 soil association in Zone 1A represents a mixture of soils, which are either completely or partially derived from volcanic ash erupted at Mount Gambier and Mount Schank. The soils which are entirely derived from volcanic ash are limited to a 5 km radius from Mount Gambier and to a 1.5 km radius from Mount Schank. These soil profiles are described as dark grey or dark brown loams with remarkably stable granular aggregation or structure (Blackburn, 1983). In addition to the above, there is a type of soil derived from volcanic ash and various other sand/*terra rossa* profiles buried by the volcanic ash deposits. The textural properties of these transitional soils depend on the thickness of the volcanic ash layer and the type of buried soil.

7.3.3 Extent and Impact of Shallow Aquitards

The presence of any low permeability horizons termed aquitards can also influence the magnitude of the vertical recharge to underlying aquifers.

Within Hydrogeological Province 1 (refer to Figure 6), no regionally extensive shallow aquitards exist and the near surface geological horizons generally have a greater permeability than those in the other Provinces. There are some localised areas where shallow aquitards occur within this Province but it was considered that these areas are not significant in relation to the assessment of vertical recharge for these particular Zones of the Designated Area.

For Hydrogeological Provinces 2 and 3 (refer to Figure 6), two shallow aquitards have been mapped for the Designated Area to determine their significance in affecting vertical recharge rates to predominantly the Tertiary Limestone Aquifer.

The two aquitards have been termed the Quaternary Aquitard and the Upper Tertiary Aquitard, as described earlier in Section 6 of this report. In summary,

- the Quaternary Aquitard comprises the Quaternary age sediments overlying essentially the Pliocene sands.

  The occurrence and thickness (isopach contours) of the Quaternary Aquitard are shown in Figure 13. A different procedure was adopted for the mapping of this aquitard in each State, as described below, because of the nature of the available data.

  For the Victorian portion of the Designated Area (Zones 4B to 11B), the plan was compiled from digital information created by the subtraction of the gridded surface of the top of the Pliocene sands from a surface topography grid. The resultant isopachs incorporate all the sediments overlying the Pliocene sands - including the Blanchetown Clay found north of Zone 9B, the Shepparton Formation found in Zones 5B to 8B, the Lowan Sands which are restricted to Zones 6B, 9B and 10B, and the Woorinen Formation which is widespread throughout the region. Of these, the Lowan Sands and to a lesser degree the Woorinen Formation are not strictly aquitards.

  To check the validity of the gridding method, the total thickness of clay, silt, and sandy clay layers overlying the Pliocene sands was determined from available borehole data and compared to the isopachs. The borehole data generally agreed with the isopachs, but where problems were likely to occur, such as in Zones 6B, 9B and 10B (the Big and Little Deserts) where the Lowan Sands are present, there was very little available borehole data for such a comparison. Therefore it is possible that the isopachs in this region may be over-estimated.

  In South Australia, the isopachs for the aquitard in Zones 4A to 8A were constructed from borehole data with the total thickness of clay or clayey layers being determined and contoured. To the north in Zones 9A to 11A, the total thickness of all sediments overlying the Pliocene sands were considered as aquitard material even though some sand layers are known to exist. It is possible therefore that the isopachs in this latter area may also be over-estimated.

It is evident from Figure 13 that the thickness of the Quaternary Aquitard varies considerably and appears to be influenced by a number of features.

In Zone 11B, a broad triangular area is formed by the juncture of a northwest trending Pliocene sands ridge and the upthrown portion of the northeast oriented Danyo Fault. The Quaternary Aquitard is generally between 10 to 20 m thick in this area. The thickness of the aquitard appears to be influenced by regional features such as the Danyo Fault, and local features such as the northwest trending Pliocene sands ridges and the east-west dunes of the Woorinen Formation. In the northern part of Zone 11B, over 30 m of aquitard is present.

In Zones 9 and 10, south of the Ouyen Highway, large areas are covered by less than 10 m of the Quaternary Aquitard.

There are two ridges through Zones 7 and 9, where the aquitard is absent and the Pliocene sands actually outcrop. Areas with an aquitard thickness exceeding 10 m are found between these ridges and the distribution of these areas tends to follow an east-west orientation influenced by the surface topography.

The hydraulic properties of the Quaternary Aquitard are likely to vary according to the lithology of the unit. The areas where the Quaternary Aquitard is composed of the Blanchetown Clay and Shepparton Formation are likely to be where the aquitard is most competent.

- the Upper Tertiary Aquitard comprises the mid to late Miocene age clays, silts and marls of the Bookpurnong Beds and Winnambool Formation. This aquitard overlies and confines the Tertiary Limestone Aquifer, and is restricted in occurrence to Hydrogeological Province 3. The aquitard separates the Tertiary Limestone Aquifer from the overlying Pliocene Sands Aquifer.

  The occurrence and thickness (isopach contours) of the Upper Tertiary Aquitard are shown in Figure 14, with the plan being compiled from contoured borehole data within the relevant region of the Designated Area.

The isopachs of the Upper Tertiary Aquitard indicate this unit is absent below Zone 4 and is generally less than 10 m thick for much of the central Zones 5 to 9. There is one area in Zone 8B around Telopea Downs, where over 20 m of the sediments comprising the Upper Tertiary Aquitard accumulated in a depression in the surface of the Murray Group limestone.

Further north in Zones 10 to 11, the thickness of the Upper Tertiary Aquitard increases and reaches a maximum thickness of over 60 m at two locations - the first being centred around the Renmark Trough in Zone 11B, and the second being situated on the down thrown side of the Danyo Fault.

The distribution of the Upper Tertiary Aquitard generally indicates a northwest to southeast orientation, with the thickness increasing to the north east off the Pinnaroo block and thinning to the south onto the Padthaway Ridge.

The significance of the two aquitards in relation to vertical recharge to either the Tertiary Limestone Aquifer or the Pliocene Sands Aquifer can be summarised as :

- For the Pliocene Sands Aquifer, the potential for vertical recharge is expected to increase southwards as the thickness of the Quaternary Aquitard generally decreases. This conclusion is based solely on the distribution of the aquitard thickness and other factors such as soil type, nature of aquitard, rainfall, vegetation and land use must also be considered to determine the actual vertical recharge to the Pliocene Sands Aquifer.

- For Hydrogeological Provinces 2 and 3; in the region where the Pliocene Sands Aquifer does not occur, the Quaternary Aquitard is either absent in local areas or is generally less than 10 m thick. Within these areas, there is potential for vertical recharge to the Tertiary Limestone Aquifer but consideration needs to be given to other factors such as soil type, rainfall, vegetation and land use, and the nature of the sediments comprising the Quaternary Aquitard to determine the actual vertical recharge rates.

- There are two areas in Hydrogeological Province 3, one in parts of Zones 5B, 6B and 7B and the other in parts of Zones 7B, 8A, 8B, 9A, 9B, 10A and 10B, where no Pliocene Sands Aquifer occurs and yet there is some presence of the Upper Tertiary Aquitard. There are also small areas where no Upper Tertiary Aquitard is found. Within these areas, there is consequently some potential for vertical recharge to the Tertiary Limestone Aquifer even though it is confined. This is discussed more fully in Section 7.6 of the report.

7.3.4 Groundwater Level Monitoring Trends

Monitoring of groundwater level trends can provide an indication of the hydrodynamics of a groundwater system in response to changes in land use or groundwater extraction. Such monitoring has been undertaken in the Designated Area since at least 1987 when a dedicated network of monitoring wells was established. The network of monitoring wells for the Tertiary Limestone Aquifer is shown in Figure 15. In both States, a number of wells had been monitored prior to 1987 with the majority being located in South Australia.

Groundwater level trends for the Tertiary Limestone Aquifer have been assessed for those observation wells with monitoring records extending over 10 years or longer. It was considered that any trends identified over shorter periods were not necessarily representative. For this reason, a large number of the observation wells in the Victorian part of the Designated Area were not assessed.

The trends have been identified and evaluated with respect to the hydrogeological provinces in which the observation wells are located, the depth to water level, the soil association and the land use occurring in the area of the observation bores.

The assessed trends through the Designated Area are shown in Figure 16, and hydrographs for selected wells are presented in Appendix A.

A plan showing the depth to groundwater level through the Designated Area was also compiled (see Figure 17) to assess possible impacts of any groundwater trends. The depths to groundwater level are generally for the Tertiary Limestone Aquifer apart for those areas where the overlying Pliocene Sands Aquifer is present.

The trends determined in each of the hydrogeological provinces are discussed below.

Hydrogeological Province 1

Within this province, groundwater levels range from less than 2 m to 26 m below ground surface. The shallowest water levels occur in the interdunal flats and swampy plains, whereas the greatest depth to water table is found in the calcarenite ridges.

The shallow water level areas have generally steady long term water levels with seasonal water level fluctuations reflecting annual recharge events.

In the Gambier and Caroline Forest softwood plantation areas, the depth to water table ranges from 5 to 22 m. No long term water level trends are evident in areas where the groundwater level depths are less than 10 m, and the hydrographs for such monitoring wells show frequent recharge events. However in deeper water level areas (> 10 m), groundwater levels are declining at a rate of about 0.05 m per annum with very low recharge events recorded during the past 20 years (see hydrographs for wells GAM 29 and Warrain 101238 in Appendix A). These declining trends have been attributed to the evapotranspiration losses of soil moisture and use of groundwater from the water table by the mature pine forests in these areas (this is discussed more fully in Section 7.3.5 of this report). These declining groundwater level trends extend beyond the limits of the pine plantations towards the west, in an area with more elevated dune ranges. The decline in water levels in this area could be a result of increased groundwater extraction from the Blue Lake or a longer term reduction in rainfall.

Declining water level trends are also evidenced in a group of wells which extend from the Hundred of Comaum (Zone 4A) to the Hundred of Penola (Zone 3A). Most of these wells (except CMM 26) are located within or adjacent to softwood plantations of the Comaum and Penola Forest areas. Compared to the wells with declining trends in the Gambier and Caroline Forests, these wells show considerably greater seasonal water level fluctuations and have shallower depths to the water table.

Another important feature shown in the water level trends in this area is the rise in groundwater levels in parts of Zone 2A occurring in the Penola Pine Forest area. The pine plantations of this area were destroyed in the 1983 bushfire and replanting of pines has been carried out since that time. This is discussed more fully in Section 7.3.5 of this report.

Hydrogeological Province 2

In this province, parts of Zones 4A and 5A represent some of the most intensely irrigated areas of the Designated Area. Even so, groundwater levels are generally showing a slight rise ranging from 0.01 to 0.03 m per year, with a few wells showing no discernible trend. Depth to the water table ranges from 6 to 22 m. There is no clear relationship with depth to water levels and the magnitude of trends (eg well JOA 4 shows a rising trend of 0.02 m per year with a water level of 22 m and well BIN 20 shows a rising trend of 0.03 m per year with a water level of 6.4 m).

For most of Zones 6A to 8A, a more significant rise in groundwater levels is evident (see hydrographs for wells BMA 8 and GGL 7 in Appendix A). The depth to water level ranges from 16 m in Zone 6A to 53 m in Zone 8A. The rising trends range from 0.01 to 0.1 m per year. The areas with rising groundwater levels span different depths to water level and three different soil associations (clay, duplex and sand). However, the highest trends of 0.04 to 0.1 m per year are evident where sand soils are dominant and the water level depth ranges from 16 to 26 m. These rising trends are associated with the clearing of native vegetation and the subsequent loss of higher water use pastures in the late 1970's due to insect infestation. This has resulted in a subsequent enhanced recharge to the aquifer. With the current minor irrigation activities and the small patches of remaining native vegetation, water levels will continue to rise until new equilibrium conditions are attained.

There are small areas of declining water level trends centred around Frances in Zone 6A and near Bordertown in Zone 7A. These trends, ranging from 0.02 to 0.04 m per year, are likely to be attributed to irrigation activities and the predominantly clay soils in these areas.

Hydrogeological Province 3

Groundwater level trends in most of the area are showing a slight decline, with the most significant decline in water levels of up to 0.2 m per year centred around Peebinga in Zone 10A. This is likely to be a result of the irrigation extractions in this area.

In the southern part of the area, there is a slight rise in groundwater levels of about 0.02 m per year.

In summary, there are a number of different groundwater level trends throughout the Designated Area which reflect varying land management practices. The dominant trends being observed are:

- a decline in groundwater levels of up to about 0.1 m per annum in the softwood plantation areas, mainly in Zones 1A and 1B.
- a rise in groundwater levels of up to 0.1 m per annum in Zones 5A, 6A and 7A due to enhanced vertical recharge following native vegetation clearance and subsequent loss of high water use perennial pastures.
- a decline in groundwater levels of up to 0.2 m per annum in Zone 11A which is likely to be related to irrigation groundwater withdrawals.

Some of the observed declining water level trends exceed the permissible rate of potentiometric lowering specified in the Border (Groundwater Agreement) Act of 0.05 m per year.

The length of monitoring period for a number of the Victorian observations wells is too short to confidently assess any trends.

Continued monitoring of groundwater levels is a requisite through the Designated Area to assess the longer term impacts of changes in land use and groundwater extraction.

7.3.5 *Impact of Softwood Afforestation*

Government and privately owned softwood forest plantations occur extensively throughout the southern part of the Designated Area. Previous studies have shown that the vertical recharge rate beneath mature pine plantations is negligible (Mitchell and Correll 1987).

Stadter (1992) conducted a review of South Australian well hydrographs before and following clearing of forests by bushfires during the Ash Wednesday fires in 1983. This study identified consistently rising water levels in Zone 2A as a result of increased vertical recharge by rainfall immediately following removal of the forest canopy by the bushfires. Hydrographs from wells indicated rises in groundwater levels in the order of 2.5 metres between 1983 to 1992. Over the same period, rises of about 1.5 metres were apparent in wells located on the fringes of the forests. Further, the hydrographs have since displayed gradual declining water levels as the forest canopies have become re-established. The hydrograph for well NAN 19 (presented in Appendix A) illustrates these water table trends.

Apart from changes in groundwater levels, there has also been some evidence of groundwater quality changes in response to the increased recharge. The salinity of some wells has increased (see salinity graph for well NAN 9 in Appendix B), possibly in response to the increased vertical recharge and leaching of salts previously stored in the soil profile.

A review of hydrographs from south-western Victoria was conducted by HydroTechnology (1993) to determine the influence of softwood plantations on groundwater levels. Wells monitoring the Tertiary Limestone Aquifer located within and up to 1.5 km from forest plantations were selected. The investigation also examined hydrographs for nested wells monitoring both the Tertiary Limestone and Tertiary Confined Sand Aquifers to determine whether trends observed in the upper aquifer were in response to regional or local processes. A later study (HydroTechnology 1993b) correlated hydrograph trends with seasonal rainfall and long term rainfall patterns. These studies highlighted declining water levels in the Tertiary Limestone Aquifer of between 0.05 and 0.15 m per year in seven out of ten wells located near plantations. Five out of six bores screened in the Tertiary Limestone Aquifer but located 1.5 km away from the forests showed steady rises in groundwater levels. This suggests that the influence of the forests on groundwater levels is localised.

Hydrographs from the deeper Tertiary Confined Sand Aquifer display overall declining trends, except in the north and north-east towards the basin margins where steady rising groundwater levels are evident.

This initially suggests that some component of the downward trends observed in the Tertiary Limestone Aquifer in these areas may be in response to regional processes. Closer inspection of hydrograph trends at three nested well sites indicates that although overall long term trends are sympathetic, there are diametrical trends over shorter time intervals. Rising levels in the Tertiary Limestone Aquifer during periods of forest development corresponded with declining trends in the Tertiary Confined Sand Aquifer.

Declining magnitudes of peak hydrograph responses can also be correlated to periods of plantation development. This characteristic which is in response to decreasing recharge as the forest canopy closes has previously been recognised by Mitchell and Correll (1987) beneath *pinus radiata* plantations in South Australia.

The water use of softwood plantations can be via both interception of infiltrating rainfall and directly from the upper part of the Tertiary Limestone Aquifer in areas where the water table occurs at shallow depths. It is apparent therefore that the depth of the root zone in relation to the groundwater level will determine whether one or both processes operate.

Hydrographs for most wells display fluctuations in sympathy with seasonal rainfall variations. Annual residual mass curves for rainfall at several stations indicate that since the 1960's rainfall has been generally below average. It is possible that declining hydrographs may also in part be due to long term rainfall patterns.

The herbicide atrazine is used during the establishment of pine plantations in the Designated Area. There have been studies undertaken to assess the impact of its use on the groundwater resources in the Tertiary Limestone Aquifer by the relevant agencies in both States. In 1992, a joint investigation involving the CSIRO, Department of Mines and Energy, Ciba-Geigy Australia Ltd and the E&WS Department revealed atrazine concentrations of up to 0.75 ųg/L in an area of young plantings within Zone 2A (Stadter et al, 1992). Hydrotechnology undertook field testing for the presence of atrazine in groundwater from 11 wells in Zones 1B and 2B during March 1994. Of these, five tests were considered to be accurate and all samples confirmed the presence of atrazine. The results of subsequent sampling and laboratory analysis of seven of these wells showed atrazine concentrations below the detection limit of 0.1 ųg/L, and further testing to confirm the field methodology is planned.

It is concluded that softwood afforestation does have an impact on groundwater levels through the reduction in vertical recharge to the aquifer. Some additional studies are warranted to examine whether the softwood plantations actually use groundwater in areas where the water levels are within or close to the root zone. It is also concluded that the use of atrazine for the establishment of pine plantations can have an impact on the groundwater quality of the Tertiary imestone Aquifer.

7.3.6 *Assessment of Vertical Recharge Rates*

For Hydrogeological Provinces 1 and 2 where the Tertiary Limestone Aquifer is unconfined (see Figure 6), the magnitude of vertical recharge through these areas was assessed using the approach adopted by Stadter (1989) and De Silva (1994) of examining the recorded hydrographic responses to seasonal recharge events.

The average annual seasonal fluctuations for the individual wells were assessed and converted to a corresponding recharge rate by assuming a storage coefficient of 0.1 for the Tertiary Limestone Aquifer.

The limitations in use of this approach are recognised as :

- not being appropriate in areas where the Tertiary Limestone Aquifer may be locally semi-confined to confined
- the adoption of a storage coefficient of 0.1 may be inappropriate for the Tertiary Limestone Aquifer, particularly in areas where the aquifer is karstic with higher storage coefficients which would result in an under-estimation of the vertical recharge rate. This is likely for parts of Zones 1A and 1B where the presence of karstic limestone is well documented.
- the possible under-estimation of vertical recharge rates in those areas where groundwater levels are rising.
- the possible over-estimation of vertical recharge rates in the cases where the seasonal response in the groundwater levels includes some drawdown in water level due to groundwater extraction.

Nevertheless, the results of this assessment indicated vertical recharge rates through Hydrogeological Provinces 1 and 2 at the individual observation well sites ranging from 2 to 130 mm per year.

These results were then used together with the distribution of soil associations (see Figure 12) and the vegetation and land use (see Figure 11) to compile a plan showing vertical recharge sub-areas for the Tertiary Limestone Aquifer in Hydrogeological Provinces 1 and 2, as shown in Figure 18.

The vertical recharge sub-areas were defined with due consideration of the nature of the soils, the type of vegetation cover and the assessed vertical recharge rates from the groundwater level responses recorded in the observation wells. A summary of the details for these vertical recharge sub-areas is given in Table 5.

The actual areas of the individual vertical recharge sub-areas within each Zone of the Designated Area were derived, and the total annual volume of vertical recharge for each Zone was then determined as shown in Table 6.

The actual areas for each recharge sub-area within the individual Zones are presented in Appendix C.

Table 6 indicates that there is a gradual reduction in the volume of the vertical recharge towards the north, which is a result of a reduction in the total rainfall, presence of clay soils and a greater depth to the water table.

The significance of these results in relation to the Permissible Annual Volumes for the Zones of the Designated Area is discussed more fully in Section 10 of this report.

TABLE 5 : SUMMARY FOR VERTICAL RECHARGE SUB-AREAS IN HYDROGEOLOGICAL PROVINCES 1 AND 2

RECHARGE SUB-AREA	SOIL TYPE	LAND USE	ADOPTED VERTICAL RECHARGE RATE (mm/year)	COMMENTS
R1	S4	C	130	Minor irrigation activities
R2	C2	C, I	100	
	T1	C, I		
R3	D2	C, I	90	
	T2	C		
R4	T1	C	80	
	S4	C		
R5	S2	C	70	
R6	V1	C, I	65	
R7	D1.1	C, I	60	
R8	S4	P, NV	45	
R9	D2	P	40	
R10	D1	C, I	35	
R11	S3	C	30	
R12	S1	C, NV	20	
	S2	P, NV		
	D1	P, NV		Lack of monitoring wells (small area)
	D2	P, NV		
R13	S3	NV, P	15	Minor irrigation and native vegetation
	D3	C		
R14	C1	C	12	Minor irrigation
R15	S5	P, NV	5	Recharge rates are likely to be less than 5 mm/year near Victorian coast
	D5	P		
	V1	P		
	T1	NV		
	T2	NV		
	C3	NV		
	S4	NV, P		
R16	S1	NV	2	

C = Cleared; I = Irrigation; P = Softwood Plantations; NV = Native Vegetation

TABLE 6: VOLUME OF ASSESSED VERTICAL RECHARGE FOR ZONES IN HYDROGEOLOGICAL PROVINCES 1 AND 2

ZONE	ASSESSED VOLUME OF VERTICAL RECHARGE (ML/ANNUM)	PREVIOUSLY ASSESSED VOLUME OF VERTICAL RECHARGE + (ML/ANNUM)
1A	31 090	67 500
1B	45 720	67 500
2A	36 390	27 100
2B	41 900	22 300
3A	45 600	31 700
3B	20 630	24 300
4A	33 580	26 400
4B	17 350	15 900
5A	19 980	16 600
5B*	2 700	11 100
6A*	10 760	11 100
6B*	10	11 100
7A	8 070	8 300
7B*	3 430	3 340
8A*	7 720	6 700
8B*	600	820
9A*	2 450	270

* Does not include those areas of the Zone where the Tertiary Limestone Aquifer is confined.

\+ Stadter and Stewart (1991)

7.4 Lateral Groundwater Throughflow

Another component of recharge to the Tertiary Limestone Aquifer is the groundwater throughflow within the aquifer. As discussed previously, for most of the Designated Area the throughflow is in a west to northwest direction with flow across the State Border from Victoria into South Australia (see Figure 8).

The PAVs for the northern part of the Designated Area, Zones 9 to 11, include a proportion of the lateral throughflow for the Tertiary Limestone Aquifer. For this five year management review it was therefore necessary to re-assess the throughflow with regard to additional data obtained from the further aquifer testing undertaken in the Victorian portion of the Designated Area.

7.4.1 Transmissivity of the Tertiary Limestone Aquifer

The available transmissivity data for the Tertiary Limestone Aquifer were compiled and a plan showing the distribution of this parameter was produced (see Figure 10). The available transmissivity data for South Australia and Victoria are presented respectively in Appendices D and E.

As discussed previously, there are considerable lateral and vertical variations in the lithology of the Tertiary Limestone Aquifer together with karst development in certain areas. As a consequence, there are similarly large variations in the hydraulic properties for the aquifer.

Aquifer pumping tests in South Australia have provided transmissivity values ranging from 200 to 400 m^2/day, with locally high values of more than 5000 m^2/day (Stadter, 1989; Stadter and Stewart, 1991).

Transmissivities range from 600 to 900 m^2/day in Zones 5B through to 7B. Lower values of less than 200 m^2/day occur in the eastern parts of Zones 3B and 4B (Stewart, 1990a and b).

7.4.2 Review of Lateral Groundwater Throughflow

The lateral groundwater throughflow for the Tertiary Limestone Aquifer has been re-assessed using flow net analysis and Darcian flow calculations. The June 1994 potentiometric surface for the Tertiary Limestone Aquifer was used for the construction of the flow net.

TABLE 7 : ESTIMATES OF LATERAL GROUNDWATER THROUGHFLOW FOR THE TERTIARY LIMESTONE AQUIFER

ZONE	CURRENT ASSESSMENT				PREVIOUS ASSESSMENT	
	FLOW NET CALCULATION		DARCIAN CALCULATION		DARCIAN CALCULATION	
	EASTERN BOUNDARY (ML/YEAR)	BORDER (ML/YEAR)	EASTERN BOUNDARY (ML/YEAR)	BORDER (ML/YEAR)	EASTERN BOUNDARY * (ML/YEAR)	BORDER# (ML/YEAR)
1B	14600	N/D	N/D	N/D	N/D	N/D
2B	15070	N/D	N/D	N/D	N/D	N/D
3B	2340	29170	3520	33150	2440	N/D
4B	1170	14620	1060	12770	1200	8760 - 20220
5B	17500	19700	13700	14125	8100	14890 - 29790
6B	4760	5950	4600	6500	5000	4380 - 8770
7B	6500	10930	4300	9600	3370	13690 - 27390
8B	2050	3650	1900	3650	2940	6900 - 13800
9B	2750	5475	2300	4050	N/D	N/D
10B	2700	3650	2000	3200	N/D	N/D
11B	4560	5475	4500	4850	N/D	N/D

N/D Not determined

* Stadter and Stewart (1990)

Stadter (1989)

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The throughflow volumes at both the State Border and the eastern boundary for the Zones of the Designated Area are presented in Table 7. Also shown in Table 7, for comparison, are previous determinations.

In Zones 1 and 2 groundwater flow is southwards with little or no flow occurring across the State Border. Groundwater flow in Zone 2A is complicated by localised recharge - discharge features superimposed on the regional flow pattern.

The comparison of the current assessment with previous determinations has shown some refinement of the throughflow estimates. Some variation is still apparent and this is largely the result of the selection of appropriate values of aquifer transmissivity for the determinations.

The values of transmissivity adopted for the current assessments of lateral groundwater throughflow at both the eastern edge of the Designated Area and at the State Border are shown in Table 8.

TABLE 8 : ADOPTED TRANSMISSIVITY FOR THE TERTIARY LIMESTONE AQUIFER FOR LATERAL THROUGHFLOW DETERMINATIONS

ZONE	TRANSMISSIVITY (m^2/d)	
	Eastern edge of Zone	State Border
1B	500	N/D
2B	1380	N/D
3B	80	1000
4B	40	500
5B	600	600
6B	650	650
7B	890	2000
8B	560	1000
9B	500	1000
10B	500	1000
11B	500	1000

N/D Not determined

7.5 Inter-Aquifer Leakage

Apart from the vertical recharge and lateral groundwater throughflow for the Tertiary Limestone Aquifer within the Designated Area, the remaining component of the overall water budget for this aquifer is the inter-aquifer leakage where any overlying or underlying aquifers are present.

This inter-aquifer leakage can be either positive or negative and is dependant on the relative potentiometric heads for the associated aquifers.

Within the Designated Area, there is the potential for:

- either upward or downward leakage between the Pliocene Sands and Tertiary Limestone Aquifers. Given the occurrence of the Pliocene Sands Aquifer, this is only a consideration in parts of Zones 4B, 5B, 9B, 10A and 10B and all of Zone 11.

- either upward or downward leakage between the Tertiary Limestone Aquifer and the Tertiary Confined Sand Aquifer. Such leakage may occur throughout the Designated Area given the general widespread occurrence of both aquifers.

There has been no assessment of the inter-aquifer leakage, as this was outside the scope of the current five year technical work plan, due to the need to obtain reliable potentiometric head data for the Pliocene Sands Aquifer and appropriate vertical hydraulic conductivity data for both the Upper and Lower Tertiary Aquitards.

Assessments of inter-aquifer leakage for the Tertiary Limestone Aquifer should be incorporated in the next five year technical work plan.

7.6 Discussion Of Results And Overview

The re-assessment of recharge to the Tertiary Limestone Aquifer has involved examination of vertical recharge to the aquifer in the southern Zones of the Designated Area, where the aquifer is unconfined, and a determination of the lateral groundwater throughflow at both the eastern edge of the Designated Area and at the State Border. Lack of adequate data has precluded an assessment of inter-aquifer leakage either to or from the Tertiary Limestone Aquifer.

The results of these investigations are discussed below in relation to the three Hydrogeological Provinces of the Designated Area (see Figure 6).

7.6.1 Hydrogeological Province 1

The Tertiary Limestone Aquifer within this province is unconfined and, in general, the overlying geological strata are relatively permeable and there is no extensive presence of any aquitard overlying the aquifer.

Vertical recharge through the area was assessed by examination of hydrographic responses observed in monitoring wells and relating these to areas of different soil types and land use.

The total volumes of vertical recharge for the Zones within this province are in the order of 40 000 ML per annum (see Table 6) for each of the Zones.

The determination of lateral groundwater throughflow indicates that there are no significant volumes of groundwater throughflow across the State Border for Zones 1 and 2 due to the almost parallel flow to the Border; although some groundwater inflow into the Designated Area occurs at the eastern edge of these Zones and is in the order of 15 000 ML per annum. For Zone 3, the volume of groundwater throughflow at the State Border is in the order of 5 000 to 6 000 ML per annum (see Table 7).

It is therefore apparent that vertical recharge is the dominant form of recharge in this province.

Although not assessed, there is potential for groundwater leakage from the Tertiary Limestone Aquifer to the Tertiary Confined Sand Aquifer through most of the province with the exception of an area in the southern part of Zones 1A and 1B. In this latter area, the potentiometric head difference between the two aquifers is reversed and there is potential for groundwater leakage in the opposite direction. The magnitude of leakage between the aquifers needs to be assessed once hydraulic data for the Lower Tertiary Aquitard has been obtained.

7.6.2 Hydrogeological Province 2

Within this province, the Tertiary Limestone Aquifer is unconfined and there are some aquitards present above the aquifer.

Within parts of Zones 3B and 4B, the Pliocene Sands Aquifer appears to directly overlie the Tertiary Limestone Aquifer and therefore these two aquifers could be considered as one system. However, in view of some limited observations of differences in both potentiometric levels and water quality between the two aquifers, there may be some (possibly localised) separation of the two aquifers. Further studies are required to clarify this situation.

The vertical recharge to the Tertiary Limestone Aquifer was assessed in the same manner as that for Hydrogeological Province 1. The vertical recharge rates are relatively lower than those in Province 1, as a result of a reduction in total rainfall, presence of areas of clay soils and a greater depth to the water table.

The total volumes of vertical recharge for the Zones within this Province range from about 8 000 to 20 000 ML per annum (see Table 6).

The volume of lateral groundwater inflow along the eastern edge of the Designated Area within this Province is in the order of 1 000 to 3 000 ML per annum for the individual Zones (see Table 7). For Zones 5A, 6A, 7A and 8A of this Province, the groundwater throughflow at the State Border ranges from about 4 000 to almost 20 000 ML per annum (see Table 7).

Comparing the vertical recharge and lateral groundwater throughflow for the Zones in this Province, it appears that vertical recharge is the dominant form of recharge to the Tertiary Limestone Aquifer. The lateral groundwater throughflow is, however, becoming a more significant component of the groundwater resource when compared to the vertical recharge.

As for Hydrogeological Province 1, there is potential for leakage of groundwater from the Tertiary Limestone Aquifer to the underlying Tertiary Confined Sand Aquifer. Further studies are required as described previously to determine the significance of this leakage.

7.6.3 Hydrogeological Province 3

The Tertiary Limestone Aquifer within this Province is confined by the Upper Tertiary Aquitard; and in the northern and eastern parts of the Zones within this Province, the Pliocene Sands Aquifer is present.

No assessment of vertical recharge to the Tertiary Limestone Aquifer was undertaken given these hydrogeological conditions.

There are small areas within Zones 5B, 6B and 9B where there is no presence of the Upper Tertiary Aquitard and therefore the potential exists for direct vertical recharge to the Tertiary Limestone Aquifer. Such recharge in these areas will depend on the land use and the nature of the overlying Quaternary Aquitard.

The hydrographs for a limited number of monitoring wells (Duddo 61571 and Mulcra 82220, see Appendix A) indicate annual recharge responses. This could result from either direct vertical recharge or annual increases in leakage from either overlying or underlying aquifers.

There are two areas within this Province (see Figure 6) where no Pliocene Sands Aquifer is present but the Tertiary Limestone Aquifer is confined with the presence of the Upper Tertiary Aquitard. Within these areas, it is considered that there is potential for vertical recharge to the Tertiary Limestone Aquifer subject to the nature of the Quaternary and Upper Tertiary Aquitards, the soil type and the land use. The Quaternary Aquitard is generally less than 10 m thick in these areas and there are both cleared and uncleared regions. It is considered therefore that some vertical recharge to the Tertiary Limestone Aquifer is probable although no assessment of the magnitude of this recharge has been undertaken.

The determinations of lateral groundwater throughflow for the Zones within this Province indicate that the volumes of groundwater inflow at the eastern edge of the Designated Area generally range from about 2 000 to 5 000 ML per year for the individual Zones (see Table 7). The exception is Zone 5B where about 17 000 ML per year of groundwater inflow is indicated. The groundwater throughflow for these Zones at the State Border is, for all cases, larger than the groundwater inflow at the eastern edge of these Zones. This suggests that either some direct vertical recharge is occurring where the Pliocene Sands Aqifer is absent or there is leakage of groundwater to the Tertiary Limestone Aquifer from either overlying or underlying aquifers.

The potentiometric head difference between the Tertiary Limestone Aquifer and the Tertiary Confined Sand Aquifer is relatively small for most of the province, and therefore the leakage is not expected to be significant. The exception is an area in Zone 11 where there is potential leakage to the Tertiary Limestone Aquifer from the Tertiary Confined Sand Aquifer due to the greater potentiometric head differences.

Little is known regarding the potentiometric head distribution for the Pliocene Sands Aquifer, but given the generally much greater salinity of the groundwater within this aquifer, it is considered that downward leakage of water into the Tertiary Limestone Aquifer is not occurring.

7.6.4 Conclusions

The main components of recharge to the Tertiary Limestone Aquifer through the Designated Area are vertical recharge, lateral groundwater throughflow and groundwater leakage from overlying or underlying aquifers.

Assessments indicate that vertical recharge is the dominant form of recharge within Hydrogeological Provinces 1 and 2 and that lateral groundwater throughflow is dominant in Hydrogeological Province 3.

No detailed assessments of inter-aquifer leakage have been undertaken due to the lack of available data. This deficiency in data needs to be addressed.

8. GROUNDWATER QUALITY OF THE TERTIARY LIMESTONE AQUIFER

8.1 General

The distribution of salinities in the Designated Area highlights several features, some of which have been previously discussed. Although full chemical analyses are available, no detailed review of the hydrochemistry of the Tertiary Limestone Aquifer has been conducted as yet but this should form part of the next five year work plan.

8.2 Salinity Monitoring

In June 1987, both States began quarterly field monitoring of groundwater salinity and two-yearly laboratory analysis of a full suite of parameters, including electrical conductivity. Since 1987 the monitoring network has remained relatively stable in South Australia. In Victoria the network has changed as a result of new Government wells drilled to replace private wells considered unreliable or unsuitable for long term monitoring. As a consequence, record lengths differ between the States, with Victorian records being generally shorter than those for South Australia.

In South Australia and Victoria respectively, 76 and 63 wells are monitored for salinity. The current network of monitoring wells for the Tertiary Limestone Aquifer in the Designated Area is shown in Figure 19.

Wells in South Australia are pumped to remove three casing volumes of water before sample collection, for both field and laboratory analyses. In Victoria, samples for field analysis of EC are collected by bailing adjacent to the screened interval while samples submitted for laboratory analysis are obtained following pumping of three casing volumes of water. Both States maintain a certain number of privately owned wells in the monitoring networks. These wells are equipped with windpumps, or petrol/diesel/electric driven pumps.

8.3 Review of the Integrity of Salinity Monitoring Data

Due to the different sampling methods between the two States, significant potential for error exists.

A review of salinity results obtained by different sampling methods (HydroTechnology 1994) concluded that results obtained from bailed samples are generally lower than those obtained by pumping. The lower results are possibly a result of density stratification within the wells.

The report also indicated that the magnitude of fluctuations in the time series field EC data is greater in Victoria than South Australia because of the sampling method.

Salinity data for wells with more than 5 years of data have been previously reported by HydroTechnology (1994). Field electrical conductivity data for all bores were plotted and a least squares linear regression used to examine the trends in groundwater salinity over the monitored period. Error bounds of 5% and 10% about the regression line provided a check on the integrity of the data.

This check of the data revealed some inaccuracies, caused by typological errors, inaccuracies caused by sampling method, operator error and instrument error.

A subsequent investigation (report to the Border Review Committee, October 1994) reviewed results from bailed and pumped samples from monitoring wells in South Australia and Victoria to examine any variation in salinities using the two sampling methods. Although the sampling was only conducted on a small sub-set of the total State networks, at least four out of the eight wells sampled by bailing were considered unreliable when compared to pumped samples, with the largest difference in salinity results between bailed and pumped samples exceeding 20%. The results of this work are presented in Table 9.

The comparison of bailed and pumped sampling results reinforced the previous recommendation that bailed samples are not considered appropriate for the collection of regional water quality data.

It was concluded that a more consistent approach to sampling is required due to the need for reliable groundwater quality monitoring data to assess any longer term trends. Options to achieve this approach have been provided to the Border Review Committee and are being considered.

TABLE 9: RESULTS OF COMPARISON BETWEEN BAILED AND PUMPED SAMPLING

WELL	SAMPLING METHOD	DATE	ELECTRICAL CONDUCTIVITY	DIFFERENCE BETWEEN PUMPED AND BAILED ELECTRICAL CONDUCTIVITY	% DIFFERENCE OF PUMPED ELECTRICAL CONDUCTIVITY
Durong 1	Bailed 1	21/9/94	840		
(61922)	Bailed 2	21/9/94	960 (?)		
	Bailed 3	21/9/94	840		
	Bailed 1	30/9/94	830	+ 30	+ 3.8
	Bailed 2	30/9/94	810	+ 10	+ 1.3
	Bailed 3	30/9/94	845	+ 45	**+ 5.6**
	Pumped	30/9/94	800	-	-
Durong 2	Bailed 1	21/9/94	3250	+ 400	**+ 14.0**
(61923)	Bailed 2	21/9/94	3200	+ 350	**+ 12.3**
	Bailed 3	21/9/94	3160	+ 310	**+ 10.9**
	Pumped	21/9/94	2850	-	-
Murrandarra 1	Bailed 1	21/9/94	1470		
(87778)	Bailed 2	21/9/94	1460		
	Bailed 3	21/9/94	1460		
	Bailed 1	30/9/94	1420	- 10	- 0.7
	Bailed 2	30/9/94	1440	+ 10	+ 0.7
	Bailed 3	30/9/94	1430	0	0
	Pumped	30/9/94	1430	-	-
Murrandarra 15001	Bailed 1	21/9/94	5400	- 700	**- 11.5**
	Bailed 2	21/9/94	5500	- 600	**- 9.8**
(82796)	Bailed 3	21/9/94	5400	- 700	**- 11.5**
	Pumped	21/9/94	6100	-	-
JES 4	Bailed 1	30/9/94	2250	- 580	**- 20.5**
	Bailed 2	30/9/94	2210	- 620	**- 21.9**
	Bailed 3	30/9/94	2400	- 430	**- 15.2**
	Pumped	30/9/94	2830	-	-
JES 50	Bailed 1	30/9/94	2400	0	0
	Bailed 2	30/9/94	2360	- 40	- 1.7
	Bailed 3	30/9/94	2400	0	0
	Pumped	30/9/94	2400	-	-
JOA 13	Bailed 1	30/9/94	3300	+ 130	+ 4.1
	Bailed 2	30/9/94	3350	+ 180	**+ 5.7**
	Bailed 3	30/9/94	3400	+ 230	**+ 7.3**
	Pumped	30/9/94	3170	-	-
CMM 81	Bailed 1	30/9/94	1170	- 190	**- 14.0**
	Bailed 2	30/9/94	1140	- 220	**- 16.2**
	Bailed 3	30/9/94	1150	- 210	**- 15.4**
	Pumped	30/9/94	1360	-	-

8.4 Salinity Monitoring Trends

As mentioned previously, most monitoring of groundwater salinity in the network of observation wells within the Designated Area was commenced in 1987 which has provided about seven years of quarterly monitoring data.

It is considered that apart from some distinct trends obvious in a few monitoring wells, the record length is still relatively short and does not provide reasonable confidence in some of the trends apparent from some wells. This confidence is further reduced by the variation in some results caused by the collection of bailed samples from the Victorian monitoring wells (discussed previously in Section 8.3).

Nevertheless, a plan showing the assessed trends for wells with a reasonable record length through the Designated Area has been compiled as shown in Figure 20, and the following features are apparent:

- the salinity monitoring wells in Zones 1A and 1B, and in parts of Zones 2A and 2B, generally show either no change in groundwater salinity or slight decreases. This is likely to be a result of the more stable land use history in the area and possibly due to the higher rainfall and corresponding higher vertical recharge rates.
- an increase in salinity in an area of Zone 2A where the softwood plantations were destroyed by the 1983 bushfire. This trend (discussed previously in Section 7.3.5) is highlighted by observation well NAN 9 which shows an annual increase in electrical conductivity of about 118 ECU.
- a group of wells in and close to Zone 2B show an increase in salinity ranging from 12 to 70 ECU per annum. This increase could be a result of salt accessions to the Tertiary Limestone Aquifer following clearance of native vegetation in the area which has increased the vertical recharge rate and mobilised salts stored in the unsaturated profile.
- a group of wells in and close to Zone 4B show an increase in salinity ranging from 10 to 67 ECU per annum. This increase may also be due to the clearance of native vegetation in this area, as discussed above.
- a group of wells in and close to Zones 5A, 5B, 6A, 6B and the lower part of Zone 7A show an increase in salinity ranging from 4 to 236 ECU per annum. This is an area where a distinct rise in groundwater levels is also obvious in some wells.

It is likely therefore that the increase in salinity is a result of remobilisation of salts within the unsaturated profile following the rise in groundwater levels, and also possibly due to increased salt accessions to the Tertiary Limestone Aquifer due to increase recharge following clearance of native vegetation.

In Zones 5A and 5B of this area, the increase in salinity could also be a result of the increased density of irrigation activity (see Figure 11).

- the remaining network of wells show no discernible patterns of salinity trends.

Some selected salinity graphs for wells through the Designated Area are presented in Appendix B.

Further on-going salinity monitoring is required to validate some of the trends which are currently apparent.

An attempt was made to compile a plan showing the distribution of groundwater salinity for the Tertiary Limestone Aquifer for the year 2004 using the trends for the individual observation wells. It was considered, however, that the plan was not particularly meaningful due to some lack of confidence in the assessed trends and the lack of data in some areas.

8.5 Reported Salinity Trends in Similar Hydrogeological Environments

An attempt was made to seek any previously published information on groundwater salinity increases in similar hydrogeological environments to those in the Designated Area in order to obtain some background information for consideration of management options.

An extensive literature search both within Australia and overseas failed to provide any reports considered suitable for the Designated Area.

It was considered that the experiences in South Australia within two groundwater irrigation areas at Padthaway and Keith, located about 20 and 35 km respectively west of the Designated Area, provide some information on groundwater salinity increase related to irrigation development which has some relevance to the Designated Area. A summary for these irrigation areas is provided below.

8.5.1 Padthaway Irrigation Area

Irrigation in the Padthaway area has been established for about 35 years. The groundwater supplies are sourced from a very shallow (about 20 m thick) and transmissive unconfined aquifer - the Quaternary Padthaway Formation which forms part of the Tertiary Limestone Aquifer within certain areas of the Designated Area.

Since the early 1960's, irrigated crops have progressively changed from pastures to more lucrative crops such as vines, various oil and grass seeds, and vegetables. The area of vines has increased significantly over the last two decades. Currently about 7500 hectares of land is irrigated using a variety of irrigation systems, ranging from flood to drip irrigation, with the salinity of the groundwater used for irrigation being generally less than 2000 mg/L.

Control of groundwater use for irrigation purposes has been in place since 1975 under the SA Water Resources Act due to concerns about sustainability of the resource, particularly with regard to the quality of the groundwater.

About 30 000 ML per annum of groundwater is currently allocated for use in the area, and during the 1993/94 irrigation season about 18 000 ML were utilised.

Regular monitoring of groundwater levels and quality has been undertaken since 1970 and 1978 respectively to determine the long term impacts of the irrigation activity.

These monitoring results indicate that there has been no long term impact on groundwater levels through the area but a progressive deterioration in groundwater quality has been observed in the more intensely irrigated areas. The recorded rates of groundwater salinity increase range up to 50 mg/L per annum.

8.5.2 *Keith Irrigation Area*

Intensive irrigation since the late 1970's has occurred in the Keith area with the almost exclusive irrigation of lucerne for seed production.

The irrigation supplies are obtained from a shallow (about 25 m thick) and transmissive unconfined aquifer, comprising the Quaternary Padthaway and Bridgewater Formations which as discussed previously form part of the Tertiary Limestone Aquifer within certain areas of the Designated Area.

Currently about 4 500 hectares of land is irrigated. Flood irrigation is the predominant irrigation system utilised due to the relatively high salinity of the groundwater supplies being used for irrigation purposes, with the salinity ranging from about 3000 to over 8000 mg/L.

Control of groundwater use has been in place since 1984 due to concerns about the sustainability of the resource. About 32 000 ML is currently allocated for irrigation use per annum and during the 1993/94 irrigation season about 27 000 ML were utilised.

Groundwater levels and quality have been regularly monitored since the early 1980's. A long term decline in groundwater levels of about 0.5 m per decade is evident in the area and a noticeable increase in groundwater salinity has been observed. The salinity increases range from about 30 to over 200 mg/L per annum, with the higher increases being associated with areas where the salinity of the groundwater exceeds 5000 mg/L.

8.5.3 *Conclusions*

The South Australian experiences in the Padthaway and Keith irrigation areas highlight a long term deterioration in groundwater quality that can be directly attributed to irrigation activity.

In relation to the Designated Area, there are similarly occurring environments such as those at Padthaway and Keith in Hydrogeological Province 1 occurring south of Zone 4.

Whilst these irrigation experiences have been documented in areas where the Tertiary Limestone Aquifer occurs at relatively shallow depths, the potential exists for similar groundwater quality deterioration in irrigation areas where the depth to the aquifer is greater. The expected time-frame for such changes to occur or be confidently recognised is likely to be longer than for those documented in shallow groundwater areas, which has generally been about ten years.

It is concluded therefore that Hydrogeological Provinces 1 and 2 are susceptible to increases in groundwater salinity, with the rate of groundwater salinity increase largely governed by:

- the density of irrigation activity
- the salinity of the groundwater used for the irrigation
- the volume of groundwater extracted relative to the sustainable yield of the aquifer
- the nature of the soils and the presence of any aquitards overlying the aquifer.

8.6 Salt Accession Mechanisms

In sedimentary sequences of marine origin the initial salinity of groundwater is that of the residual (connate) water from the time of deposition of the sediments. Several mechanisms contribute to the subsequent modification of the relict groundwater salinity. These include:

- groundwater residence time and flow velocities
- mobilisation of salt stored in the unsaturated zone
- groundwater recycling
- salt importation
- rainfall chemistry

A brief description of these processes is provided below.

8.6.1 Groundwater Residence Time and Flow Velocity

Chebotarev (1955) first outlined the variation in groundwater chemistry that occurs as a result of its progressive chemical modification from recharge to discharge area. The chemical variation, which reflects the tendency of groundwater towards the composition of sea water, results from dissolution of the aquifer matrix by the moving groundwater. The concentration of dissolved minerals in groundwater is therefore directly proportional to the length of the flow path and to the residence time of the groundwater. Rapidly moving groundwater is therefore likely to have lower concentrations of salts than slowly flowing groundwater over an equivalent distance, through an equivalent aquifer matrix.

8.6.2 Mobilisation of Salt Stored in the Unsaturated Zone

Where evapotranspiration exceeds rainfall, the absence of a leaching fraction can result in accumulation of salts within the root zone. This may occur seasonally, such as over the summer period, or over longer periods depending on the climatic conditions.

Some of these salts are leached downwards to the aquifer with infiltrating rainfall.

Other salts stored in the soil profile can be re-mobilised when groundwater levels rise. Alternatively, an increased water flux through the unsaturated zone can remobilise salts and form pulses of hyper-saline recharge water. This increase in water flux can result from increased recharge following vegetation clearance, changes in land use, large episodic recharge events or regional climatic changes.

8.6.3 Groundwater Recycling

Use of groundwater can result in recycling of groundwater and a gradual increase in salinity where inadequate throughflow and consequently insufficient salt export occurs.

Excessive pumping can cause an extensive drawdown cone which can induce lateral and/or vertical migration of higher salinity water in adjacent aquitards and aquifers into the pumped aquifer.

8.6.4 *Salt Importation*

Runoff from urban areas, particularly where access to the watertable is enhanced by the use of drainage wells in a karstic hydrogeological environment, can increase the total dissolved salt concentration of the recharge water.

8.6.5 *Rainfall Chemistry*

Distance from the coastline and long term climatic trends can change the chemistry of the rainfall, and therefore the vertical recharge water. Such changes are unlikely to be observed in the short term but rather after many years of monitoring (if at all).

8.6.6 *Conclusions*

The significance of the salt accession mechanisms in the Designated Area is dependant on the hydrogeological conditions and the land use. For example, mobilisation of salts in the unsaturated zone is likely to be an important mechanism in areas where the native vegetation has been cleared and increased recharge is occurring. In irrigation areas, the recycling of groundwater and possible inter-aquifer leakage may be significant. In Zones 10 and 11, where long groundwater flow paths are evident, residence time and groundwater flow velocity may have an impact on water quality.

It is therefore essential to have a good understanding of the dominant groundwater processes operating in particular areas to assess the nature and significance of the salt accession mechanisms to the Tertiary Limestone Aquifer.

8.7 Consequences of Groundwater Salinity Increases

In order to gain some understanding of the impact of groundwater salinity increases should these occur through the Designated Area, the general consequences of such salinity changes were considered in relation to groundwater use for agricultural, domestic and municipal purposes. The socio-economic impacts that would occur have not been considered but would need to be broadly addressed in the adoption of specific groundwater management policies.

8.7.1 Agricultural Impacts

The agricultural impacts of most likely significance are related to stock water use and effect on irrigated produce.

The groundwater salinity for stock water use is, apart from the northern areas in Zone 11, considered to be well within accepted stock salinity tolerance levels. Significant annual increases in groundwater salinity would need to occur for some impact to become manifest. It is unlikely that this situation would occur as such salinity increases would have resulted in earlier more severe consequences, as described below, requiring management intervention. Should management fail to prevent such salinity increases from occurring, landowners would need to seek alternate water supplies - with the Tertiary Confined Sand Aquifer being the most appropriate source.

In relation to groundwater use for irrigated agricultural production, salinity increases would result in declining crop yields until the salinity tolerance levels of individual crops are reached. Irrigators faced with this situation would need to change their irrigated crops to more salt tolerant species, or if this is not possible, retire from the industry.

