DWLBC REPORT

Padthaway Salt Accession Study. Volume One: Methodology, site description and instrumentation

2004/61

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Padthaway Salt Accession Study. Volume One: Methodology, site description and instrumentation

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Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

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Government of South Australia
Department of Water, Land and Biodiversity Conservation

SENRCC
South East Natural Resource Consultative Committee

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continues to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Rob Freeman
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

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1. INTRODUCTION

1.1 BACKGROUND

The Padthaway area is a long established and important irrigation district located in the South East region of South Australia (Fig. 1). Most groundwater for irrigation is extracted from a high yielding unconfined limestone aquifer (the Padthaway Formation) that occurs at shallow depth throughout the main irrigation area. Annual groundwater salinity increases of between 5 and 18 mg/L/yr have been recorded in the aquifer beneath the irrigation area, threatening the long-term viability of some local business, in particular a well established viticulture industry.

The following mechanisms are believed to be responsible for the salinity increases in the aquifer:

1. Pumping in excess of vertical recharge, and re-cycling of the irrigation water, resulting in accession of the salt back to the unconfined aquifer in the main irrigation area.
2. Mobilization of salt in the unsaturated zone of the adjacent Naracoorte Ranges due to clearance of native vegetation and high water use perennial pastures and the resulting increase in groundwater recharge.

The aim of the *Padthaway Salt Accession Investigations and Determination of Sustainable Extraction Limits (PAV)* study was to quantify and compare salt accession to the water table aquifer, under different land use practices and particularly irrigation activity, in the Padthaway Prescribed Wells Area (PWA). The results of this study will be used to determine sustainable groundwater management strategies for the PWA and to use the results as a guide for sustainable groundwater management in other areas in the South East region with similar hydrogeological characteristics.

The salt accession project is largely funded under the *National Action Plan for Salinity and Water Quality (NAP)*, which is administered through the South East Natural Resource Consultative Committee (SENRCC), and by the local Padthaway Grape Grower's Association (PGGA) and the South East Catchment Water Management Board (SECWMB). The project is managed by the Department of Water, Land and Biodiversity Conservation (DWLBC) who also has provided significant in-kind funding by way of staff support.

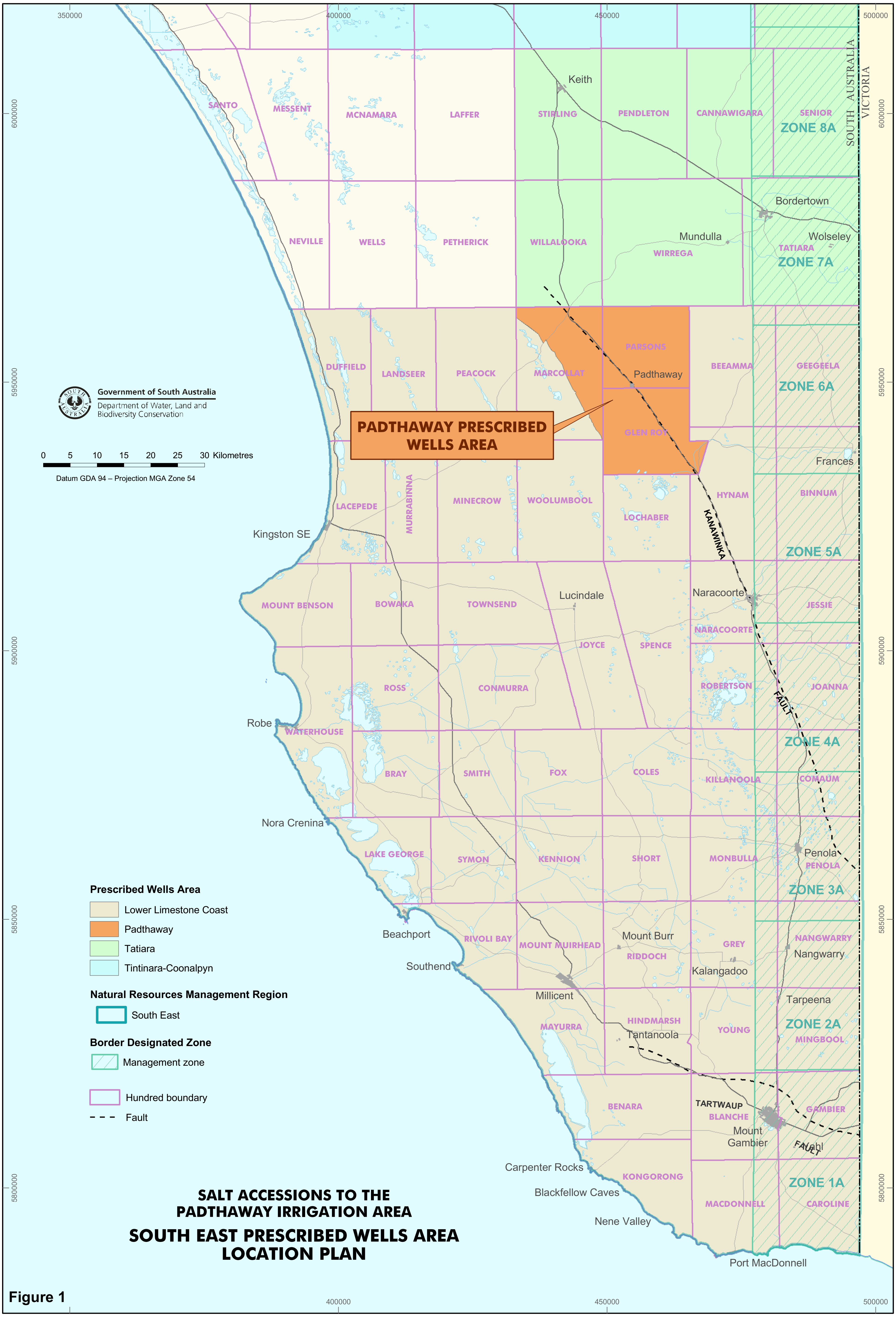
Management and technical direction of the project was the responsibility of the Knowledge and Information Division, DWLBC.