Available information demonstrating the relationship between crop yield and irrigation water salinity was sourced (Ayers, 1977) and data for several of the more commonly irrigated crops were examined to determine the likely impacts, as shown in Table 10.

TABLE 10: INFLUENCE OF IRRIGATION WATER SALINITY ON YIELD POTENTIAL OF SELECTED CROPS

CROP	YIELD POTENTIAL			
	EC* - 100%	EC* - 90%	EC* - 75%	EC* - 50%
Potato	1100	1700	2500	3900
Onion	800	1200	1800	2900
Clover Pasture	1000	2200	3900	6800
Grape	1000	1700	2700	4500

* EC is Electrical Conductivity as microsiemens/cm at 25°C

Table 10 indicates that reductions in irrigated crop yields are related to the salinity tolerances of the crops. Other factors which may also have some influence are soil type, climatic conditions and nature of irrigation application.

To examine what may be an accepted groundwater salinity increase for these crops, it was assumed that a 25% loss in irrigated production could possibly be tolerated. The data from Table 10 were used to determine rates of salinity increase for various time-frames (10, 20, 50 and 100 years) for such groundwater salinity changes to occur. The results for these cases are presented in Table 11.

TABLE 11: GROUNDWATER SALINITY INCREASES FOR VARIOUS TIME-FRAMES RESULTING IN A 25% LOSS IN IRRIGATED CROP YIELD FOR SELECTED CROPS

CROP	EC* INCREASE FOR 25% LOSS IN IRRIGATED CROP YIELD	CORRESPONDING RATE OF ANNUAL EC* INCREASE FOR VARIOUS TIME-FRAMES			
		YEARS			
		10	20	50	100
Potato	1400	140	70	28	14
Onion	1000	100	50	20	10
Clover Pasture	2900	290	145	58	29
Grape	1700	170	85	34	17

* EC is Electrical Conductivity as microsiemens/cm at 25°C

It is apparent from Table 11 that the rates of groundwater salinity increase vary according to the salt tolerance of the particular irrigated crops. If it is assumed that groundwater salinities need to be managed to achieve a 50 year sustainable irrigated agricultural production and accepting a 25% loss in crop yield, then the rate of groundwater salinity increase needs to be contained to about 20 to 30 electrical conductivity units (12 to 18 mg/L) per annum for more salt sensitive irrigated crops. This assumes that currently the groundwater salinities are well within the salinity tolerance levels of irrigated crops and no yield reduction is presently occurring.

8.7.2 Domestic Water Supply Impacts

Groundwater use for domestic water supplies occurs through large parts of the Designated Area, apart from some localised areas and the northern part of Zone 11. Most domestic water supply installations would only be used for non-potable supplies, with the exception of those areas in the southern part of the Designated Area where the groundwater salinity is less than 1000 mg/L.

Such groundwater users would need to seek alternate water supplies if unacceptable salinity increases occur. Possible options would include increased use of rainwater installations, sourcing groundwater from the Tertiary Confined Sand aquifer (subject to economic considerations) and, in the worst cases, being serviced by a reticulated supply.

8.7.3 Municipal Water Supply Impacts

Several towns located either within or near the Designated Area source reticulated groundwater supplies from the Tertiary Limestone Aquifer (eg Pinnaroo, Bordertown, Penola and Mount Gambier). Other towns throughout the Designated Area rely on the groundwater resources of the Tertiary Confined Sand Aquifer.

In the event that groundwater salinities for the Tertiary Limestone aquifer increase to unacceptable levels, municipal water supplies sourced from this aquifer would need to be abandoned and alternate supplies be sought where possible from the Tertiary Confined Sand Aquifer.

8.7.4 Conclusions

It is difficult to precisely quantify the consequences to existing groundwater users of an increase in groundwater salinity for the Tertiary Limestone Aquifer.

It would appear that the greatest impact is likely to be experienced by the irrigation industry, particularly irrigators of less salt tolerant crops who could be affected by groundwater salinity increases in the order of 20 mg/L per annum.

Predictive groundwater salinity modelling of the Tertiary Limestone Aquifer for various groundwater management scenarios would assist in assessing more fully the likely consequences of any groundwater salinity increases.

8.8 Reported Salinity Increases in Zones 4A and 5A

As a result of studies of vertical recharge rates in Zones 4A to 7A by the CSIRO Division of Water Resources (Herczeg and Leaney, 1993), it was concluded that long term increases in groundwater salinity in Zones 4A and 5A had been caused by the irrigation activities within these areas.

This conclusion was based on the results of sampling a number of private water supply wells through the area for which historic groundwater chloride concentrations were available, and examining the changes for this parameter. The results for these wells are presented in Table 12.

The historic changes in chloride concentration were plotted on a base plan showing the vegetation and land use (see Figure 21) to examine whether any relationships were evident.

The results indicate that there is no obvious correlation between the changes in chloride concentrations and land use, particularly irrigation areas. Whilst there are some increases in chloride concentrations in the vicinity of irrigation areas, there are some chloride concentration increases that are well removed from any irrigation activity and there are some decreases in chloride concentrations that occur near irrigation areas.

In addition, there appears to be no clear correlation between changes in chloride concentrations and the area of groundwater salinity increase in Zone 6A (see Section 8.4 of this report), although this observation is only based on a few data points.

TABLE 12 : COMPARISON OF HISTORIC AND 1990/91 GROUNDWATER CHLORIDE CONCENTRATIONS

WELL	HISTORICAL CHLORIDE (mg/L)	YEAR	RECENT CHLORIDE (mg/L)	YEAR	ANNUAL CHLORIDE CHANGE (mg/L)
ZONE 4A					
7023-1124	542	1954	708	1991	+4.49
7023-1317	239	1947	330	1991	+2.07
7023-1311	396	1946	337	1991	-1.31
7023-1161	441	1950	611	1991	+4.15
7023-1155	1352	1952	1170	1991	-4.67
7023-1132	537	1955	608	1991	+1.97
7023-1177	519	1947	663	1991	+3.27
7023-1224	441	1947	611	1991	+3.86
7023-1030	293	1954	241	1990	-1.44
7023-1129	421	1954	572	1990	+4.19
7023-1152	748	1956	726	1990	-0.65
7023-1163	590	1950	630	1990	+1.00
7023-1325	400	1946	175	1990	-5.11
7023-1357	195	1949	263	1990	+1.66
7023-1494	124	1953	154	1990	+0.81
7023-1578	221	1938	223	1990	+0.04
ZONES 5A and 6A					
7024-0525	355	1947	438	1991	+1.89
7024-0607	472	1947	760	1991	+6.55
7024-0532	355	1957	325	1991	-0.88
7024-0609	258	1958	410	1991	+4.61
7024-1055	391	1955	336	1990	-1.57
7024-1054	234	1957	533	1990	+9.06
7024-1238	616	1956	702	1990	+2.53
7024-1236	254	1955	346	1990	+2.63
7024-0766	467	1955	787	1990	+9.14
7024-0769	311	1957	525	1990	+6.48
7024-0911	451	1955	417	1990	-0.97

A small sub-set of these wells were re-sampled in March 1994 by the Department of Mines and Energy, with the samples being analysed for chloride and total dissolved salts. These chloride analysis results are presented in Table 13. The results show that the 1994 chloride concentrations are essentially the same as those recorded in 1991, thereby still indicating a historic increase in chloride concentration.

TABLE 13 : COMPARISON OF HISTORIC, 1991 AND 1994 GROUNDWATER CHLORIDE CONCENTRATIONS

WELL	HISTORICAL CHLORIDE (mg/L)	1991 CHLORIDE (mg/L)	MARCH 1994 CHLORIDE (mg/L)
7023-1177	519 (47)	663	578
7023-1155	1352 (52)	1170	1150
7023-1124	542 (54)	708	667
7023-1132	537 (55)	608	600
7024-0607	472 (47)	760	706
7024-0525	355 (47)	438	418
7024-0532	355 (57)	325	310

It is concluded that whilst an increase in chloride concentration of the groundwater in the Tertiary Limestone Aquifer has been in recorded in some wells, the conclusion that this is solely related to irrigation activity is considered tenuous.

The increases in chloride concentration can also be related to other factors such as enhanced vertical recharge following clearance of native vegetation and remobilisation of salts stored within the soil profile, and dissolution of salts in the unsaturated profile in areas of rising groundwater levels.

Additional longer term monitoring data are required to determine the extent of the increase in groundwater salinity in these irrigation areas. A more intense network of monitoring wells has been established by the Department of Mines and Energy to provide these data.

9. OPTIONS FOR GROUNDWATER SALINITY MANAGEMENT

The maintenance of groundwater salinity to sustain the groundwater resources of the Tertiary Limestone Aquifer for both current and future use is a key objective of the Groundwater (Border Agreement) Act.

Whilst there are provisions within this Act to manage groundwater quality by setting a permissible level of salinity for any Zone of the Designated Area, this management approach has not been adopted for any Zone at this stage.

The section below discusses the options that could be considered for such management.

Three options for groundwater salinity management have previously been proposed (Evans, 1992). Because of an insufficient understanding of the likely causes of groundwater salinisation, however, no management option has been adopted at this time. A summary of these options is provided below.

- setting an upper permissible level of salinity for each Zone. The level of salinity specified would be relative to the beneficial use of the groundwater. The permissible level of salinity would likely vary between Zones, depending on the actual salinity of the groundwater in each Zone and its predominant use . Given the variation in groundwater salinity of the Tertiary Limestone Aquifer within the individual Zones of the Designated Area, this approach could result in significant degradation of the groundwater resource prior to any management intervention.

- setting an increase in salinity expressed as a percentage of a base salinity. The base salinities for each Zone could be those from the first monitoring report (ie. March 1988). Due to the variation in groundwater salinity within the individual Zones, such an approach could also result in significant degradation of the groundwater resource prior to any management intervention.

- specification of an acceptable annual rate of salinity change for each Zone on the basis of observed trends. This is considered to be the most useful management option to provide an early warning of possible impending salinity problems. For adoption of this management approach, however, there needs to a certain confidence in the salinity monitoring results and the salinity trends need to be determined over a reasonable time-frame. The experience in existing irrigation areas in the South East of South Australia suggests that the minimum time-frame for the assessment of reliable salinity trends should be at least ten years. It is likely that some salinity trends may not become manifest for some decades.

An additional difficulty with this management approach is that the salinity trends are assessed at the individual monitoring sites. Any observed water quality degradation could be a very localised impact and may not pose a serious threat to the overall groundwater resources of a particular Zone.

Also, there could be some instances (such as in Zone 6A) where an increase in groundwater salinity may not be due to groundwater withdrawals and use but rather results from increased salt accessions to the aquifer from other land use practices (clearance of native vegetation and removal of pine plantations are two documented examples). For these cases, there may be some justification for no restrictive management approach but rather encourage groundwater use prior to its degradation.

It is clear that the management of groundwater salinity within the Designated Area is difficult. It is essential to have a good understanding of the dominant groundwater processes operating in particular areas to assess the nature and significance of the salt accession mechanisms to the Tertiary Limestone Aquifer. It is possible that in some cases a number of different processes may occur.

It is also clear that salinity changes may only occur in part of a particular Zone and this should not disadvantage groundwater users in the remainder of the Zone.

There is a need for a flexible approach and agreed rates of salinity increase should be used as indicators of the need to review management policies.

Predictive groundwater salinity modelling of the Tertiary Limestone Aquifer for various groundwater management scenarios is considered necessary to determine the most appropriate salinity management option.

10. REVIEW OF PERMISSIBLE ANNUAL VOLUMES

The Permissible Annual Volumes (PAVs) for the Zones of the Designated Area are based on the groundwater resources of the Tertiary Limestone Aquifer.

The PAVs have been determined taking into consideration the components of vertical recharge, lateral groundwater throughflow and groundwater held in storage for the aquifer.

For Zones 1 through to 8, the PAVs have previously been solely based on the volume of vertical recharge to the Tertiary Limestone Aquifer and have not included either a proportion of the lateral groundwater throughflow or a proportion of the groundwater held in storage. The basis for this management approach has been to maintain the lateral groundwater throughflow to mitigate any possible longer term changes in groundwater quality that may occur as a result of intensive irrigation development.

For the remaining Zones 9, 10 and 11, the PAVs have previously been based on all three components of the groundwater resource mentioned earlier. The basis for this management approach has been that there is a reasonably significant volume of groundwater held in storage through this area that could be economically utilised. If any groundwater quality deterioration was to occur, it would take a considerable period of time to become manifest given the relatively great depth to the water table. Also, it was considered that some deterioration of groundwater quality was ultimately expected as a result of salt accessions to the aquifer following clearance of native vegetation in the area.

In order to review the current Permissible Annual Volumes, the results for this five year technical work plan have been summarised for the individual Zones of the Designated Area in South Australian and Victoria as shown in Tables 14 and 15 respectively. Specifically:

- the volumes of vertical recharge are those determined by examination of the hydrographic responses recorded in observation wells throughout Hydrogeological Provinces 1 and 2, and correlating these responses to both soil types and land uses (as described in Section 7.3.6). A consistent storage co-efficient of 0.1 was used to assess the vertical recharge rates.

- the volumes of lateral groundwater inflow to the Zones are based on the current assessments of throughflow as described in Section 7.4.2.

- the proportion of lateral groundwater throughflow for each Zone was determined by multiplying the groundwater inflow to the Zone by the ratio of the average length of groundwater flow path through the Zone to that of the length of the flow path from the eastern edge of the Zone to the discharge point (either being the coast or the River Murray).

This is a slight departure from the original determinations of this component, where the total length of the flow path was used.

TABLE 14: COMPARISON OF CURRENT PAVS AND RESULTS OF FIVE YEAR ASSESSMENT FOR ZONES IN THE SOUTH AUSTRALIAN PORTION OF THE DESIGNATED AREA

ZONE	CURRENT PAV (ML/yr)	LAND AREA (km^2)	VOLUME OF VERTICAL RECHARGE (ML/yr)§	APPROXIMATE VOLUME OF LATERAL GROUNDWATER INFLOW TO ZONE+	PROPORTION OF LATERAL THROUGH-FLOW (ML/yr)	VOLUME OF GROUNDWATER FROM STORAGE* (ML/yr)	
						S = 0.1	S = 0.15
1A	71 000	665	31 090	N/D	N/D	3 330	5 000
2A	25 000	556	36 390	N/D	N/D	2 780	4 170
3A	24 000	556	45 600	6 000	1 300	2 780	4 170
4A	20 000	556	33 580	13 700	2 710	2 780	4 170
5A	18 500	556	19 980	16 900	3 320	2 780	4 170
6A	8 500	556	10 760	6 200	1 340	2 780	4 170
7A	7 500	556	8 070	10 300	1 930	2 780	4 170
8A	3 500	556	7 720	3 650	570	2 780	4 170
9A	6 000	1110	2 450	4 700	830	5 550	8 330
10A	6 000	1110	N/A	3 400	1 100	5 550	8 330
11A	12 000	2146	N/A	5 200	2 360	10 730	16 100

§ The volumes of vertical recharge are those shown in Table 6.

N/A Not applicable due to the confined nature of Tertiary Limestone Aquifer, with the vertical recharge assumed to be zero.

N/D Not determined due to groundwater flow being parallel to the State Border.

\+ The volumes of groundwater inflow were based on the determinations shown in Table 7.

* The volume of groundwater from storage is derived by assuming an annual decline in the potentiometric head of the Tertiary Limestone aquifer of 0.05 m, for two values of storage co-efficient (0.1 and 0.15).

TABLE 15: COMPARISON OF CURRENT PAVS AND RESULTS OF FIVE YEAR ASSESSMENT FOR ZONES IN THE VICTORIAN PORTION OF THE DESIGNATED AREA

ZONE	CURRENT PAV (ML/yr)	LAND AREA (km^2)	VOLUME OF VERTICAL RECHARGE (ML/yr)§	APPROXIMATE VOLUME OF LATERAL GROUNDWATER INFLOW TO ZONE+	PROPORTION OF LATERAL THROUGH-FLOW (ML/yr)	VOLUME OF GROUNDWATER FROM STORAGE* (ML/yr)	
						S = 0.1	S = 0.15
1B	71 000	782	45 720	14 600	12 780	3 910	5 870
2B	25 000	556	41 900	15 100	5 650	2 780	4 170
3B	16 500	556	20 630	2 900	690	2 780	4 170
4B	14 000	556	17 350	1 100	180	2 780	4 170
5B	18 500	556	2 700	15 600	2 600	2 780	4 170
6B	6 000	556	10	4 600	830	2 780	4 170
7B	7 000	556	3 430	5 400	930	2 780	4 170
8B	3 500	556	600	2 000	270	2 780	4 170
9B	6 000	1110	N/A	2 500	380	5 550	8 330
10B	6 000	1110	N/A	2 300	770	5 550	8 330
11B	12 000	2115	N/A	4 500	1 850	10 580	15 870

§ The volumes of vertical recharge are those shown in Table 6.

N/A Not applicable due to the confined nature of Tertiary Limestone Aquifer, with the vertical recharge assumed to be zero.

\+ The volumes of groundwater inflow were based on the determinations shown in Table 7.

* The volume of groundwater from storage is derived by assuming an annual decline in the potentiometric head of the Tertiary Limestone aquifer of 0.05 m, for two values of storage co-efficient (0.1 and 0.15).

- the volumes of groundwater storage were derived by using the current permissible annual rate of potentiometric head lowering of 0.05 m, and using two values of storage co-efficient 0.1 and 0.15.

  Previous assessments of the volumes of groundwater from storage were based on a specific yield of 0.1. Additional technical data comprising geophysical logging, computer modelling and investigations by the CSIRO indicate that a storage co-efficient of 0.15 could be used for the northern Zones (S. Barnett, pers. comm.)

Comparison of the current PAVs with the components of vertical recharge, proportion of lateral groundwater throughflow and volume of groundwater from storage for each of the Zones as shown in Tables 14 and 15, indicates the following groups of Zones with broad similarities.

- **Zones 1A and 1B**

  The PAVs for both these Zones are based on the vertical recharge. The assessed volumes of vertical recharge are considerably less than the current PAVs (about 40 000 ML/yr less for Zone 1A and about 25 000 ML/yr less for Zone 1B).

  These differences arise from the earlier adopted vertical recharge rate of 175 mm per year for cleared areas and the current assessments which only range up to 130 mm per year. These current assessments may be quite conservative as the Tertiary Limestone Aquifer is particularly karstic in these Zones and the storage co-efficient of 0.1 used for the determination of the recharge rates may not be appropriate. Although not incorporated in the PAVs, the volumes from storage for the Zones are not particularly significant compared to the PAVs. Similarly the lateral groundwater throughflow is not included in the PAVs, and was not calculated for Zone 1A and is a minor volume relative to the PAV for Zone 1B.

  Whilst there should be consideration of a reduction in the PAVs for these Zones, it is felt that the assessment of vertical recharge is conservative and needs to be further examined. A storage co-efficient of 0.2, for example, would result in the current vertical recharge assessments being similar to the PAVs.

  The groundwater salinity of the Tertiary Limestone Aquifer has remained static or is even showing some decrease through these Zones. The groundwater level trends for the Tertiary Limestone Aquifer indicate a longer term decline which is predominantly related to the areas of softwood afforestation. This decline exceeds in some cases the currently adopted rate of potentiometric surface lowering of 0.05 m per annum.

  Based on the above factors, it is considered that the current PAVs should be retained but the vertical recharge be reviewed as a priority in the next five technical work plan.

- **Zones 2A, 2B, 3A, 3B, 4A and 4B**

  The PAVs for these Zones are also based solely on the vertical recharge. The assessed volumes of vertical recharge are significantly greater than the current PAVs (by about 11 000, 17 000, 22 000, 4 000, 14 000 and 3 000 ML per year respectively).

For each of the Zones, both the proportion of lateral groundwater throughflow and the volume of groundwater from storage are less than the PAVs although these components are not incorporated in the PAVs.

Although there appears to be some justification for an increase in the PAVs to match the assessed vertical recharge, there are some monitoring wells through these Zones that indicate some possible increase in groundwater salinity.

It would therefore be prudent to adopt a conservative management approach and retain the current PAVs. It is also considered that these PAVs be reviewed as a matter of priority once the predictive groundwater salinity modelling has been undertaken.

- **Zones 5A and 7A**

  The PAVs for these Zones are similarly based solely on the vertical recharge. The assessed volumes of vertical recharge are about the same as the current PAVs.

  For both Zones, the proportions of lateral groundwater throughflow and the volumes of groundwater from storage have become more significant when compared to the PAVs.

  Given that there are some monitoring wells which indicate an increase in groundwater salinity, it is considered that the current PAVs be retained and also be reviewed as a matter of priority once the predictive groundwater salinity modelling has been undertaken.

- **Zones 6A and 8A**

  The PAVs for these Zones are also based solely on the vertical recharge. The assessed volumes of vertical recharge for both Zones exceed the PAVs by about 2 000 and 4 000 ML per year respectively.

  The volume of groundwater from storage for both Zones has become more significant when compared to the PAVs although these components are not included in the PAVs.

  An increase in groundwater salinity is evident within Zone 6A and this is attributed to mobilisation of salts stored in the unsaturated profile following the increased vertical recharge apparent in this area. There is also a general rise in groundwater levels evident in this Zone.

  A long term rise in groundwater levels is evident within Zone 8A but no particular long term changes in groundwater quality are apparent.

Given that there is a deterioration in groundwater quality within Zone 6A, which is not due to irrigation withdrawals but results from more natural causes, it is considered that there is some justification for an increase to the PAV for this Zone up to the level of the assessed vertical recharge. Similarly for Zone 8A, the PAV should be increased up to the level of the assessed vertical recharge given the longer term rise in groundwater levels.

- **Zones 5B, 6B, 7B and 8B**

The current PAVs for all these Zones are also solely based on the vertical recharge. The assessed volumes of vertical recharge are significantly less than the current PAVs. This is a result of the recognition of the confined nature of the Tertiary Limestone Aquifer through all or part of these Zones, with no vertical recharge occurring to the aquifer in these areas.

The volumes of groundwater from storage and the proportions of the lateral groundwater throughflow for these Zones are significant when compared to the PAVs.

It is considered that the current management prescription for Zones 5B, 6B 7B and 8B is not appropriate and needs to be reviewed. A similar management prescription to that currently adopted for the northern Zones of the Designated Area where the Tertiary Limestone Aquifer is confined would seem appropriate. This approach would result in a significant reduction in the PAVs for Zones 5B and 6B, and a slight increase in the PAV for Zone 7B. For Zone 8B, this approach would result in a similar PAV to that currently endorsed.

- **Zones 9A, 9B, 10A, 10B, 11A and 11B**

The PAVs for these Zones are based on the three components of the groundwater resources of the Tertiary Limestone Aquifer as mentioned previously. The assessed volumes of vertical recharge indicate that there is no direct vertical recharge to the Zones, apart from an area in Zone 9A, due to the confined nature of the Tertiary Limestone Aquifer.

The volumes of groundwater from storage using a storage co-efficient of 0.15 are larger than the current PAVs.

There is some justification for increasing the current PAV for Zone 9A as the total of the vertical recharge, proportion of the lateral groundwater throughflow and the volume of groundwater from storage (using a storage co-efficient of 0.15) exceed the adopted PAV. The Border Review Committee are currently considering a recommendation for such an increase for Zone 10A.

For Zones 9B, 10B, 11A and 11B, data for the storage co-efficient are sparse or do not exist and therefore the currently adopted value of 0.1 should be retained. The total of the volumes of groundwater from storage and the proportion of lateral throughflow for each of these Zones are similar to the currently adopted PAVs. The present PAVs should in this case be retained.

It is concluded that the current PAVs for some Zones are not appropriate and should be reviewed, and the manner of determination of the PAVs for some Zones should be reconsidered. The predictive groundwater salinity modelling proposed for the Designated Area would assist in the review of the PAVs.

The recommended PAVs for the Zones of the Designated Area based on results of the five-year technical review are presented in Table 16.

The review of the PAVs for the Zones highlights the importance of knowledge of both the vertical recharge and the storage co-efficient of the Tertiary Limestone Aquifer and the need for further assessment of these parameters through the Designated Area.

TABLE 16: CURRENT AND RECOMMENDED PAVS BASED ON FIVE-YEAR TECHNICAL REVIEW

ZONE	CURRENT PAV (ML/year)	RECOMMENDED PAV (ML/year)	COMMENT
1A	71 000	71 000	No change
1B	71 000	71 000	No change
2A	25 000	25 000	No change
2B	25 000	25 000	No change
3A	24 000	24 000	No change
3B	16 500	16 500	No change
4A	20 000	20 000	No change
4B	14 000	14 000	No change
5A	18 500	18 500	No change
5B	18 500	8 100	Decrease
6A	8 500	10 700	Increase
6B	6 000	3 600	Decrease
7A	7 500	7 500	No change
7B	7 000	7 100	Slight increase
8A	3 500	7 700	Increase
8B	3 500	3 600	Slight increase
9A	6 000	11 600	Increase
9B	6 000	6 000	No change
10A	6 000	9 400	Increase
10B	6 000	6 000	No change
11A	12 000	12 000	No change
11B	12 000	12 000	No change

11. REVIEW OF OTHER COMPONENTS OF THE GROUNDWATER (BORDER AGREEMENT) ACT

11.1 Review Of The Permissible Distance From The South Australian And Victorian Border

Under the Groundwater (Border Agreement) Act, the Border Review Committee must consider and approve all applications for well construction and groundwater extractions within one kilometre of the State Border in order to manage the cross border impact of groundwater extractions. This distance is referred to as the permissible distance. The permissible distance of 1 km is defined by the hydrogeological properties of the aquifer. New data compiled in this report on the hydrogeological properties of the aquifer is consistent with previous results and it is recommended that the permissible distance remains at one kilometre.

11.2 Review Of The Permissible Rate Of Potentiometric Surface Lowering

The Groundwater (Border Agreement) Act also specifies a permissible average annual rate of decline of the potentiometric surface of the Tertiary Limestone Aquifer. This rate of decline is currently set at 0.05 m per annum for all Zones of the Designated Area. Under this criterion, approval for well construction (including alteration of existing wells) or groundwater extraction will not be given in Zones where the rate of potentiometric decline exceeds the permissible rate over the preceding 5 years.

The permissible rate of decline has been exceeded in parts of Zones 1A, 1B, 11A and possibly 11B, as shown in Figure 16. The decline in groundwater levels in Zones 1A and 1B is due to the impact of softwood afforestation on the groundwater resources and, as has been previously discussed, this impact is essentially restricted to the areas of the softwood plantations. The decline in groundwater levels in Zones 11A and possibly 11B is considered to be a result of irrigation groundwater withdrawals. The rate of decline exceeding 0.05 m per annum may only be a localised impact.

The Border Review Committee will need to consider the implications to existing and potential groundwater users should this aspect of the Act be enforced in these Zones.

It is considered that the permissible rate of decline is currently set at an appropriate level to prevent over extraction and maintain the groundwater resources of the Tertiary Limestone Aquifer, and should not be changed.

12. STATUS OF THE TERTIARY CONFINED SAND AQUIFER

The Tertiary Confined Sand Aquifer is less developed as a groundwater resource than the Tertiary Limestone Aquifer because of higher drilling and pumping costs, and the availability of a fresh groundwater resource from the overlying Tertiary Limestone Aquifer. For this reason there has generally been less emphasis on investigation of the Tertiary Confined Sand Aquifer and less is known hydrogeologically and hydrochemically about this aquifer.

In south-western Victoria and in south-eastern South Australia, the Tertiary Confined Sand Aquifer is predominantly utilised for town water supplies. In Zones 1 through to 10, available groundwater chemistry data indicates that the salinity of the Tertiary Confined Sand Aquifer is between 600 and 3000 mg/l. This quality is within the range that is useful for stock, domestic and most agricultural purposes.

Additionally in the northern part of Zone 10 and in Zone 11, the water quality is poor in the Tertiary Confined Sand Aquifer and there is potential for upward leakage of more saline water from the Tertiary Confined Sand Aquifer to the Tertiary Limestone Aquifer. This potential is enhanced in close proximity to structural features such as the Danyo Fault, which passes through Zone 10. A more detailed explanation of the hydrogeology of the Tertiary Confined Sand Aquifer is given in Sections 5 and 6 of this report.

Some monitoring of water levels of the Tertiary Confined Sand Aquifer has been ongoing since 1988, although there has been no regular monitoring of the salinity of the aquifer. In recognition of the Tertiary Confined Sand Aquifer as a potential and important groundwater resource, some water chemistry monitoring programs were initiated in May 1994 to enable an assessment of the Tertiary Confined Sand Aquifer to be undertaken.

In South Australia and Victoria respectively, 23 and 22 wells form the monitoring networks. The locations of the groundwater level monitoring wells through the Designated Area are shown in Figure 22.

Although data are sparse, a preliminary assessment of the Tertiary Confined Sand Aquifer resource has been undertaken. Throughflow for the Tertiary Confined Sand Aquifer was calculated from a flow net analysis using potentiometry from the June 1994 water level data. Examination of published hydraulic data for this aquifer indicated that the transmissivity of the aquifer does not vary as markedly as that for the Tertiary Limestone Aquifer, and that the adoption of an uniform transmissivity of 1100 m^2/day for this preliminary assessment was appropriate.

The volumes of groundwater inflow at the eastern boundary of Zones 1B to 9B were determined as shown in Table 17. No determinations were made for Zones 10B and 11B due to the lack of hydraulic data.

TABLE 17 : ESTIMATES OF GROUNDWATER THROUGHFLOW FOR THE TERTIARY CONFINED SAND AQUIFER

ZONE	GROUNDWATER INFLOW AT EASTERN BOUNDARY (ML/YEAR)
1B	4 000
2B	10 000
3B	8 000
4B	16 000
5B	32 000
6B	8 000
7B	8 000
8B	4 000
9B	4 000
10B	N/D
11B	N/D

N/D Not determined

As shown in Table 16, the volume of groundwater inflow to the Zones of the Designated Area ranges from approximately 4 000 to 32 000 ML per annum. Should a similar management approach be adopted for this aquifer as that for the groundwater throughflow in the Tertiary Limestone Aquifer, the individual volumes for some Zones would represent a viable resource.

There has been no assessment of the volume of inter-aquifer leakage for this aquifer due to a general lack of data.

This preliminary assessment indicates that the Tertiary Confined Sand Aquifer groundwater resources can provide an alternate resource to that of the Tertiary Limestone Aquifer for some Zones of the Designated Area. The determination and adoption of a separate set of Permissible Annual Volumes for the Tertiary Confined Sand Aquifer should be a priority in the next five year technical work plan.

13. SUMMARY AND CONCLUSIONS

The following conclusions are made based on the investigations and assessments undertaken for the five year technical review of the Border (Groundwater Agreement) Act for the period 1991 to 1995.

► **Groundwater Use** (Section 2)

- the Permissible Annual Volumes in some South Australian Zones are fully allocated
- the data for licensed groundwater usage in both States are generally poor which precludes an accurate assessment of some groundwater trends
- licensed groundwater use compared with allocated volumes is generally low
- there is a lack of data for the total groundwater usage in both States

► **Hydrogeological Provinces Of Designated Area** (Section 6.2)

- three Hydrogeological Provinces have been defined within the Designated Area based on the varying hydrogeological conditions of the Tertiary Limestone Aquifer

► **Land Use And Vegetation** (Section 7.3.1)

- large tracts of native vegetation and broad acre cropping and grazing are the dominant land uses in the northern Zones 9, 10 and 11
- agricultural cropping and dryland grazing is by far the dominant land use in the central Zones 5 to 8, whilst the majority of irrigated agriculture is found in South Australia
- mixed land uses are evident in Zones 1 to 4 with grazing being dominant and pine plantations covering substantial areas especially in South Australia. Native vegetation also covers significant areas, mainly in Victoria, whilst areas of irrigated agriculture mainly occur in South Australia.

► **Soil Associations** (Section 7.3.2)

- the four major soil types through the southern part of the Designated Area are the duplex, clay, sand and *terra rossa* soils.

- **Extent And Impact Of Shallow Aquitards** (Section 7.3.3)

  - regionally extensive aquitards which influence the magnitude of vertical recharge to the Tertiary Limestone Aquifer only occur through Hydrogeological Provinces 2 and 3 of the Designated Area.

- **Groundwater Level Monitoring Trends** (Section 7.3.4)

  - there are a number of different groundwater level trends for the Tertiary Limestone Aquifer throughout the Designated Area which reflect varying land management practices.
  - a decline in groundwater levels of up to about 0.1 m per annum in the softwood plantation areas, mainly in Zones 1A and 1B.
  - a rise in groundwater levels of up to 0.1 m per annum in Zones 5A, 6A and 7A due to enhanced vertical recharge following native vegetation clearance and subsequent loss of high water use perennial pastures.
  - a decline in groundwater levels of up to 0.2 m per annum in Zone 11A is likely to be related to irrigation groundwater withdrawals.
  - some of the observed declining water level trends (Zones 1A, 1B, 11A and possibly 11B) exceed the permissible rate of potentiometric lowering specified in the Border (Groundwater Agreement) Act of 0.05 m per year.
  - the length of monitoring period for a number of the Victorian observations wells is too short to confidently assess any trends.
  - continued monitoring of groundwater levels is a requisite through the Designated Area to assess the longer term impacts of changes in land use and groundwater extraction.

- **Impact Of Softwood Afforestation** (Section 7.3.5)

  - softwood plantations are having an impact on groundwater levels in the Tertiary Limestone Aquifer with a reduction in vertical recharge causing a longer term decline in water levels.
  - in some areas with shallow groundwater levels, the pine plantations may be extracting groundwater directly from the aquifer.
  - the chemical atrazine has been detected in some pine plantation areas and is attributed to its use in areas of juvenile plantings.

- an increase in groundwater salinity has been observed in an area of pine plantations that were destroyed in the 1983 bushfire. This indicates the evaporative storage of salts within the unsaturated profile with little or no vertical recharge to the aquifer.

▶ **Assessment Of Vertical Recharge Rates** (Section 7.3.6)

- vertical recharge to the Tertiary Limestone Aquifer occurs predominantly throughout Hydrogeological Provinces 1 and 2, and is influenced by the nature of both soil types and the land uses.
- vertical recharge rates of 2 to 130 mm per year have been assessed from the examination of the recorded hydrographic responses in observation wells.
- there is a gradual reduction in vertical recharge towards the north as a result of a reduction in the total rainfall, the presence of clay soils and the greater depth to the water table.

▶ **Lateral Groundwater Throughflow** (Section 7.4)

- from the additional aquifer testing undertaken in the Victorian portion of the Designated Area, the volumes of lateral groundwater throughflow for the Tertiary Limestone Aquifer have been refined with some Zones showing a general increase from previous estimates.
- the volumes of lateral groundwater throughflow mainly vary according to the transmissivity of the Tertiary Limestone Aquifer.

▶ **Inter-Aquifer Leakage** (Section 7.5)

- there is the potential for either upward or downward leakage between the Pliocene Sands and Tertiary Limestone Aquifers. Given the occurrence of the Pliocene Sands Aquifer, this is only a consideration in parts of Zones 4B, 5B, 9B, 10A and 10B and all of Zone 11.
- there is the potential for either upward or downward leakage between the Tertiary Limestone Aquifer and the Tertiary Confined Sand Aquifer. Such leakage may occur throughout the Designated Area given the general widespread occurrence of both aquifers.
- there has been no assessment of the inter-aquifer leakage due to a lack of adequate data.

- **Groundwater Salinity Monitoring Results** (Sections 8.3, 8.4)
  - bailed samples are not considered reliable enough for the collection of regional water quality data.
  - a more consistent approach to sampling is required due to the need for reliable groundwater quality monitoring data to assess any longer term trends.
  - the salinity monitoring record length is still relatively short and does not provide reasonable confidence in some of the trends apparent from some wells. This confidence is further reduced by the variation in some results caused by the collection of bailed samples from the Victorian monitoring wells.
  - increasing salinity trends are apparent in some areas (such as in Zone 6A) which can be attributed to remobilisation of salts stored in the unsaturated profile following increases in vertical recharge rates and in other cases resulting from irrigation activity.
  - further on-going salinity monitoring is required to validate some of the trends which are currently apparent.

- **Reported Salinity Trends In Similar Hydrogeological Environments** (Section 8.5)
  - the South Australian experiences in the Padthaway and Keith irrigation areas highlight a long term deterioration in groundwater quality that can be directly attributed to irrigation activity.
  - based on these experiences, it is considered that irrigation areas in Hydrogeological Provinces 1 and 2 are susceptible to increases in groundwater salinity.
  - the expected time-frame for such changes to occur or be confidently recognised is likely to be longer than for those documented in shallow groundwater areas, which has generally been about ten years.

- **Salt Accession Mechanisms** (Section 8.6)
  - the dominant salt accession mechanisms to the Tertiary Limestone Aquifer within the Designated Area are the remobilisation of salts stored in the unsaturated profile and the recycling of groundwater in irrigation areas.

- **Consequences Of Groundwater Salinity Increases** (Section 8.7)

  - it is difficult to precisely quantify the consequences to existing groundwater users of an increase in groundwater salinity for the Tertiary Limestone Aquifer.

  - there are likely to be impacts affecting groundwater use for agricultural, domestic and municipal purposes.

  - it would appear that the greatest impact is likely to be experienced by the irrigation industry, particularly irrigators of less salt tolerant crops who could be affected by groundwater salinity increases in the order of 20 mg/L per annum.

  - predictive groundwater salinity modelling of the Tertiary Limestone Aquifer for various groundwater management scenarios would assist in assessing more fully the likely consequences of any groundwater salinity increases.

- **Reported Salinity Increases In Zones 4A And 5A** (Section 8.8)

  - an increase in chloride concentration of the groundwater in the Tertiary Limestone Aquifer has been recorded in some wells in Zones 4A, 5A and 6A.

  - the conclusion that this is solely related to irrigation activity is considered tenuous.

  - the increases in chloride concentration can also be related to other factors such as enhanced vertical recharge following clearance of native vegetation and remobilisation of salts stored within the soil profile, and dissolution of salts in the unsaturated profile in areas of rising groundwater levels.

  - additional longer term monitoring data are required to determine the extent of the increase in groundwater salinity in these irrigation areas.

- **Salinity Management Options** (Section 9)

  - there are three main options for groundwater salinity management :

    - setting an upper permissible level of salinity for each Zone, relative to the beneficial use of the groundwater.

    - setting a rate of salinity increase expressed as a percentage of a base salinity.

- setting an annual rate of salinity change for each Zone on the basis of observed trends to provide early warnings of possible impending salinity problems.

- given the variation in groundwater salinity of the Tertiary Limestone Aquifer within the individual Zones of the Designated Area, the first two options could result in significant degradation of the groundwater resource prior to any management intervention.

- the third option is considered to be the most useful management approach. However, there is a need for confidence in the salinity monitoring results and the salinity trends need to be determined over a reasonable time-frame. The experience in existing irrigation areas in the South East of South Australia suggests that the minimum time-frame for the assessment of reliable salinity trends should be at least five years.

  An additional difficulty with this management approach is that the salinity trends are assessed at the individual monitoring sites. Any observed water quality degradation could be a very localised impact and may not pose a serious threat to the overall groundwater resources of the particular Zone.

  There could also be some instances where an increase in groundwater salinity may not be due to groundwater withdrawals and use but rather results from increased salt accessions to the aquifer from other land use practices (clearance of native vegetation and removal of pine plantations are two documented examples). For these cases, there may be some justification for no restrictive management approach but rather encouragement of groundwater use prior to its degradation.

- it is essential to have a good understanding of the dominant groundwater processes operating in particular areas to assess the nature and significance of the salt accession mechanisms to the Tertiary Limestone Aquifer.

- predictive groundwater salinity modelling of the Tertiary Limestone Aquifer for various groundwater management scenarios is considered necessary to determine the most appropriate salinity management option.

- **Review Of Permissible Annual Volumes** (Section 10)

  - the current PAVs were reviewed by examining the re-assessed components of vertical recharge, lateral groundwater throughflow and groundwater held in storage for the Tertiary Limestone Aquifer.

  - for Zones 1A and 1B, the PAVs are significantly less than the assessed vertical recharge. Whilst there should be consideration of a reduction in the PAVs for these Zones, it is felt that the assessment of vertical recharge is conservative and needs to be further examined. A storage co-efficient of 0.2 would result in the current vertical recharge assessments being similar to the PAVs. In addition, the groundwater salinity of the Tertiary Limestone Aquifer has remained static or is even showing some decrease. Based on these factors, it is concluded that the current PAVs should be retained but the vertical recharge be reviewed as part of the next five technical work plan.

  - for Zones 2A, 2B, 3A, 3B, 4A and 4B, the current PAVs are significantly less than the vertical recharge. Although there appears to be some justification for an increase in the PAVs to match the assessed vertical recharge rates, there are some monitoring wells through these Zones that indicate some increase in groundwater salinity even though the length of record is relatively short. It would therefore be prudent to adopt a conservative management approach and retain the current PAVs. The PAVs should be reviewed as a matter of priority once the predictive groundwater salinity modelling has been undertaken.

  - for Zones 5A and 7A, the current PAVs are about the same as the assessed volumes of vertical recharge. Given that there are some monitoring wells which indicate an increase in groundwater salinity, it is considered that the current PAVs be retained and also be reviewed as a matter of priority once the predictive groundwater salinity modelling has been undertaken.

  - for Zones 6A and 8A, the current PAVs are less than the assessed volumes of vertical recharge. An increase in groundwater salinity is indicated for monitoring wells within Zone 6A and this is attributed to mobilisation of salts stored in the unsaturated profile following the increased vertical recharge evident in this area. There is also a general rise in groundwater levels evident in both Zones. It is considered that there is some justification for an increase to the PAVs up to the level of the assessed vertical recharge.

- for Zones 5B, 6B and 7B, the current PAVs are significantly greater than the assessed volumes of vertical recharge due to the confined nature of the Tertiary Limestone Aquifer through all or part of these Zones, with little vertical recharge occurring to the aquifer. The volumes of groundwater from storage and the proportions of the lateral groundwater throughflow for these Zones are significant when compared to the PAVs. It is considered that the current PAVs are not appropriate and need to be reduced. There should also be some review of the manner of the determination of the PAV for these Zones, as the adopted PAVs are based on the assessed vertical recharge. Maintaining this approach would result in a significant reduction in the current PAVs with the licensed allocation exceeding a revised PAV in Zone 6B.

- for Zone 8B, the current PAV is significantly greater than the assessed volume of vertical recharge occurring in those parts of the Zone where the Tertiary Limestone Aquifer is not confined. In other parts of the Zone no vertical recharge occurs to the aquifer due to its confined nature. The manner of determination of the PAV for this Zone should be reviewed and a similar approach adopted to that of the northern Zones 9, 10 and 11. This would result in a similar PAV to that currently adopted.

- for Zones 9A, 9B, 10A, 10B, 11A and 11B, the PAVs for these Zones are based on the three components of the groundwater resources of the Tertiary Limestone Aquifer. The assessed volumes of vertical recharge indicate that there is no direct vertical recharge to the Zones, apart from an area in Zone 9A, due to the confined nature of the Tertiary Limestone Aquifer.

  The volumes of groundwater from storage using a storage co-efficient of 0.15 are larger than the current PAVs.

  There is some justification for increasing the current PAVs for the Zones 9A and 10A, as the total of the vertical recharge, proportion of the lateral groundwater throughflow and the volume of groundwater from storage (using a storage co-efficient of 0.15) exceed the adopted PAVs.

  The PAVs for Zones 9B, 10B, 11A and 11B should remain at the current levels, due to the sparcity of data for the storage co-efficient of the Tertiary Limestone Aquifer. The total of the volumes of groundwater from storage and proportion of the lateral throughflow are similar to the current PAVs.

- it is concluded that the current PAVs for some Zones are not appropriate and should be reviewed, and the manner of determination of the PAVs for some Zones should be reconsidered. The predictive groundwater salinity modelling proposed for the Designated Area would assist in the review of the PAVs.

- the review of the PAVs highlights the importance of knowledge of the vertical recharge and storage co-efficient of the Tertiary Limestone Aquifer and the need for further assessment of these parameters through the Designated Area.

▶ **Review Of Other Components Of The Groundwater (Border Agreement) Act** (Section 11)

- the permissible distance from the State Border as specified in the Groundwater (Border Agreement) Act is currently set at 1 km. This distance is defined by the hydrogeological properties of the aquifer and is set at a distance to manage the cross border impact of groundwater extractions.

- the new data compiled in this report on the hydrogeological properties of the aquifer is consistent with previous results and the permissible distance should remain at 1 km.

- the Groundwater (Border Agreement) Act also specifies a permissible average annual rate of decline of the potentiometric surface of the Tertiary Limestone Aquifer. The rate of decline is currently set at 0.05 m per annum for all Zones of the Designated Area.

  Under this criterion, approval for well construction (including alteration of existing wells) or groundwater extraction will not be given in Zones where the rate of potentiometric decline exceeds the permissible rate over the preceding 5 years.

- the permissible rate of decline has been exceeded in parts of Zones 1A, 1B, 11A and possibly 11B. Should the provisions of the Act be enforced, there will be a marked impact on groundwater resource management in these Zones which the Border Review Committee will need to consider.

- the permissible rate of decline is currently set at an appropriate level to prevent the over extraction and maintain the groundwater resources of the Tertiary Limestone Aquifer.

▸ **Status Of The Tertiary Confined Sand Aquifer** (Section 12)

- the Tertiary Confined Sand Aquifer is less developed as a groundwater resource than the Tertiary Limestone Aquifer because of higher drilling and pumping costs, and the availability of a fresh groundwater resource from the overlying Tertiary Limestone Aquifer.
- some monitoring of water levels of the Tertiary Confined Sand Aquifer has been ongoing since 1988, although there has been no regular monitoring of the salinity of the aquifer. In recognition of the Tertiary Confined Sand Aquifer as a potential and important groundwater resource, some water chemistry monitoring programs were initiated in May 1994 to enable an assessment of the Tertiary Confined Sand Aquifer to be undertaken.
- a preliminary assessment of the Tertiary Confined Sand Aquifer resource has been undertaken, although data are sparse. Lateral groundwater throughflow for the Tertiary Confined Sand Aquifer was calculated from a flow net analysis using potentiometry from the June 1994 water level data and the adoption of an uniform transmissivity of 1100 m^2/day.
- the volumes of groundwater inflow were determined at the eastern boundary of Zones 1B to 9B. No inflow calculations were made for Zones 10B and 11B due to the lack of hydraulic data.
- the volumes of groundwater inflow to the Zones of the Designated Area range from about 4 000 to 32 000 ML per annum.
- there has been no assessment of the volume of inter-aquifer leakage for this aquifer due to a general lack of data.
- the preliminary assessment indicates that the Tertiary Confined Sand Aquifer groundwater resources can provide an alternate resource to that of the Tertiary Limestone Aquifer for some Zones of the Designated Area.
- the determination and adoption of a separate set of Permissible Annual Volumes for the Tertiary Confined Sand Aquifer should be a priority in the next five year technical work plan.

14. RECOMMENDATIONS

The following recommendations are made in relation to the five-yearly review of the Groundwater (Border Agreement) Act.

▶ **Permissible Annual Volumes**

- the Border Review Committee retain the current PAV for Zones 1A, 1B, 2A, 2B, 3A, 3B, 4A, 4B, 5A, 7A, 8B, 9B, 10B, 11A and 11B.
- the Border Review Committee increase the current PAV for Zones 6A and 8A to the level of assessed vertical recharge.
- the Border Review Committee consider a change in management approach for Zones 5B, 6B, 7B and 8B to reflect the confined nature of the Tertiary Limestone Aquifer. This would result in a reduction in the PAV for Zones 5B and 6B, and a slight increase for Zone 7B.
- the Border Review Committee increase the PAV for Zones 9A and 10A.

▶ **Permissible Distance From The Border**

- the Border Review Committee retain the current permissible distance from the border of South Australia and Victoria as 1 km.

▶ **Rate Of Potentiometric Surface Lowering**

- the Border Review Committee retain the current rate of potentiometric surface lowering as 0.05 m per annum.
- the Border Review Committee consider the evident exceedance of the permissible rate of potentiometric surface lowering in parts of Zones 1A, 1B, 11A and possibly 11B, and be aware of the management implications of enforcing the conditions of the Act in relation to this exceedance.

▶ **Permissible Level of Salinity**

- the Border Review Committee do not set a permissible level of salinity for any Zone of the Designated Area, as this is not considered an appropriate management approach and could result in significant degradation of the resource before any management intervention. A rate of groundwater salinity change should be used as an indicator of the appropriateness of management policies. The magnitude of such groundwater salinity changes may vary between Zones subject to the specific land uses and the actual groundwater salinity within the Zones.

The following recommendations are made for consideration in the 1996 to 2001 technical work plan.

- the groundwater resources of the Tertiary Confined Sand Aquifer be fully evaluated, and a set of Permissible Annual Volumes for this aquifer be determined.
- detailed assessment be undertaken to determine the inter-aquifer leakage between the three regional aquifers occurring within the Designated Area.
- an assessment be made of the Pliocene Sands Aquifer within the Designated Area to determine the vertical recharge and the aquifer's inter-action with the Tertiary Limestone Aquifer.
- groundwater flow modelling of the Tertiary Limestone Aquifer be undertaken.
- predictive groundwater salinity modelling be undertaken for the Tertiary Limestone Aquifer.
- investigations be undertaken to obtain better estimates of the transmissivity and storage co-efficient of the Tertiary Limestone Aquifer, particularly in Hydrogeological Provinces 1 and 2 of the Designated Area.
- a detailed hydrochemical investigation of the groundwater resources for the Tertiary Limestone Aquifer be undertaken given that sufficient data are now available. The planned 1996 full chemical analysis sampling should be undertaken.
- an assessment be made of the total groundwater use from the Tertiary Limestone and Tertiary Confined Sand Aquifers in both States.
- an investigation be undertaken to assess the direct use of groundwater from the Tertiary Limestone Aquifer by softwood plantations. Some further studies should also be undertaken to examine the impacts of softwood afforestation management practices on the groundwater quality of the Tertiary Limestone Aquifer, to determine whether contamination of the aquifer is occurring.

The following general recommendations are also made.

- the responsible agencies in both States continue appropriate groundwater level and groundwater quality monitoring programs.
- a more consistent groundwater sampling approach be undertaken in Victoria to obtain reliable groundwater salinity monitoring data.
- sampling of newly drilled irrigation wells in Victoria be undertaken to obtain some background salinity data.

- the responsible agencies in both States improve their estimates of licensed groundwater use.

- plans be compiled on a regular basis showing the distribution of irrigated areas in order to assess possible changes in groundwater levels and quality.

- the use of a geographic information system (GIS) be adopted for the various data within the Designated Area.

15. REFERENCES

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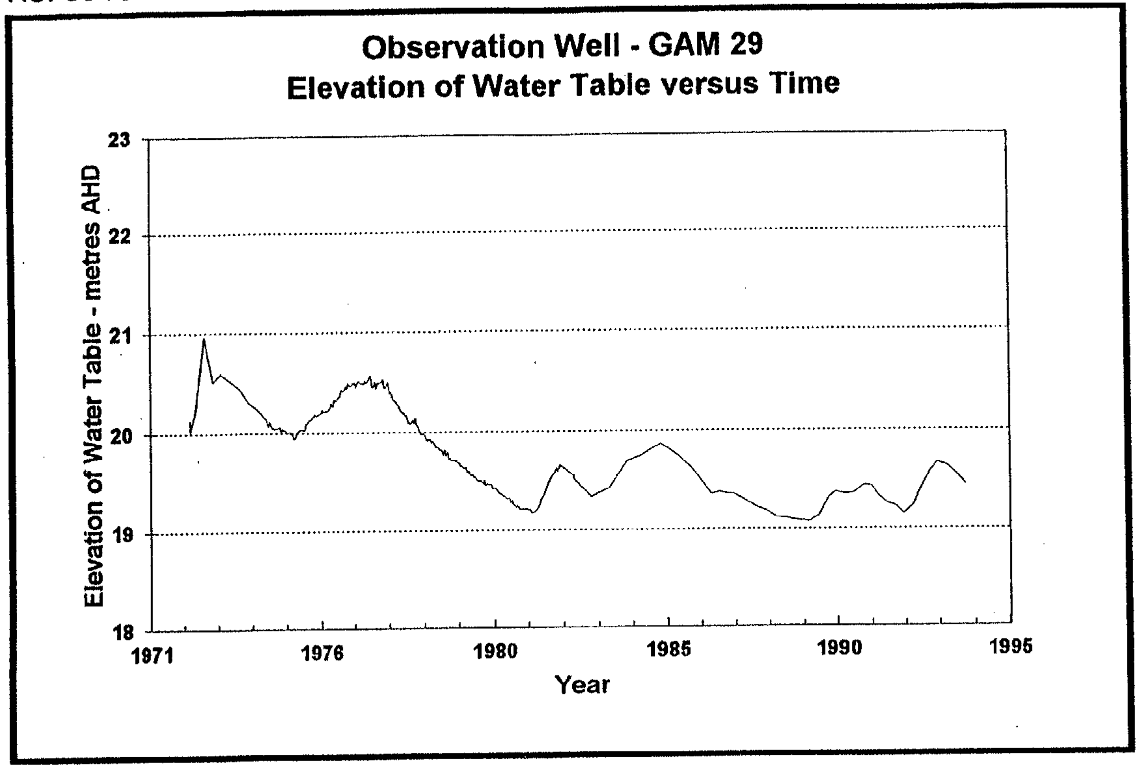
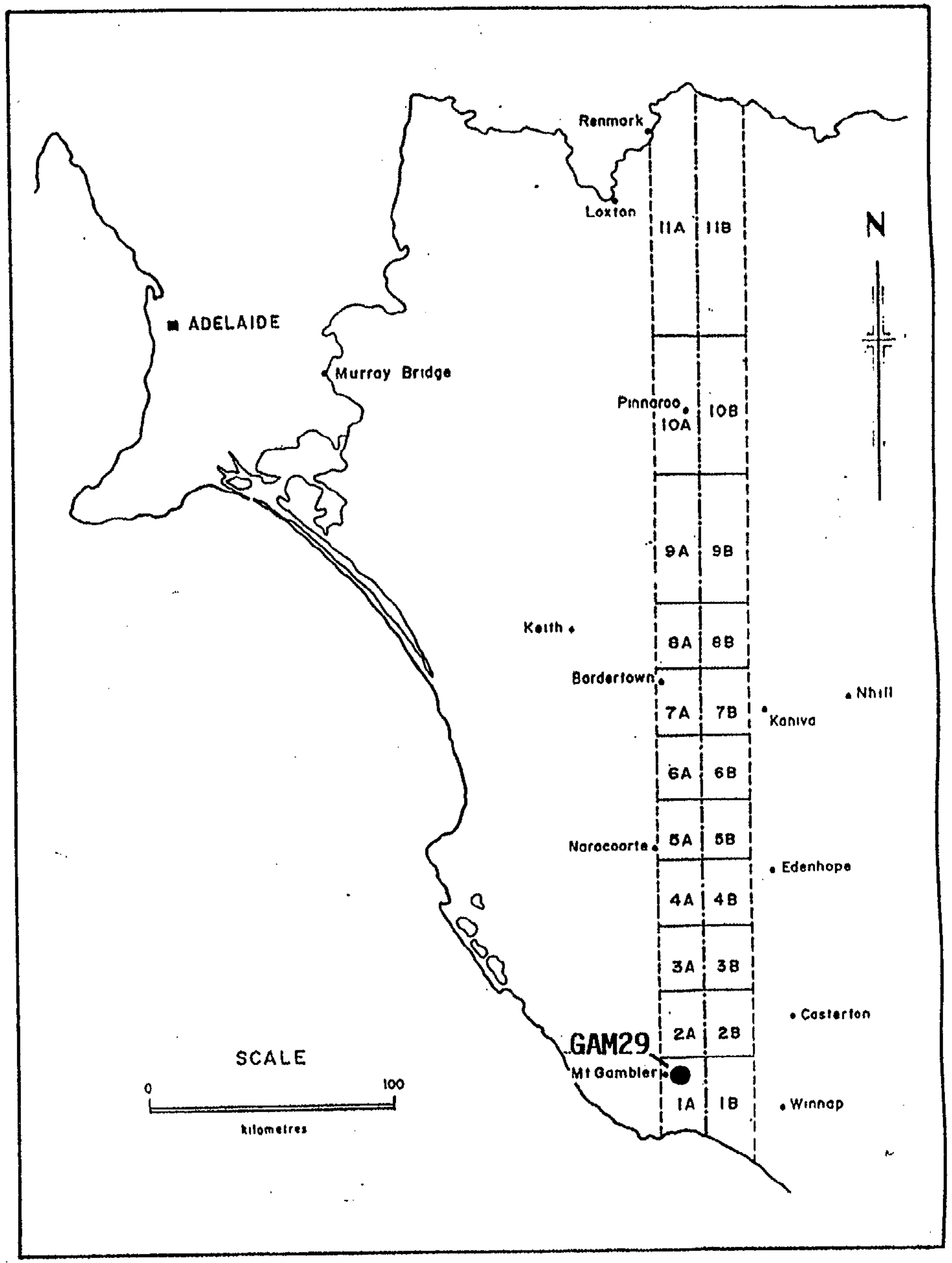
APPENDIX A

SELECTED SOUTH AUSTRALIAN AND VICTORIAN HYDROGRAPHS FOR THE TERTIARY LIMESTONE AQUIFER AND TERTIARY CONFINED SAND AQUIFER

OBSERVATION WELL	ZONE	AQUIFER MONITORED	FIGURE
GAM 29	1A	Tertiary Limestone	A1
101238	1B		A2
58587	Adj 1B		A3
NAN 19	2A		A4
CMM 22	4A		A5
CMM 23	4A		A6
74255	4B		A7
BMA 8	6A		A8
GGL 7	6A		A9
TAT 9	Adj 7A		A10
TAT 23	7A		A11
75651	7B		A12
PEB 3	10A		A13
61571	Adj 10B		A14
82220	10B		A15
BLA 88	1A	Tertiary Confined Sand	A16
101239	1B		A17
87527	1B		A18
69962	Adj 1B		A19
MIN 17	2A		A20

Job No. 5916

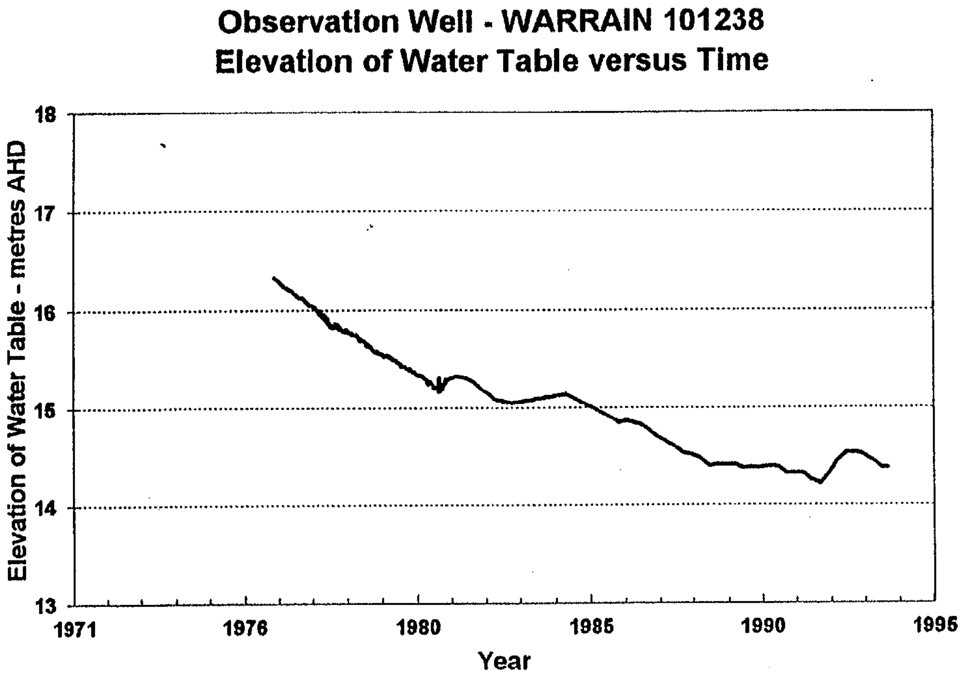




Hundred of:	GAMBIER
Well No:	GAM 29
Coordinates:	Easting 486527 Northing 5812623
Unit No:	7022-1686
Ground Elevation (AHD):	42.48m
Formation:	Gambier Limestone
Water Level Trend:	0.065 m/year Decrease

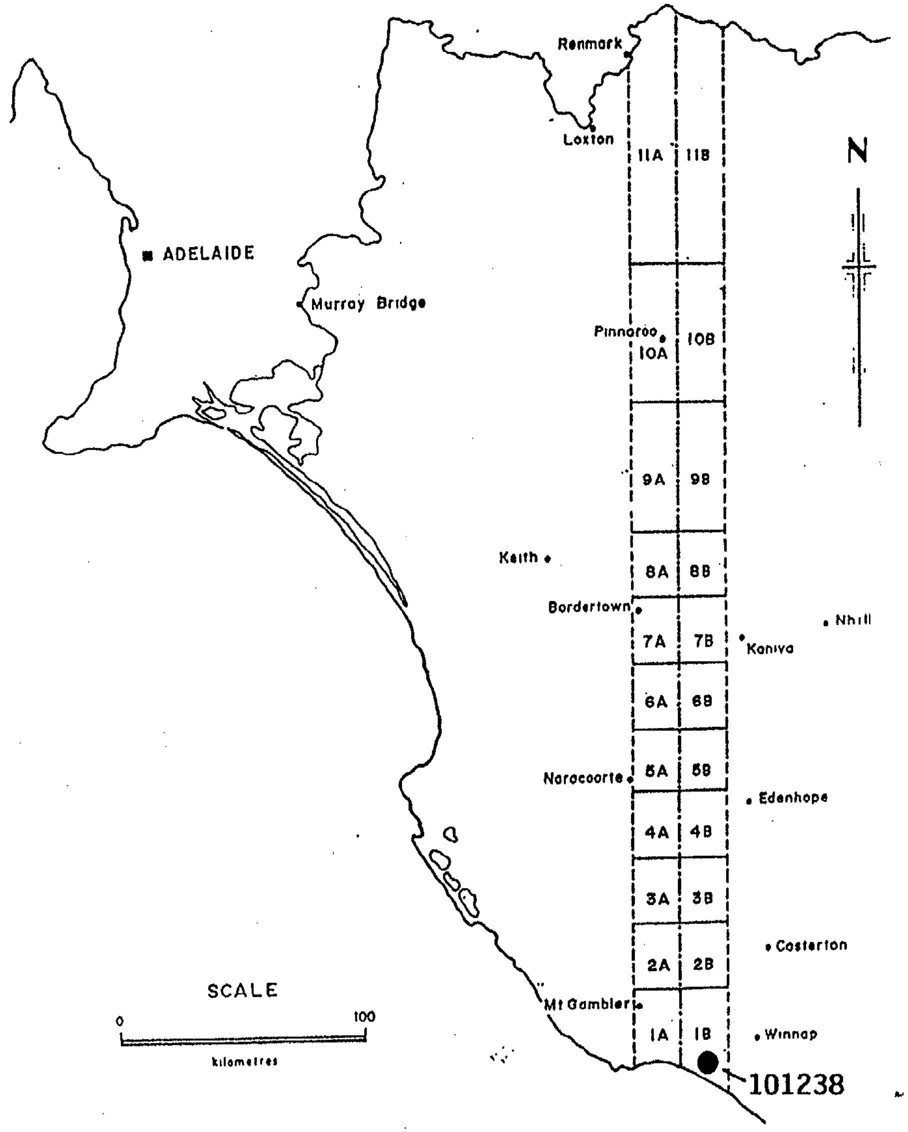
Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	152	0	5.8
	Open Hole	152	5.8	36

Job No. 5916



Parish of:	WARRAIN			
Well No:	101238			
Coordinates:	Easting 510083		Northing 5787088	
Ground Elevation (AHD):	34.66m			
Formation:	Bridgewater			
Water Level Trend:	0.01m/year Decrease			

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	150	0	12.4
	Open Hole	150	12.4	23
	Blocked	0	23	29



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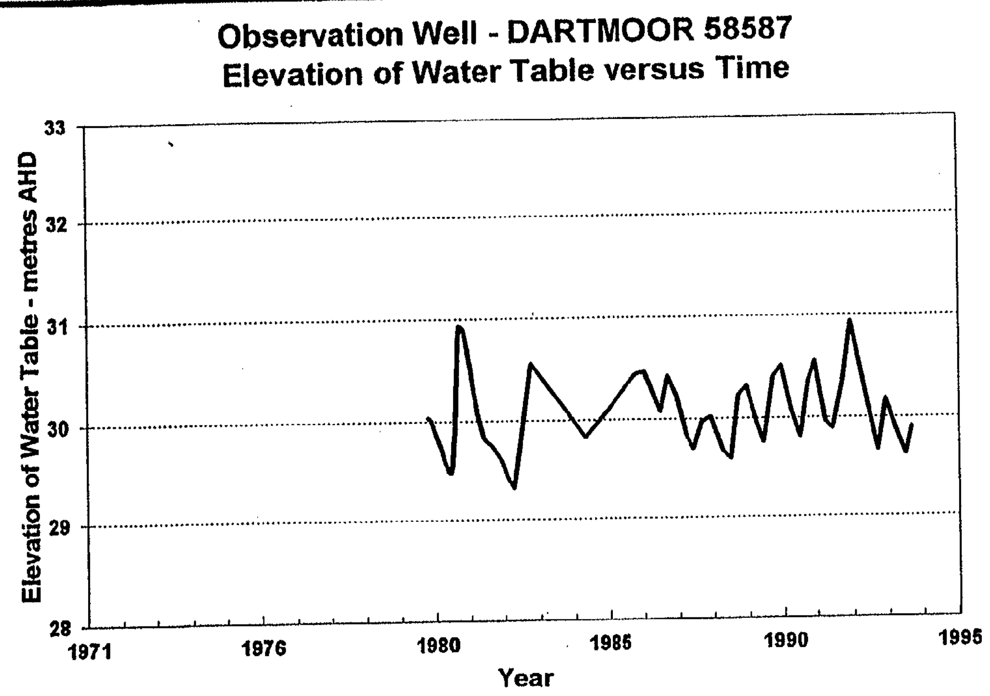
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. 101238

FIGURE A2

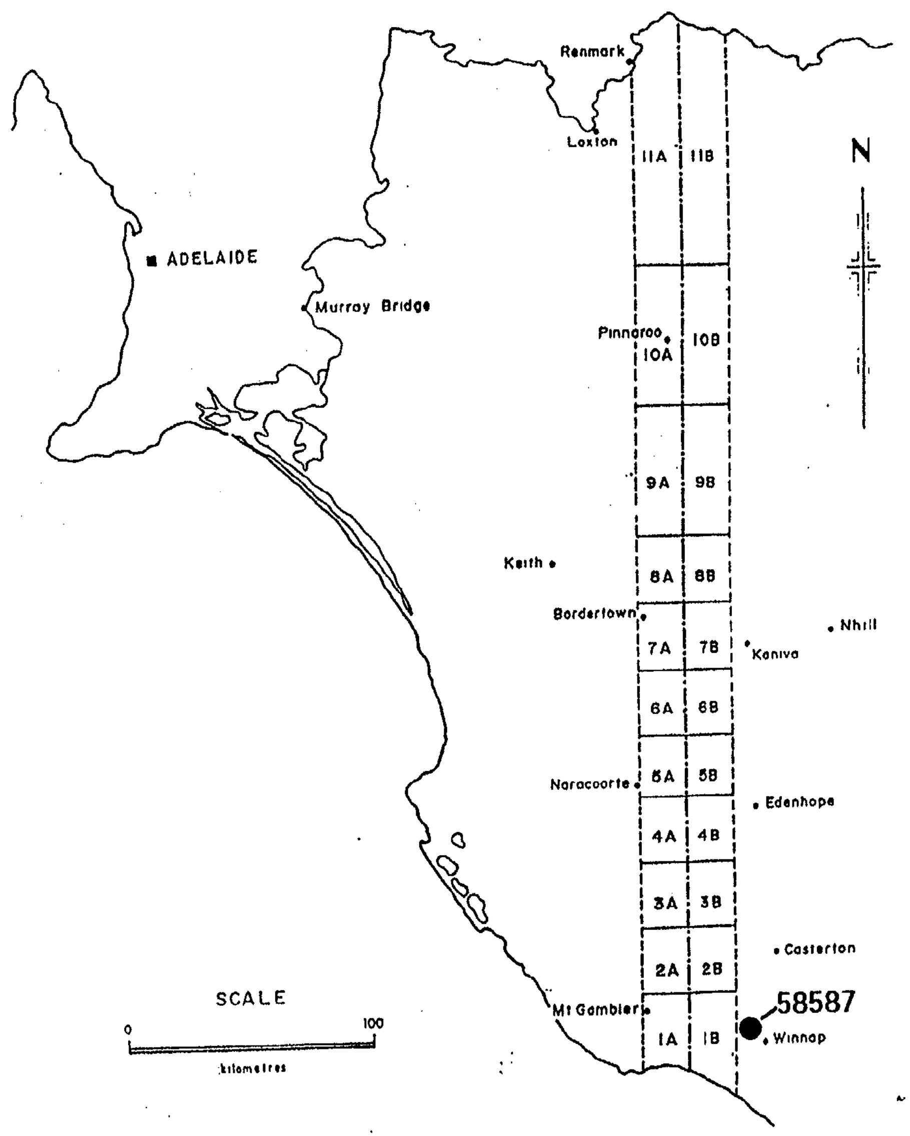
MESA 95-188

Job No. 5916



Parish of:	DARTMOOR	
Well No:	58587	
Coordinates:	Easting 523140	Northing 5803414
Ground Elevation (AHD):	36.22m	
Formation:	Bridgewater	
Water Level Trend:	No Significant Change	

Construction Details:	*Casing*	*Diam (mm)*	*From (m)*	*To (m)*
	Steel	150	0	10
	Slotted	150	10.4	13



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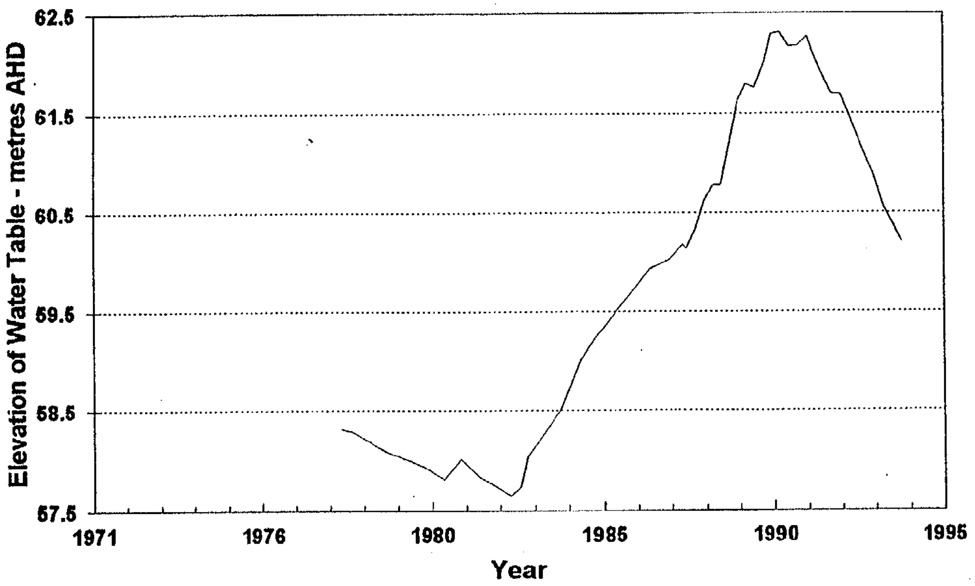
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. 58587

FIGURE A3

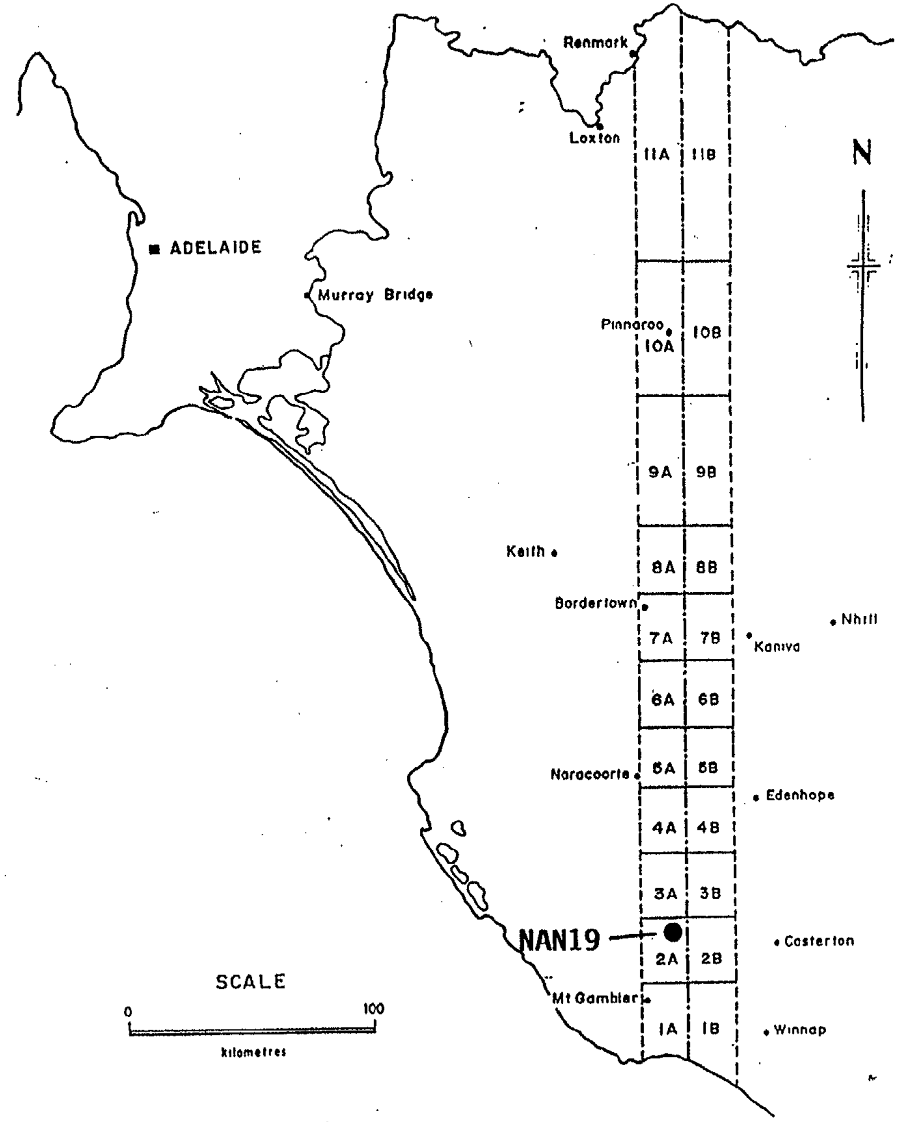
MESA 95-189

Job No. 5916



Hundred of:	NANGWARRY	
Well No:	NAN 19	
Coordinates:	Easting 491668	Northing 5844050
Unit No:	7022-3880	
Ground Elevation (AHD):	71.2m	
Formation:	Gambier Limestone	
Water Level Trend:	1978-83 Decrease, 1983-91 Increase, 1991-94 Decrease	

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Galv. Pipe	76	-1.2	18.6
	Slotted	76	16.5	18.6



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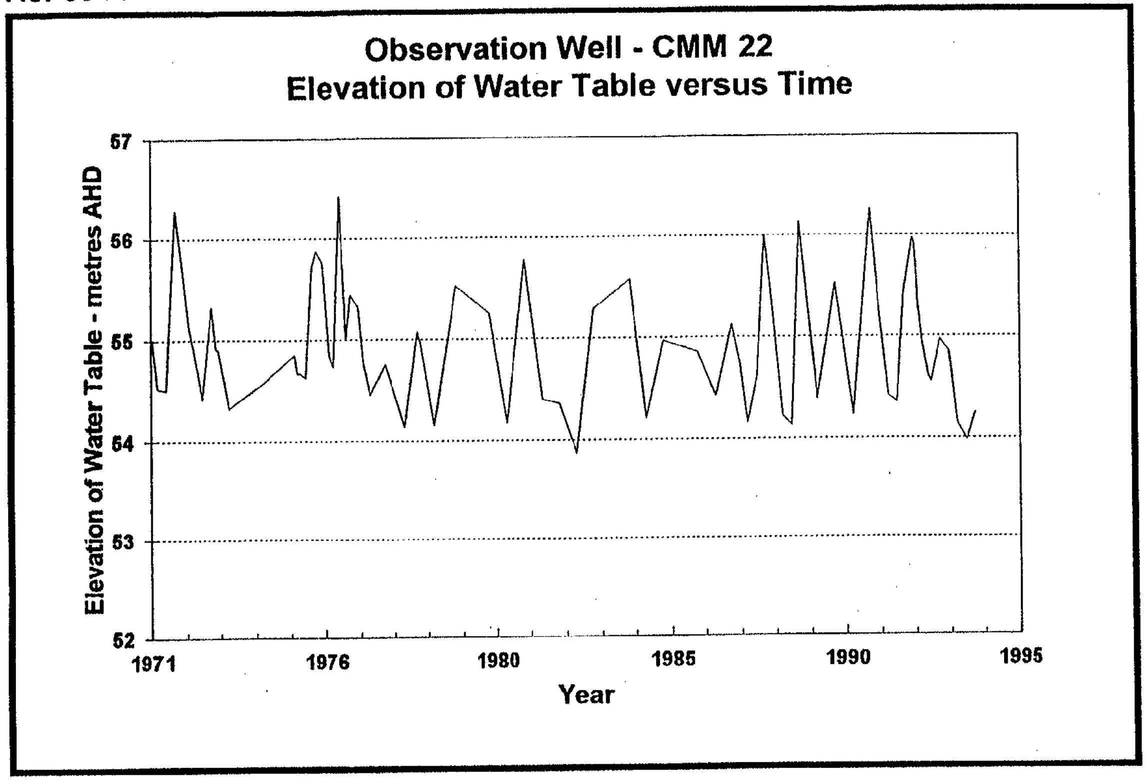
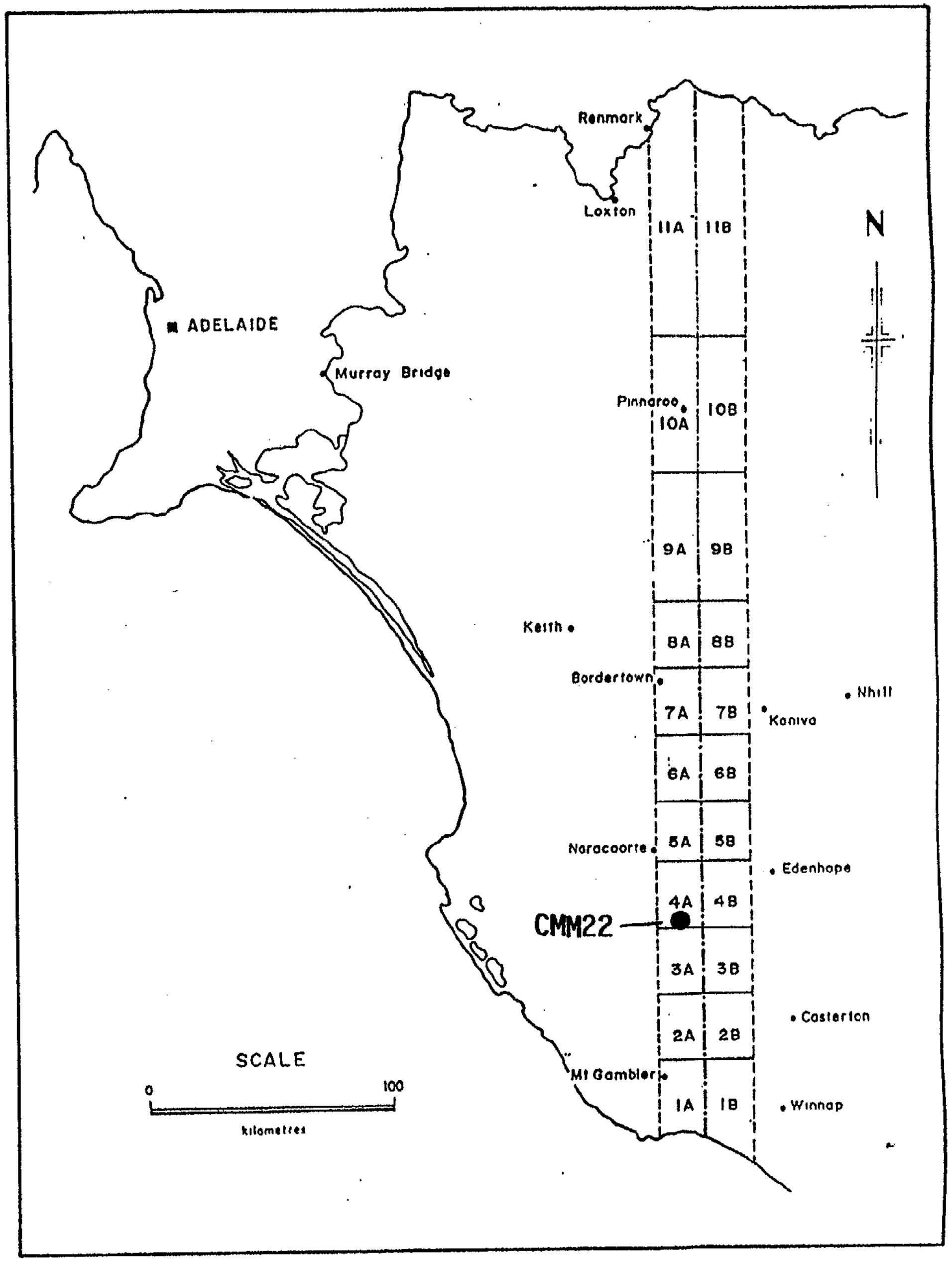
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. NAN 19

FIGURE A4

MESA 95-190

Job No. 5916





Hundred of:	COMAUM	
Well No:	CMM 22	
Coordinates:	Easting 486605	Northing 5878845
Unit No:	7023-1488	
Ground Elevation (AHD):	57.78m	
Formation:	Padthaway Formation	
Water Level Trend:	No Significant Change	

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	127	0	?

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OBSERVATION WELL No. CMM 22

FIGURE A5

MESA 95-191

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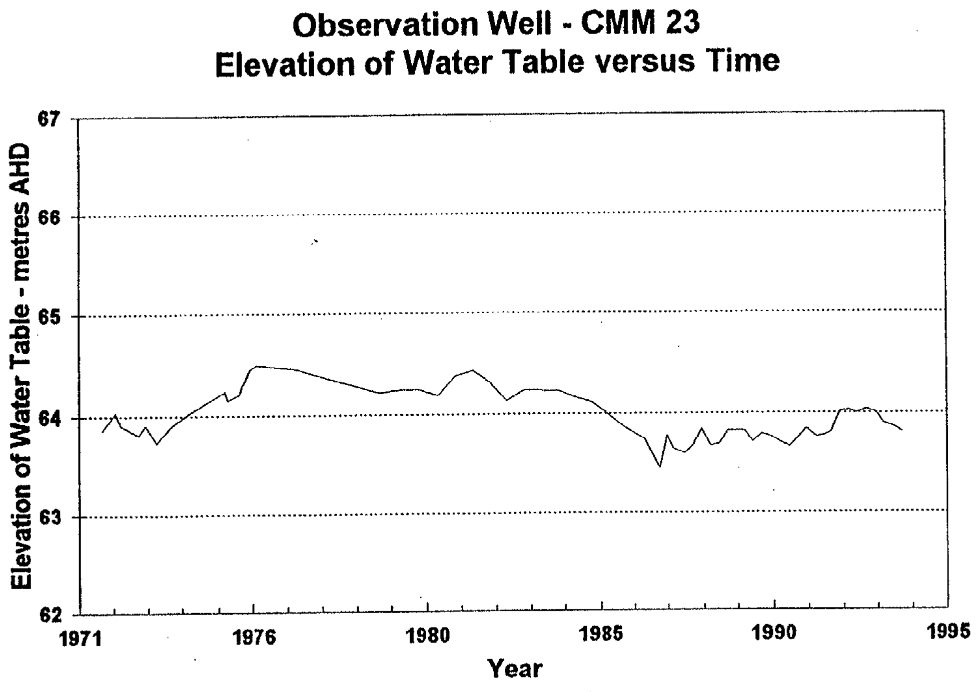
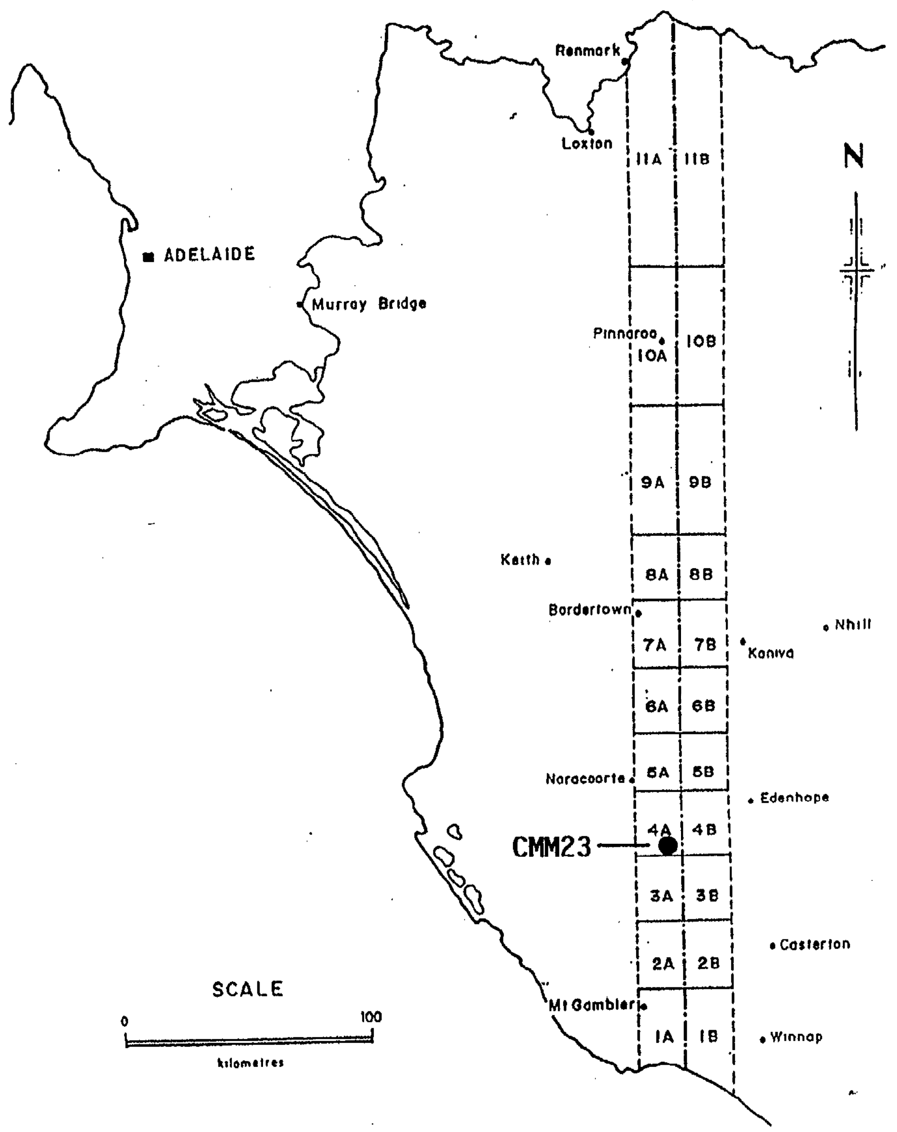
Job No. 5916





Hundred of:	COMAUM	
Well No:	CMM 23	
Coordinates:	Easting 491523	Northing 5879787
Unit No:	7023-1545	
Ground Elevation (AHD):	69.92m	
Formation:	Bridgewater Formation/Gambier Limestone	
Water Level Trend:	No Significant Change	

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	PVC	76	0	13.7
	Slotted	76	13.7	19.8

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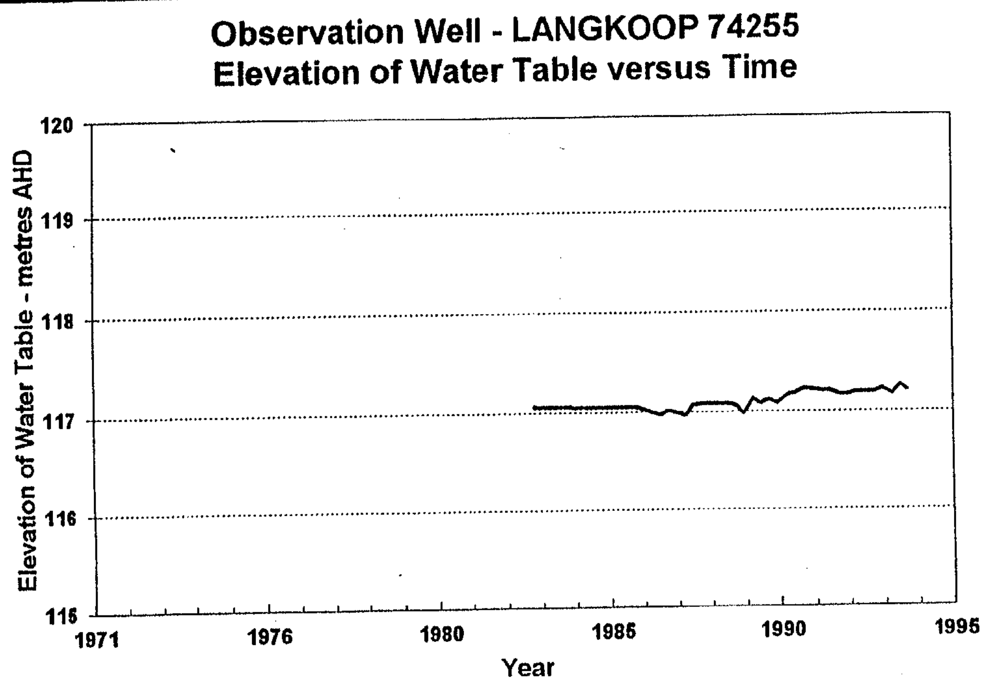
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. CMM 23

FIGURE A6

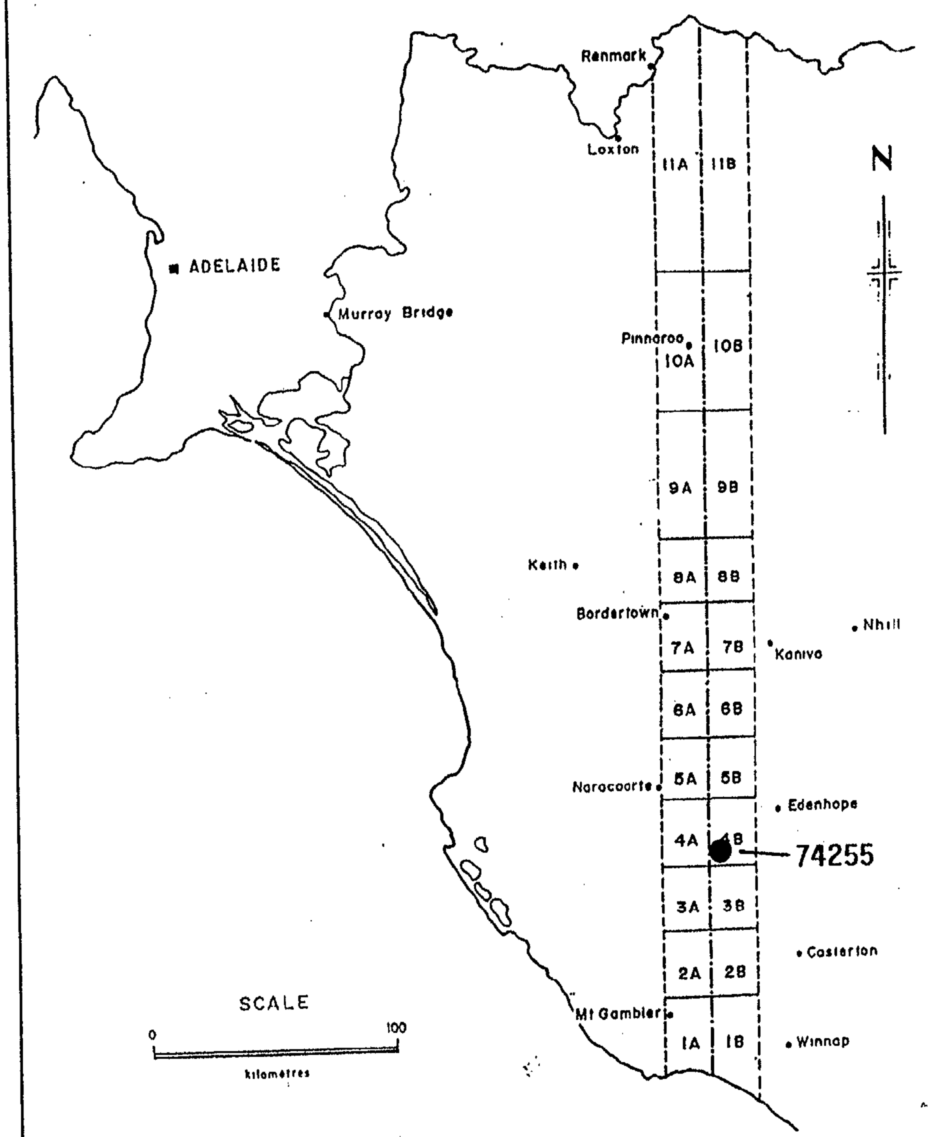
MESA 95-192

Job No. 5916



Parish of:	LANGKOOP
Well No:	74255
Coordinates:	Easting 500692 Northing 5883493
Ground Elevation (AHD):	138.6m
Formation:	Gambier Limestone
Water Level Trend:	0.02m/year Increase

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	PVC	90	0	24
	Slotted	90	24	30



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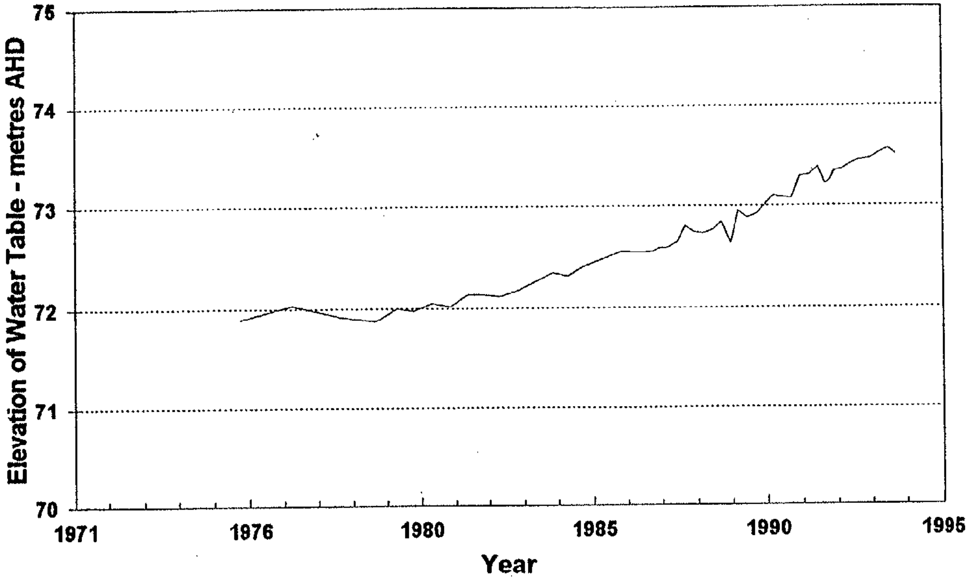
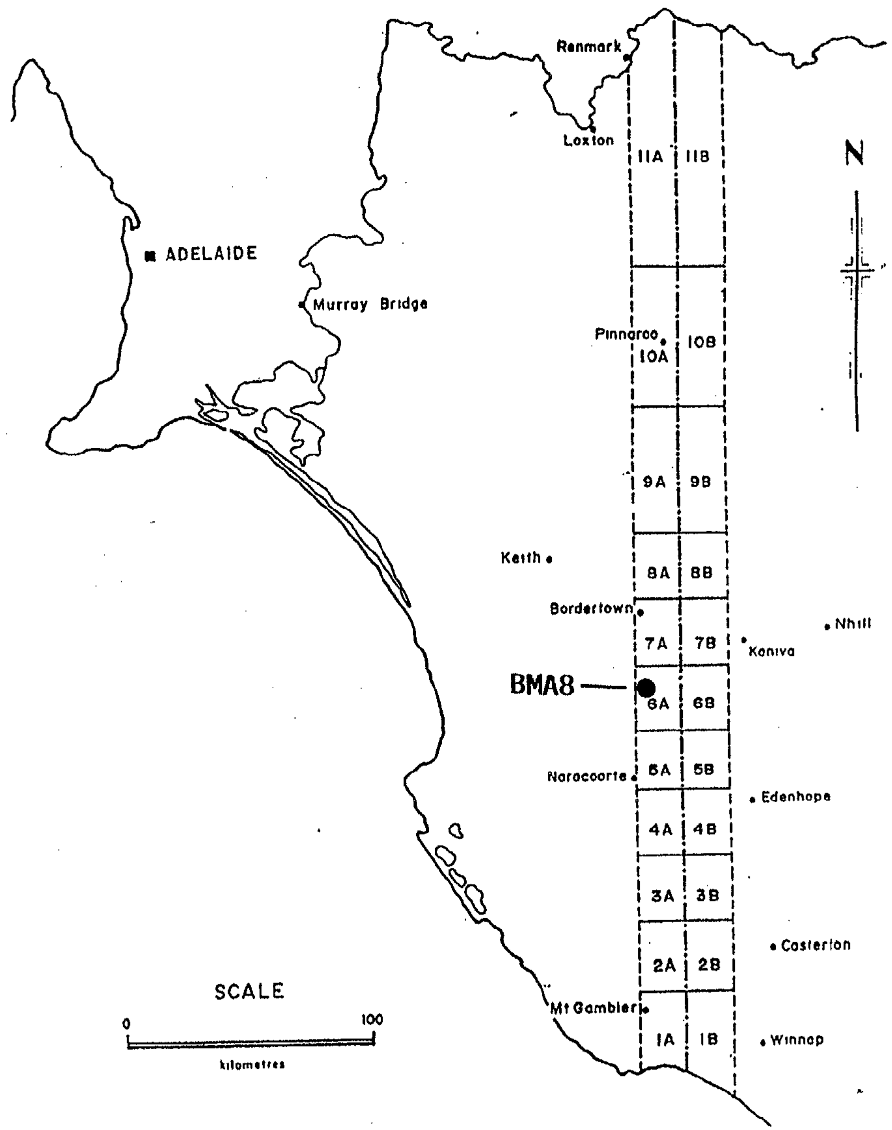
OBSERVATION WELL No. 74255

FIGURE A7

MESA 95-193

Job No. 5916





Hundred of:	BEEAMMA
Well No:	BMA 8
Coordinates:	Easting 480177 Northing 5950479
Unit No:	7024-954
Ground Elevation (AHD):	89.657m
Formation:	Murray Group Limestone
Water Level Trend:	0.1 m/year Increase