This report details the background, approach, instrumentation, and site details of the study. It is the first of four reports and will be followed by Results, Models and, Discussion and Conclusions volumes.

1.2 OBJECTIVES

The overall objectives of the project that began in July 2002 were to:

1. Quantify the historic salt store contained within the soil profile, determine recharge rates and the time lag associated with groundwater salinisation at selected sites.
2. Quantify groundwater extraction, irrigation application, crop water use, evaporation, and salt/water accession to the unconfined aquifer using different irrigation practices and the risk of groundwater salinisation at selected sites.
3. Undertake a qualitative risk assessment by the extrapolation of the site specific results obtained from (1) and (2), and determine the current salt and water budgets for the critical sub-areas of concentrated irrigation activity, and for the region as a whole.
4. Determine the sustainable extraction limit (PAV) for individual groundwater management areas that will result in sustainable resource management and arrest groundwater quality deterioration (and, where relevant, groundwater level decline) for the areas of concentrated irrigation activity, and the region as a whole, and revise management prescriptions.
5. Develop effective groundwater resource management strategies for the areas of concentrated irrigation activity, and the region as a whole, predict the response of the aquifer system to them, and implement these management strategies with community consultation.
6. Ensure the ongoing groundwater salinity monitoring program is effective and relevant.



SALT ACCESSIONS TO THE PADTHAWAY IRRIGATION AREA

SOUTH EAST PRESCRIBED WELLS AREA LOCATION PLAN

Figure 1

PIRSA Publishing Services 202561_001

2. INTRODUCTION TO THE PADTHAWAY PRESCRIBED WELLS AREA

2.1 GENERAL

The Padthaway Prescribed Wells Area (PWA), one of three water management zones in the South East region of South Australia, is located approximately 300 km south-east of Adelaide and covers an area of approximately 700 km^2 (Fig. 1). It includes the Hundreds of Glen Roy, Parsons and the north-eastern half of Marcollat. A Water Allocation Plan, prepared by the South East Catchment Water Management Board (SECWMB) under the Water Resources Act (1997) and adopted by the Minister for Water Resources in 2001 is currently used to govern the use of water resources in the Padthaway PWA. A threat to the long term viability of the groundwater resource by rising salinity levels was identified in the Water Allocation Plan as a critical problem to be resolved within the five year life of the plan.