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	PVC	76	0	56

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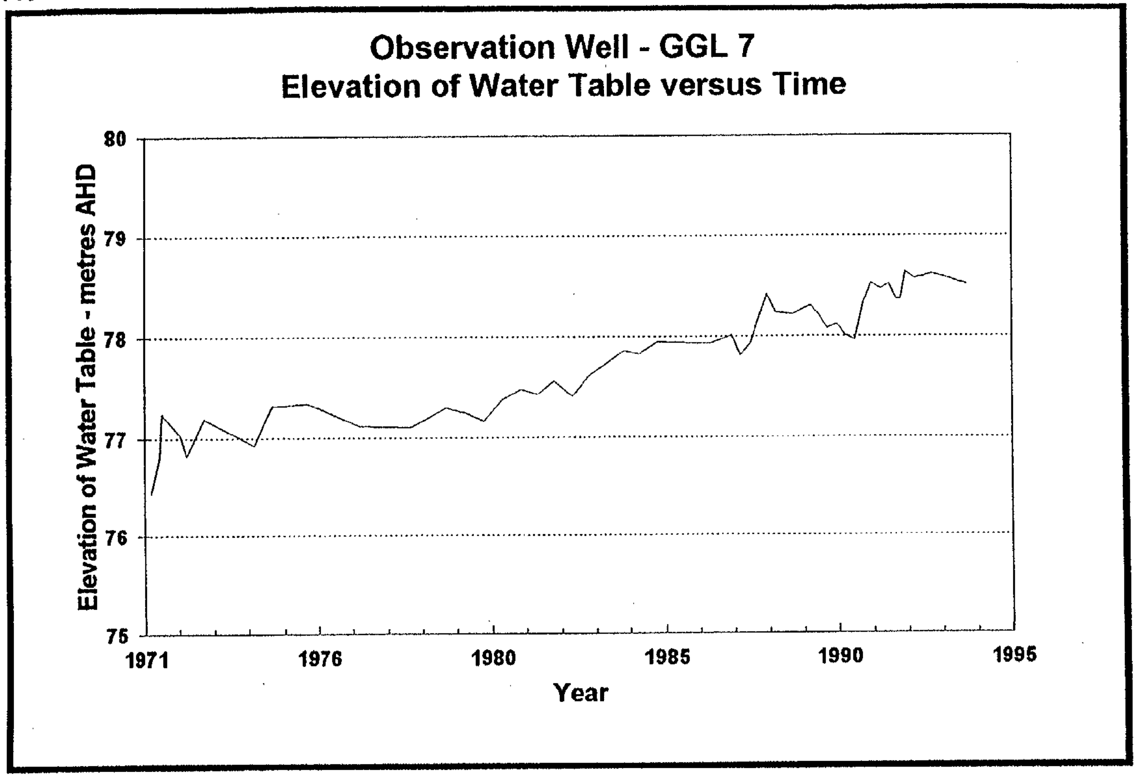
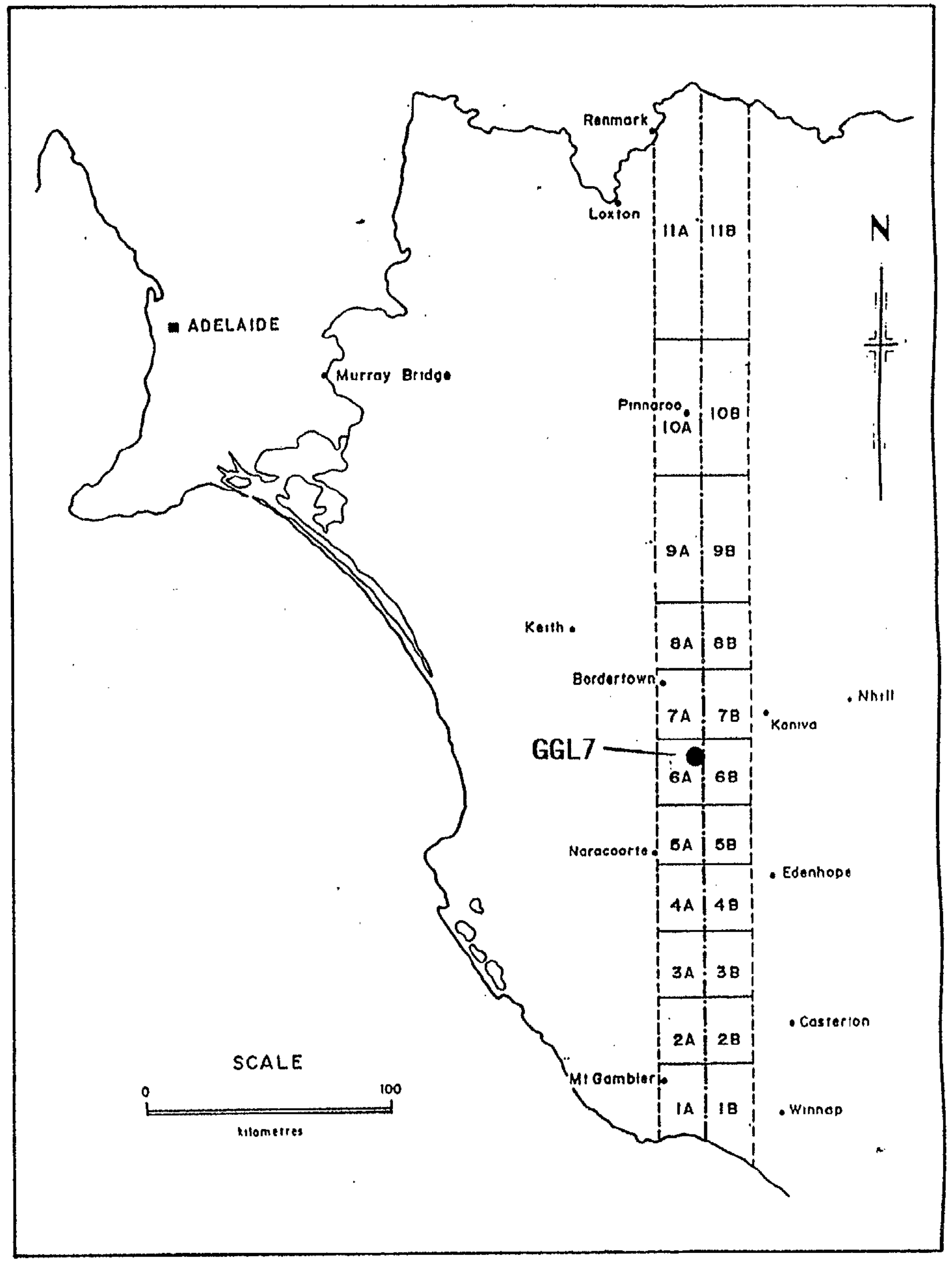
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. BMA 8

FIGURE A8

MESA 95-194

Job No. 5916





Hundred of:	GEEGEELA	
Well No:	GGL 7	
Coordinates:	Easting 494137	Northing 5951620
Unit No:	7024-1080	
Ground Elevation (AHD):	104.457m	
Formation:	Murray Group Limestone	
Water Level Trend:	0.075 m/year Increase	

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	127	0	43.3
	Open Hole	76	43.3	44.8

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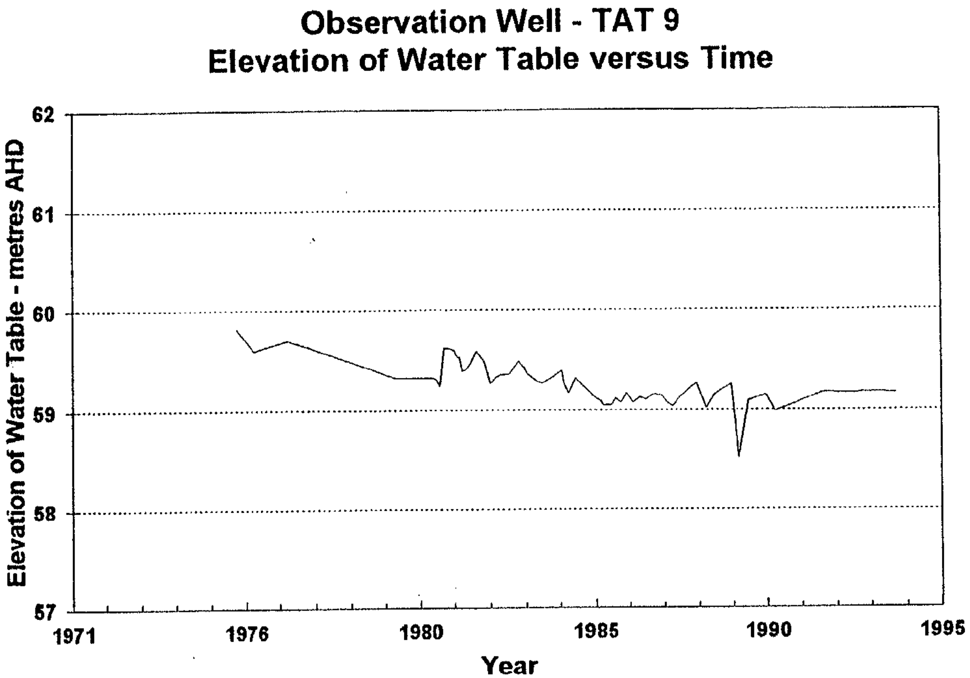
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. GGL 7

FIGURE A9

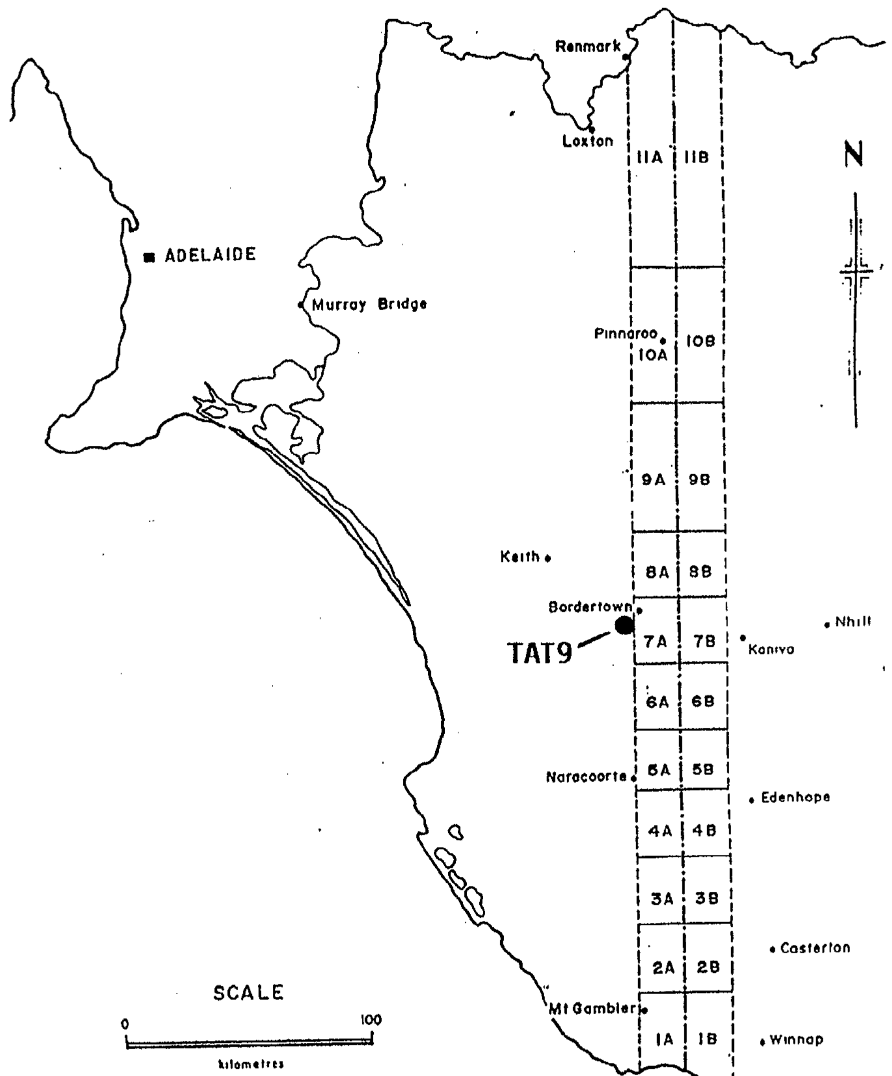
MESA 95-195

Job No. 5916



Hundred of:	TATIARA
Well No:	TAT 9
Coordinates:	Easting 475639 Northing 5976167
Unit No:	7025-1398
Ground Elevation (AHD):	72.327m
Formation:	Murray Group Limestone
Water Level Trend:	0.04 m/year Decrease

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Fluming	102	0	?



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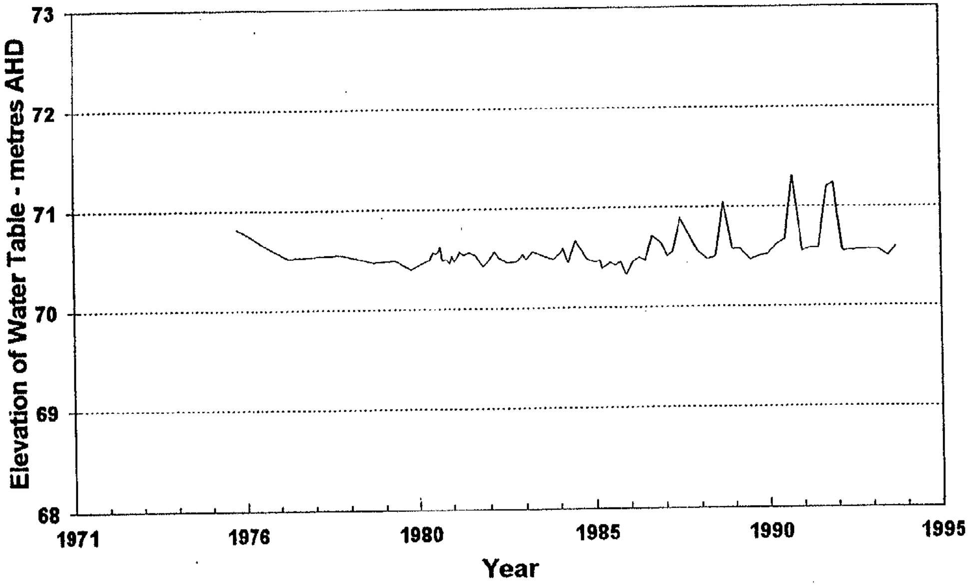
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. TAT 9

FIGURE A10

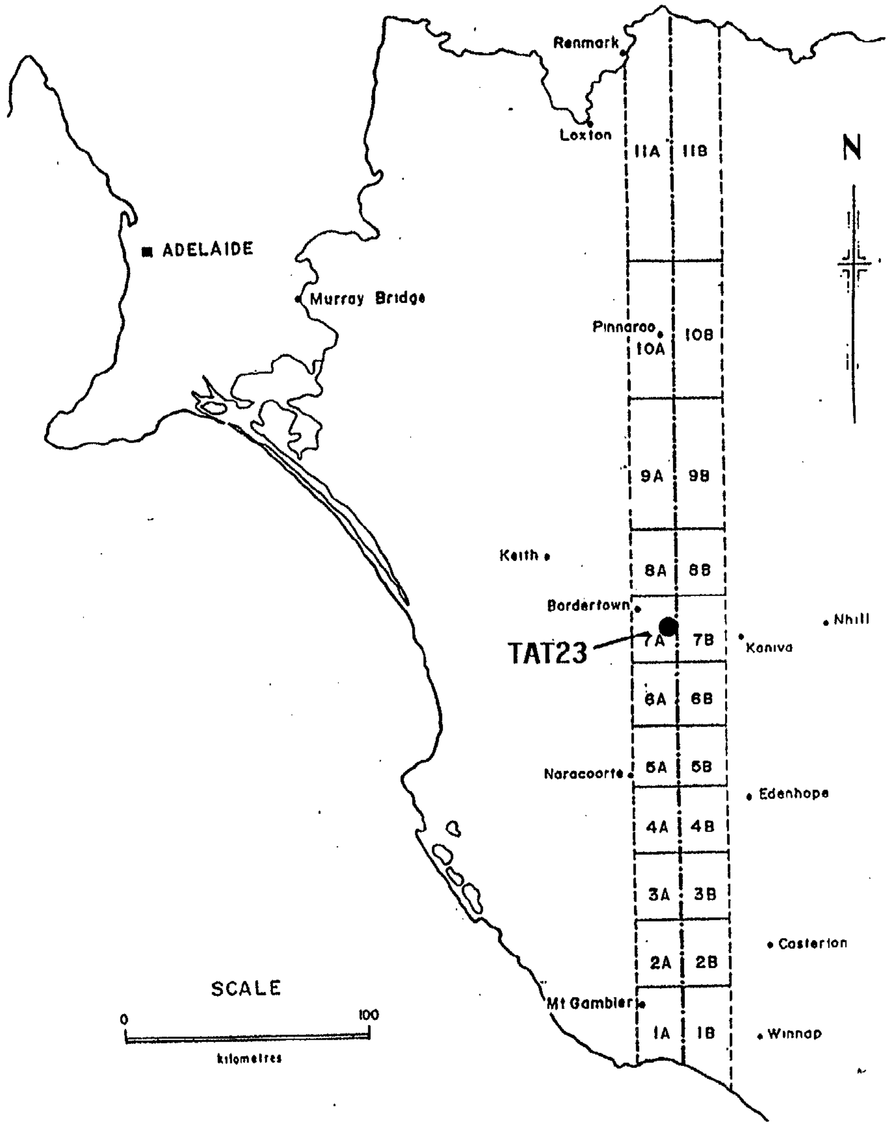
MESA 95-196

Job No. 5916



Hundred of:	TATIARA
Well No:	TAT 23
Coordinates:	Easting 494905 Northing 5976690
Unit No:	7025-2299
Ground Elevation (AHD):	112.54m
Formation:	Murray Group Limestone
Water Level Trend:	No Significant Change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	PVC	76	0	43.7
	Slotted	76	43.7	48.5



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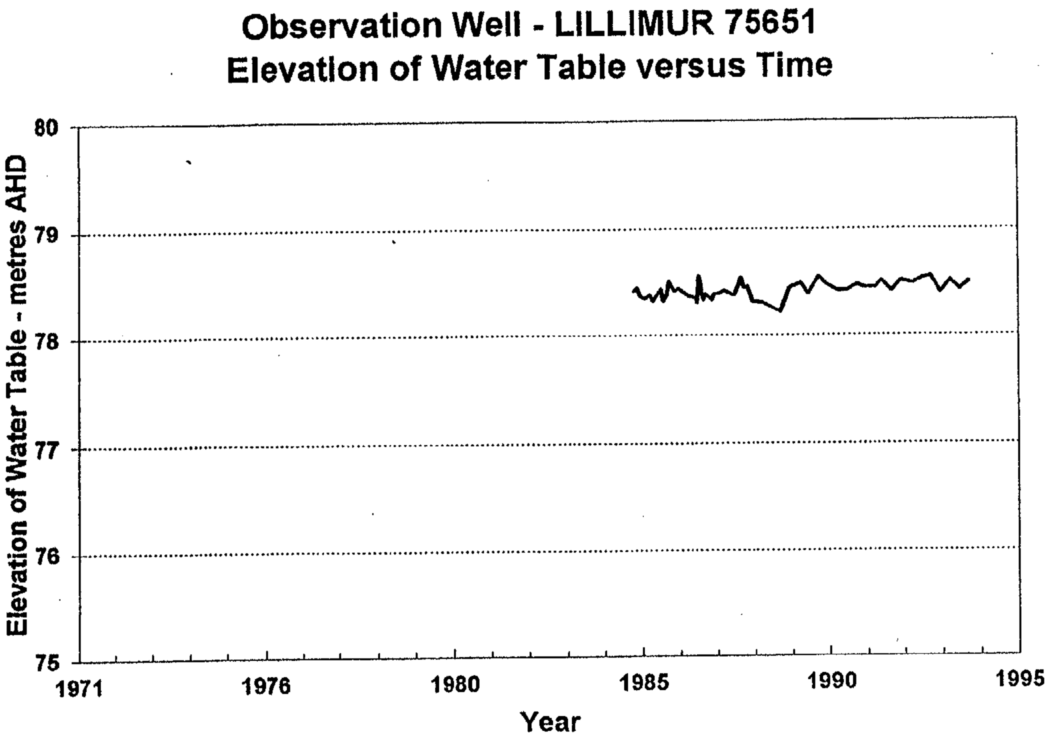
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. TAT 23

FIGURE A11

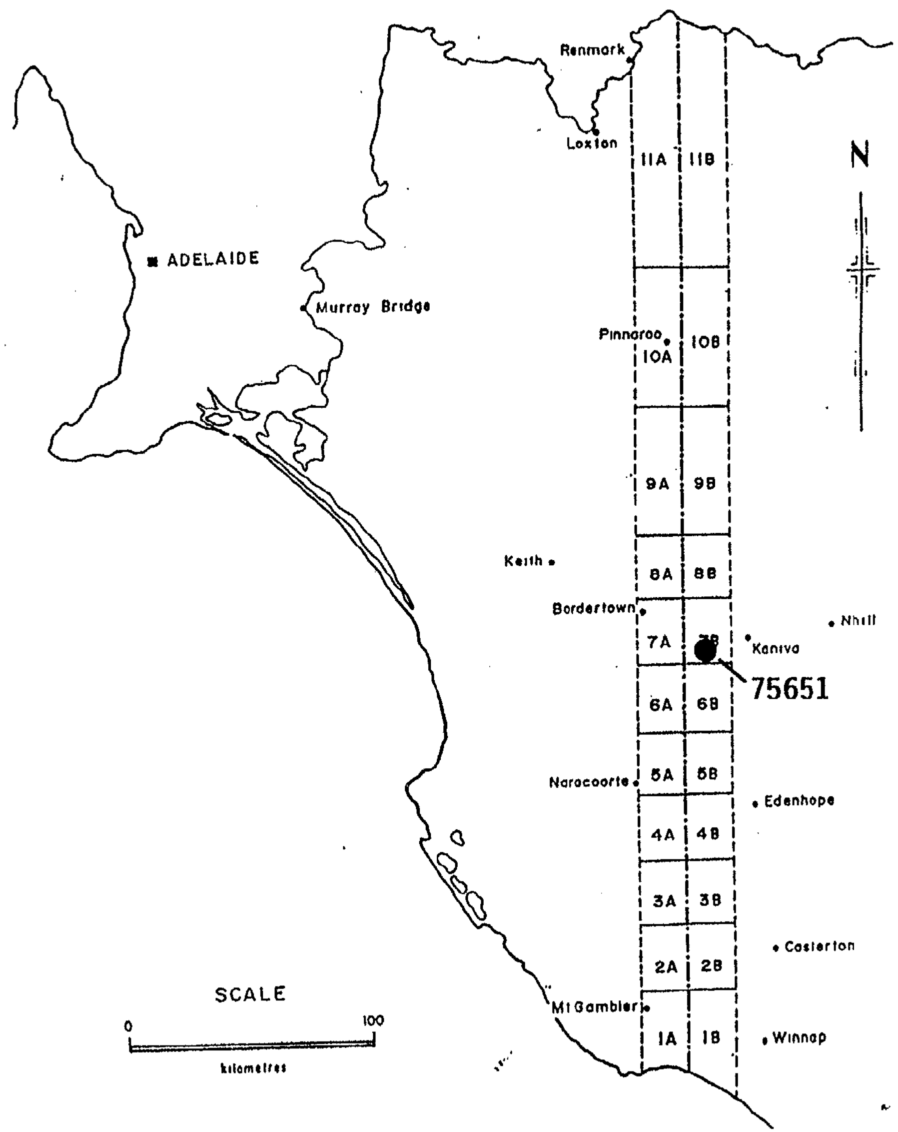
MESA 95-197

Job No. 5916



Parish of:	LILLIMUR
Well No:	75651
Coordinates:	Easting 506600 Northing 5967100
Ground Elevation (AHD):	142m
Formation:	Murray Group Limestone
Water Level Trend:	No Significant Change

Construction Details:	*Casing*	*Diam (mm)*	*From (m)*	*To (m)*
	Steel	127	0	52
	Slotted	127	52	137



MINES AND ENERGY SOUTH AUSTRALIA

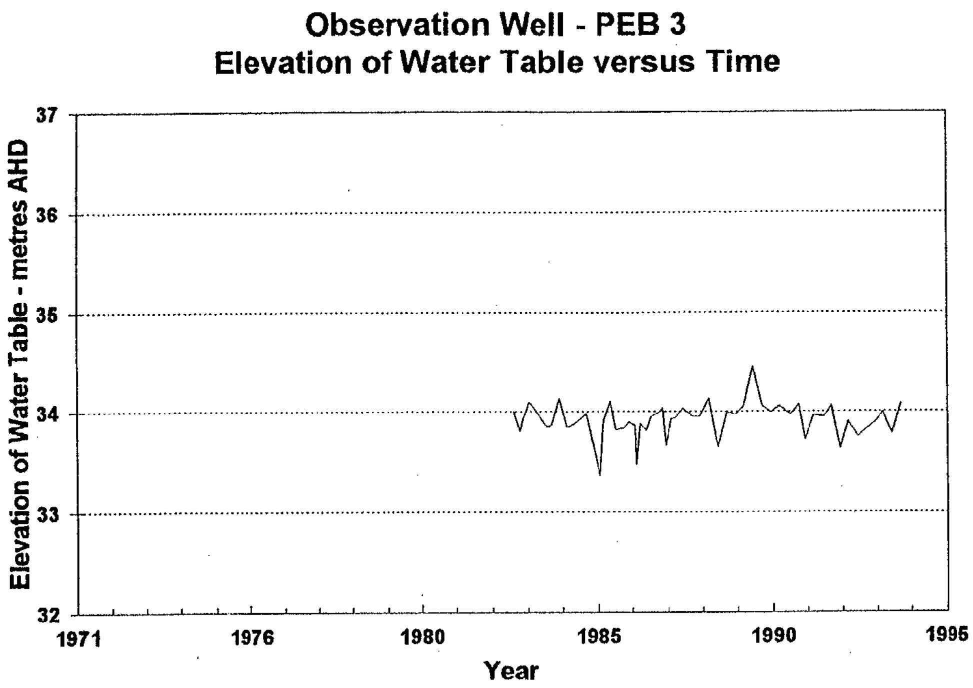
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

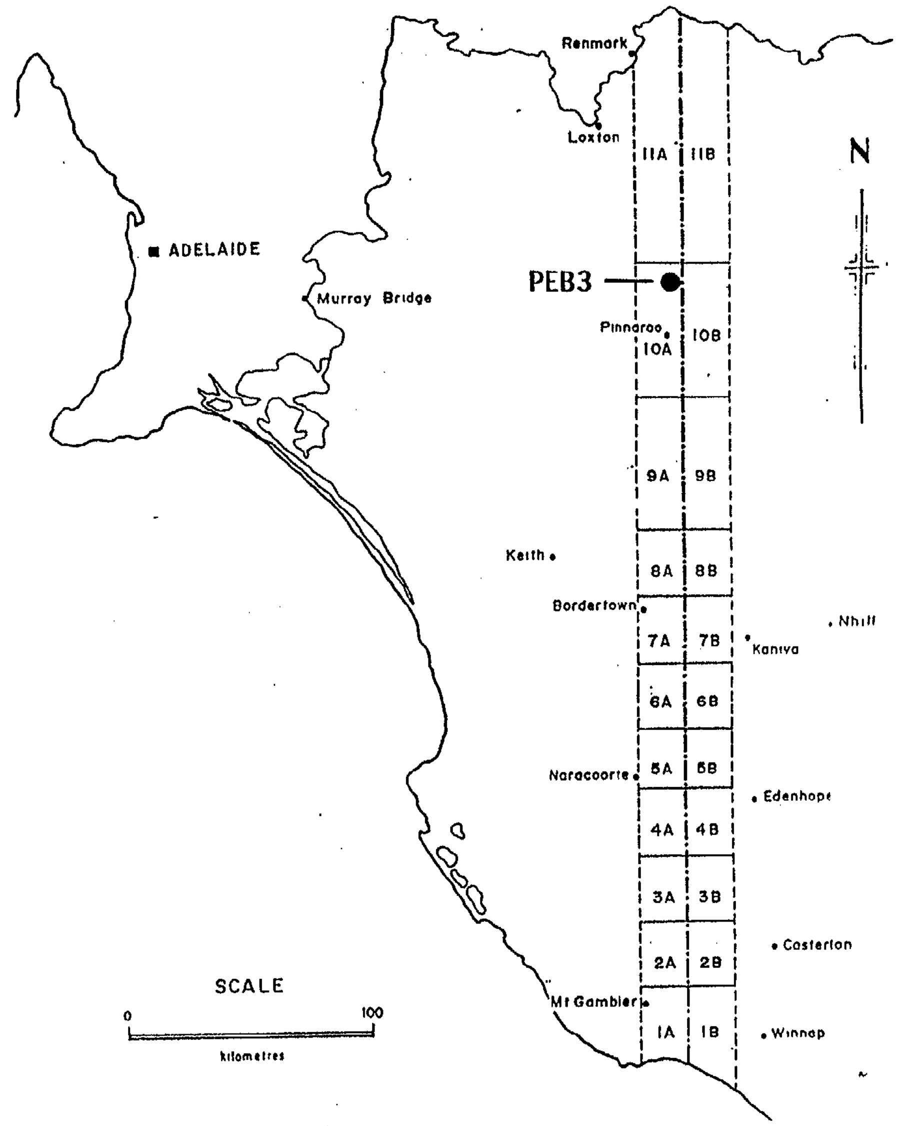
OBSERVATION WELL No. 75651

FIGURE A12

MESA 95-198

Job No. 5916





Hundred of:	PEEBINGA	
Well No:	PEB 3	
Coordinates:	Easting 493969	Northing 6118395
Unit No:	7027-9	
Ground Elevation (AHD):	80.79m	
Formation:	Murray Group Limestone	
Water Level Trend:	No Significant Change	

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Unknown			

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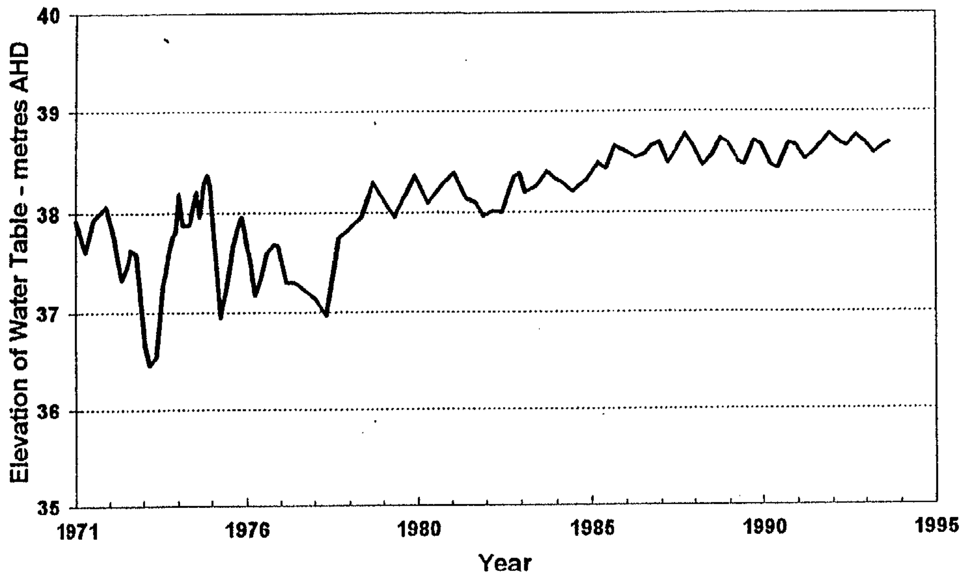
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

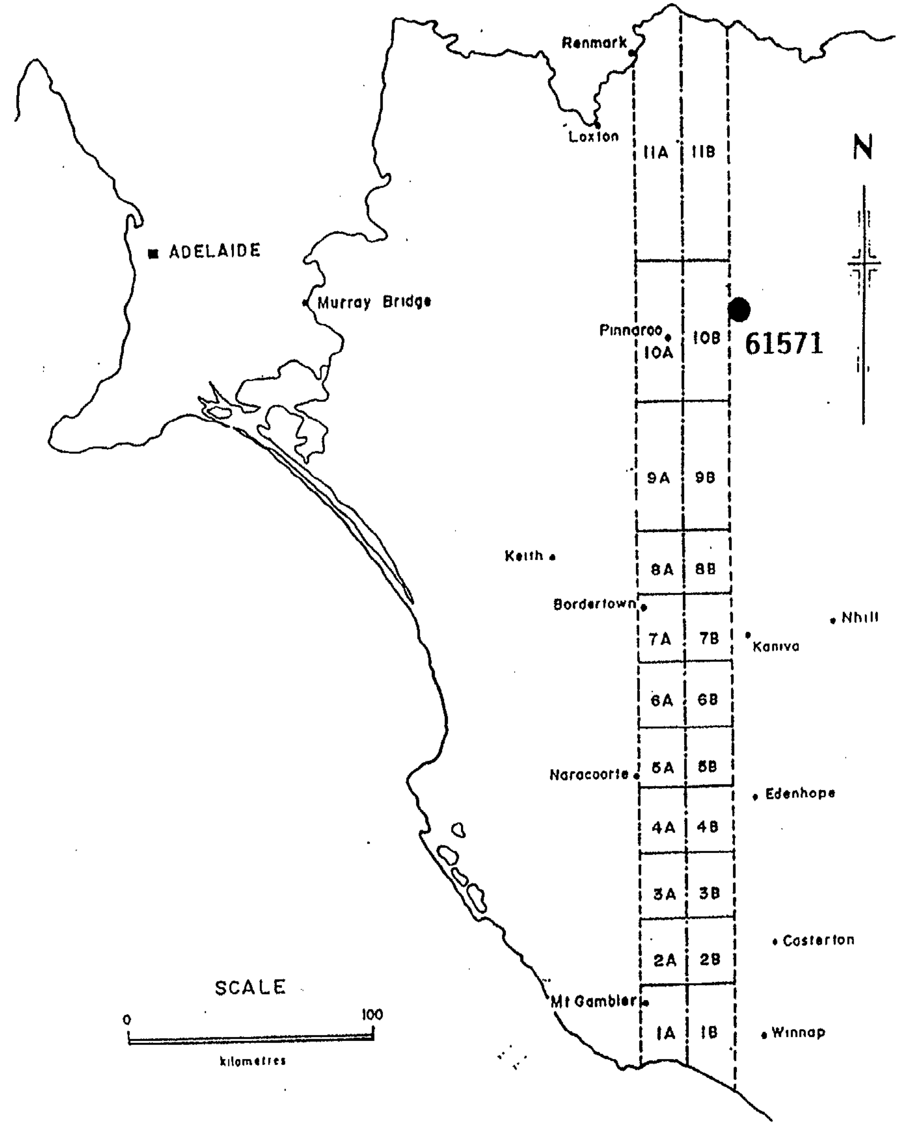
OBSERVATION WELL No. PEB 3

FIGURE A1:

MESA 95-199

Job No. 5916





Parish of:	DUDDO	
Well No:	61571	
Coordinates:	Easting 519442	Northing 6110062
Ground Elevation (AHD):	50.37m	
Formation:	Murray Group Limestone	
Water Level Trend:	0.06m/year Increase	

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	152	0	76.8
	Slotted	152	76.8	131

MINES AND ENERGY
SOUTH AUSTRALIA

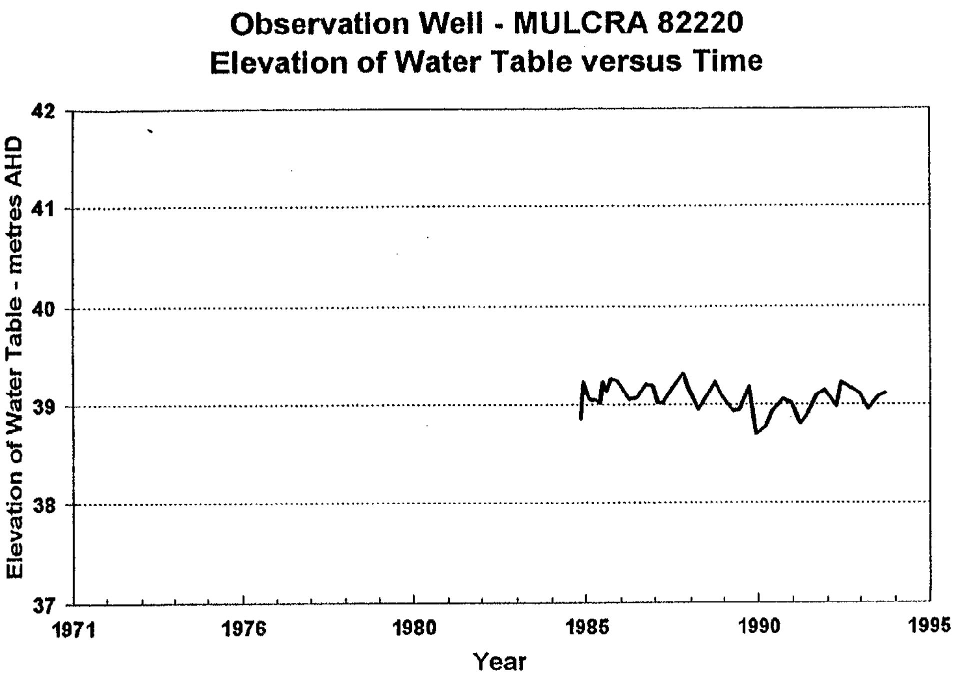
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. 61571

FIGURE A1(

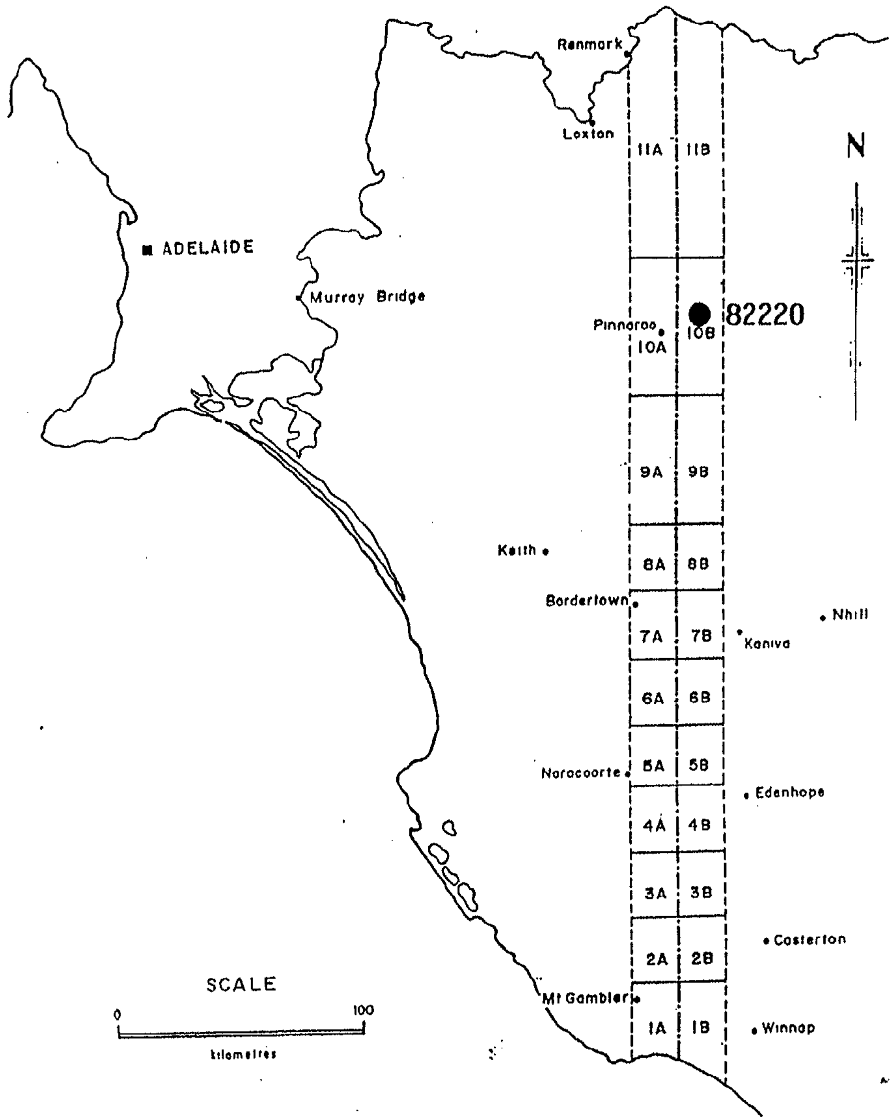
MESA 95-20(

Job No. 5916



Parish of:	MULCRA	
Well No:	82220	
Coordinates:	Easting 506150	Northing 6106760
Ground Elevation (AHD):	80.54m	
Formation:	Murray Group Limestone	
Water Level Trend:	No Significant Change	

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	130	0	61
	Slotted	130	61	167



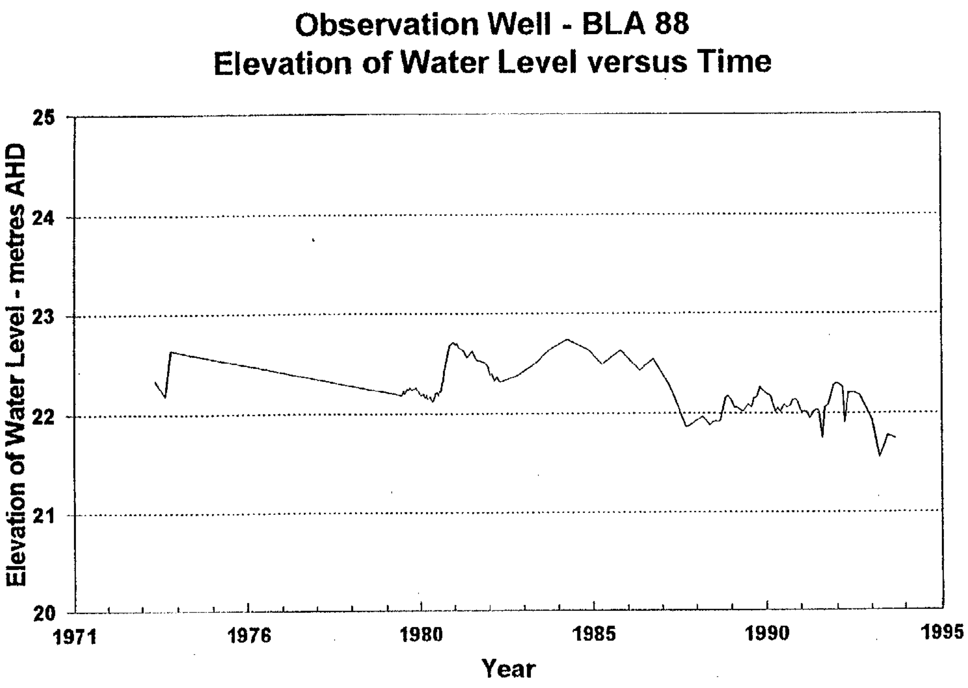
MINES AND ENERGY SOUTH AUSTRALIA

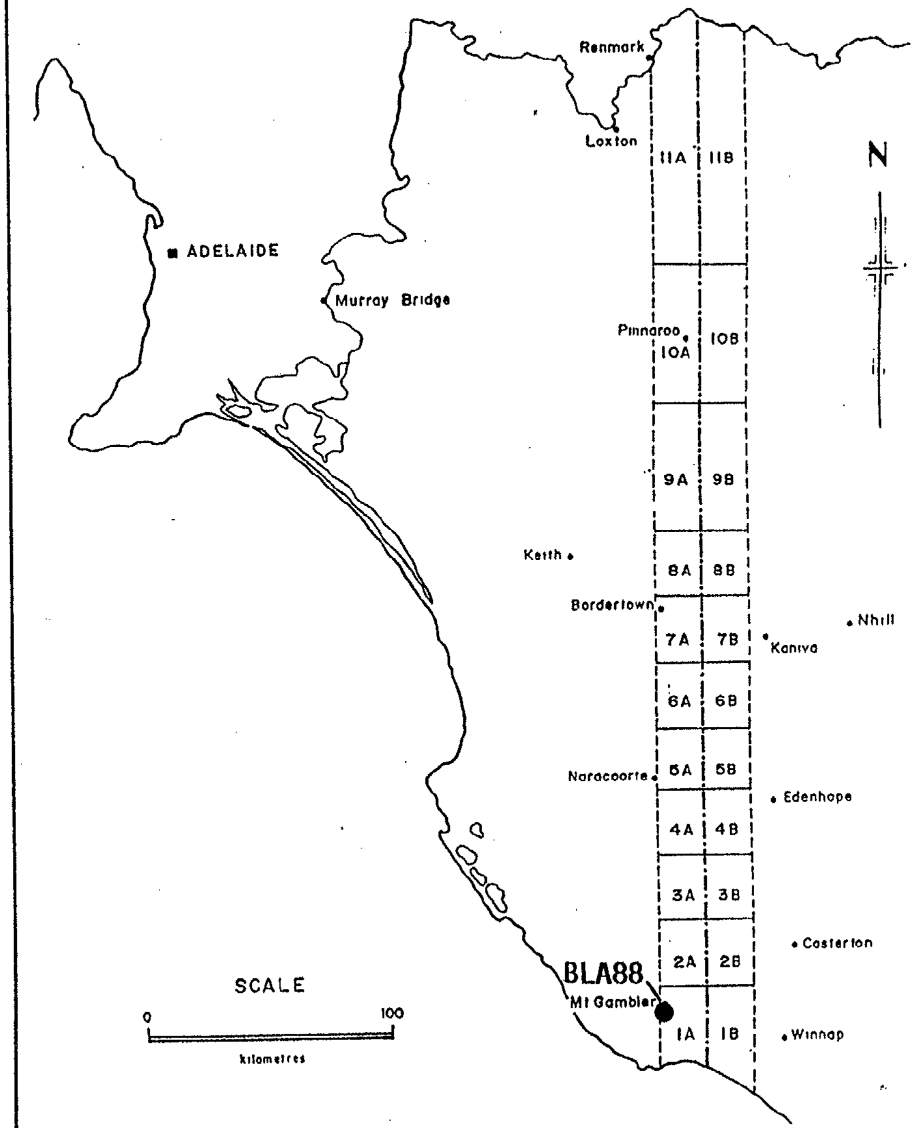
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. 82220

FIGURE A15

MESA 95-201

Job No. 5916





Hundred of:	BLANCHE	
Well No:	BLA 88	
Coordinates:	Easting 478234	Northing 5814145
Unit No:	7022-2782	
Ground Elevation (AHD):	40.85m	
Formation:	Lower Tertiary Confined	
Water Level Trend:	0.028 m/year Decrease	

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	203	0	80
	Steel	127	69.25	106.05
	Sandscreen	127	106.05	118.55

MINES AND ENERGY SOUTH AUSTRALIA

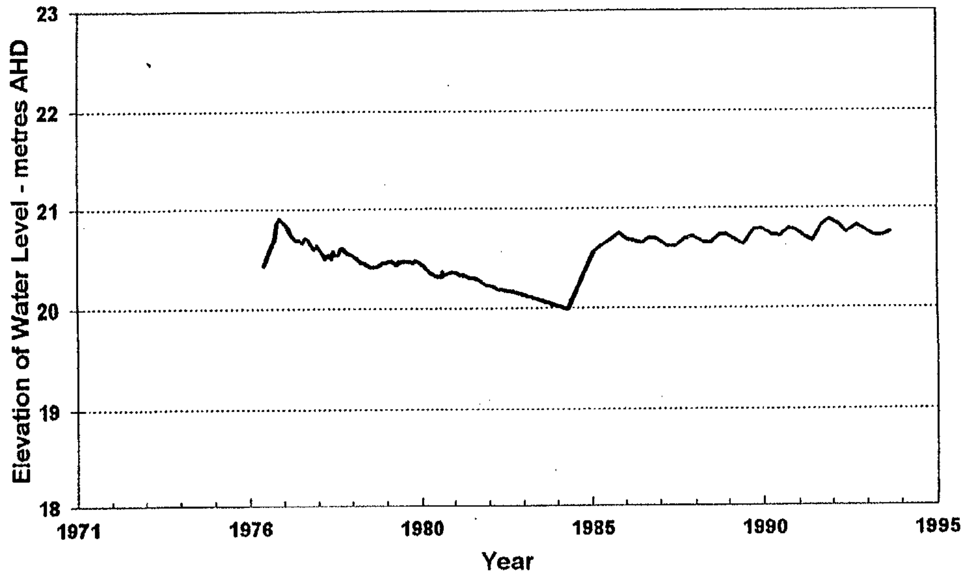
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. BLA 88

FIGURE A16

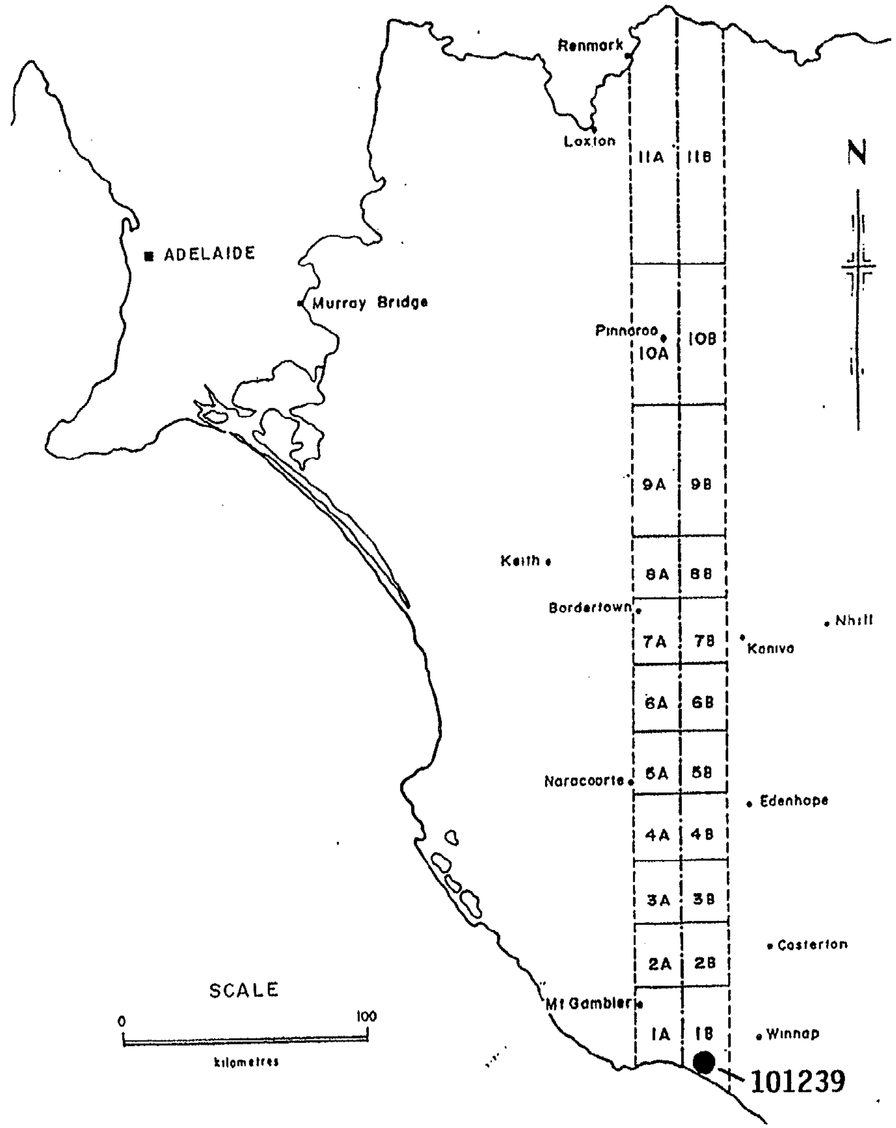
MESA 95-202

Job No. 5916



Parish of:	WARRAIN
Well No:	101239
Coordinates:	Easting 509565 Northing 5787397
Ground Elevation (AHD):	33.4m
Formation:	Lower Tertiary Confined
Water Level Trend:	1976 - 1984 Decrease, 1985 - 1994 Increase

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	203	0	51.2
	Steel	150	51.2	274
	Steel	125	?	292
	Sandscreen	125	292	298
	Steel	125	298	322



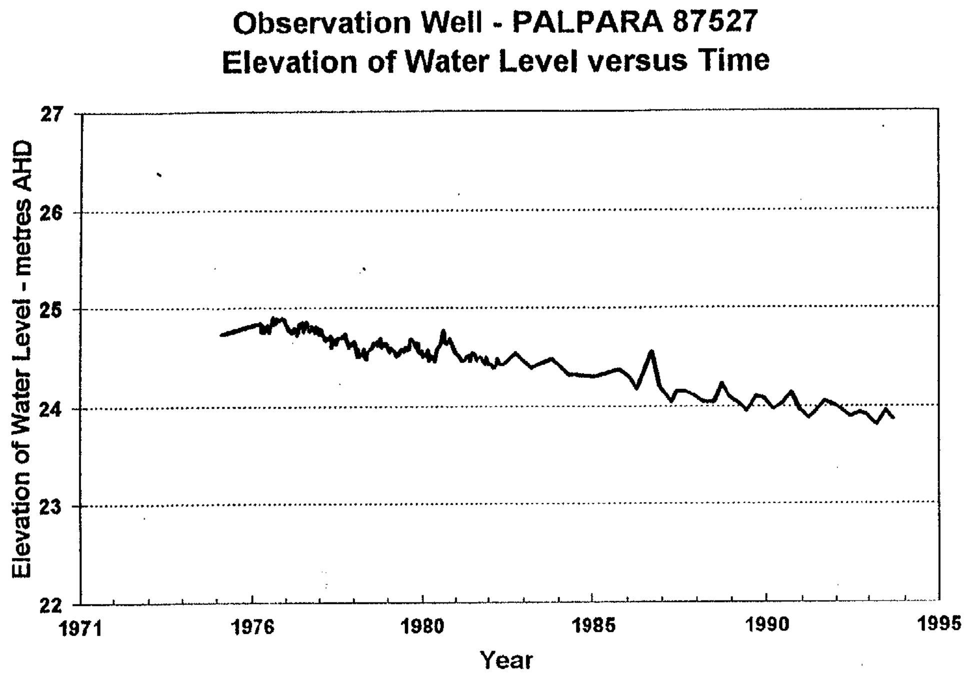
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. 101239

FIGURE A17

MESA 95-203

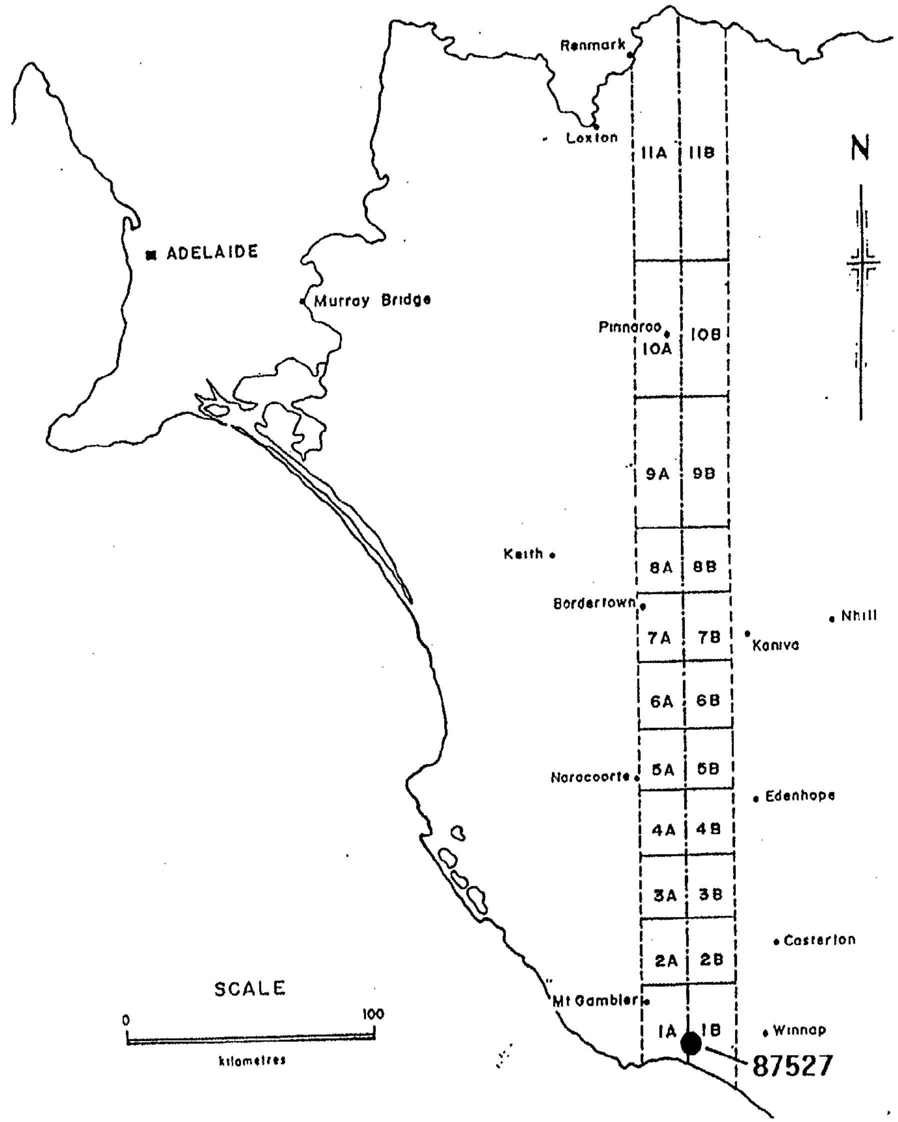
MINES AND ENERGY SOUTH AUSTRALIA

Job No. 5916



Parish of:	PALPARA
Well No:	87527
Coordinates:	Easting 497000 Northing 5796800
Ground Elevation (AHD):	25.31m
Formation:	Lower Tertiary Confined
Water Level Trend:	0.06m/year Decrease

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	203	0	65
	Steel	150	65	340.6
	Steel	125	320.9	439.4
	Sandscreen	125	439.4	445.9
	Steel	125	445.9	491.9

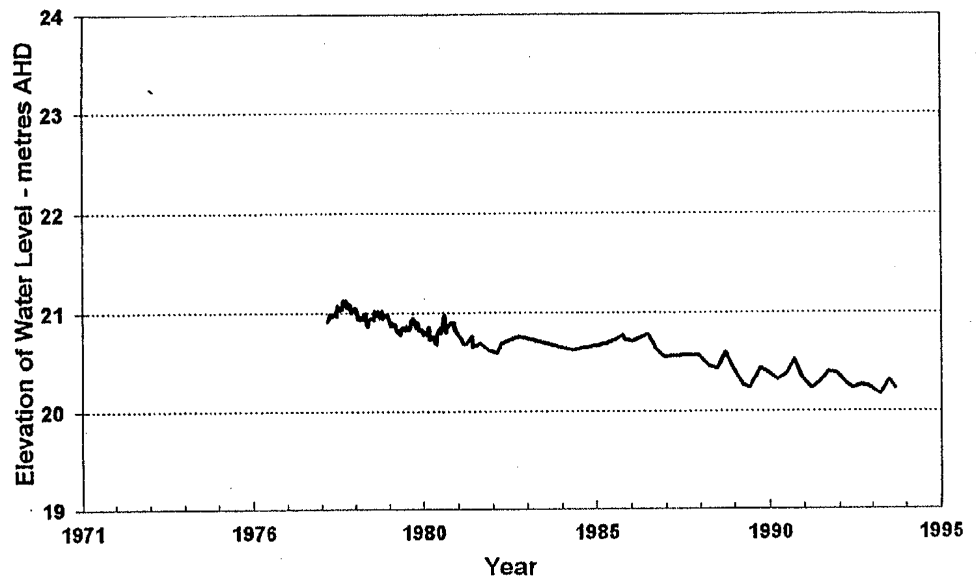


MINES AND ENERGY
SOUTH AUSTRALIA

S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. 87527

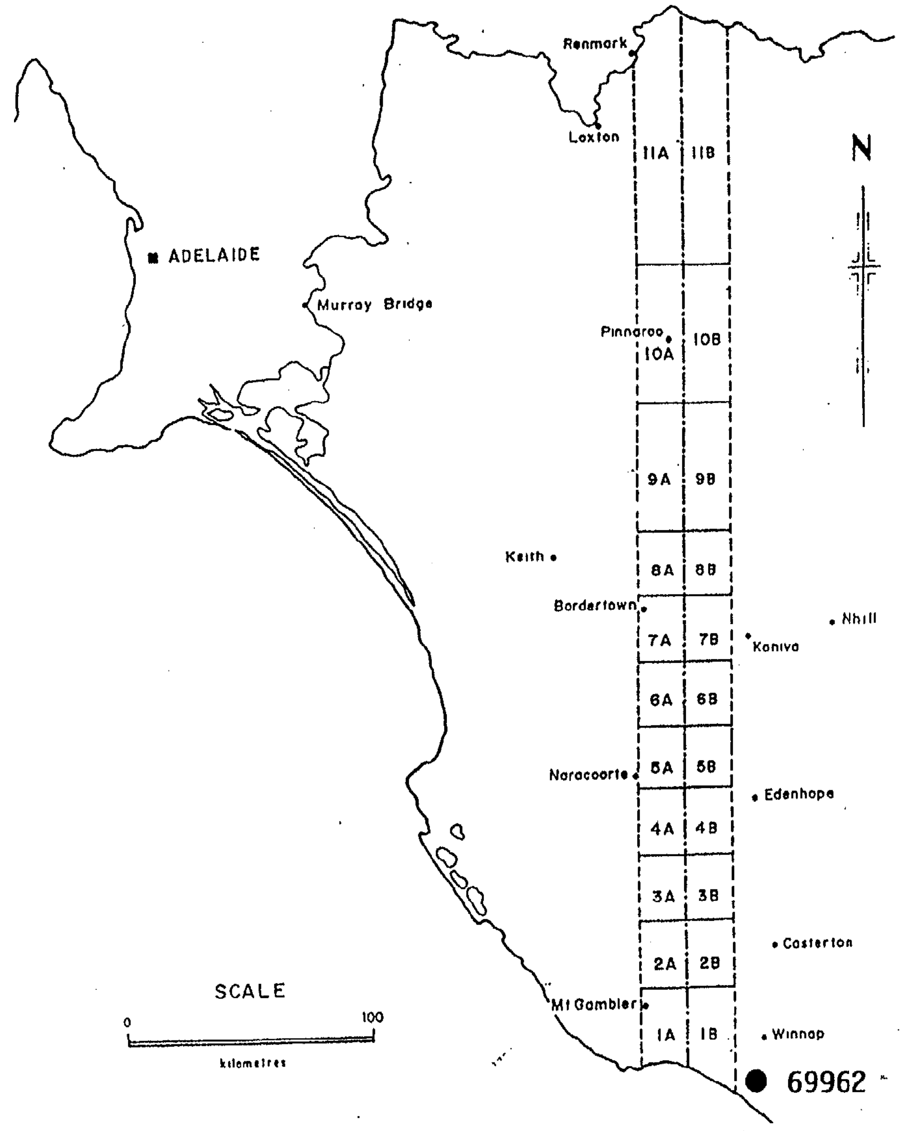
FIGURE A18
MESA 95-204

Job No. 5916



Parish of:	KENTBRUCK
Well No:	69962
Coordinates:	Easting 524969 Northing 5780187
Ground Elevation (AHD):	43.4m
Formation:	Lower Tertiary Confined
Water Level Trend:	0.06m/year Decrease

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	203	0	39.7
	Steel	150	39.7	559.2
	Steel	125	559.2	560.2
	Sandscreen	125	560.2	570
	Steel	125	570	588.6

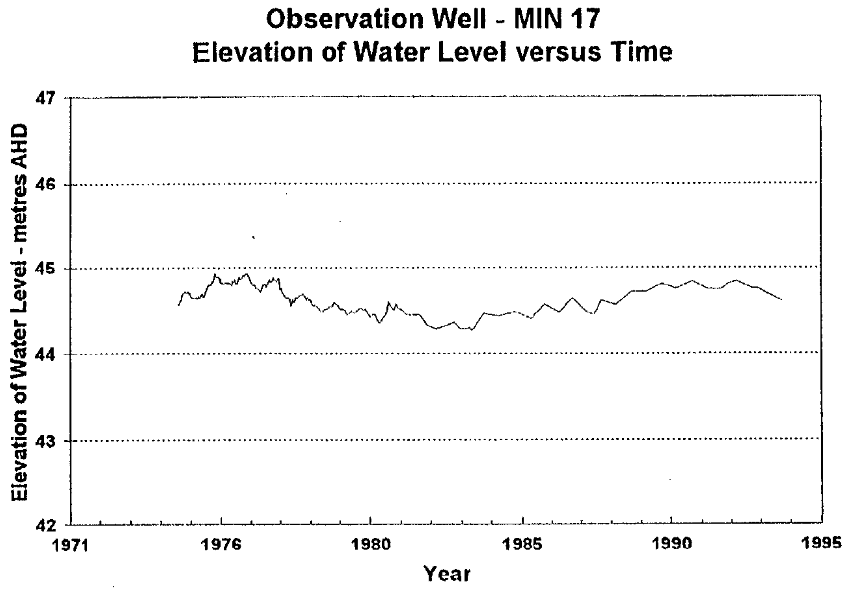


MINES AND ENERGY SOUTH AUSTRALIA

S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. 69962

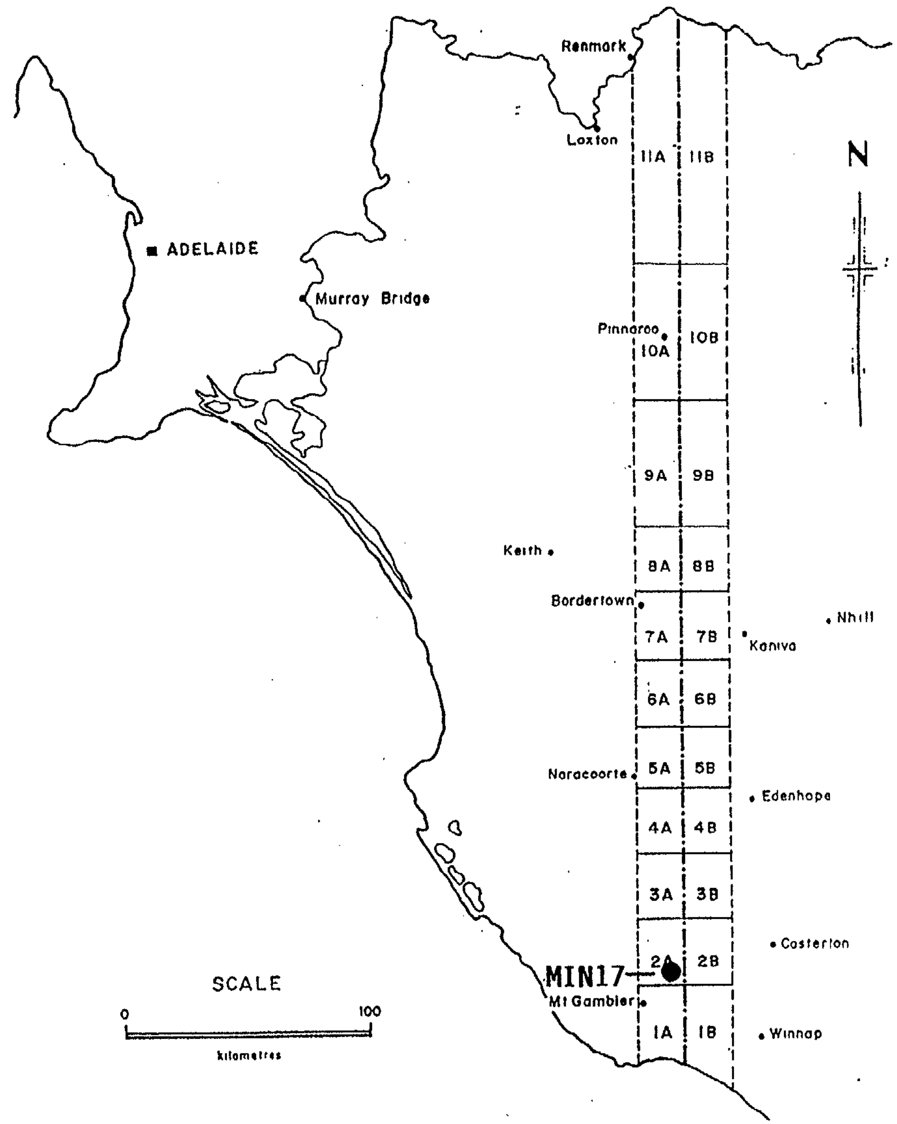
FIGURE A19
MESA 95-205

Job No. 5916



Hundred of:	MINGBOOL
Well No:	MIN 17
Coordinates:	Easting 491896 Northing 5829398
Unit No:	7022-1278
Ground Elevation (AHD):	70.73m
Formation:	Lower Tertiary Confined
Water Level Trend:	No Significant Change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	203	0	130
	Steel	152	57	184
	Steel	127	124	199.85
	Sandscreen	127	199.85	212.15
	Steel	127	212.15	213
	Galv. Pipe	100	213	221.6



MINES AND ENERGY
SOUTH AUSTRALIA

S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. MIN 17

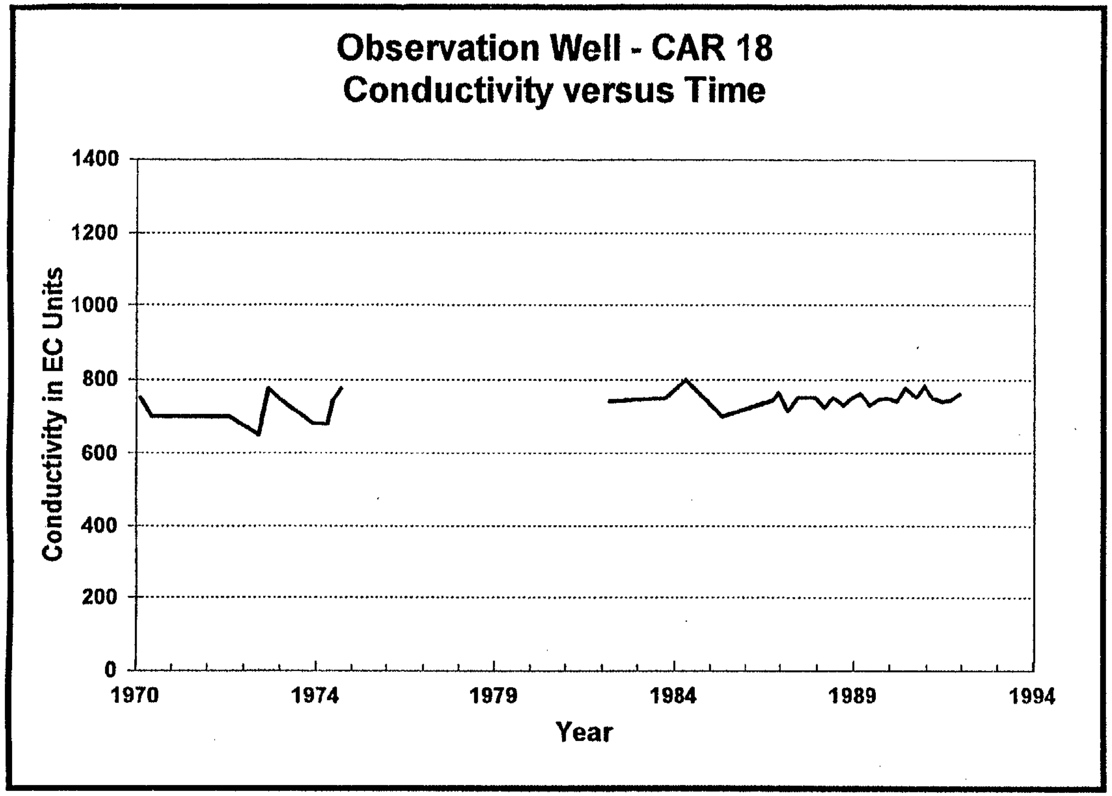
FIGURE A2(
MESA 95-20(

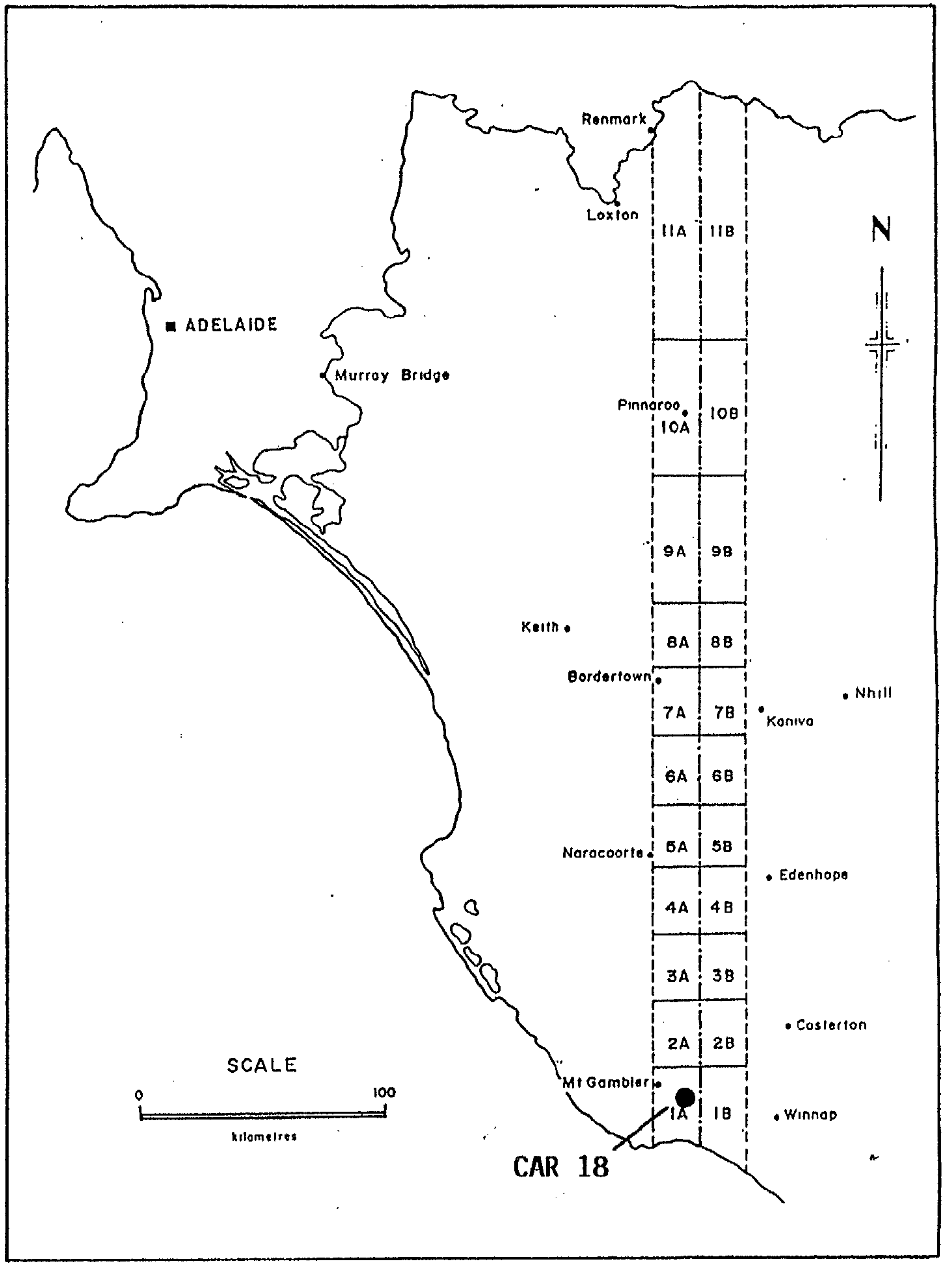
APPENDIX B

SELECTED SOUTH AUSTRALIAN AND VICTORIAN SALINITY GRAPHS FOR THE TERTIARY LIMESTONE AQUIFER

OBSERVATION WELL	ZONE	FIGURE
CAR 18	1A	B1
101241	1B	B2
113474	1B	B3
NAN 9	2A	B4
103113	2B	B5
PEN 20	3A	B6
113475	3B	B7
JES 54	4A	B8
111321	4B	B9
GGL 10	6A	B10
85628	6B	B11
SEN 17	8A	B12
PNR 6	10A	B13
54642	10B	B14
77199	10B	B15
PEB 5	11A	B16

Job No. 5916





Hundred of:	CAROLINE
Well No:	CAR 18
Coordinates:	Easting 491896 Northing 5800533
Unit No:	7022-469
Formation:	Gambier Limestone
Conductivity Trend:	No significant change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	152	0	31.7
	Open Hole	152	31.7	48.8

MINES AND ENERGY SOUTH AUSTRALIA

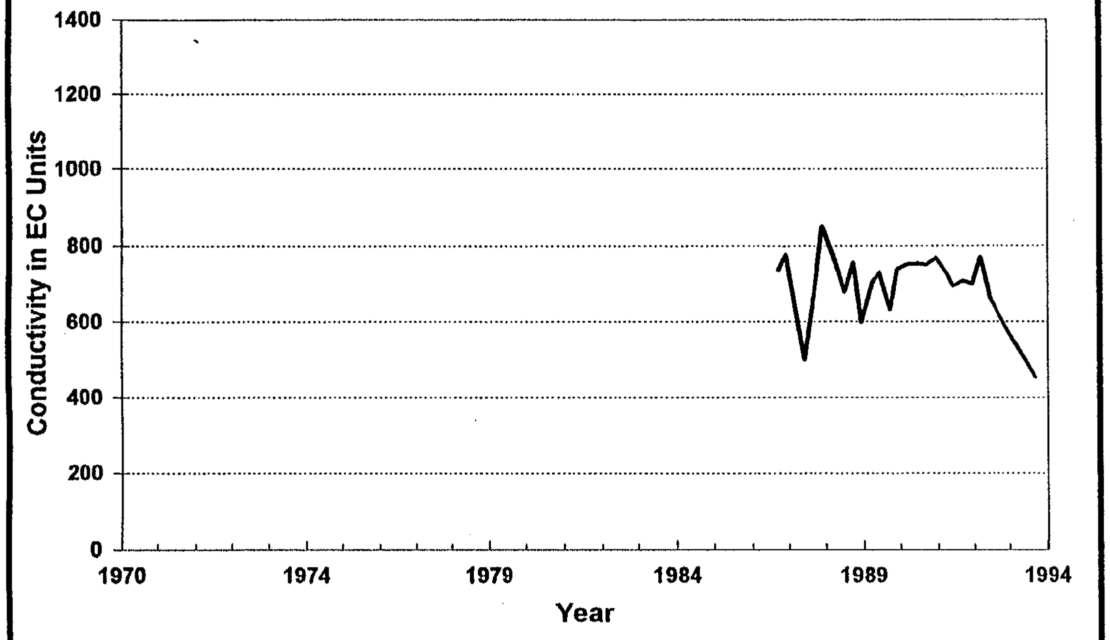
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. CAR 18

FIGURE B

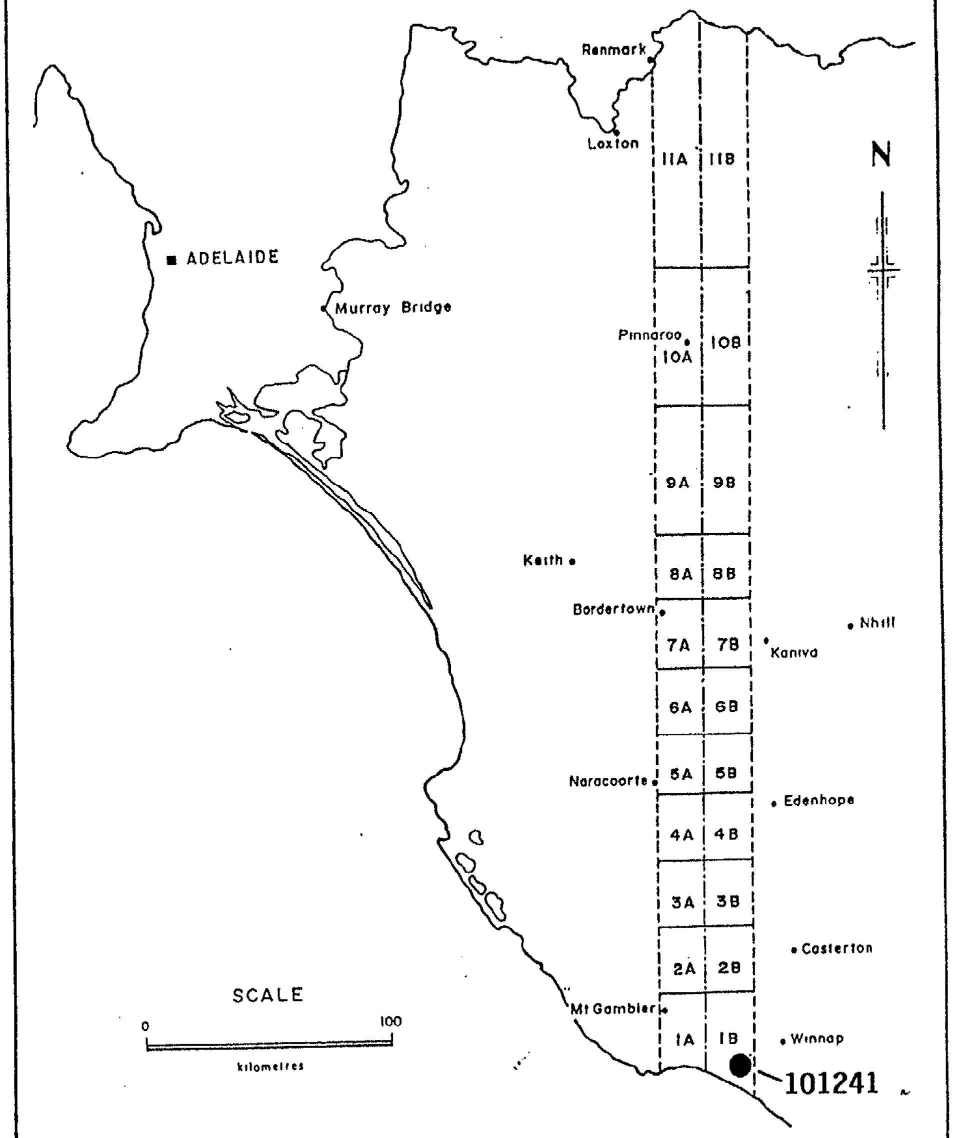
MESA 95-207

Job No. 5916



Parish of:	WARRAIN
Well No:	101241
Coordinates:	Easting 514400 Northing 5785600
Formation:	Bridgewater
Conductivity Trend:	No significant change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	100	0	10



MINES AND ENERGY SOUTH AUSTRALIA

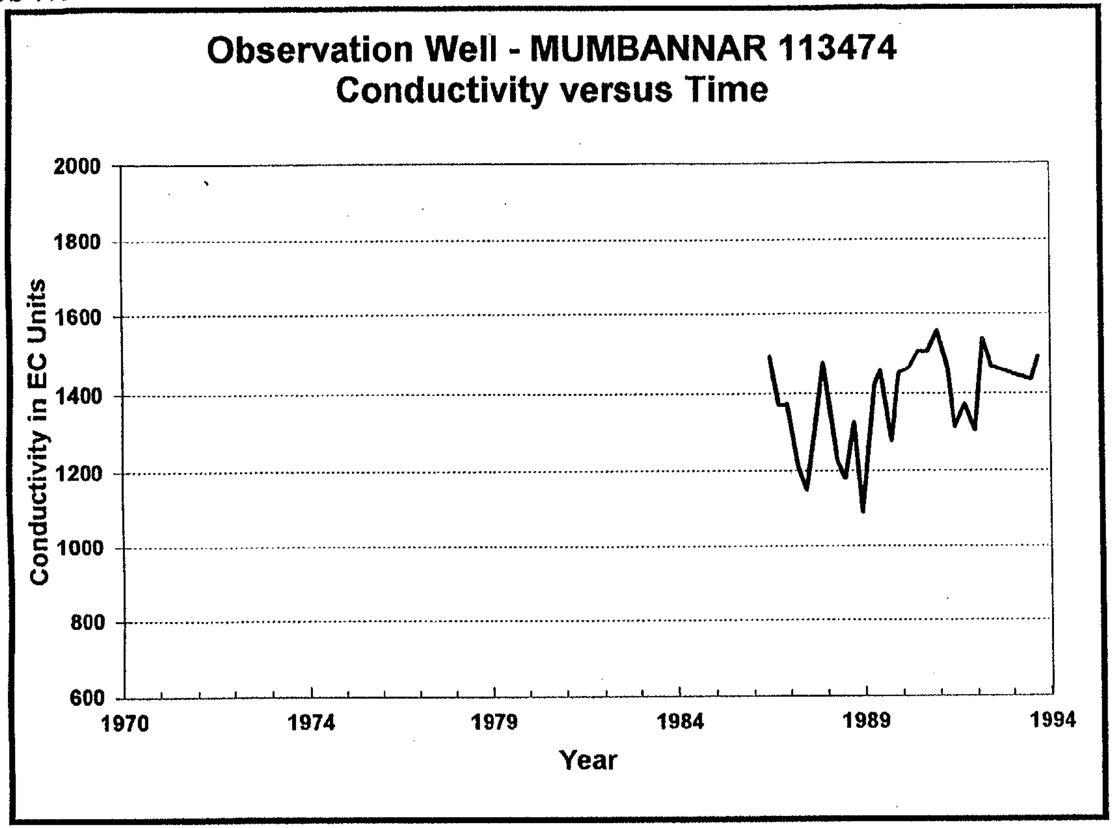
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. 101241

FIGURE B2

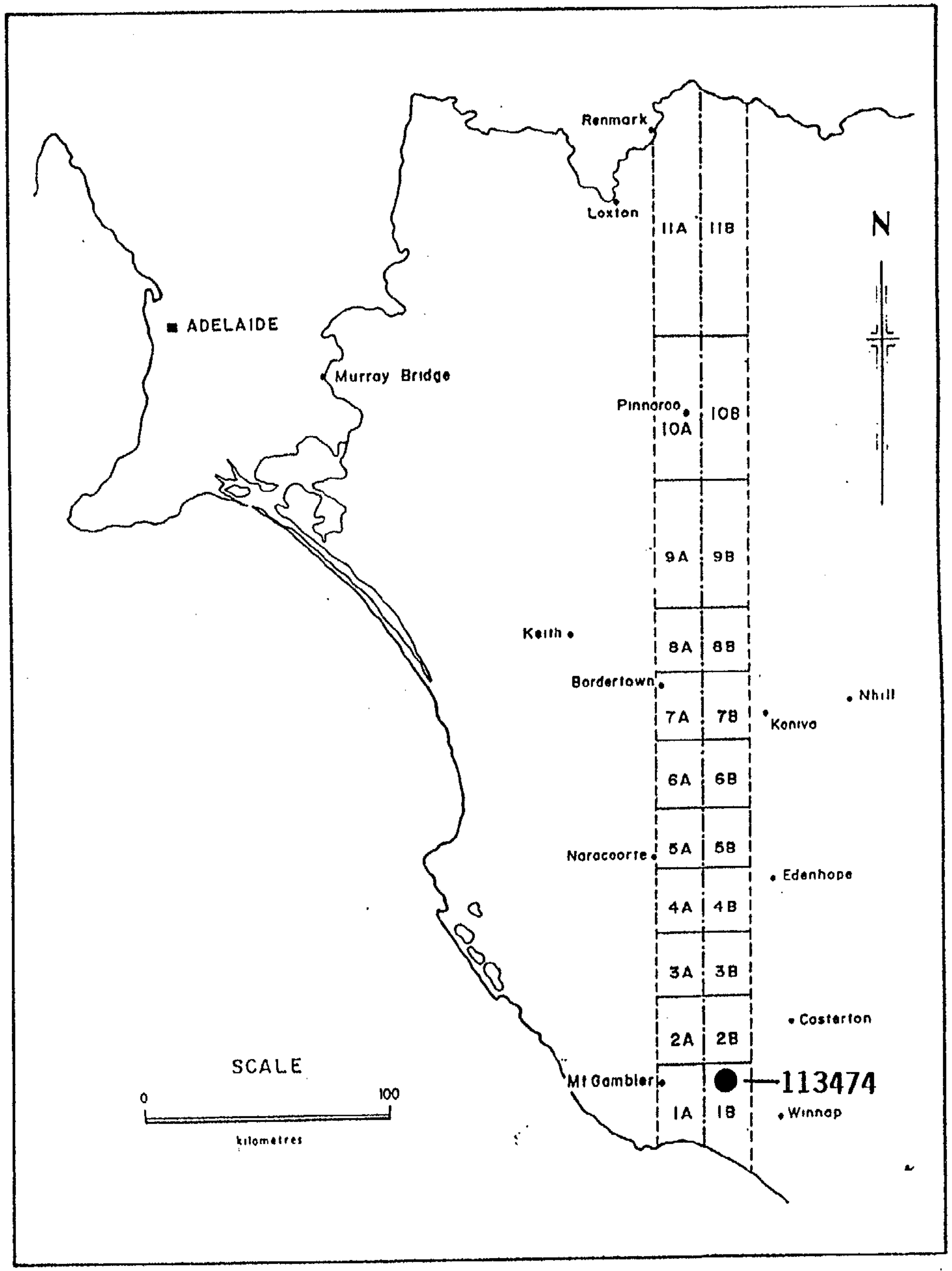
MESA 95-20?

Job No. 5916



Parish of:	MUMBANNAR
Well No:	113474
Coordinates:	Easting 507200 Northing 5814150
Formation:	Limestone
Conductivity Trend:	No significant change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	100	0	5



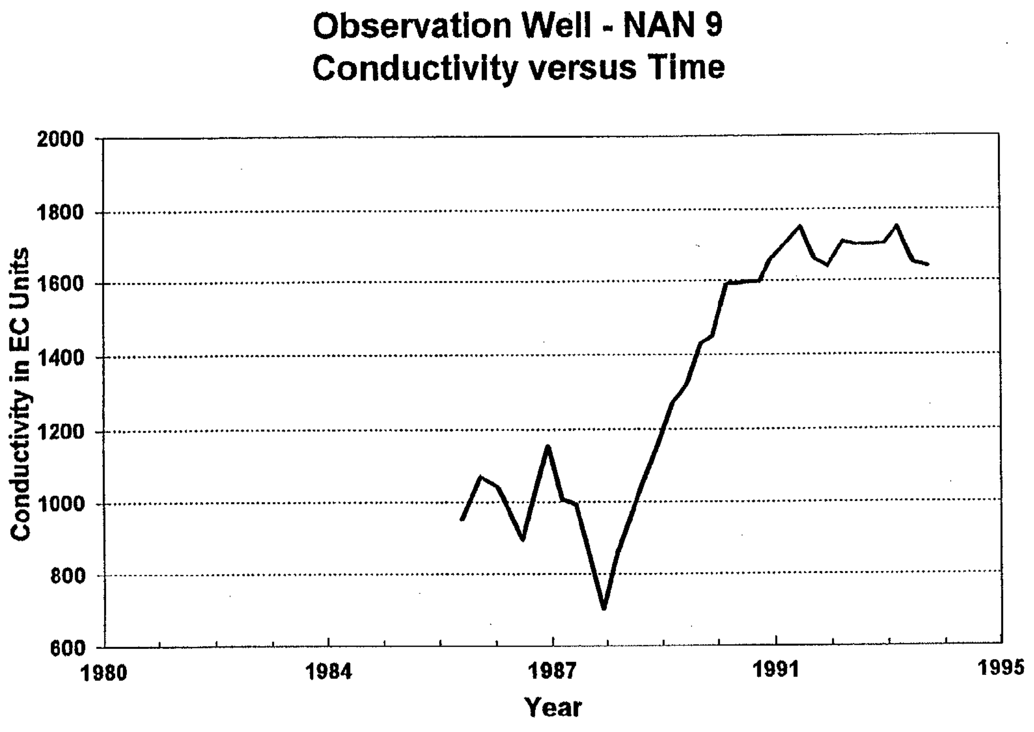
MINES AND ENERGY SOUTH AUSTRALIA

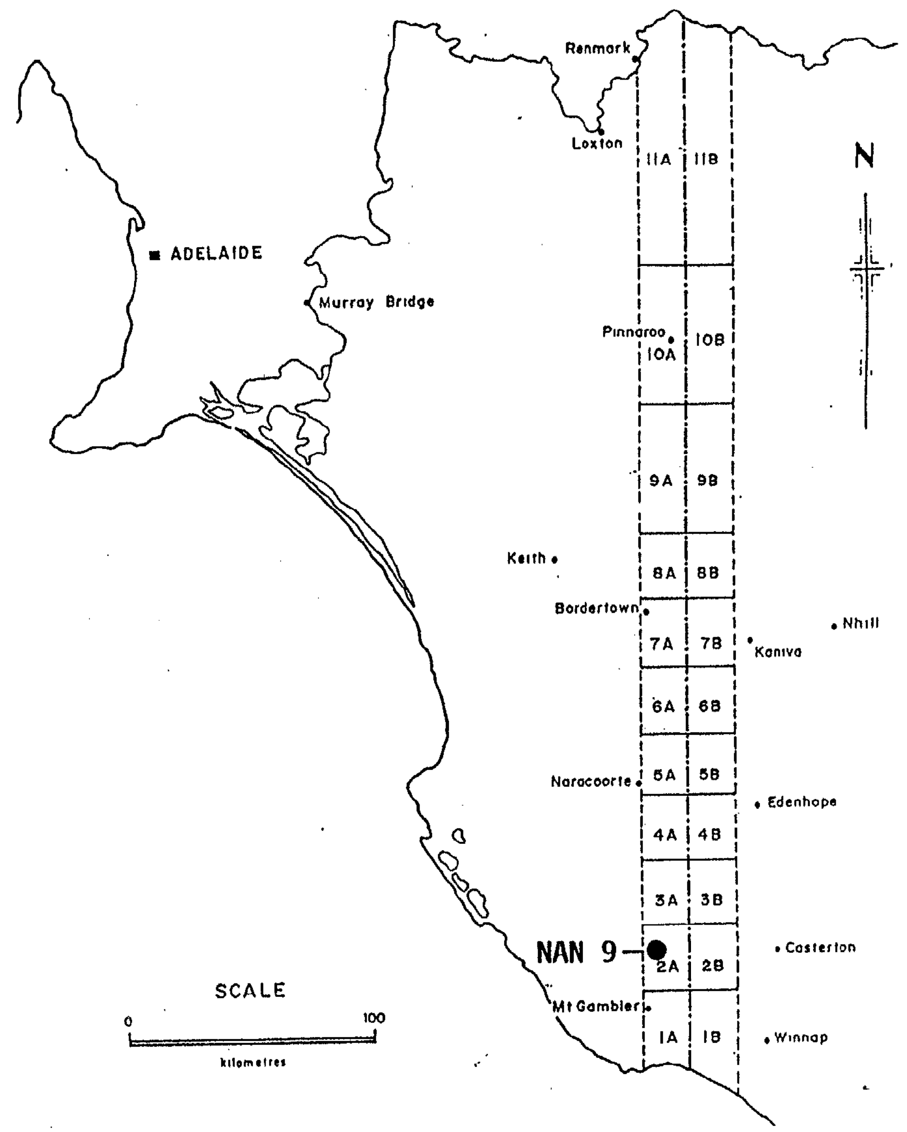
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. 113474

FIGURE B3

MESA 95-209

Job No. 5916





Hundred of:	NANGWARRY	
Well No:	NAN 9	
Coordinates:	Easting 485589	Northing 5840116
Unit No:	7022-1094	
Formation:	Gambier Limestone	
Conductivity Trend:	Overall Increase	

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	254	0	6.7
	Open Hole	254	6.7	7.3

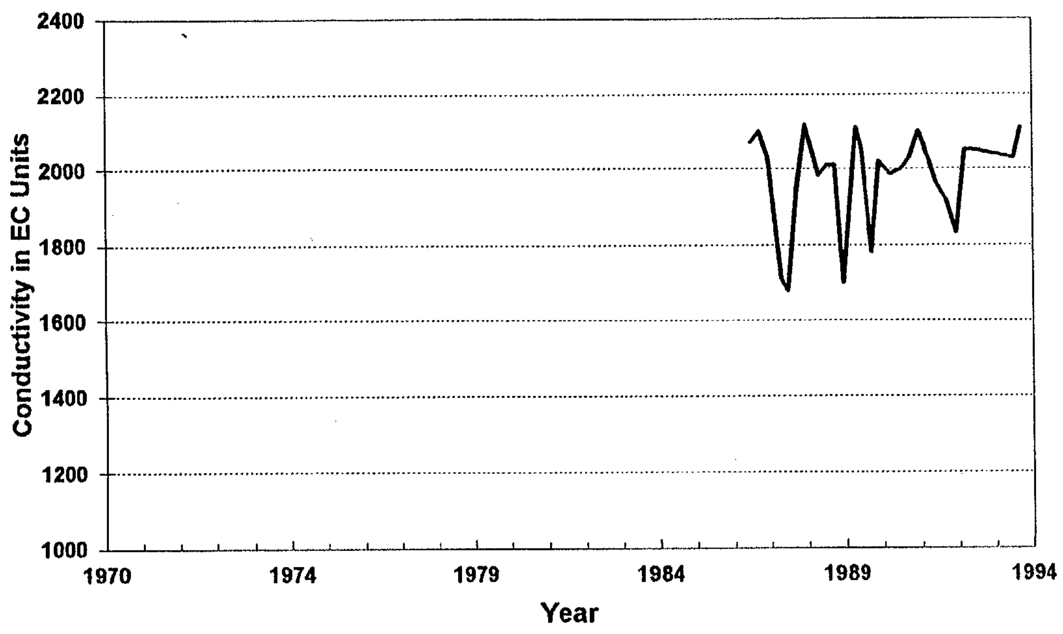
MINES AND ENERGY SOUTH AUSTRALIA

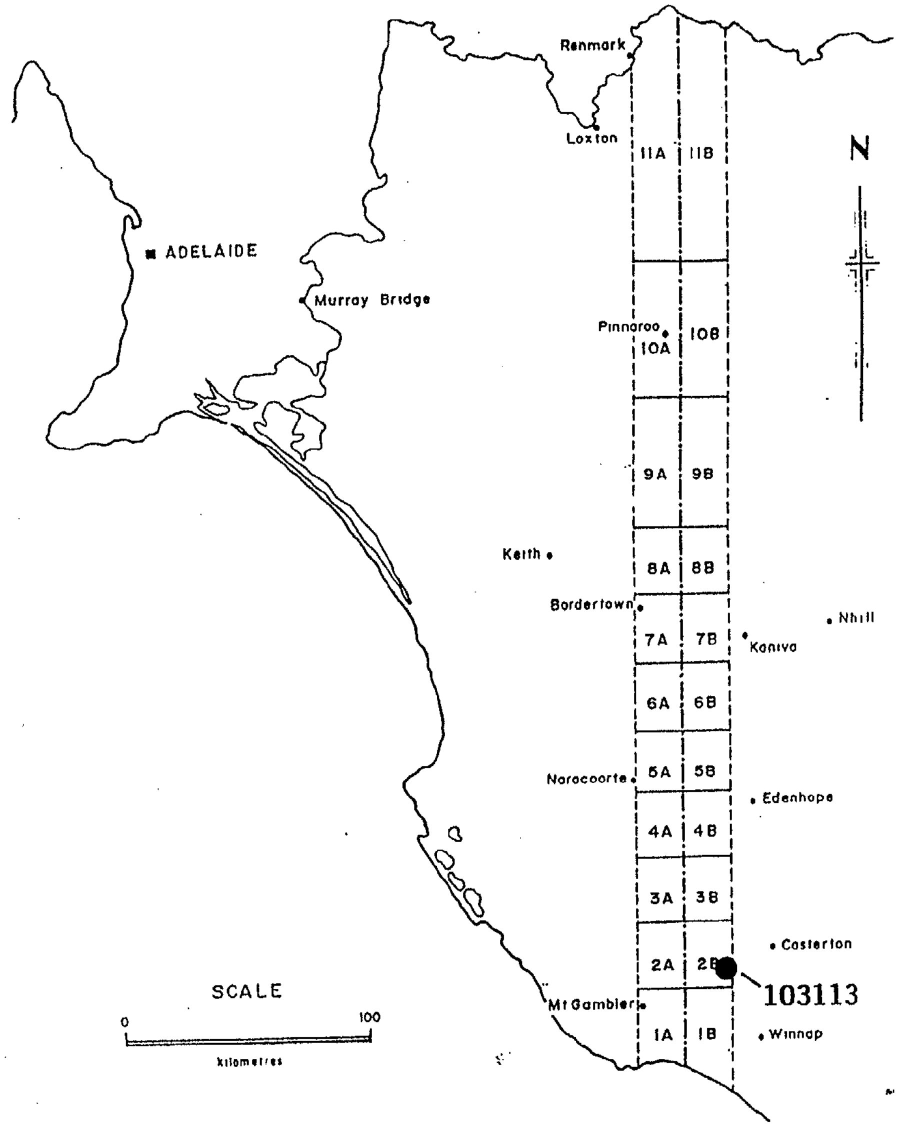
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. NAN 9

FIGURE B4

MESA 95-210

Job No. 5916





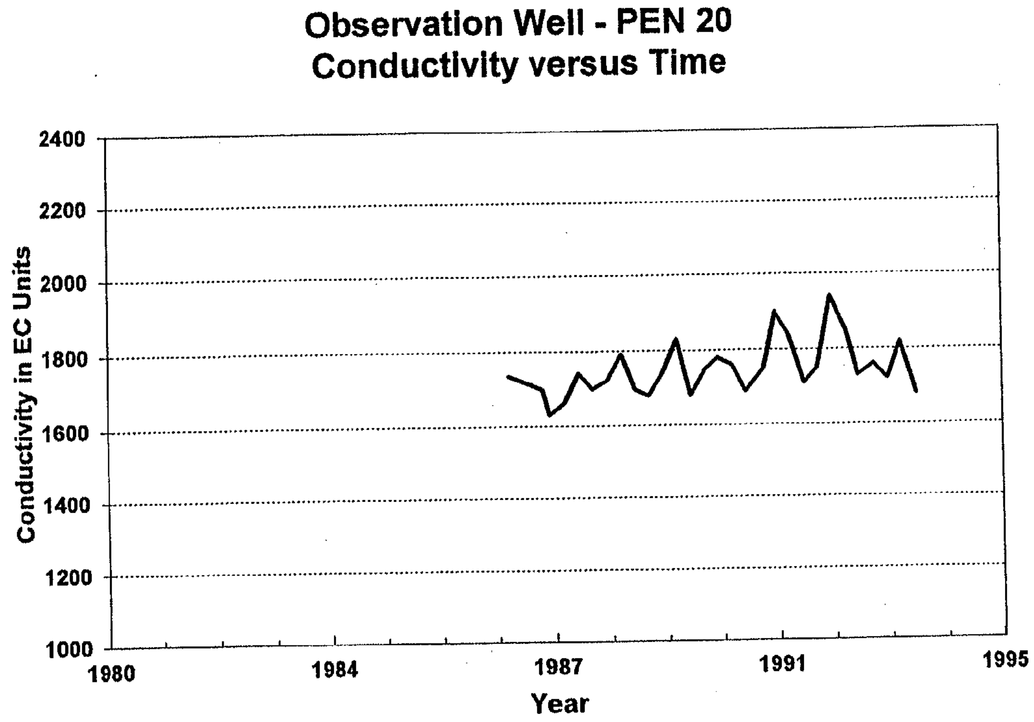
Parish of:	WILKIN	
Well No:	103113	
Coordinates:	Easting 513700	Northing 5831200
Formation:	Murray Group Limestone	
Conductivity Trend:	No significant change	

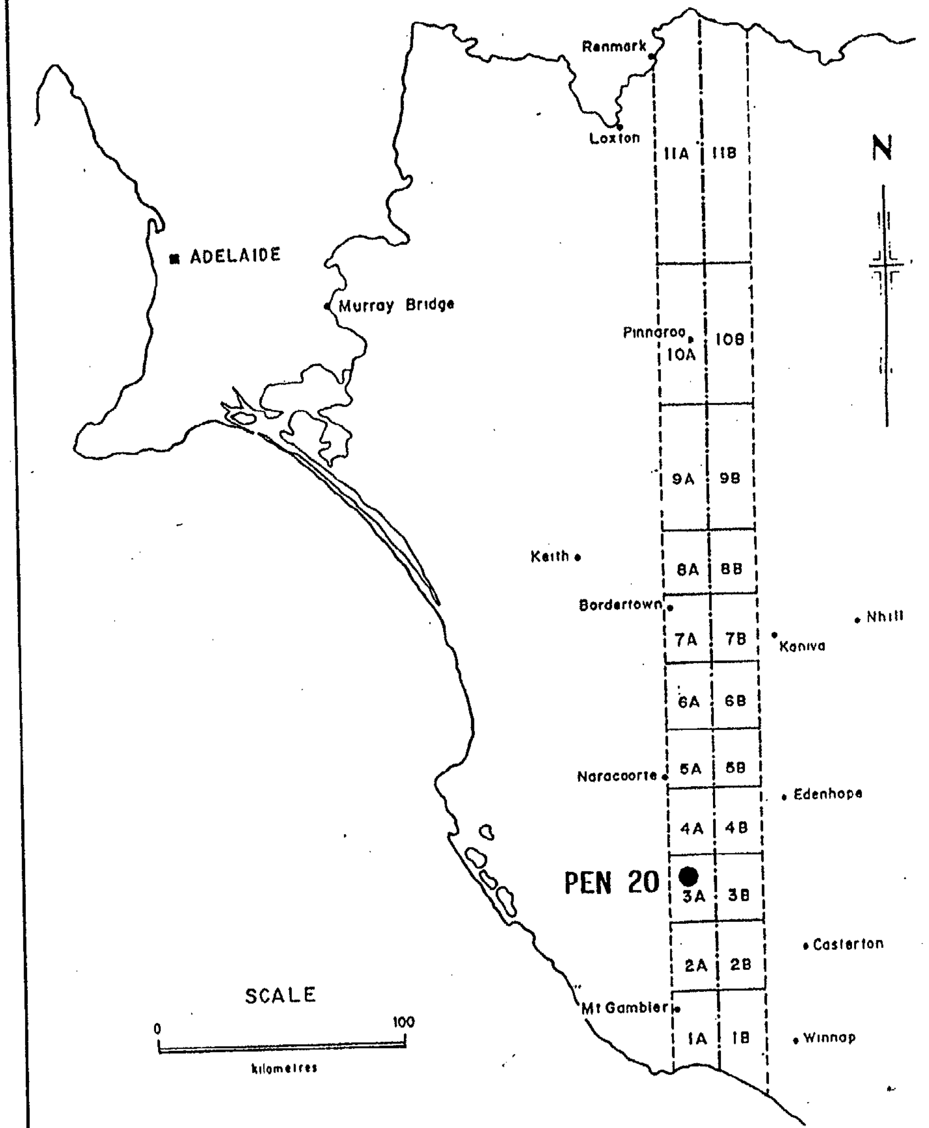
Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	100	0	26

S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. 103113

Job No. 5916





Hundred of:	PENOLA
Well No:	PEN 20
Coordinates:	Easting 486395 Northing 5868648
Unit No:	7023-2920
Formation:	Gambier Limestone
Conductivity Trend:	Slight Increase

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	203	0	6
	Open Hole	203	6	12

MINES AND ENERGY SOUTH AUSTRALIA

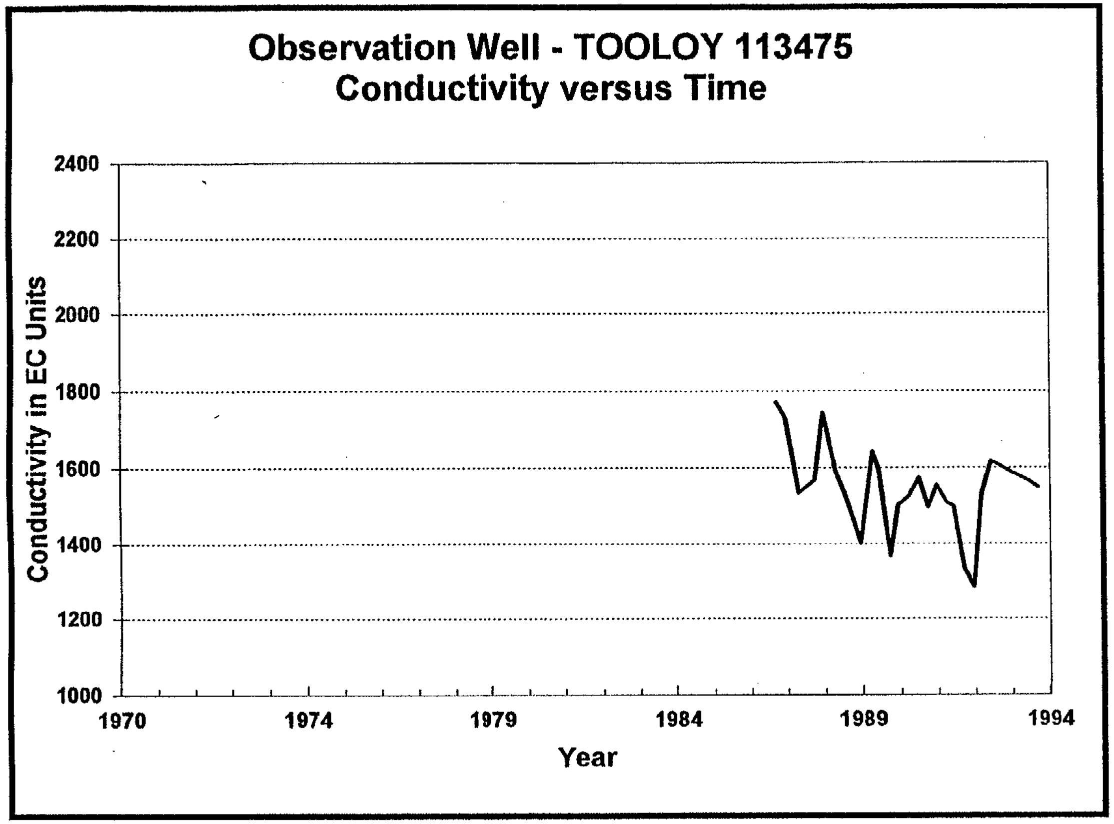
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. PEN 20

FIGURE B6

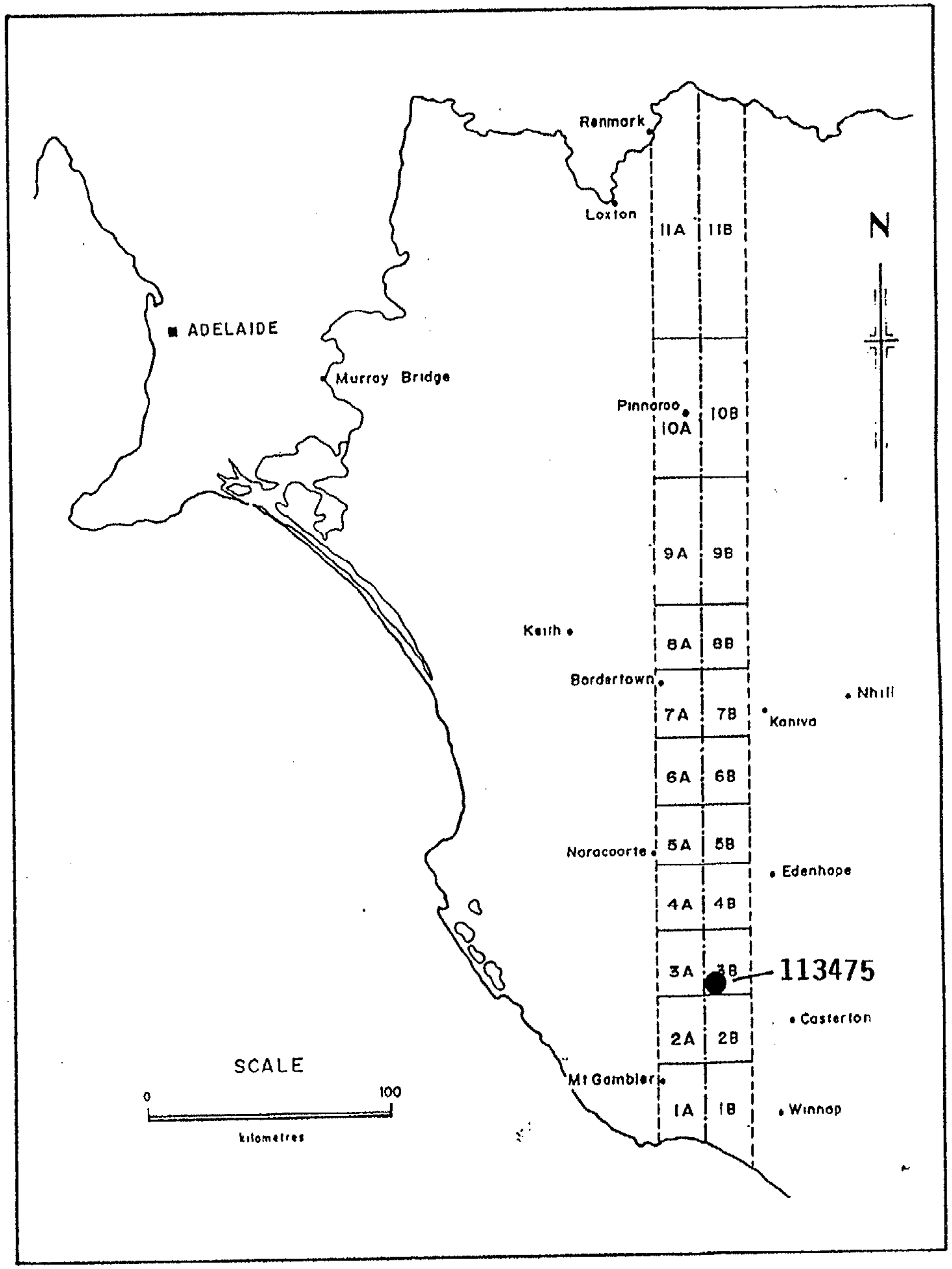
MESA 95-212

Job No. 5916



Parish of:	TOOLOY			
Well No:	113475			
Coordinates:	Easting 500800	Northing 5855400		
Formation:	Gambier Limestone			
Conductivity Trend:	Slight decrease			

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	100	0	5



S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

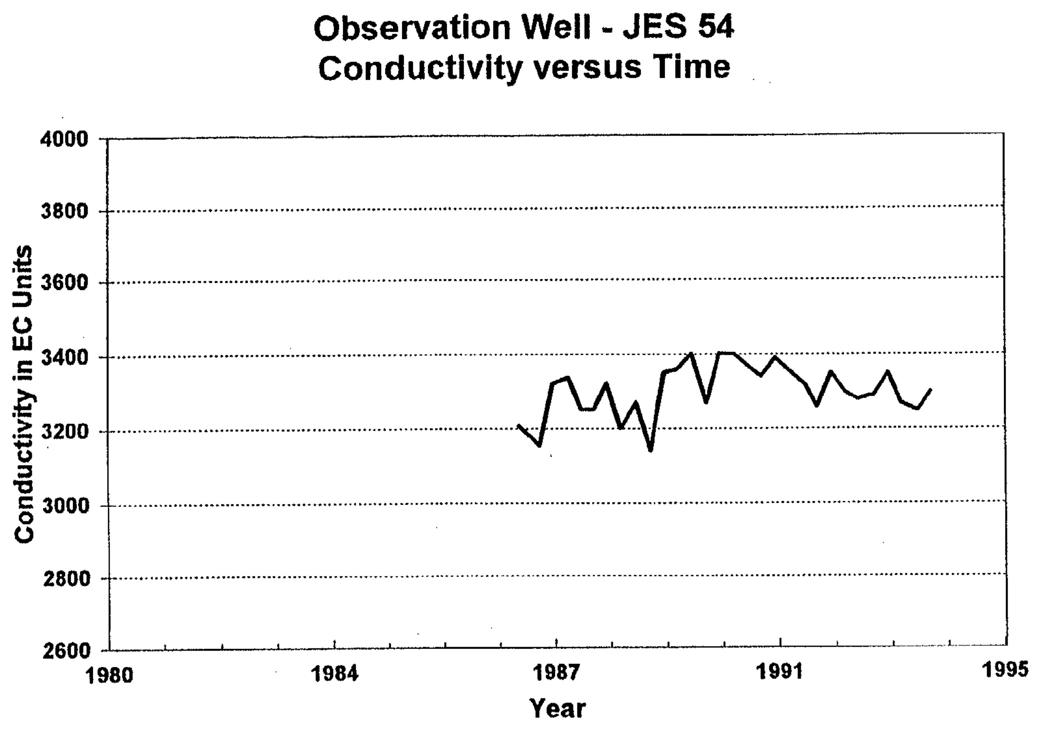
OBSERVATION WELL No. 113475

FIGURE B7

MESA 95-213

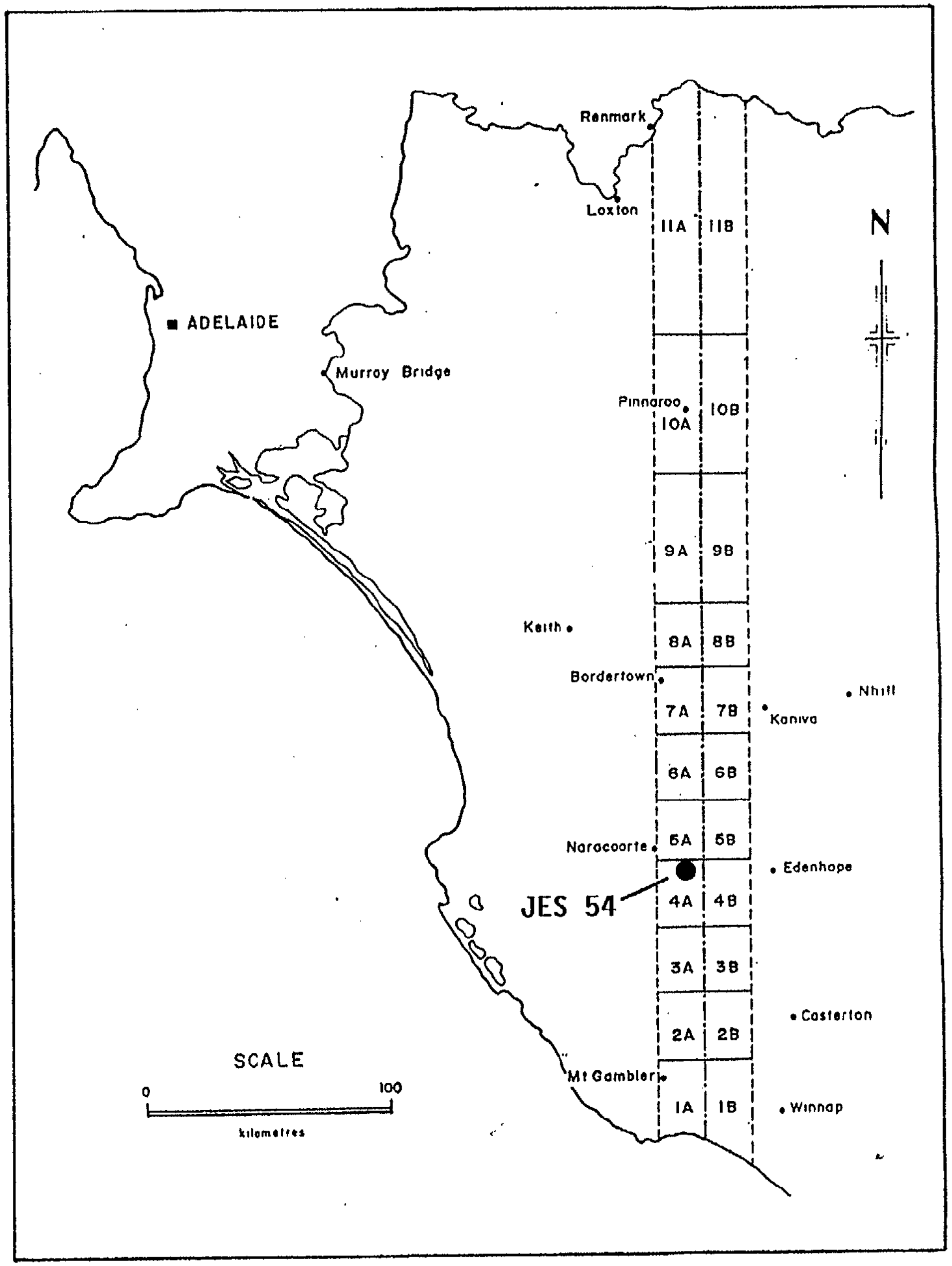
MINES AND ENERGY SOUTH AUSTRALIA

Job No. 5916



Hundred of:	JESSIE
Well No:	JES 54
Coordinates:	Easting 488500 Northing 5902167
Unit No:	7023-1723
Formation:	Gambier Limestone
Conductivity Trend:	No significant change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Fluming	102	0	?

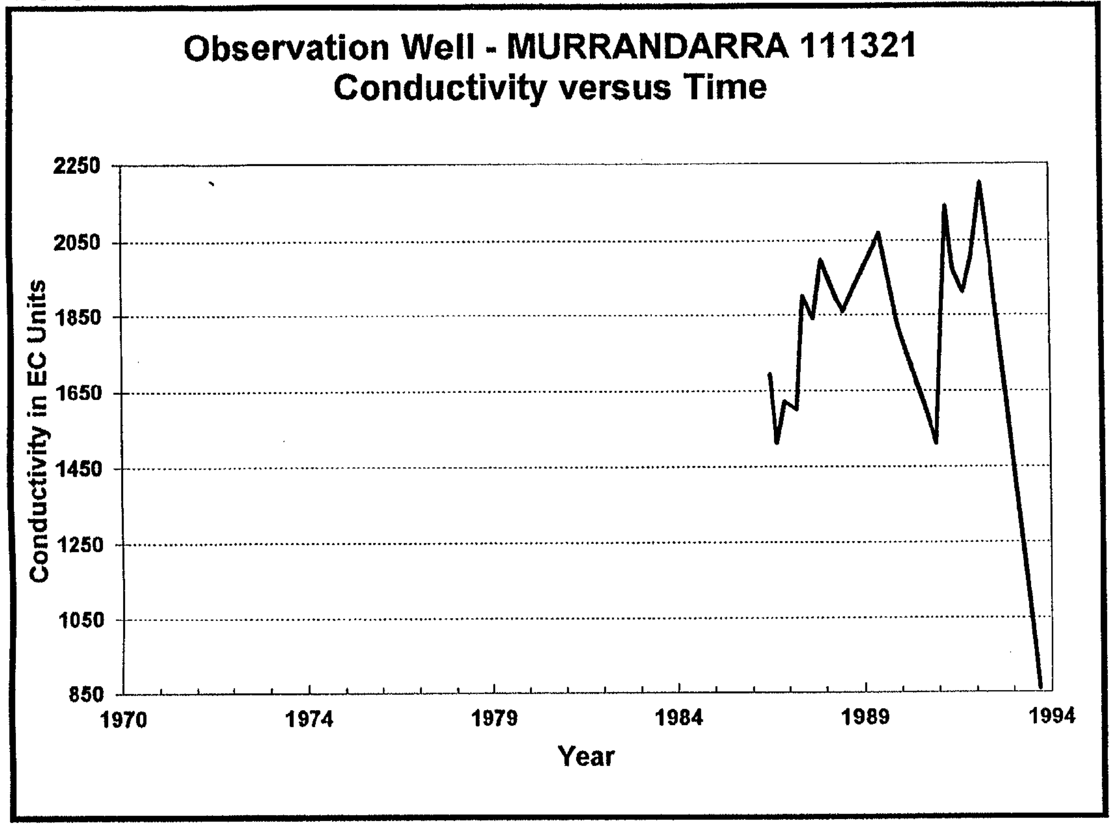


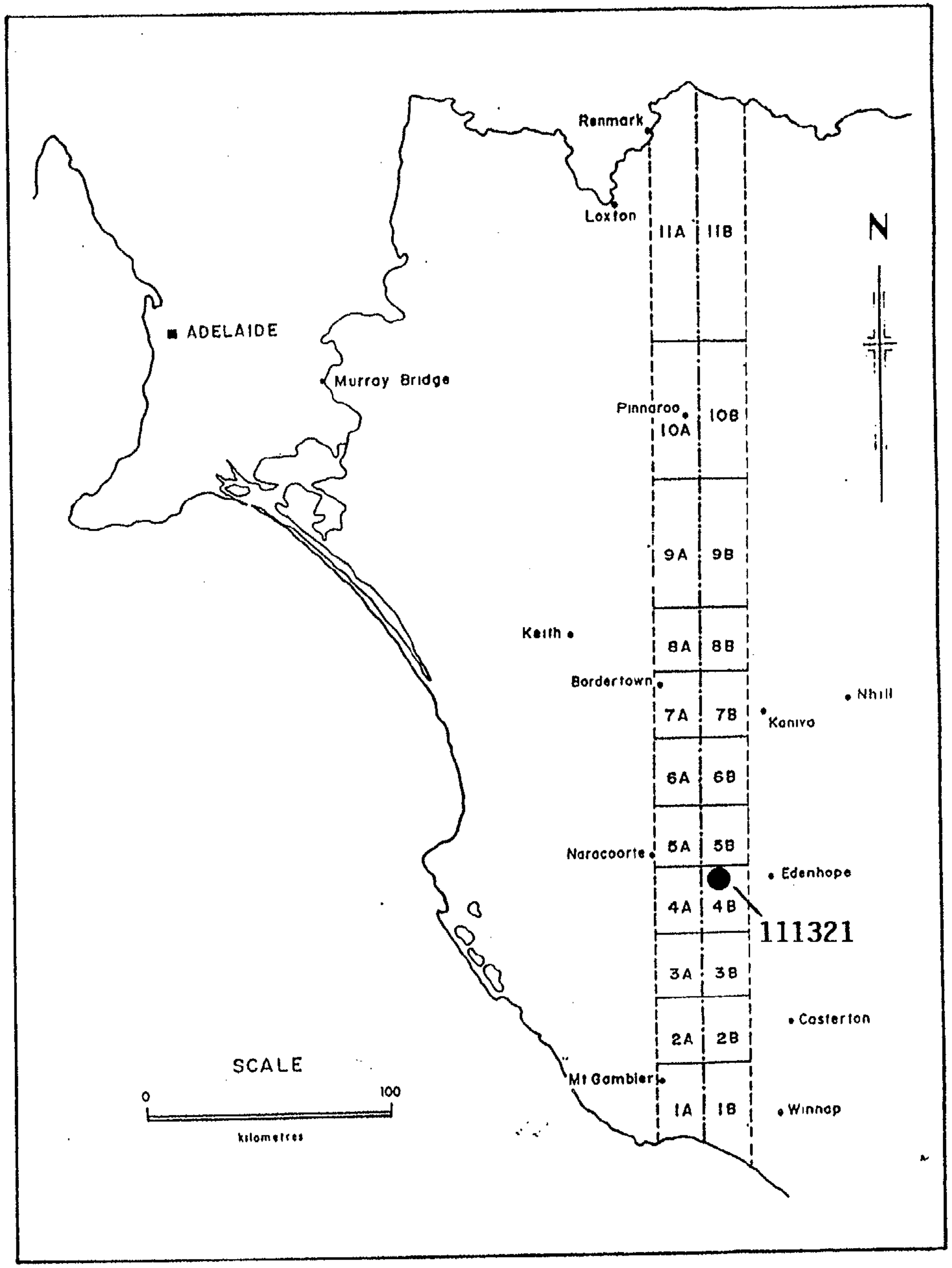
MINES AND ENERGY SOUTH AUSTRALIA

S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. JES 54

FIGURE B8
MESA 95-214

Job No. 5916





Parish of:	MURRANDARRA
Well No:	111321
Coordinates:	Easting 504700 Northing 5899200
Formation:	Murray Group Limestone
Conductivity Trend:	No significant change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	?	0	17

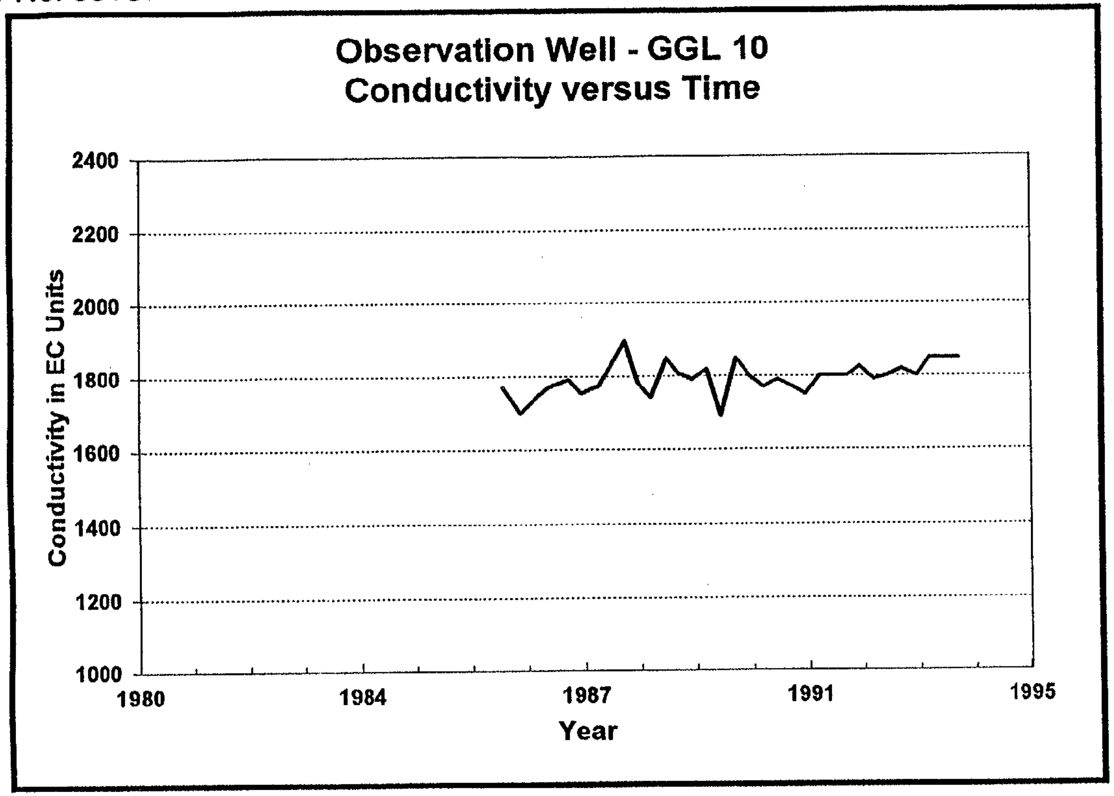
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. 111321

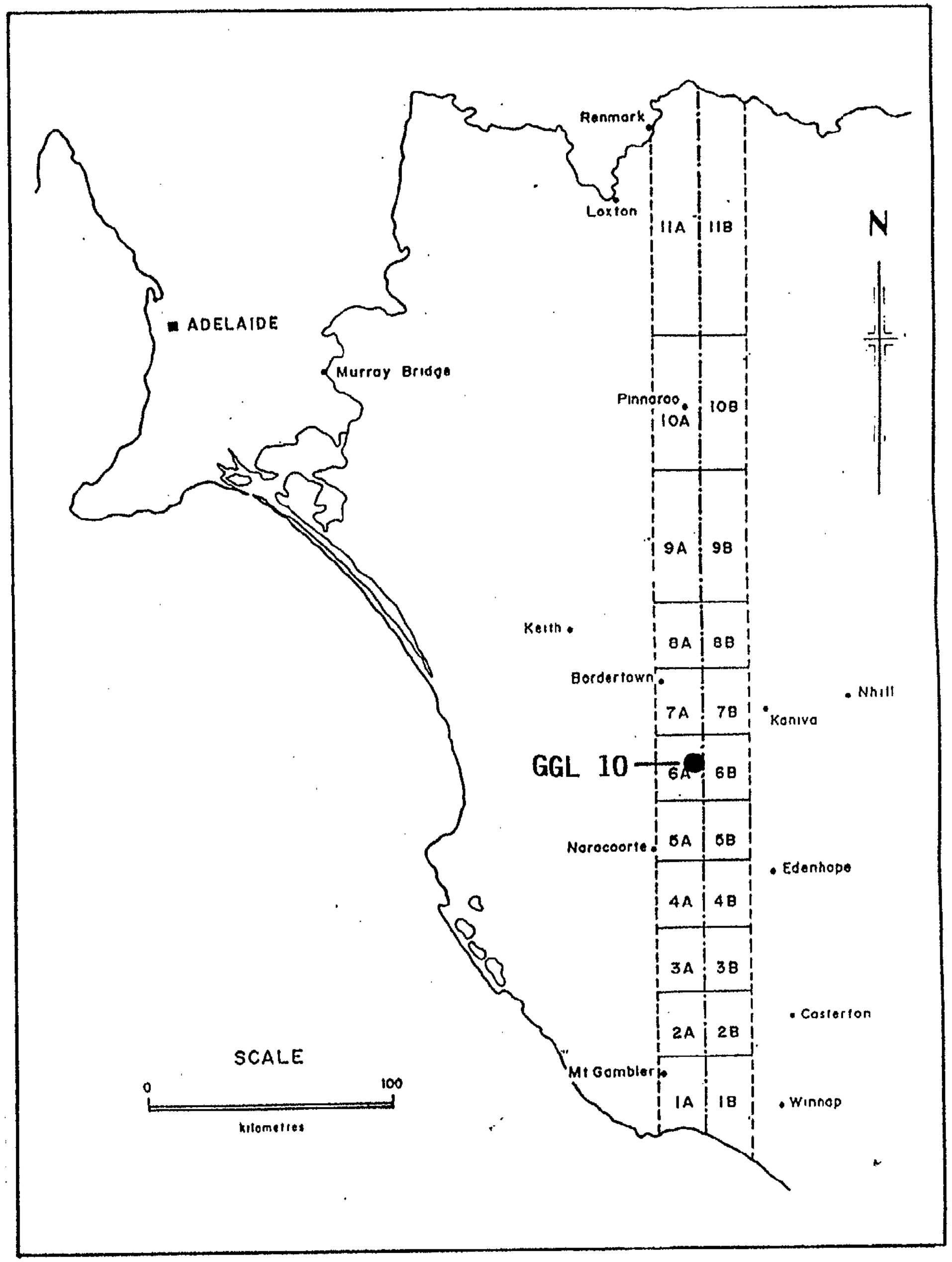
FIGURE B9

MESA 95-215

MINES AND ENERGY SOUTH AUSTRALIA

Job No. 5916





Hundred of:	GEEGEELA
Well No:	GGL 10
Coordinates:	Easting 495885 Northing 5946751
Unit No:	7024-1099
Formation:	Murray Group Limestone
Conductivity Trend:	No significant change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	127	0	12.1
	Open Hole	127	12.1	30.5

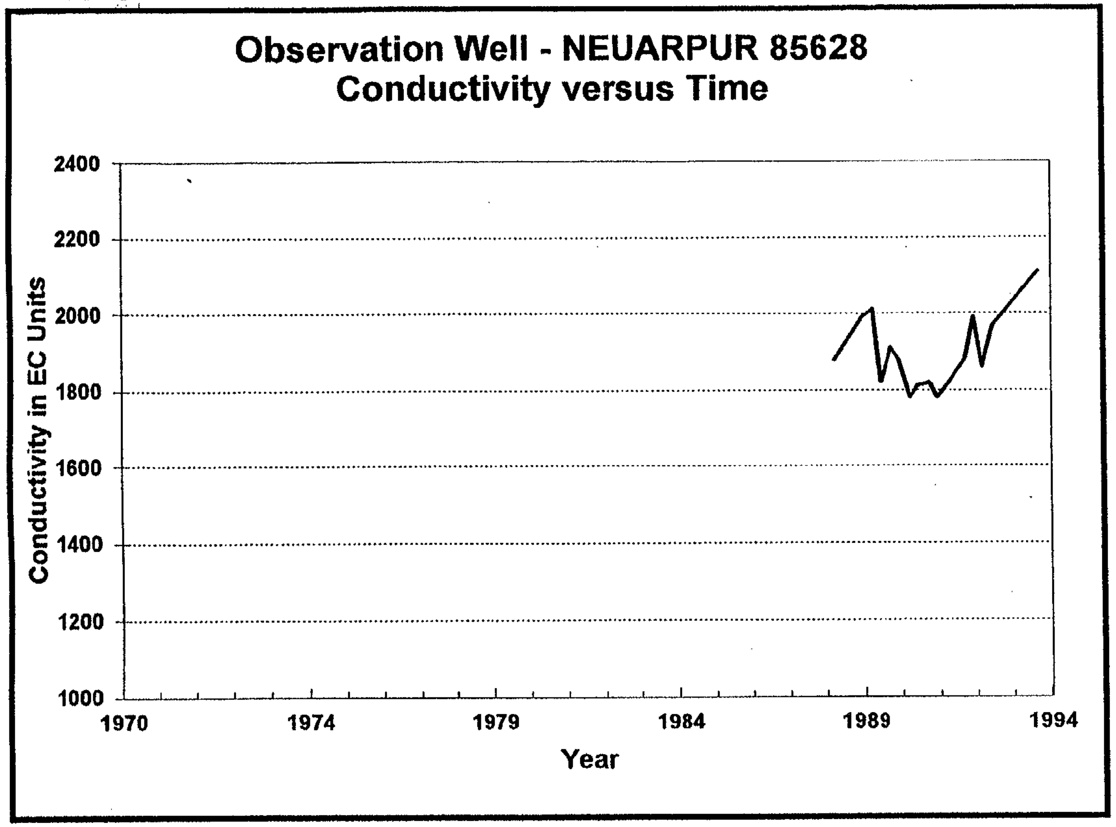
MINES AND ENERGY SOUTH AUSTRALIA

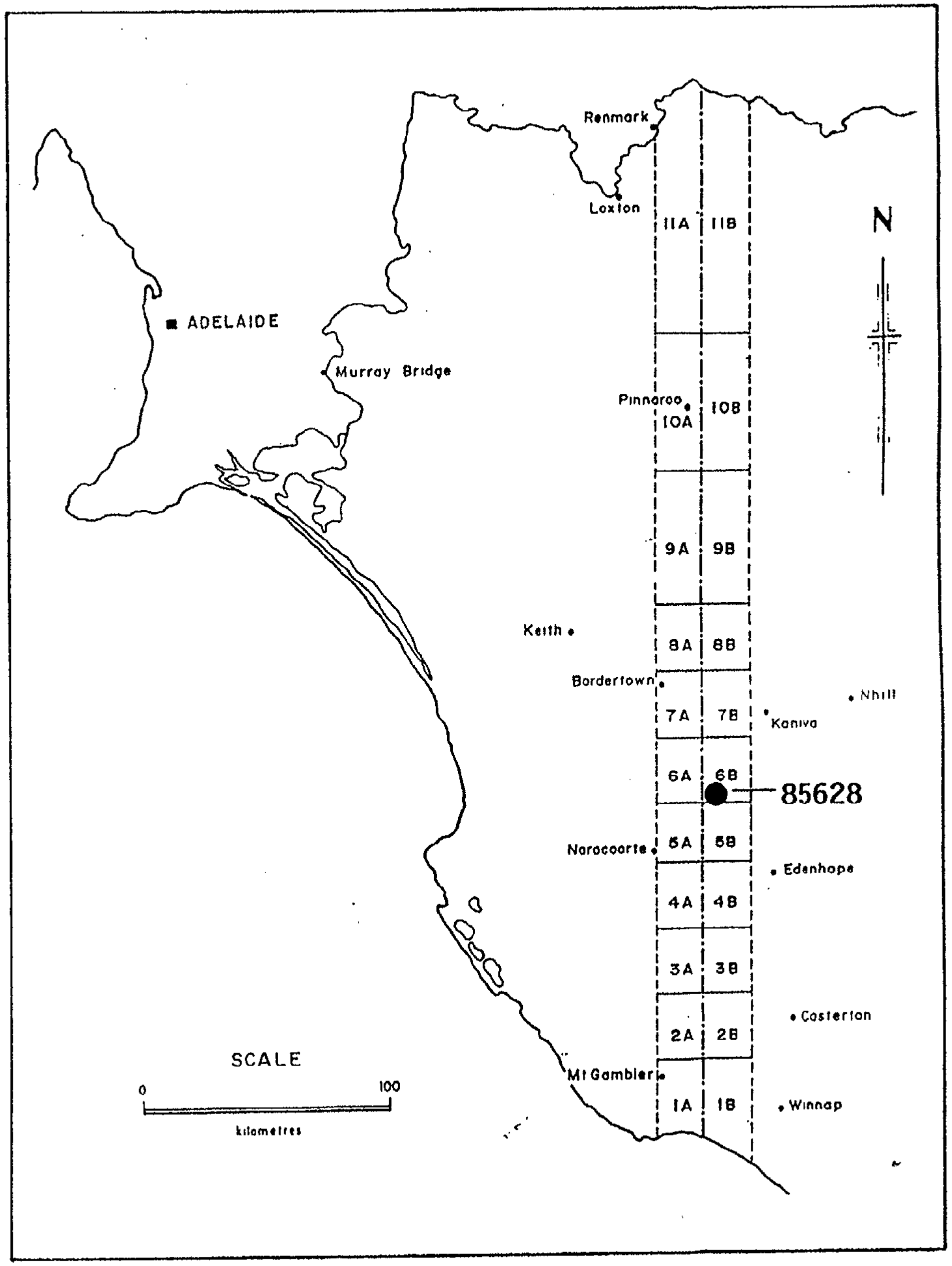
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW
OBSERVATION WELL No. GGL 10

FIGURE B1(

MESA 95-21(

Job No. 5916





Parish of:	NEUARPUR
Well No:	85628
Coordinates:	Easting 500656 Northing 5934213
Formation:	Murray Group Limestone
Conductivity Trend:	No significant change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	125	0	24
	Open Hole	125	24	30

MINES AND ENERGY SOUTH AUSTRALIA

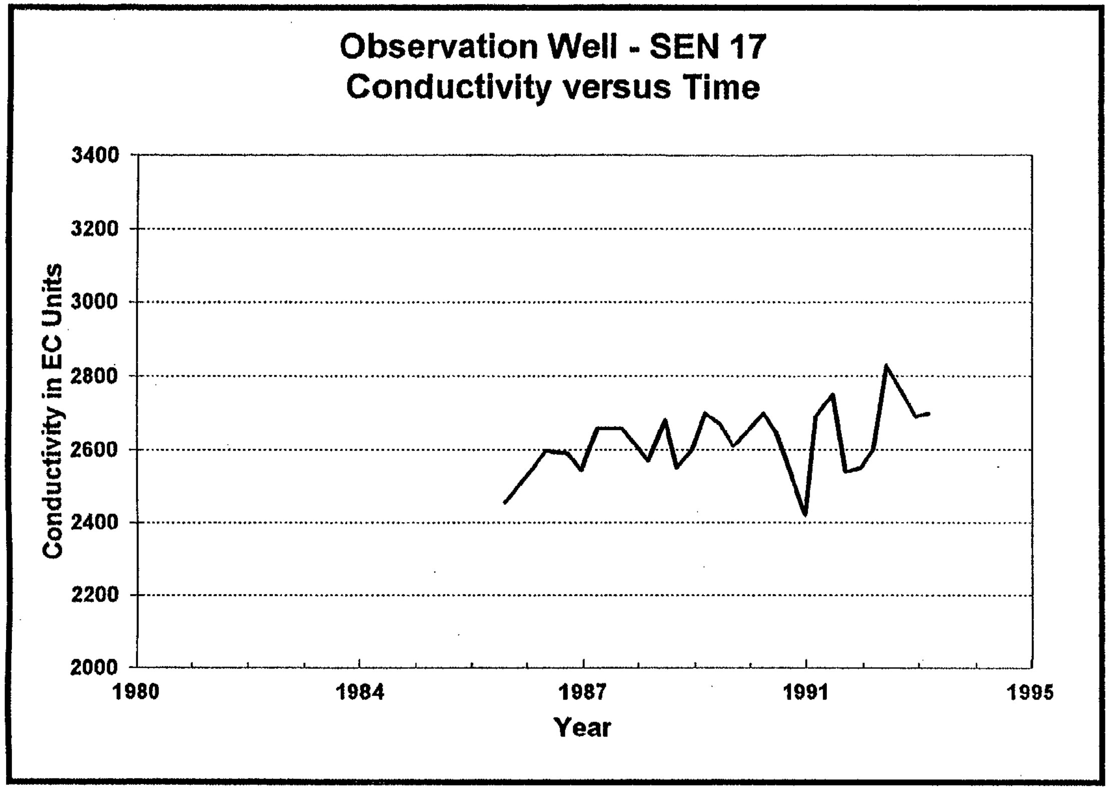
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

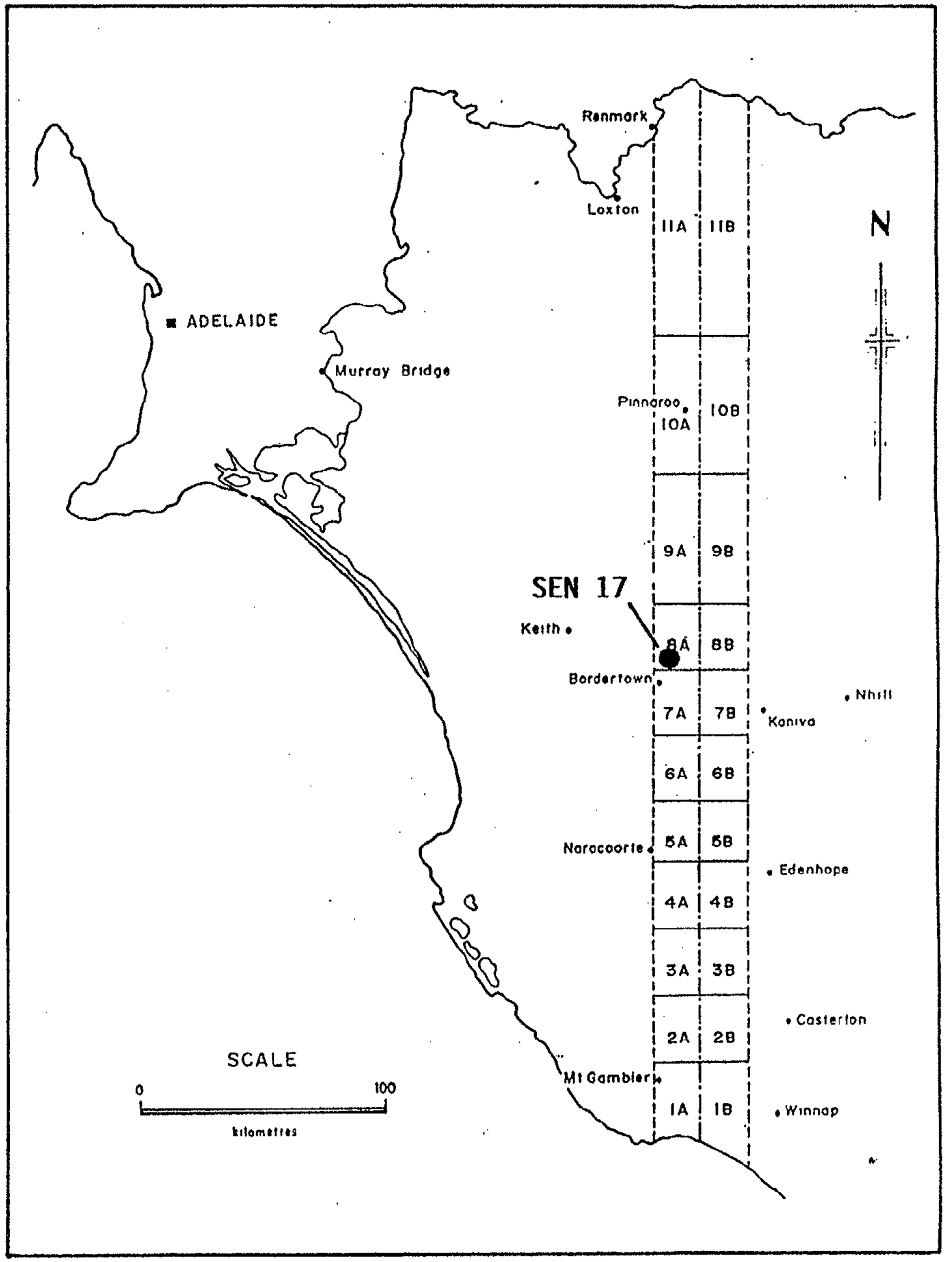
OBSERVATION WELL No. 85628

FIGURE B11

MESA 95-217

Job No. 5916





Hundred of:	SENIOR
Well No:	SEN 17
Coordinates:	Easting 481863 Northing 5994997
Unit No:	7025-2820
Formation:	Murray Group Limestone
Conductivity Trend:	Slight Increase

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	152	0	?

MINES AND ENERGY SOUTH AUSTRALIA

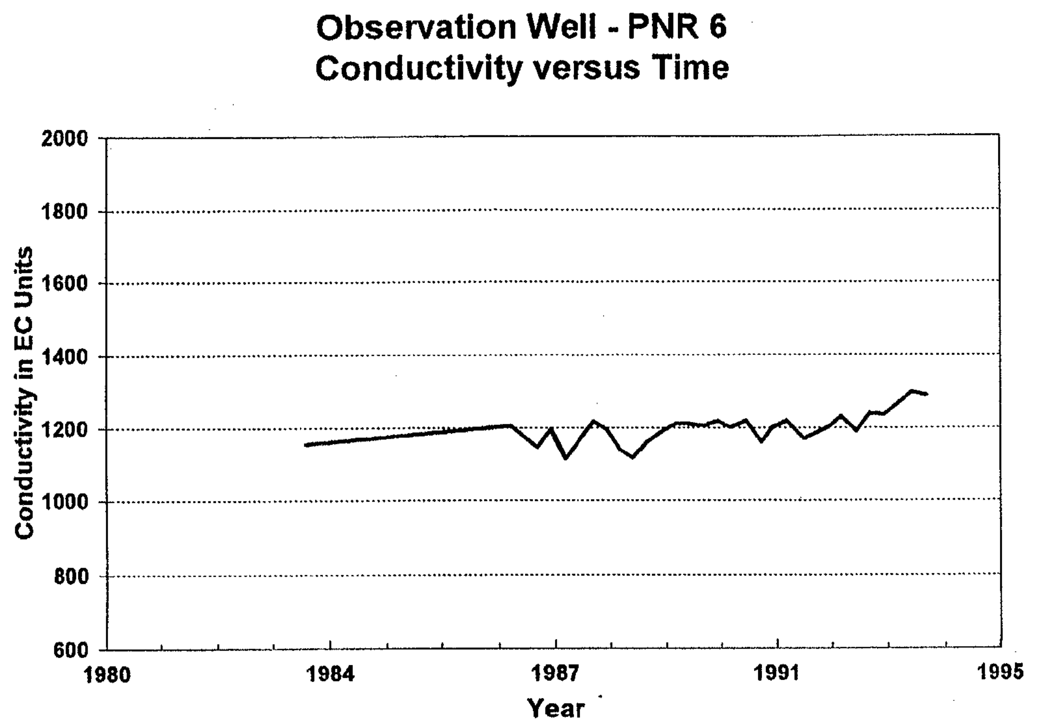
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

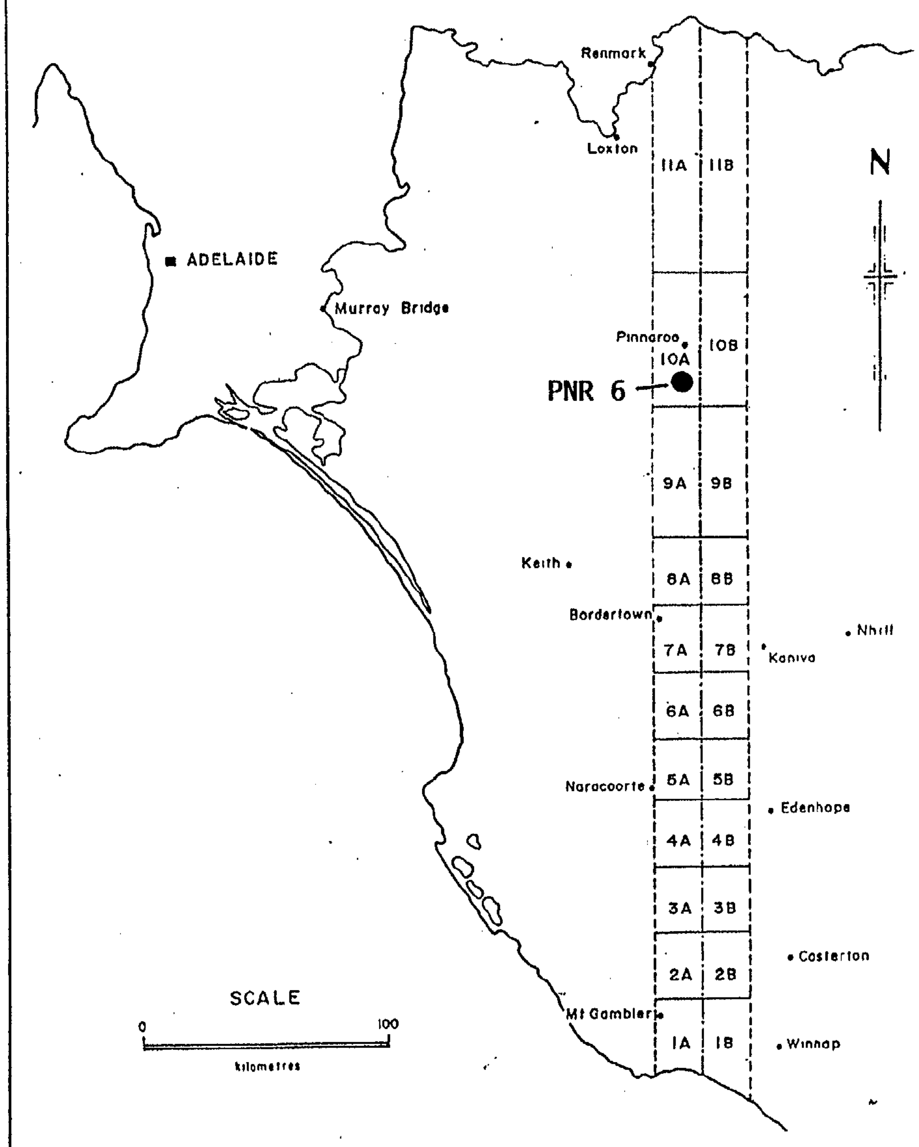
OBSERVATION WELL No. SEN 17

FIGURE B12

MESA 95-218

Job No. 5916





Hundred of:	PINNAROO
Well No:	PNR 6
Coordinates:	Easting 487757 Northing 6082593
Unit No:	7027-577
Formation:	Murray Group Limestone
Conductivity Trend:	Slight Increase

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	127	0	?

MINES AND ENERGY SOUTH AUSTRALIA

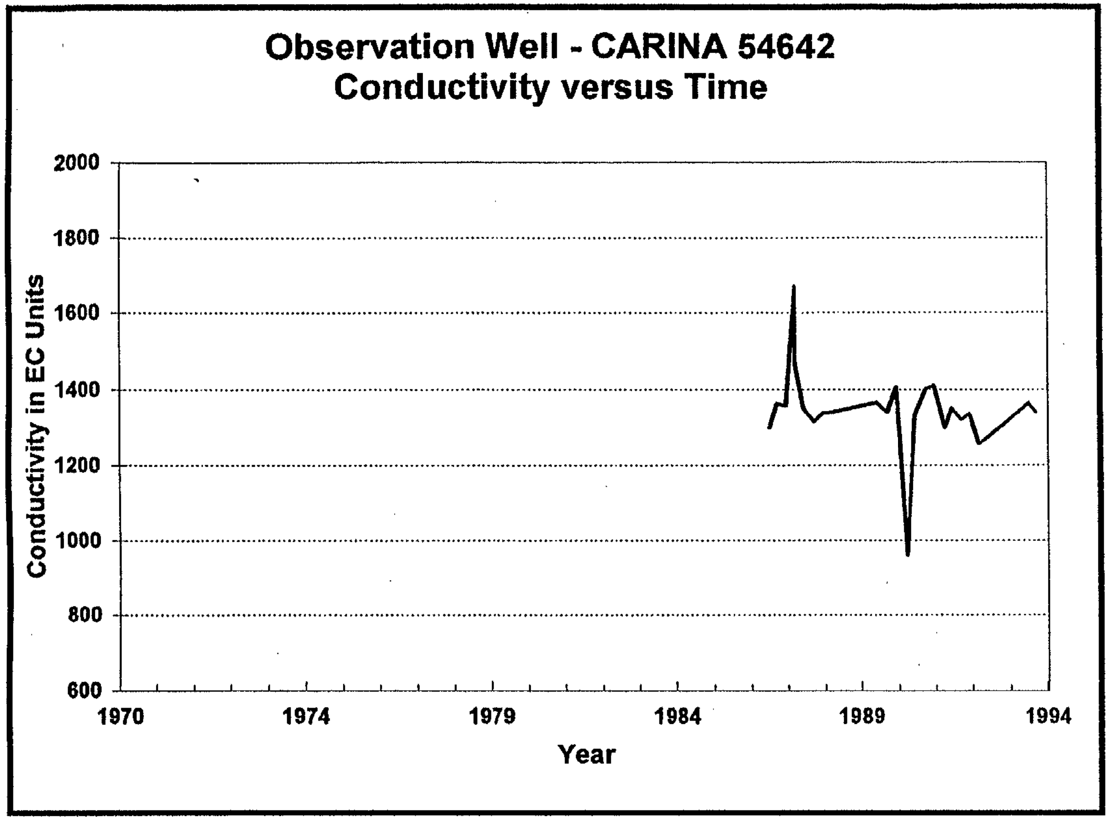
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

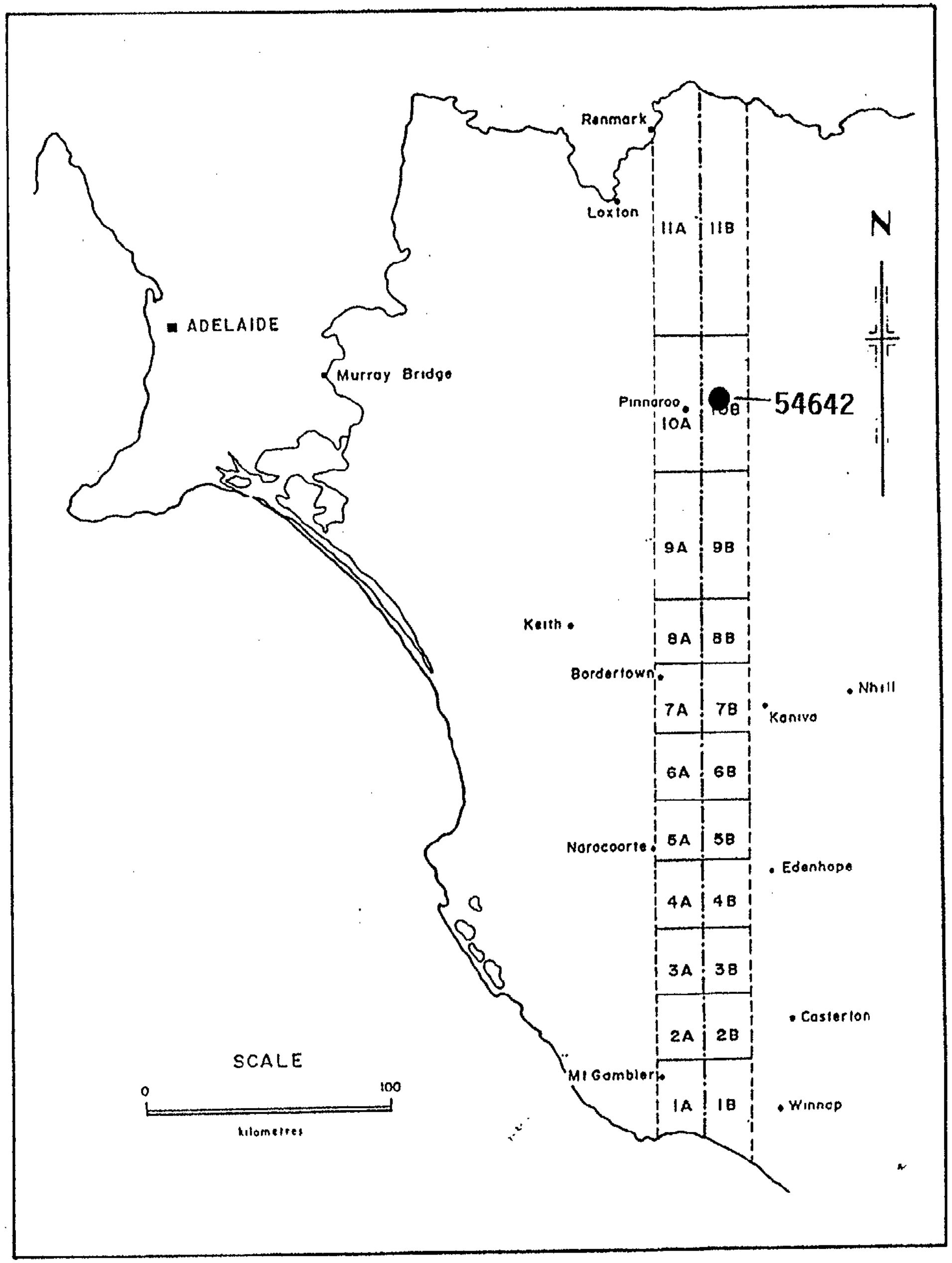
OBSERVATION WELL No. PNR 6

FIGURE B13

MESA 95-219

Job No. 5916





Parish of:	CARINA
Well No:	54642
Coordinates:	Easting 503728 Northing 6100298
Formation:	Murray Group Limestone
Conductivity Trend:	No significant change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	PVC	168	0	75
	?	?	75	122

MINES AND ENERGY SOUTH AUSTRALIA

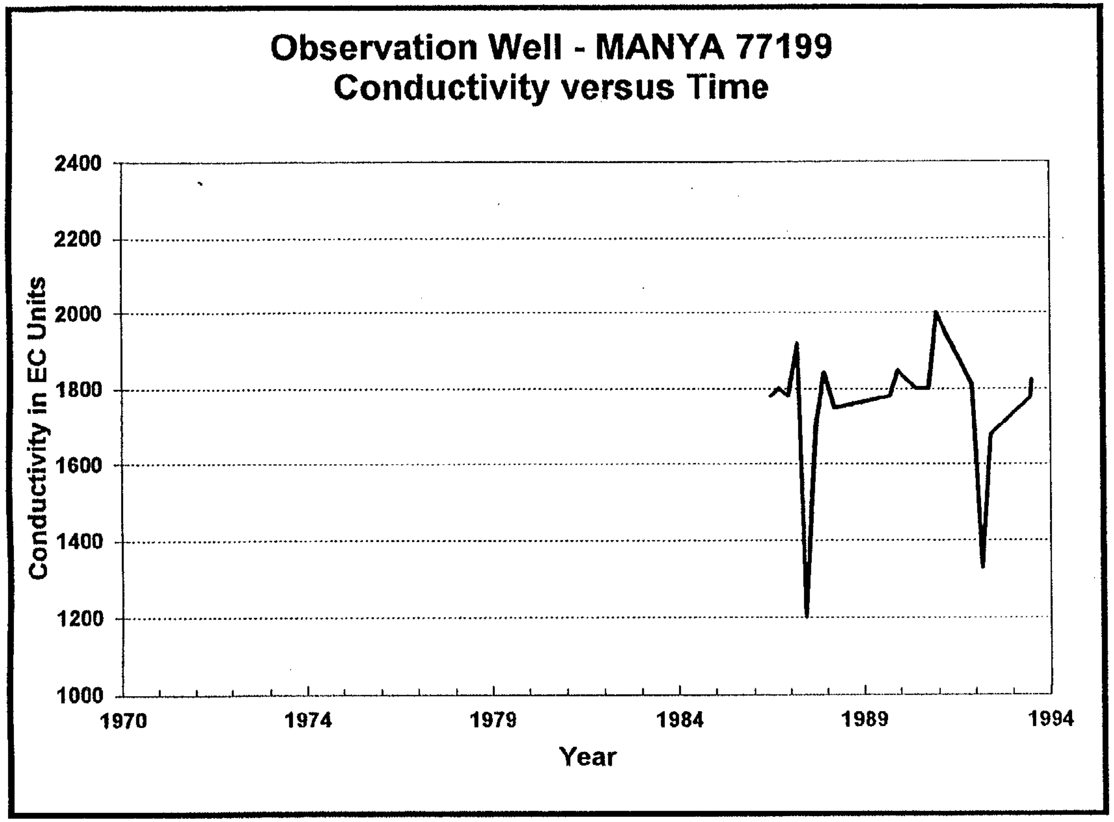
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. 54642

FIGURE B14

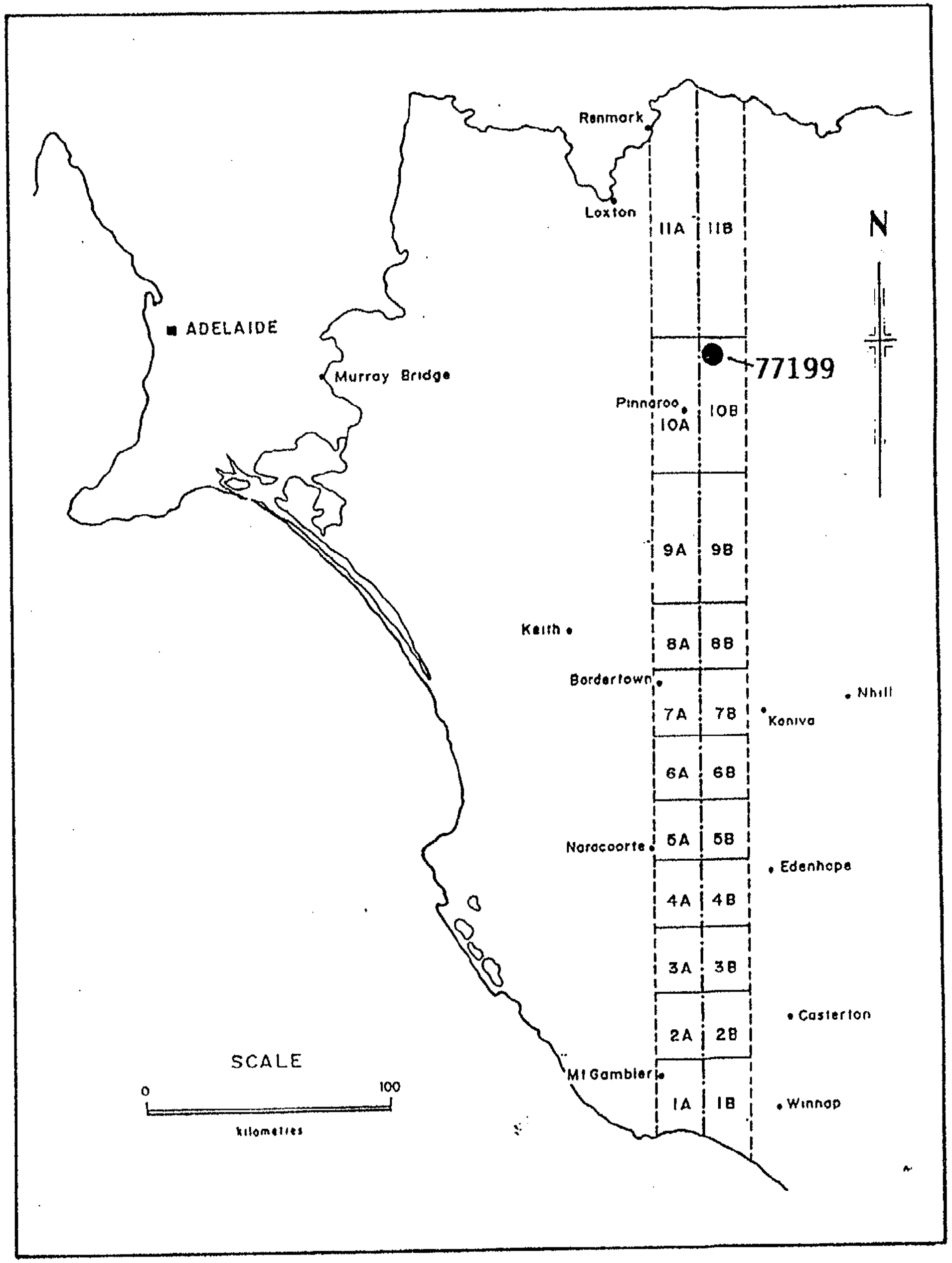
MESA 95-220

Job No. 5916



Parish of:	MANYA
Well No:	77199
Coordinates:	Easting 503142 Northing 6120819
Formation:	Murray Group Limestone
Conductivity Trend:	No significant change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	?	?	0	67



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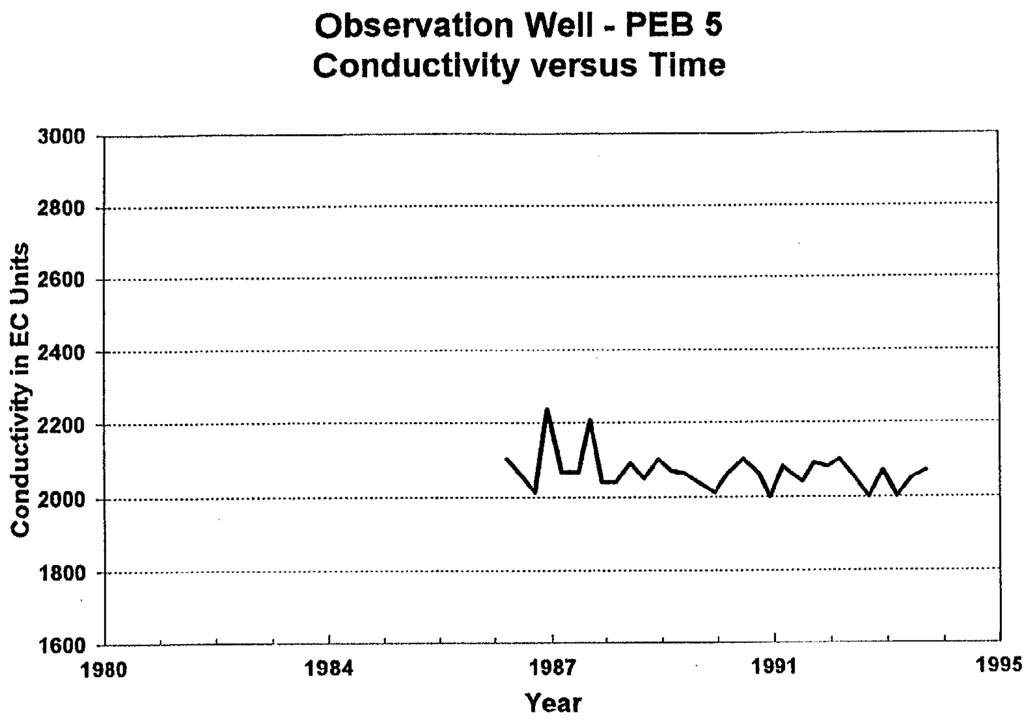
S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

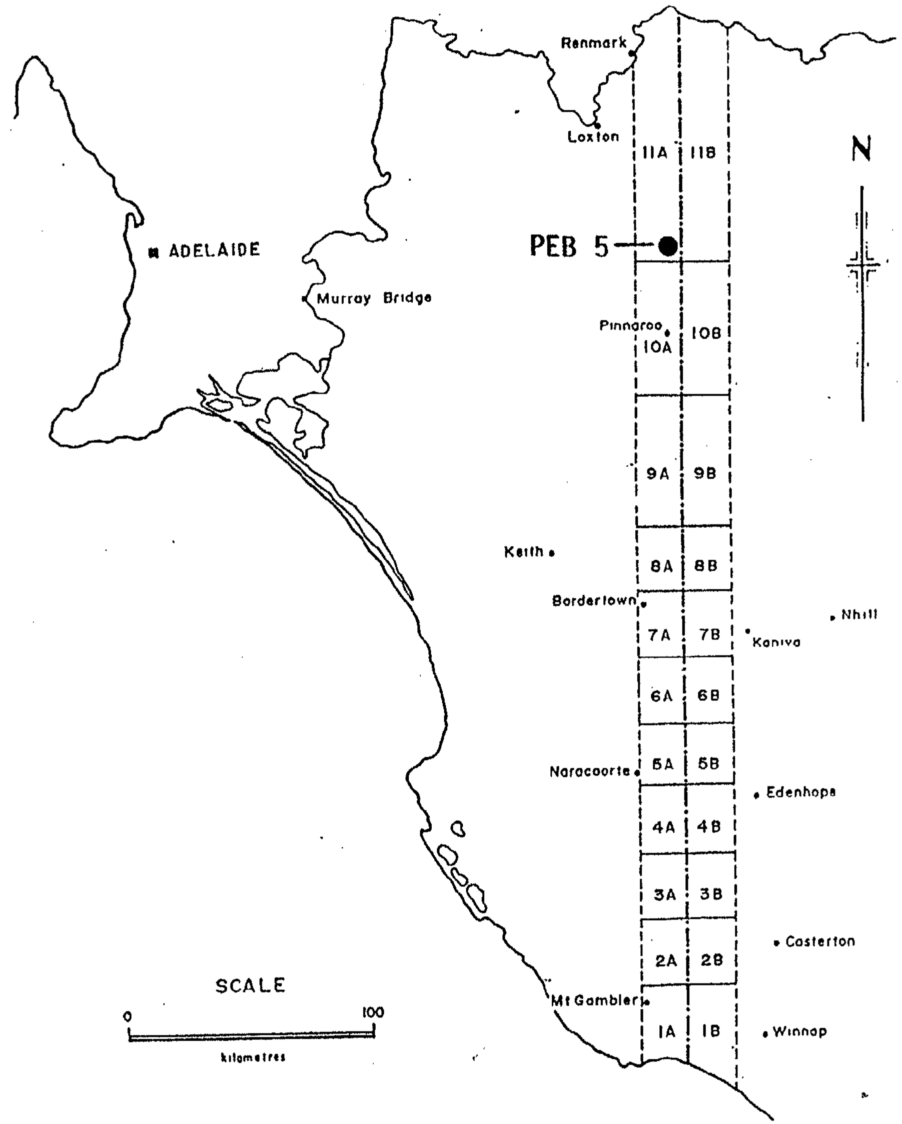
OBSERVATION WELL No. 77199

FIGURE B1!

MESA 95-22

Job No. 5916





Hundred of:	PEEBINGA
Well No:	PEB 5
Coordinates:	Easting 491342 Northing 6134506
Unit No:	7028-151
Formation:	Murray Group Limestone
Conductivity Trend:	No significant change

Construction Details:	***Casing***	***Diam (mm)***	***From (m)***	***To (m)***
	Steel	152	0	69.9
	Open Hole	152	69.9	80.8

MINES AND ENERGY
SOUTH AUSTRALIA

S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

OBSERVATION WELL No. PEB 5

FIGURE B1(

MESA 95-22

APPENDIX C

DETAILS FOR VERTICAL RECHARGE SUB-AREAS IN HYDROGEOLOGICAL PROVINCES 1 AND 2

ZONE	RECHARGE SUB-AREA	ADOPTED VERTICAL RECHARGE RATE (mm/year)	AREAL EXTENT (Km^2)	VOLUME OF VERTICAL RECHARGE (ML/year)
1A	R1	130	4.47	581.1
	R3	90	55.98	5038.2
	R4	80	75.59	6047.2
	R6	65	179.54	11670.1
	R7	60	100.37	6022.2
	R9	40	9.47	378.8
	R13	15	15.61	234.15
	R15	5	224.04	1120.2
		TOTAL	**665**	**31092**
1B	R1	130	215.82	28056.6
	R3	90	147.6	13284
	R7	60	41.51	2490.6
	R15	5	377.4	1887
		TOTAL	**782**	**45718**
2A	R3	90	281.59	25343.1
	R4	80	14.2	1136
	R7	60	4.29	257.4
	R8	45	189.3	8518.5
	R12	20	53.77	1075.4
	R15	5	11.46	57.3
		TOTAL	**555**	**36388**
2B	R3	90	375.47	33792.3
	R4	80	18.61	1488.8
	R7	60	16.33	979.8
	R8	45	103.12	4640.4
	R12	20	48.28	965.6
	R15	5	7.51	37.55
		TOTAL	**569**	**41904**

ZONE	RECHARGE SUB-AREA	ADOPTED VERTICAL RECHARGE RATE (mm/year)	AREAL EXTENT (Km^2)	VOLUME OF VERTICAL RECHARGE (ML/year)
3A	R2	100	193.49	19349
	R3	90	200.38	18034.2
	R4	80	14.75	1180
	R5	70	17.27	1208.9
	R8	65	94.25	6126.25
	R10	35	0.66	23.1
	R12	20	33.81	676.2
		TOTAL	**555**	**46598**
3B	R3	90	4.09	368.1
	R4	80	8.2	656
	R5	70	66.63	4664.1
	R8	45	181.13	8150.85
	R10	35	17.44	610.4
	R11	30	123.66	3709.8
	R12	20	32.8	656
	R13	15	120.66	1809.9
		TOTAL	**555**	**20625**
4A	R2	100	145.57	14557
	R3	90	5.92	532.8
	R5	70	95.08	6655.6
	R7	60	84.97	5098.2
	R10	35	151.79	5312.65
	R11	30	1.41	42.3
	R12	20	68.42	1368.4
	R14	12	1.43	17.16
		TOTAL	**555**	**33584**
4B	R10	35	380.37	13312.95
	R11	30	95.26	2857.8
	R13	15	78	1170
	R14	12	0.82	9.84
		TOTAL	**554**	**17351**

ZONE	RECHARGE SUB-AREA	ADOPTED VERTICAL RECHARGE RATE (mm/year)	AREAL EXTENT (Km^2)	VOLUME OF VERTICAL RECHARGE (ML/year)
5A	R5	70	32.02	2241.4
	R7	60	51.4	3084
	R10	35	305.75	10701.25
	R11	30	129.23	3876.9
	R12	20	0.34	6.8
	R14	12	5.84	70.08
		TOTAL	**525**	**19980**
5B	R10	35	71.38	2498.3
	R14	12	17.15	205.8
		TOTAL	**89**	**2704**
6A	R10	35	93.9	3286.5
	R11	30	11.98	359.4
	R12	20	329.26	6585.2
	R14	12	35.39	424.68
	R16	2	51.89	103.78
		TOTAL	**522**	**10760**
6B	R16	2	7.37	14.74
		TOTAL	**7**	**15**
7A	R12	20	131.38	2627.6
	R13	15	90.61	1359.15
	R14	12	339.35	4072.2
	R16	2	6.72	13.44
		TOTAL	**568**	**8072**
7B	R12	20	15.98	319.6
	R13	15	4.31	64.65
	R14	12	249.29	2991.48
	R16	2	25.42	50.84
		TOTAL	**295**	**3427**
8A	R13	15	411.79	6176.85
	R14	12	128.93	1547.16
		TOTAL	**541**	**7724**
8B	R13	15	32.55	488.25
	R14	12	9.16	109.92
		TOTAL	**42**	**598**
9A	R13	15	163.43	2451.45
		TOTAL	**163**	**2451**

APPENDIX D

TRANSMISSIVITY DATA FOR THE TERTIARY LIMESTONE AQUIFER IN SOUTH AUSTRALIA

WELL NUMBER	TRANSMISSIVITY (m^2/day)			
	Definite	Lower limit	Range	
			Lower	Upper
6928-77	204			
7022-538	300			
7022-1152	350			
7022-2777	11200			
7023-1047	1100			
7023-1687		10400		
7023-3784	1347			
7023-3790		3500		
7023-3956			464	773
7023-4073			1905	3809
7023-4169	1748			
7023-4233			500	1000
7023-4322		2650		
7024-0700	1150			
7024-1225		1000		
7024-3701	26000			
7024-3921	3558			
7024-4102	1600			
7024-4116	5800			
7024-4136	3500			
7025-677	2600			
7025-864	460			
7025-954			640	940
7025-2245		1200		
7025-2588		3990		
7025-2883	2300			
7027-22	206			
7027-507	900			
7027-512	475			
7027-554	535			
7027-597	950			
7027-606	455			
7028-83	125			
7028-134	515			
7028-318	1023			

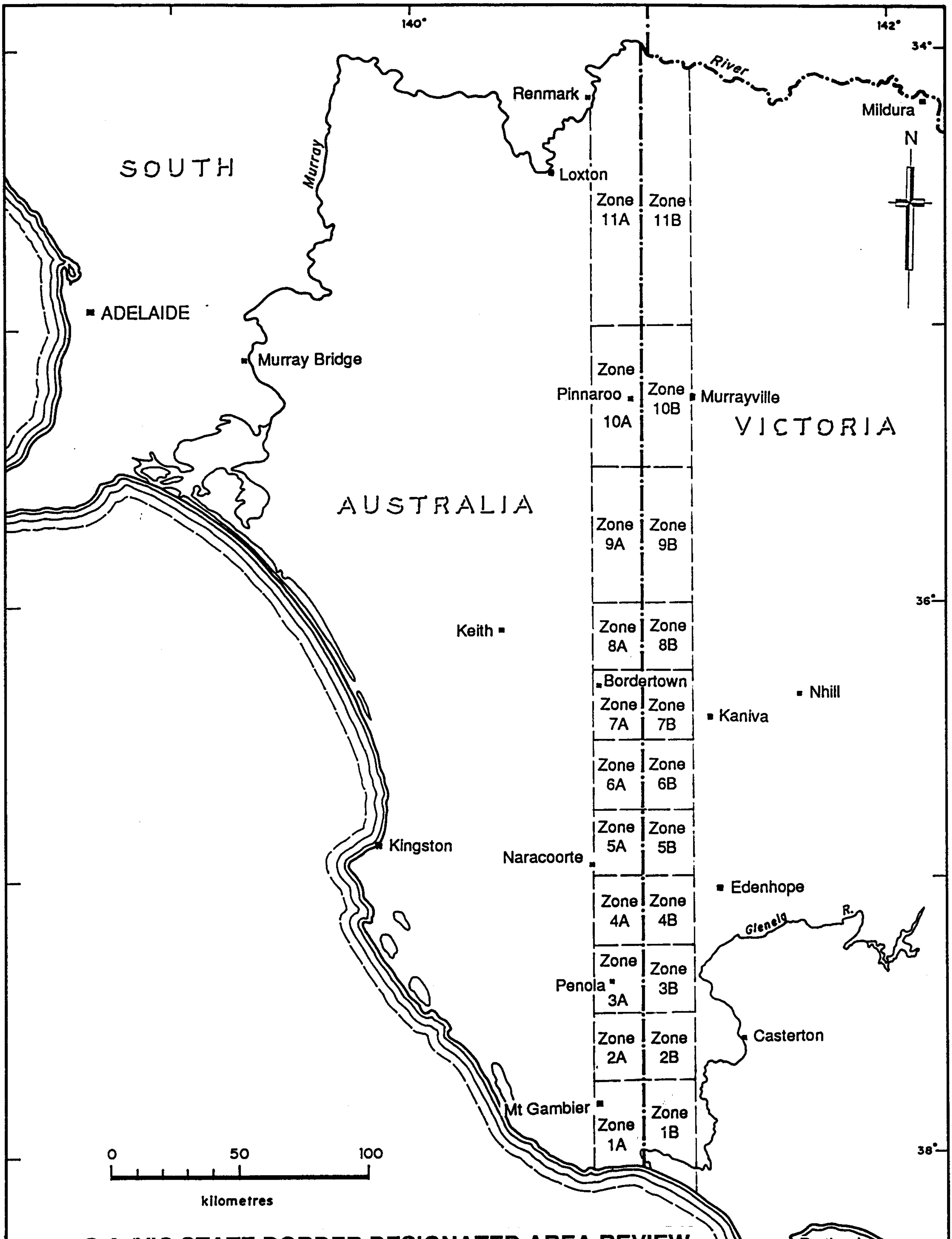
APPENDIX E

TRANSMISSIVITY DATA FOR THE TERTIARY LIMESTONE AQUIFER IN VICTORIA

BORE	PARISH	EASTING	NORTHING	T (m^2/day)	SOURCE
47496	BALROOTAN	558862	5978476	50	Lawrence (1975)
47501	BALROOTAN	559128	5978411	96	Lawrence (1975)
48559	BEEWAR	526500	5946400	192	"Stewart (1990,d)"
50350	BOIKERBERT	507303	5908140	56	Lawrence (1975)
57151	COYNALLAN	557465	5956175	120	Lawrence (1975)
60623	DOPEWORA	530500	5926400	37	"Stewart (1990,c)"
61922	DURONG	523550	5886000	33	"Stewart (1990,a)"
62197	EDENHOPE	524581	5900476	5	Lawrence (1975)
62199	EDENHOPE	519953	5903267	52	Lawrence (1975)
66802	HARROW	552788	5894101	8	Lawrence (1975)
66803	HARROW	552999	5895460	48	Lawrence (1975)
67829	JALLAKIN	527250	5907150	6	"Stewart (1990,a)"
68434	JUNGKUM	558100	5953000	11	Lawrence (1975)
68569	KALADBRO	501075	5835558	1378	RWC#
68586	KALADBRO	503800	5835000	64	RWC#
69352	KANIVA	521109	5973879	920	Lawrence (1975)
75650	LILLIMUR	511191	5975518	920	Lawrence (1975)
75651	LILLIMUR	506600	5967100	855	"Stewart (1990,a)"
77004	MALANGANEE	505721	5809178	457	RWC#
319769	MERINO	548165	5827434	130	
79529	MINIMAY	515420	5940878	652	Lawrence (1975)
79654	MIRAMPIRAM	531408	5979404	290	Lawrence (1975)
79736	MOCAMBORO	541368	5825557	720	Riha (1974)
	MOCAMBORO*	539000	5824000	39	Lawrence (1975)
82796	MURRANDARRA	506300	5907100	770	"Stewart (1990,b)"
83494	NAGWARRY	502600	5846050	5800	RWC#
83502	NAGWARRY	498637	5848114	1361	RWC#
83505	NAGWARRY	498450	5849400	4405	RWC#
85647	NEUARPUR	500800	5936100	1151	RWC#
89851	ROSENEATH	511000	5865000	10	"Stewart (1990,a)"
91853	SPINIFEX*	550000	5950000	42	Lawrence (1975)
92808	TALLAGEIRA	506900	5927100	600	"Stewart (1990,a)"
97072	TULLYVEA	582356	5999975	235	Lawrence (1975)
107454	YANIPY	529756	5972903	299	Lawrence (1975)
108157	YARRANGOOK	508118	6002187	564	Lawrence (1975)

* Bore location not available, so Parish centroid chosen as location

RWC# Transmissivity calculated from RWC bore performance test



S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

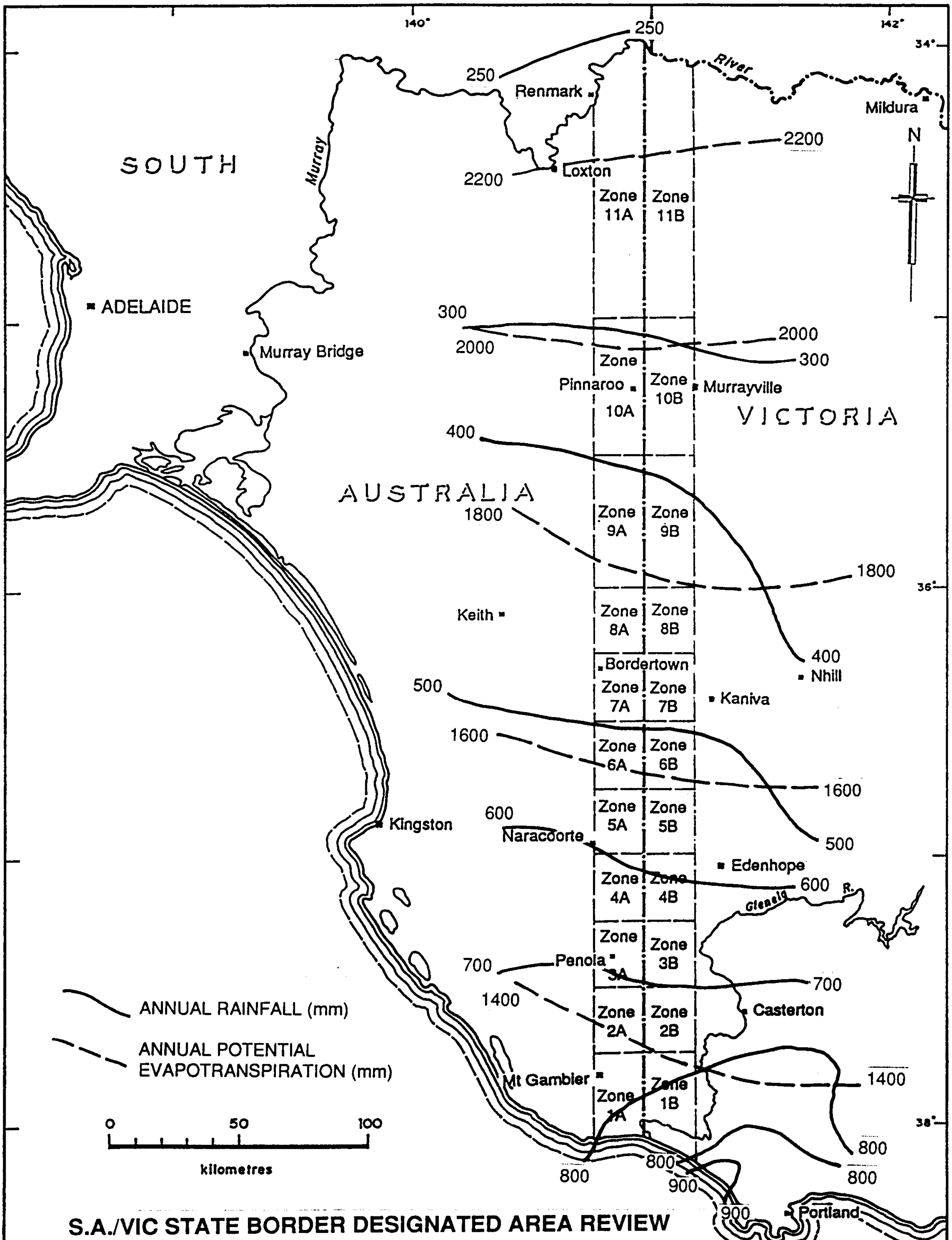
LOCATION OF DESIGNATED AREA

FIGURE 1

MESA 95-59

MINES AND ENERGY
SOUTH AUSTRALIA

Job No. 5916



S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

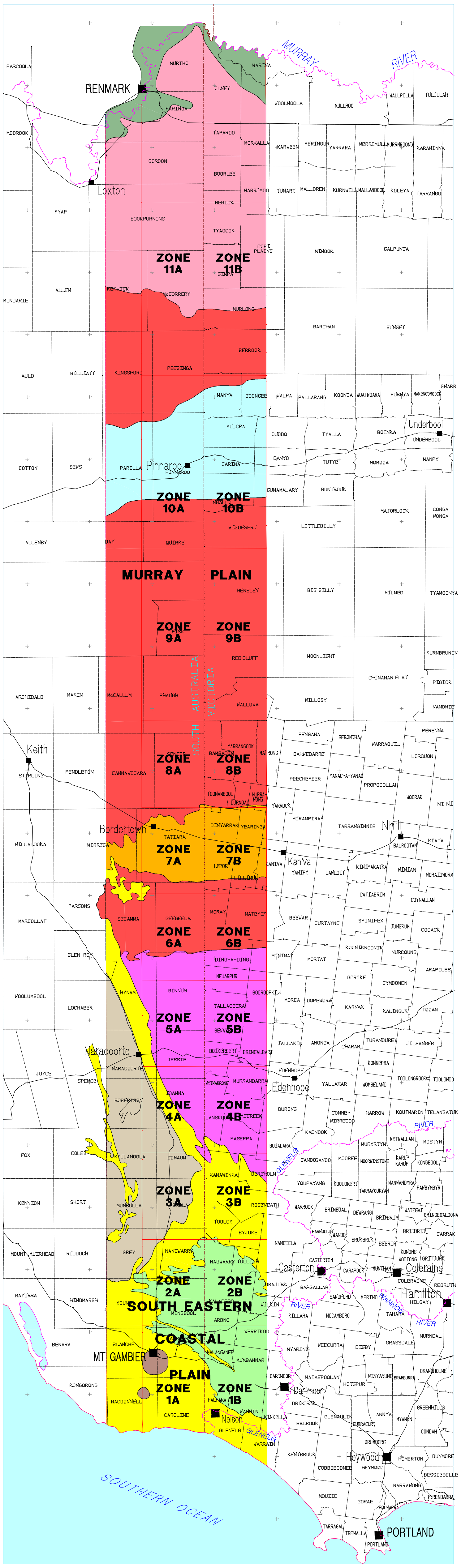
RAINFALL AND EVAPORATION DISTRIBUTION

FIGURE 2

MINES AND ENERGY SOUTH AUSTRALIA

MESA 95-60

Job No. 5916



N

L E G E N D

MURRAY BASIN PLAIN

- Naracoorte Plateau (Wimmera Plain)
- Dunefields
- Undulating plain
- Undulating plain with east-west dunes
- Undulating plain with Pliocene stranded beach ridges and east-west dunes
- Floodplain

SOUTH EAST PLAIN

- Calcarenite dune ridges and sand sheets
- Interdunal flats
- Swampy plain with low sand dunes and sheets
- Volcanic rises

SCALE OF KILOMETRES
0 25 50

HydroTechnology

Figure........3

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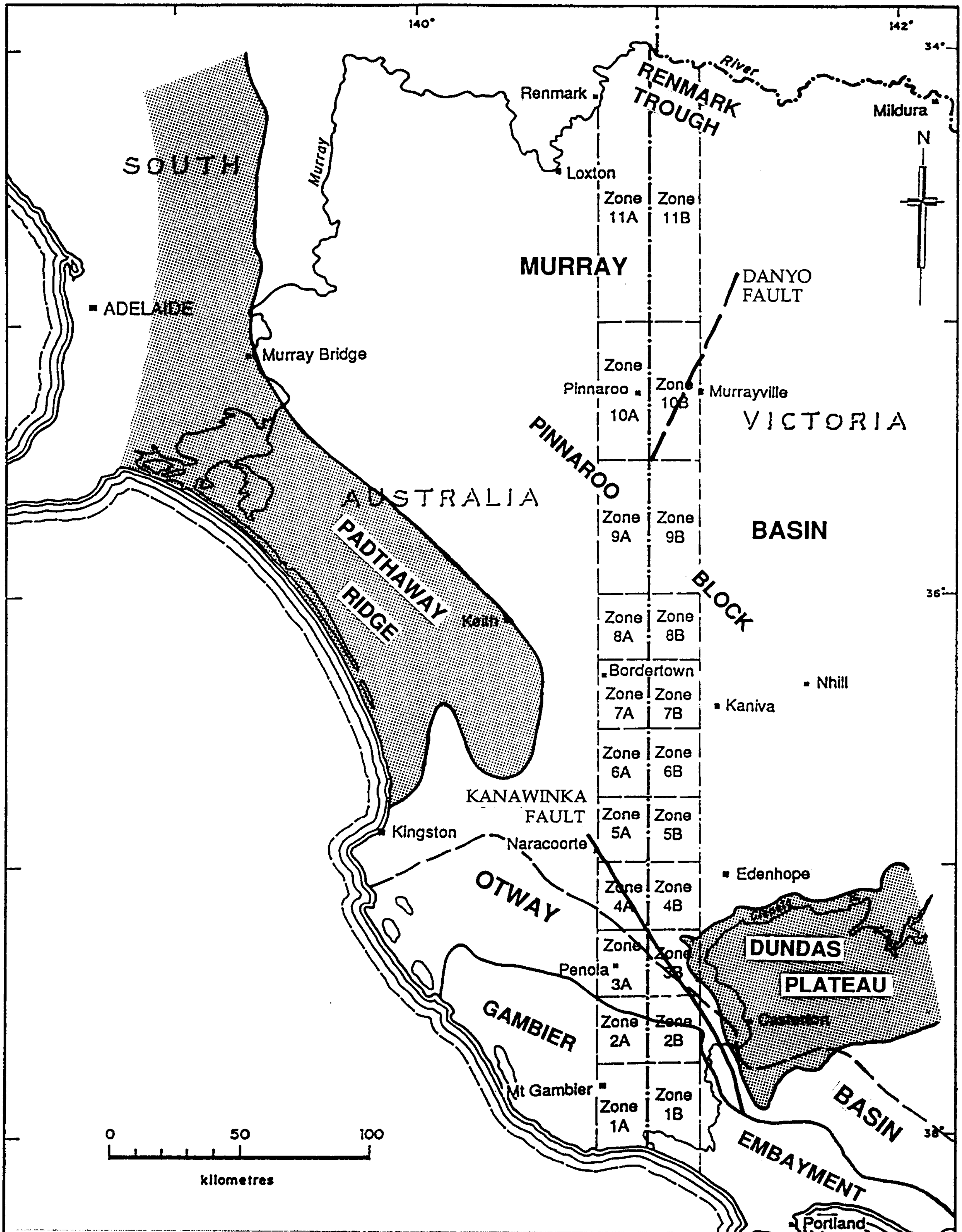
MINES and ENERGY RESOURCES SOUTH AUSTRALIA

S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

LANDFORMS IN THE DESIGNATED AREA

95-61



S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

GEOLOGICAL PROVINCES OF DESIGNATED AREA

FIGURE 4

MINES AND ENERGY SOUTH AUSTRALIA

MESA 95-62

Job No. 5916

			OTWAY BASIN			MURRAY BASIN			
ERA	EPOCH	GROUP	GEOLOGICAL FM	ENVIRONMENT LITHOLOGY	GROUP	GEOLOGICAL FM	ENVIRONMENT LITHOLOGY	HYDROSTRATIGRAPHIC UNIT	COMMENTS
Q	PLEISTOCENE			LIMESTONE, SAND CLAY LAGOONAL, LACUSTRINE, BEACH RIDGE		WOORINEN SANDS	AEOLIAN	QUATERNARY AQUITARD	CONSISTS OF BLANCHETOWN CLAY, SHEPPARTON FM, WOORINEN SAND
TERTIARY	PLIOCENE		PADTHAWAY BRIDGEWATER COOMANDOOK			LOXTON-PARILLA SAND BOOKPURNONG BEDS	QTZ SAND, MINOR CLAY STRANDED BEACHRIDGES INTER-RIDGE FLUVIO LACUSTRINE DEPOSITS MARL, RESTRICTED MARINE SHELF	PLIOCENE SANDS AQUIFER UPPER TERTIARY AQUITARD	LOXTON-PARILLA SANDS ARE REGIONAL UNCONFINED AQUIFER IN MURRAY BASIN IN MUCH OF SA THE GAMBIER LIMESTONE IS UNCONFINED
TERTIARY	MIOCENE	HEYTESBURY	GAMBIER LIMESTONE	FOSSILIFEROUS LIMESTONE OPEN MARINE PLATFORM	MURRAY	DUDDO LIMESTONE	FOSSILIFEROUS LIMESTONE SHALLOW MARINE PLATFORM	TERTIARY LIMESTONE AQUIFER	LIMESTONE AQUIFER IS UNCONFINED IN PARTS OF SA. ELSEWHERE CONFINED BY BOOKPURNONG BEDS. MAJOR GROUNDWATER RESOURCE IN DESIGNATED AREA.
TERTIARY	OLIGOCENE	HEYTESBURY	GELLIBRAND MARL	MARL MARL & DOLOMITE	MURRAY	ETTRICK MARL	GREY-GREEN GLAUCONITIC MARL SHALLOW MARINE-LAGOONAL	LOWER TERTIARY AQUITARD	
TERTIARY	EOCENE	NIRRANDA	NARRAWATURK MARL MEPUNGA FM	GLAUCONITIC FOSSILIFEROUS MARL SAND	RENMARK	OLNEY FM	CARBONACEOUS SILTS, SANDS, CLAYS, LIGNITIC	TERTIARY CONFINED SAND AQUIFER	OLNEY FORMATION IS TIME EQUIVALENT OF DILWYN FORMATION
TERTIARY	PALAEOCENE	WANGERRIP	DILWYN FM PEMBER MUDSTONE	INTERBEDDED SEQUENCE OF SAND, GRAVEL, CLAY, FLUVIAL DELTAIC PRODELTA MUDS	RENMARK	OLNEY FM	FLUVIO-LACUSTRINE FLOOD PLAIN & SWAMP ENVIRONMENT	TERTIARY CONFINED SAND AQUIFER	
CRETACEOUS	LATE	SHERBROOK	PEBBLE PT FM TIMBOON SAND BELFAST SST	CLAYSTONE				CRETACEOUS AQUIFER/AQUITARD SYSTEM	CRETACEOUS AQUIFER SYSTEM PRESENT IN OTWAY BASIN. SEPARATED FROM MURRAY BASIN BY PADTHAWAY RIDGE
CRETACEOUS	EARLY	OTWAY	EUMERELLA FM PRETTY HILL SST	SHALES: LACUSTRINE VOLCANOGENIC SAND, CLAY FLUVIAL					
E/O		KANMANTOO		METAMORPHIC & IGNEOUS				HYDRAULIC BASEMENT	FORMS BASEMENT HIGHS OF PADTHAWAY RIDGE & DUNDAS PLATEAU

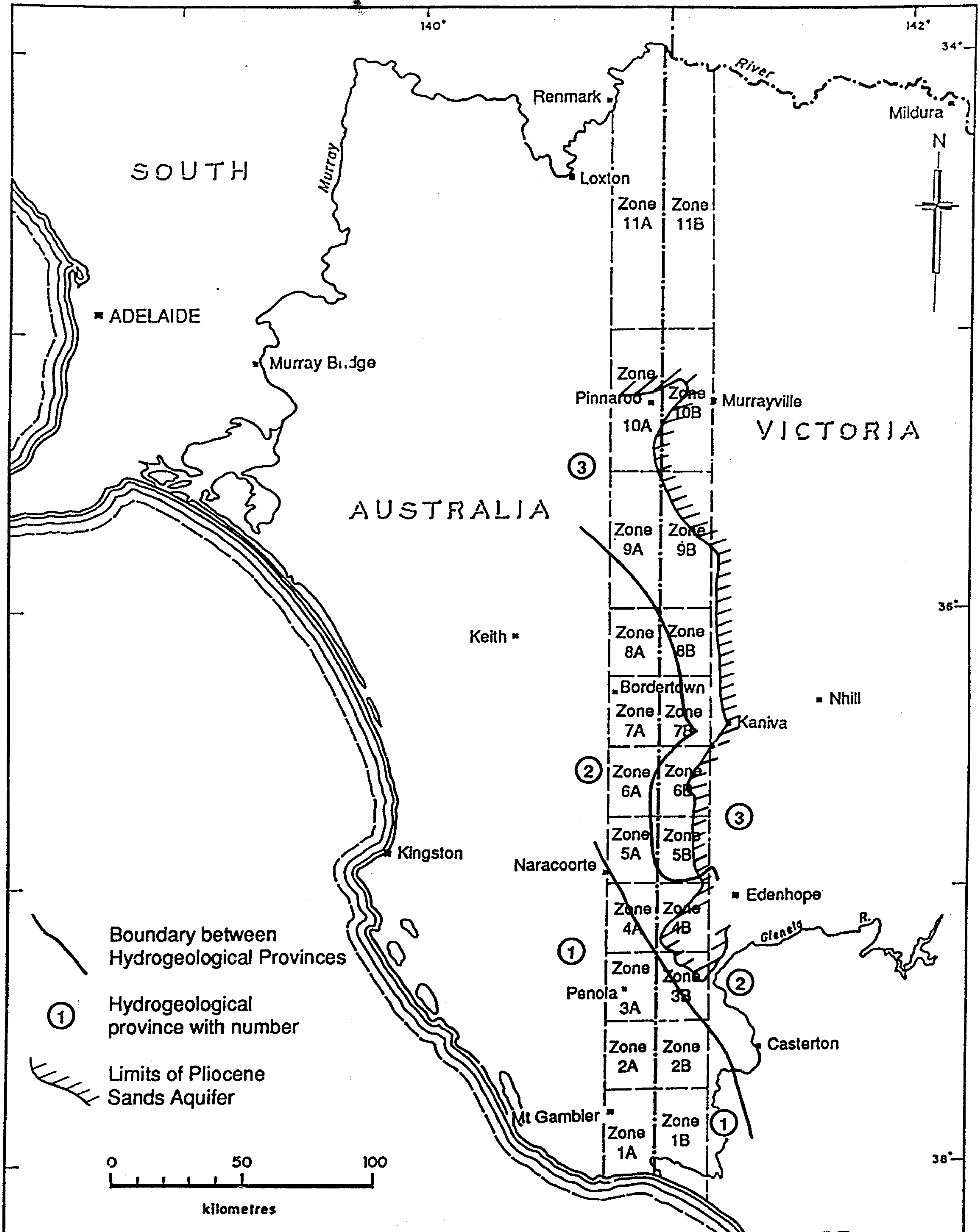
MINES AND ENERGY
SOUTH AUSTRALIA

S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

STRATIGRAPHIC AND HYDROSTRATIGRAPHIC UNITS FOR BOTH BASINS AND TERMINOLOGY

FIGURE 5

MESA 95-63



S.A./VIC STATE BORDER DESIGNATED AREA REVIEW

HYDROGEOLOGICAL PROVINCES OF DESIGNATED AREA

FIGURE 6

MESA 95-64

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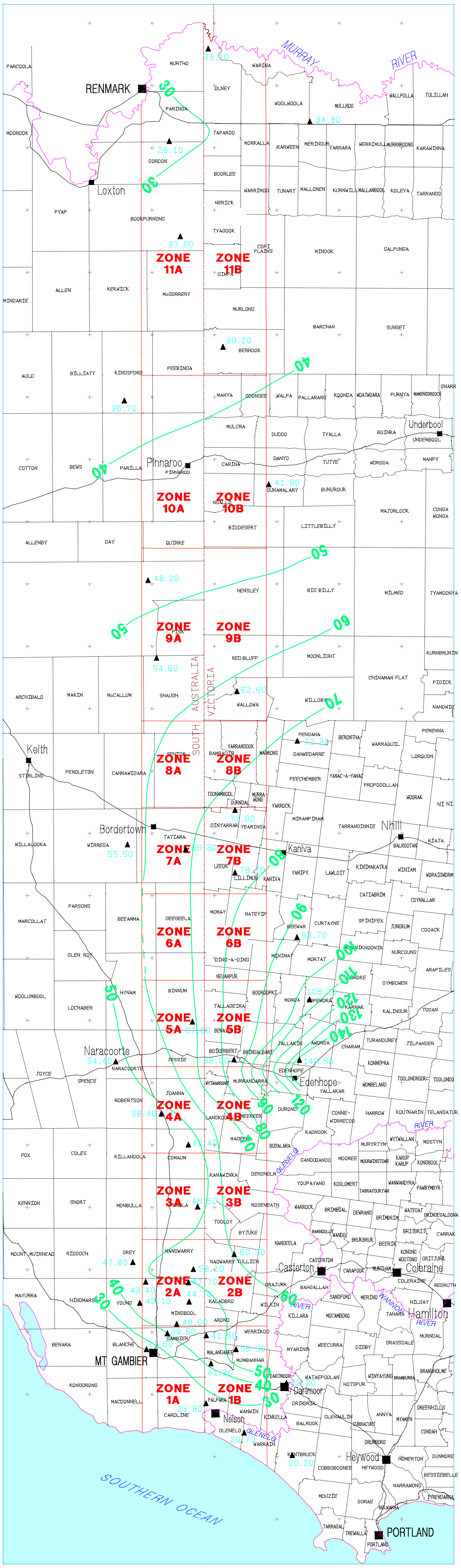

N

LEGEND

38.40 ▲ Tertiary confined sand aquifer observation well with potentiometric head (m) reading, March 1994

50 Potentiometric head contour (m) for Tertiary confined sand aquifer March 1994

SCALE OF KILOMETRES

0 25 50

Figure.......7

S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

POTENTIOMETRIC SURFACE OF TERTIARY CONFINED SAND AQUIFER MARCH 1994

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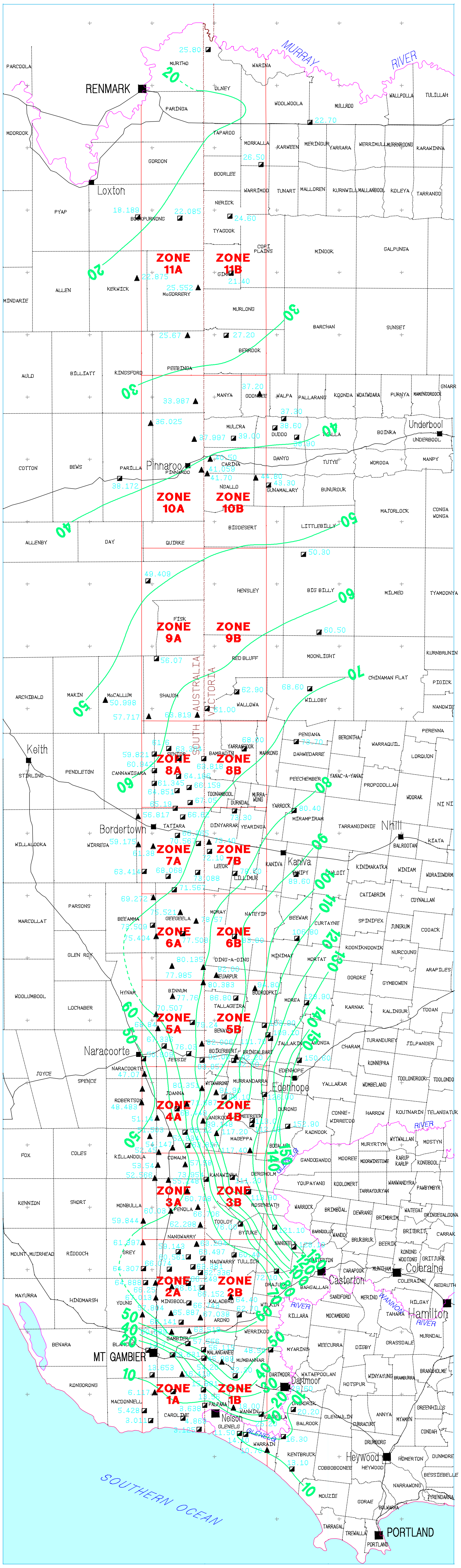
95-65



N

L E G E N D

Government observation well

Privately owned observation well

50.30 Potentiometric head for Tertiary Limestone Aquifer (m AHD), March 1994

60 Potentiometric contour for Tertiary Limestone Aquifer (m AHD) March 1994

SCALE OF KILOMETRES
0 25 50

Figure........8

S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

POTENTIOMETRIC SURFACE OF TERTIARY LIMESTONE AQUIFER MARCH 1994

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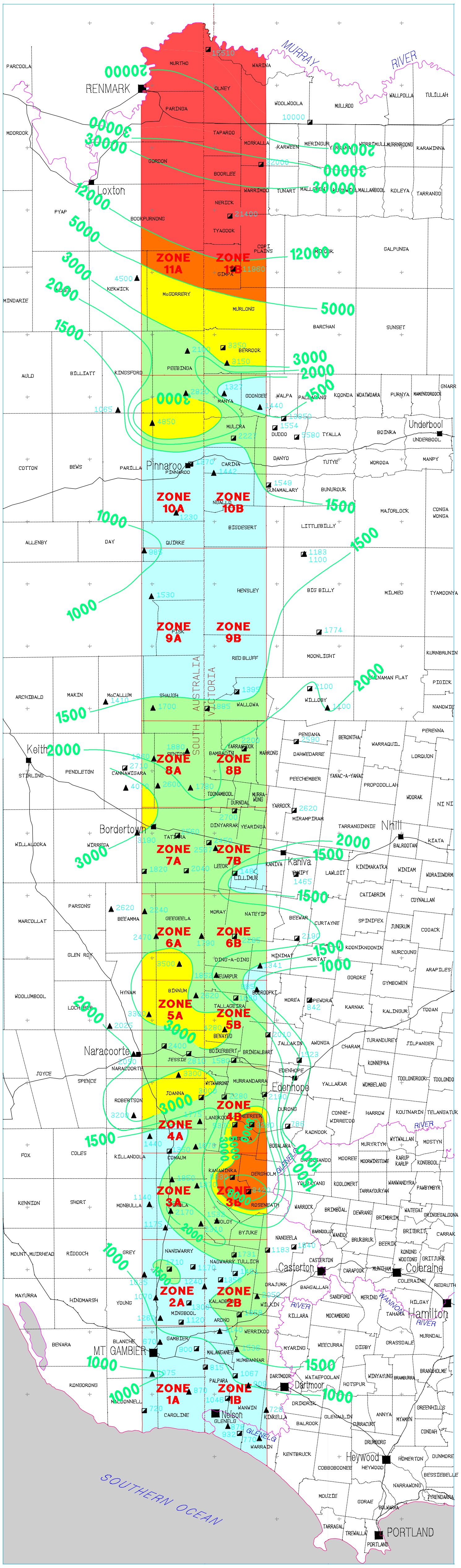
95-66



N

L E G E N D

Government observation well

Privately owned observation well

3350 Electrical Conductivity value (ECU), March 1993

1500 Electrical Conductivity contour for Tertiary Limestone Aquifer (ECU) March 1993

Electrical Conductivity value (ECU) between –

- 0 – 1500
- 1500 – 3000
- 3000 – 5000
- 5000 – 12000
- > 12000

SCALE OF KILOMETRES
0 25 50

Figure........9

S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

DISTRIBUTION OF ELECTRICAL CONDUCTIVITY FOR TERTIARY LIMESTONE AQUIFER MARCH 1993

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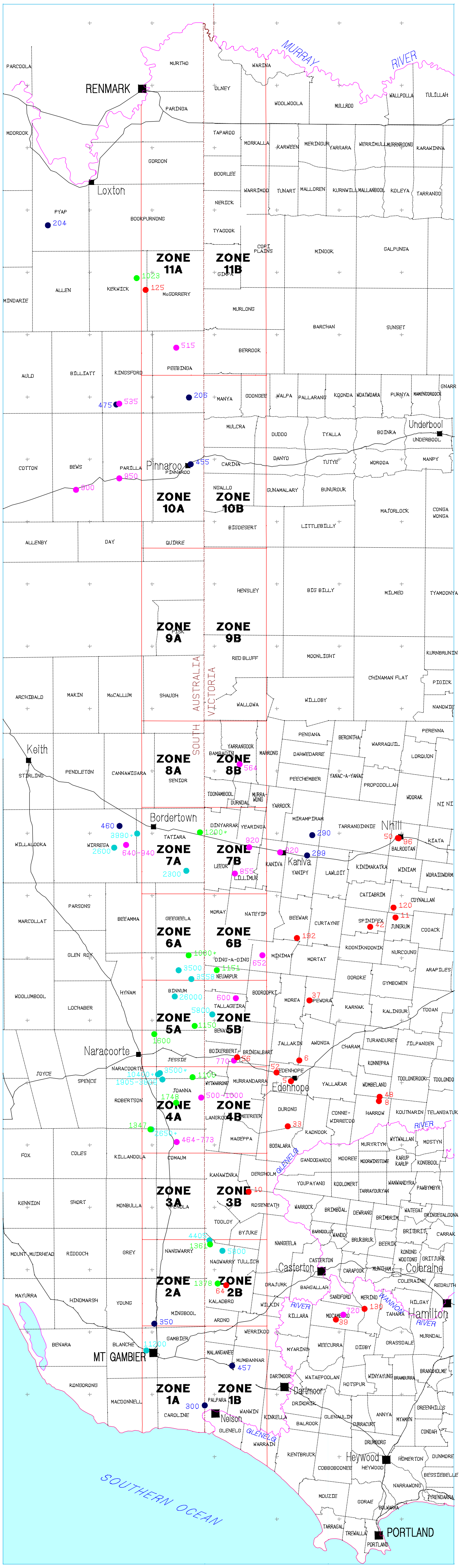
95-67



N

L E G E N D

TERTIARY LIMESTONE TRANSMISSIVITY SITES ($m^3/d/m$)

1347	Definite Transmissivity value
2650+	Lower Limit Transmissivity value
500-1000	Range in Transmissivity

- Transmissivity value < 200 $m^3/d/m$
- Transmissivity value 200–500 $m^3/d/m$
- Transmissivity value 500–1000 $m^3/d/m$
- Transmissivity value 1000–2000 $m^3/d/m$
- Transmissivity value > 2000 $m^3/d/m$

SCALE OF KILOMETRES
0 25 50

Figure........10

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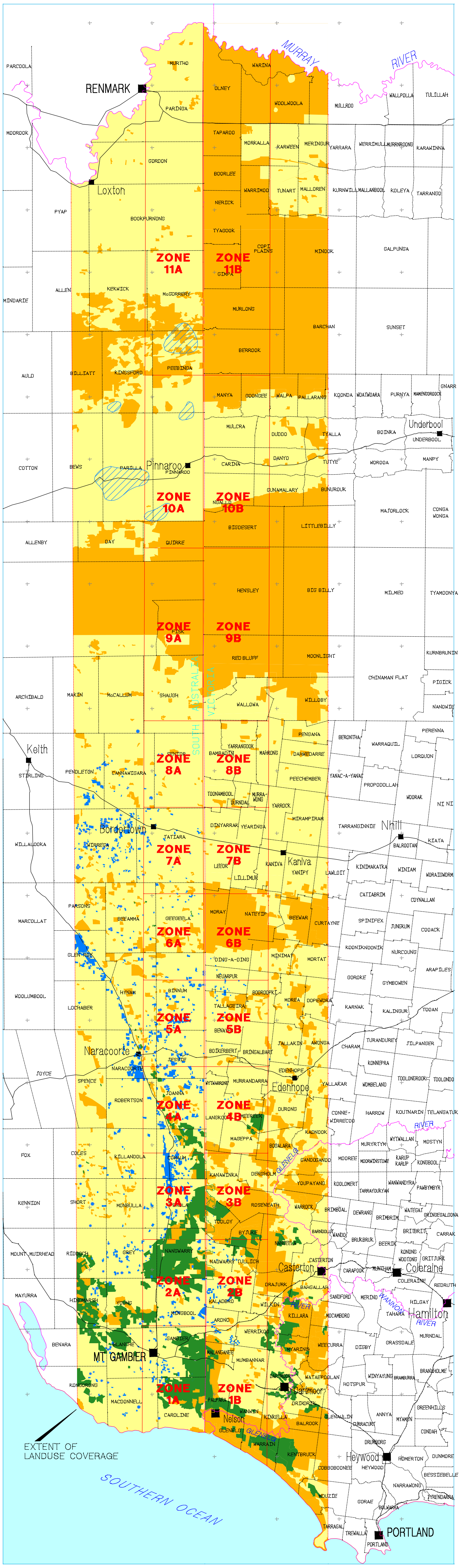
DISTRIBUTION OF TRANSMISSIVITY FOR TERTIARY LIMESTONE AQUIFER

95-68



L E G E N D

- Native vegetation
- Pine
- Irrigation
- Groupings of centre pivot irrigation
- Other

NOTES For S.A. Zones 9A, 10A and 11A, irrigation areas shown represent groupings of individual centre pivots and not total area irrigated

Victorian land use data provided by the Department of Conservation and Natural Resources, Victoria

SCALE OF KILOMETRES
0 25 50

Figure........11

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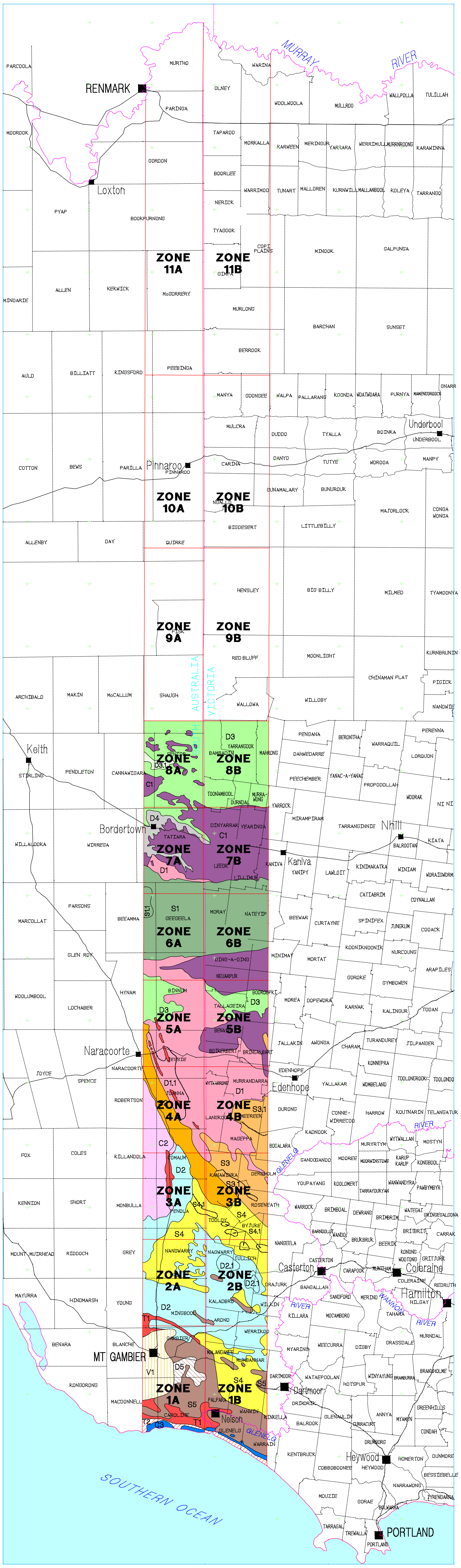
S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

LAND USE AS AT FEBRUARY 1992

95-69



N

L E G E N D

SOIL ASSOCIATIONS

DUPLEX SOIL ASSOCIATIONS

- D1 Duplex soils (90%)
  - D1.1 Duplex soils, depth to limestone 3 to 5 m
- D2 Duplex soils (70%), sand soils, clay soils and Terra Rossa
  - D2.1 Large swamp areas
- D3 Duplex soils (60%), sand soils
  - D3.1 Areas where deep sands are dominant
- D4 Duplex soils (60%), clay soils
- D5 Duplex soils (90%), Terra Rossa

CLAY SOIL ASSOCIATIONS

- C1 Clay soils (60%), Duplex soils
- C2 Shallow clay soils (90%)
- C3 Peat, clay soils

SAND SOIL ASSOCIATIONS

- S1 Sand soils (60%), Duplex Soils (40%)
  - S1.1 areas with clay soils
- S2 Sand soils (65%), Duplex (25%), Terra Rossa (10%)
- S3 Sand soils, Duplex soils associated with Tertiary formations
  - S3.1 Areas where humus podsols are dominant
  - S3.2 Areas where sand sheets are very thin or absent
- S4 Sand soils (60%), Duplex soils (40%) associated with Quaternary formations
  - S4.1 Areas where sand sheets are thin or absent
- S5 Sand soils (90%), Terra Rossa

TERRA ROSSA SOIL ASSOCIATIONS

- T1 Terra Rossa, Red brown earth, skeltal soils
- T2 Terra Rossa, Peat

OTHER SOIL ASSOCIATIONS

- V1 Soils developed on volcanic ash with various sand profiles

NOTE: Soil associations only shown for areas south of Zone 9 due to lack of data in the northern part of the Designated Area

SCALE OF KILOMETRES
0 25 50

HydroTechnology

Figure........12

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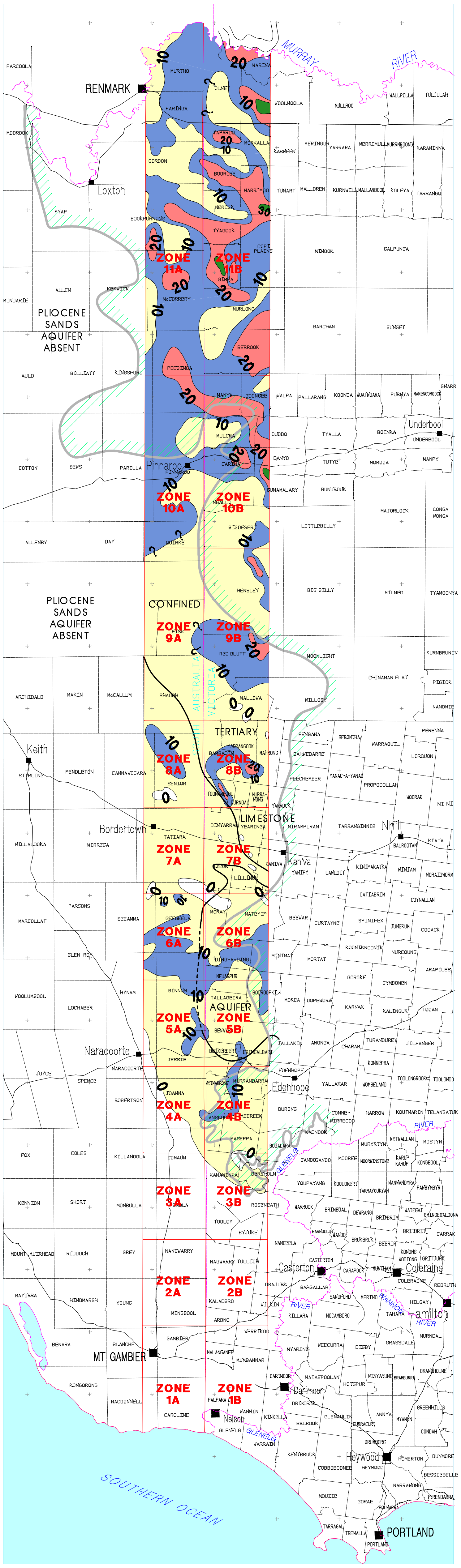
MINES and ENERGY RESOURCES SOUTH AUSTRALIA

S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

SOIL ASSOCIATIONS OF THE DESIGNATED AREA

95-70



N

L E G E N D

Quaternary aquitard generally not present

Quaternary Aquitard thickness between –

0 – 10m

10 – 20m

20 – 30m

30 – 40m

Limit of Pliocene Sands Aquifer

10 Isopach of Quaternary Aquitard (m)

Boundary between confined and unconfined parts of Tertiary Limestone Aquifer

NOTE For the Victorian part of the Designated Area and Zones 9A to 11A, the isopach of the Quaternary Aquitard was compiled from the difference between elevations of the ground surface and the top of the Pliocene Sands. This therefore may also include more permeable horizons.

For Zones 4A to 8A, the isopach distribution was compiled for individual well lithologies and therefore represents thickness of only low permeable horizons.

SCALE OF KILOMETRES
0 25 50

HydroTechnology

Figure........13

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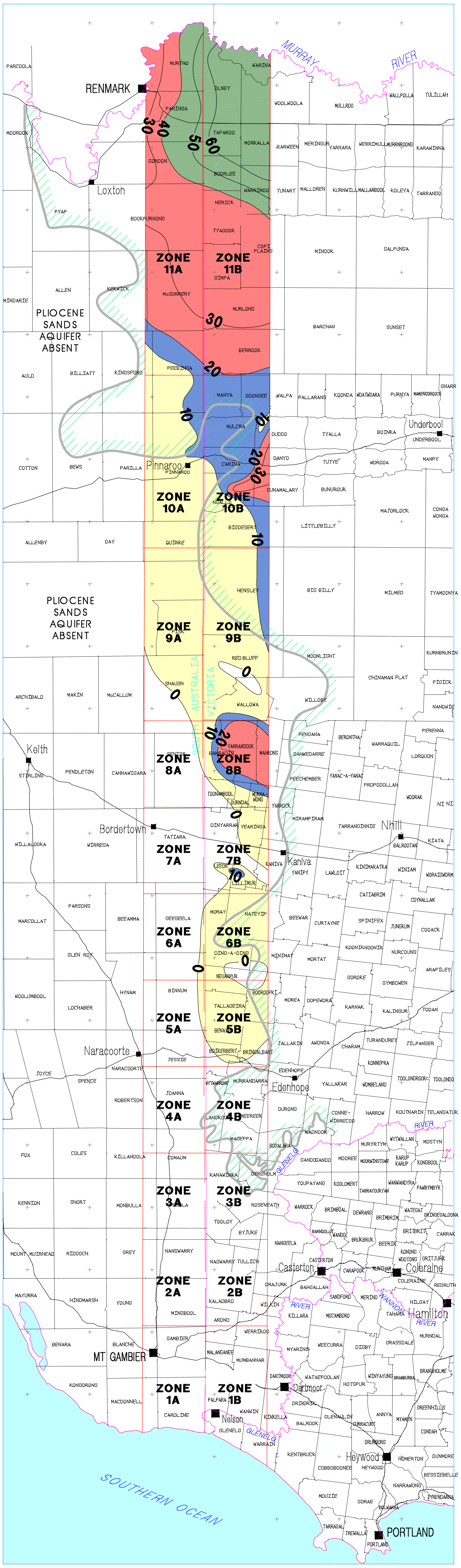
MINES and ENERGY RESOURCES SOUTH AUSTRALIA

S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

QUATERNARY AQUITARD ISOPACH DISTRIBUTION

95–71



N

L E G E N D

< 0	Upper Tertiary Aquitard not present

Upper Tertiary Aquitard thickness between –

	0 – 10m
	10 – 20m
	20 – 40m
	> 40m +

—50— Isopach of Upper Tertiary Aquitard (m)

Limit of Pliocene Sands Aquifer

SCALE OF KILOMETRES
0 25 50

Figure........14

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MINES and ENERGY RESOURCES SOUTH AUSTRALIA

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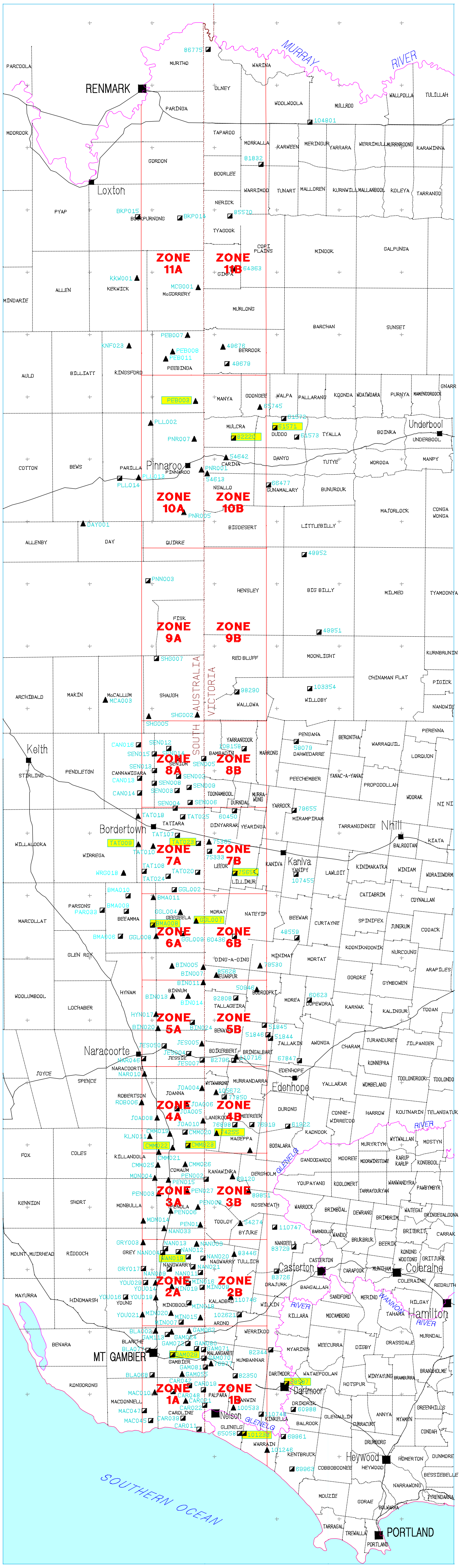
S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

UPPER TERTIARY AQUITARD ISOPACH DISTRIBUTION

95–72



N

L E G E N D

PEB 1	Government observation well
65745	Privately owned observation well
65745	Observation well with hydrograph (See Appendix A of report)

SCALE OF KILOMETRES
0 25 50

Figure........15

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MINES and ENERGY RESOURCES SOUTH AUSTRALIA

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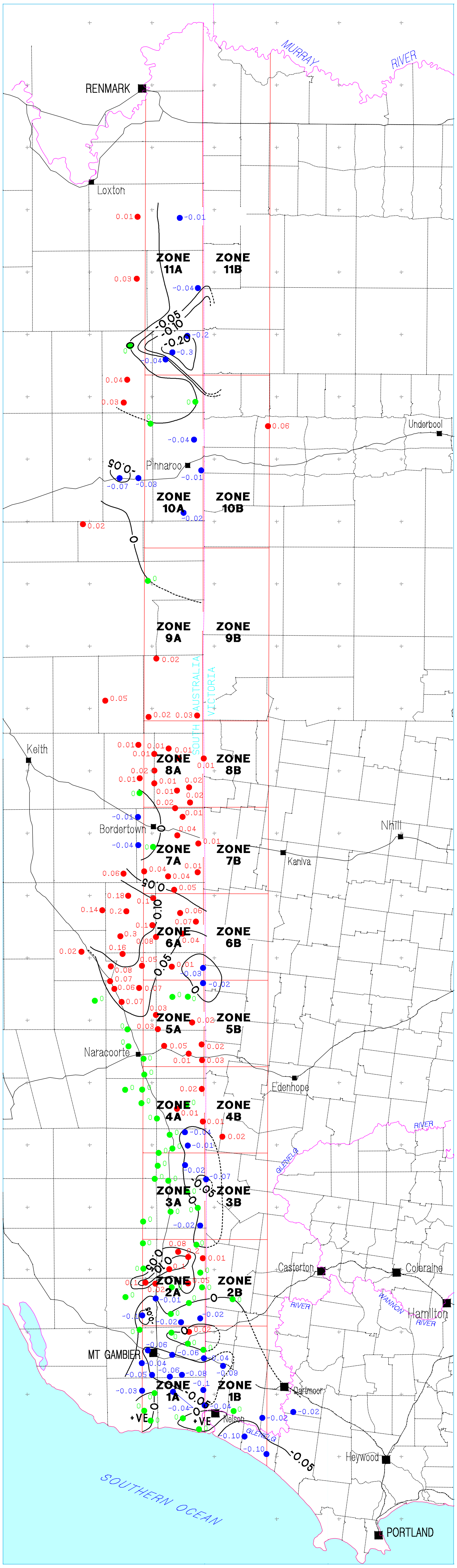
S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

LOCATION OF TERTIARY LIMESTONE AQUIFER WATER LEVEL MONITORING WELLS

95-73



N

L E G E N D

WATER LEVEL TRENDS (m per year)

0.03 ● Long term groundwater level rise

0 ● Stable long term groundwater levels

-0.01 ● Long term fall in groundwater level

0.05 Groundwater trend contour (m per year)

NOTE The groundwater level trends have been assessed using long term data (generally more than 10 years).
For the Victorian section of the Designated Area, the lack of data points reflects a shorter monitoring length for most wells

SCALE OF KILOMETRES
0 25 50

Figure........16

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MINES and ENERGY RESOURCES SOUTH AUSTRALIA

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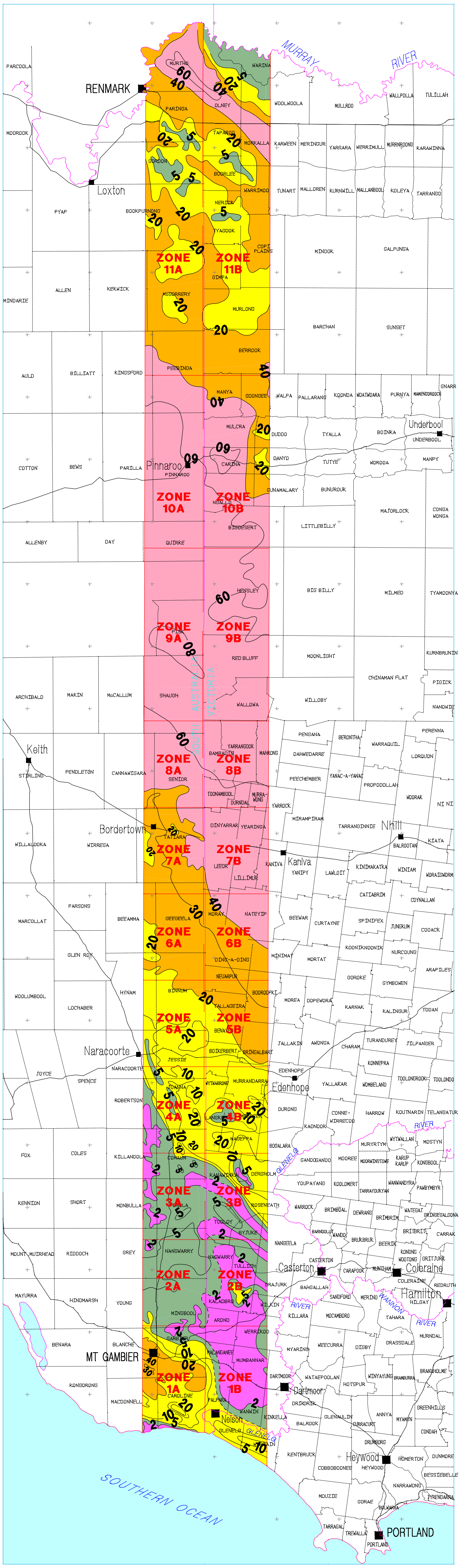
S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

GROUNDWATER LEVEL TRENDS FOR TERTIARY LIMESTONE AQUIFER

95-74



N

LEGEND

20 Contour of depth to water table (m)

Depth to Water Table between –

Magenta	0 – 2m
Green	2 – 5m
Yellow	5 – 20m
Orange	20 – 40m
Pink	> 40m

NOTE Water table is related to the shallowest occurring aquifer (Tertiary Limestone Aquifer in the south, and Pliocene Sands Aquifer in the north)

SCALE OF KILOMETRES

0 25 50

HydroTechnology

Figure........17

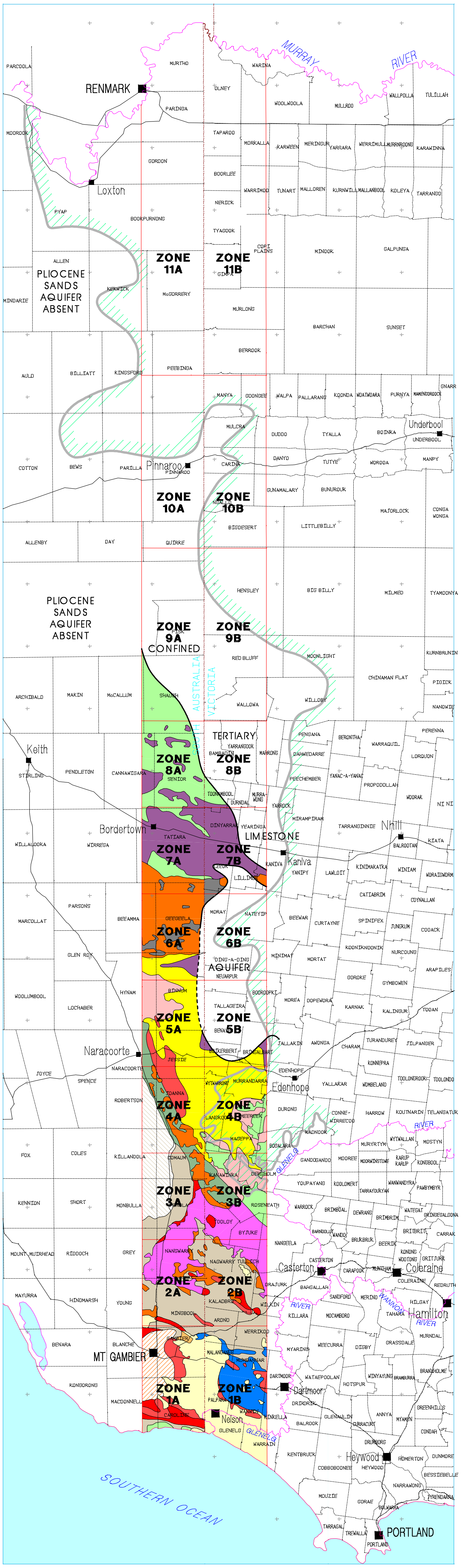
S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

GENERALISED DEPTH TO GROUNDWATER LEVEL IN THE DESIGNATED AREA

MINES and ENERGY RESOURCES SOUTH AUSTRALIA

Job No. 5916FS.DTA

95–75



N

L E G E N D

RECHARGE SUB-AREA	ADOPTED RECHARGE RATE (mm per year)
R1	130
R2	100
R3	90
R4	80
R5	70
R6	65
R7	60
R8	45
R9	40
R10	35
R11	30
R12	20
R13	15
R14	12
R15	5
R16	2

Limit of Pliocene Sands Aquifer

Boundary between confined and unconfined parts of Tertiary Limestone Aquifer

AREA IN KM^2 OF RECHARGE SUB-AREAS WITHIN EACH ZONE

ZONE	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	TOTALS
1A	4.47	---	55.98	75.59	---	179.54	100.37	---	9.47	---	---	---	15.61	---	224.04	---	665.07
1B	215.82	---	147.6	---	---	---	41.51	---	---	---	---	---	---	---	377.40	---	782.33
2A	---	---	281.59	14.2	---	---	4.29	189.30	---	---	---	53.77	---	---	11.46	---	554.61
2B	---	---	375.47	18.61	---	---	16.33	103.12	---	---	---	48.28	---	---	7.51	---	569.32
3A	---	193.49	200.38	14.75	17.27	---	---	94.25	---	0.66	---	33.81	---	---	---	---	554.61
3B	---	---	4.09	8.20	66.63	---	---	181.13	---	17.44	123.66	32.80	120.66	---	---	---	554.61
4A	---	145.57	5.92	---	95.08	---	84.97	---	---	151.79	1.41	68.42	1.43	---	---	---	554.59
4B	---	---	---	---	---	---	---	---	---	380.37	95.26	---	77.99	0.82	---	---	554.44
5A	---	---	---	---	32.02	---	51.40	---	---	305.75	129.23	0.34	---	5.84	---	---	524.58
5B	---	---	---	---	---	---	---	---	---	71.38	---	---	---	17.15	---	---	88.53
6A	---	---	---	---	---	---	---	---	---	93.90	11.98	329.26	---	35.39	---	51.89	522.42
6B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	7.37	7.37
7A	---	---	---	---	---	---	---	---	---	---	---	131.38	90.61	339.35	---	6.72	568.06
7B	---	---	---	---	---	---	---	---	---	---	---	15.98	4.31	249.29	---	25.42	295.00
8A	---	---	---	---	---	---	---	---	---	---	---	---	411.79	128.93	---	---	540.72
8B	---	---	---	---	---	---	---	---	---	---	---	---	32.55	9.16	---	---	41.71
9A	---	---	---	---	---	---	---	---	---	---	---	---	163.43	---	---	---	163.43

SCALE OF KILOMETRES
0 25 50

Figure........18

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MINES and ENERGY RESOURCES SOUTH AUSTRALIA

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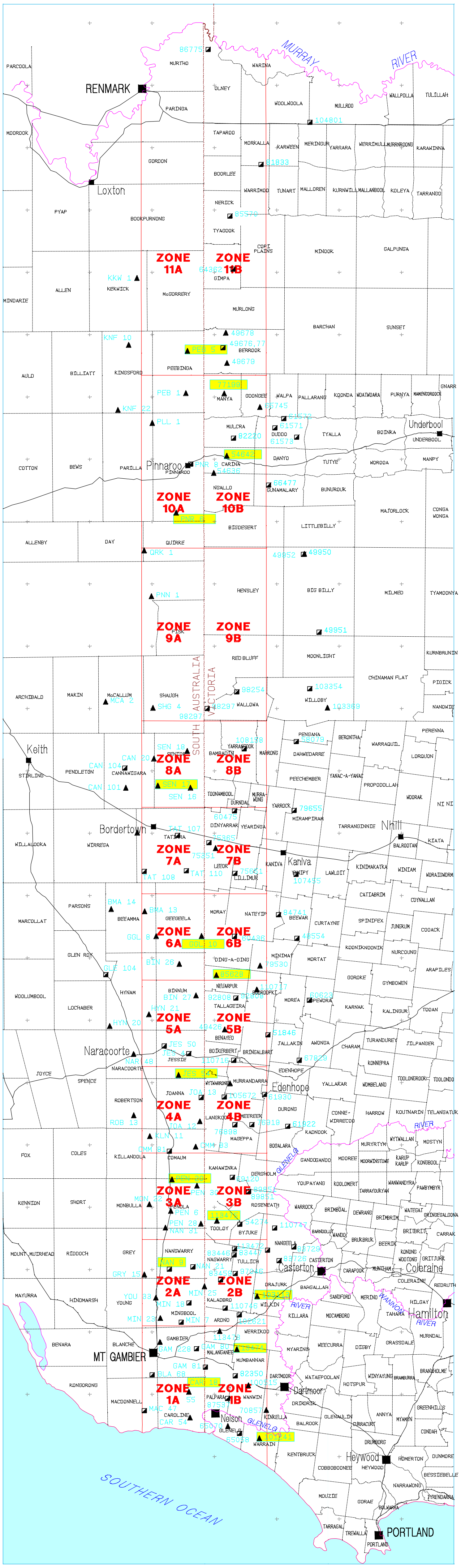
S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

VERTICAL RECHARGE SUB AREAS FOR TERTIARY LIMESTONE AQUIFER

95-76



N

L E G E N D

PEB 1 ◪	Government observation well
65745 ▲	Privately owned observation well
65745 ▲	Well with salinity graph (See Appendix B of report)

SCALE OF KILOMETRES
0 25 50

Figure........19

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MINES and ENERGY RESOURCES SOUTH AUSTRALIA

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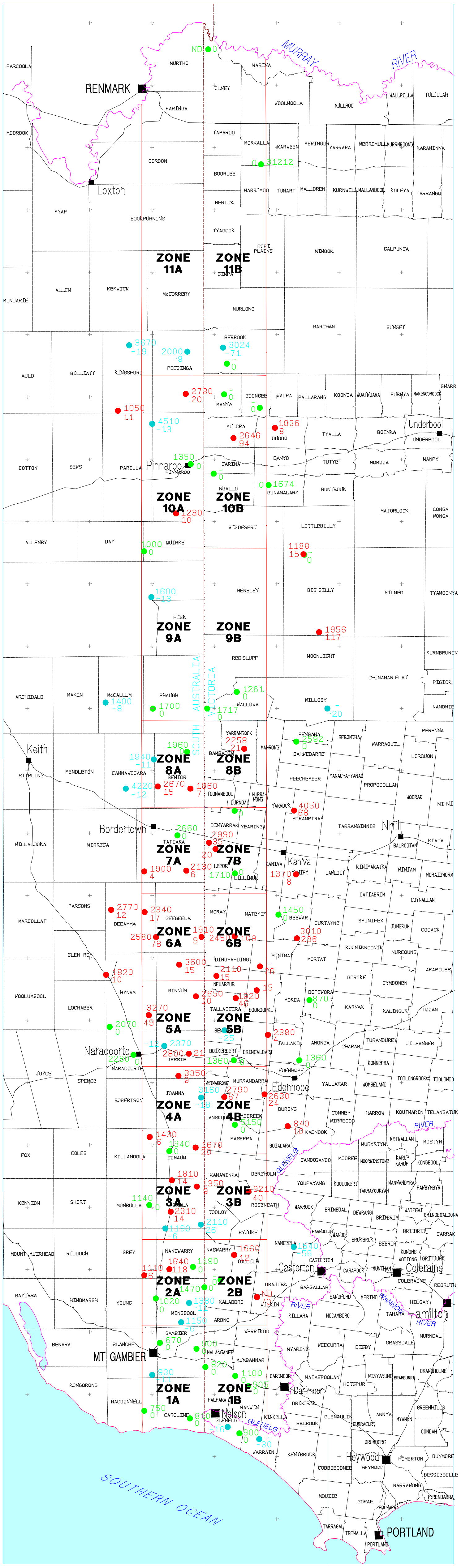
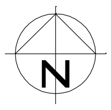
S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

LOCATION OF TERTIARY LIMESTONE AQUIFER SALINITY MONITORING WELLS

95-77





LEGEND

2030 Dec 1994 EC

SALINITY TRENDS (ECU per year)

- 94 Salinity increase
- 0 Salinity static
- -71 Salinity decrease

Note The salinity trends are based on relatively short term data, generally not exceeding 7 years, therefore the trends may not be representative.

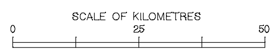


Figure........20

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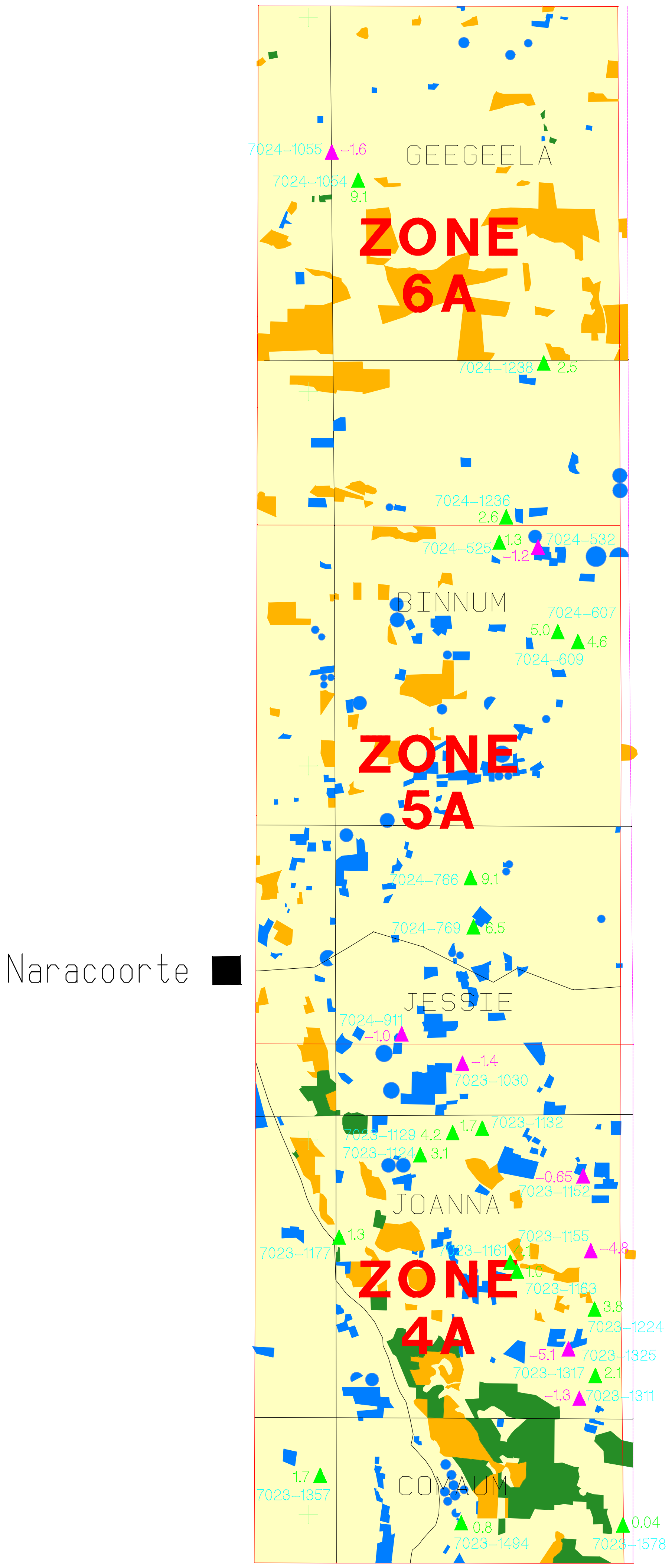
S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

SALINITY TRENDS FOR TERTIARY LIMESTONE AQUIFER

95-78



N

L E G E N D

7024–532 Water supply well with historic chloride concentration Sampled in either 1990–91 or 1994 showing unit number

1.3 Annual increase in chloride concentration (mg per L)

–1.2 Annual decrease in chloride concentration (mg per L)

Native vegetation

Pine

Irrigation

Other

SCALE OF KILOMETRES

0 25

HydroTechnology

Figure........21

S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

HISTORIC CHANGE IN GROUNDWATER CHLORIDE CONCENTRATIONS FOR TERTIARY LIMESTONE AQUIFER IN ZONES 4A TO 6A

MINES and ENERGY RESOURCES SOUTH AUSTRALIA

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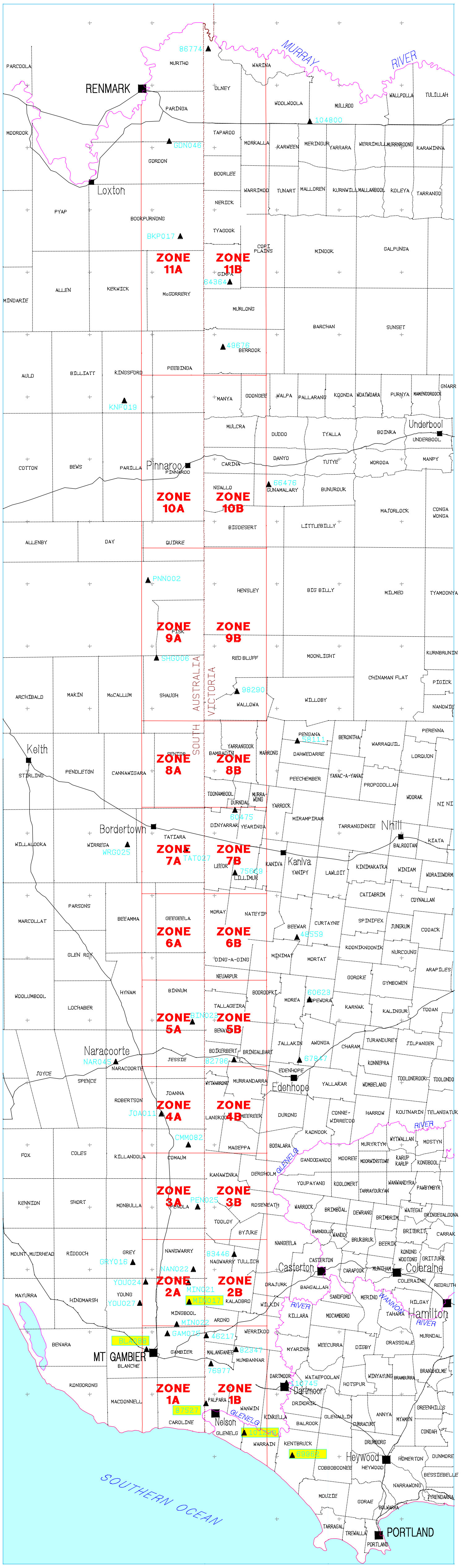
95–79



N

LEGEND

PNN002 ▲ Tertiary confined sand aquifer observation well and number

PNN002 ▲ Observation Well with Hydrograph (See Appendix A in report)

SCALE OF KILOMETRES
0 25 50

Figure........22

S.A. / VIC. STATE BORDER DESIGNATED AREA REVIEW

LOCATION OF TERTIARY CONFINED SAND AQUIFER WATER LEVEL MONITORING WELLS

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95-80