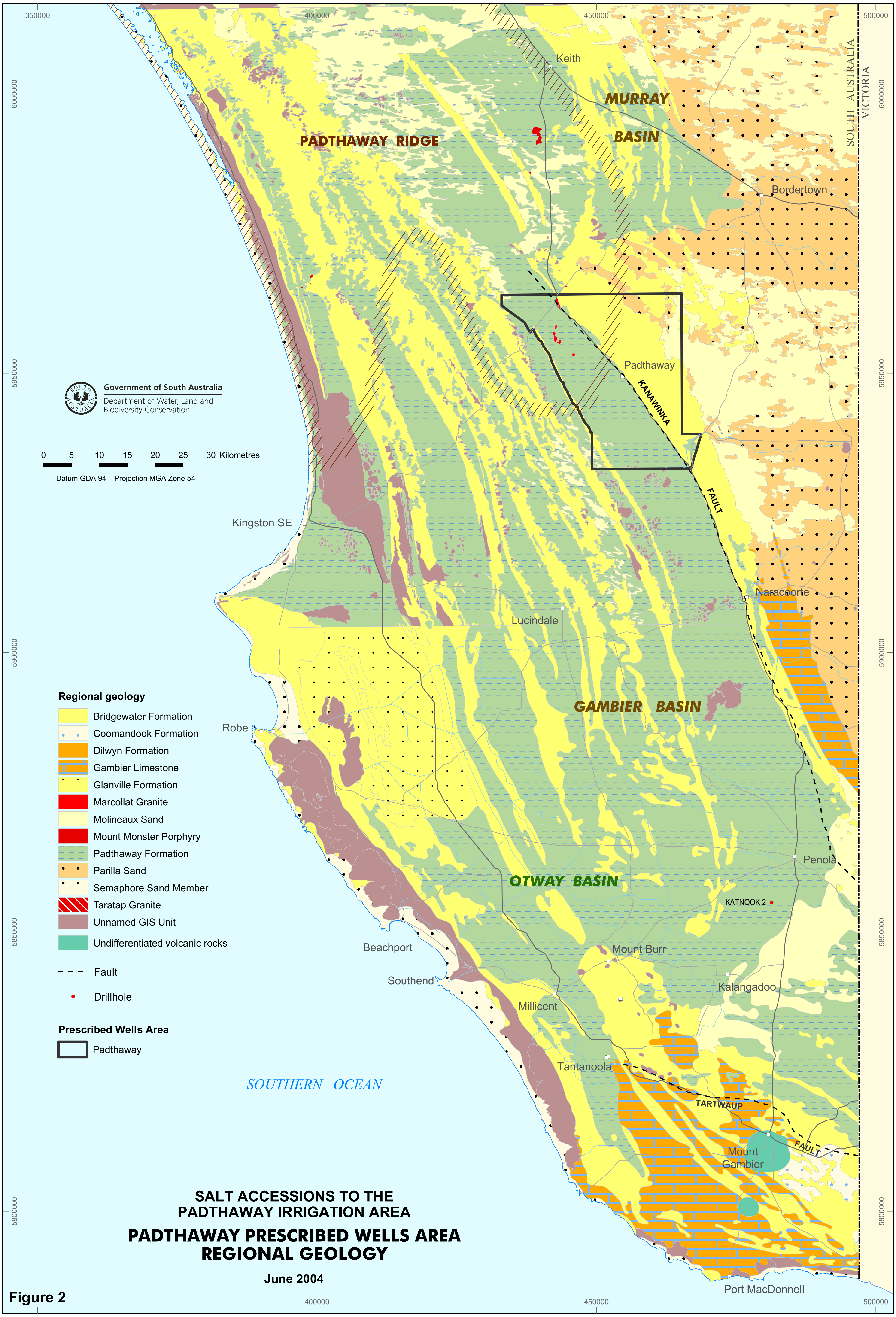
2.2 GEOGRAPHICAL FEATURES

The topography in the South East region is generally low lying and slopes from the more elevated Naracoorte Ranges, located on the South Australia-Victorian Border, towards the coast, and is broken only by a series of low lying remnant cemented sand dune ridges that run sub-parallel to the existing coastline. The Padthaway PWA comprises two distinct landscapes, separated by the NW-SE trending Kanawinka Fault (Fig. 2). South-west of the fault is a low-lying interdunal flat, approximately 10 km wide that slopes gently towards the north-west. North-east of the fault, a remnant dunal ridge rises approximately 50–60 m above the flat, forming part of the Naracoorte Ranges.

The climate in the Padthaway PWA is typical of the South East, with warm to hot, dry summers and cool, wet winters. Climate data is available via the Bureau of Meteorology website which dates back to 1977. A mean daily minimum temperature of 5°C occurs in July and a mean daily maximum of 29°C occurs in February. The lowest and highest recorded temperatures at Padthaway are –4°C and 44°C respectively.

Average annual rainfall at Padthaway is 509 mm/y and is concentrated during the cooler months (June – September). Annual potential evapotranspiration is approximately 1600 mm/y (Stadter et al., 1995).

Most of the 700 km^2 of the Padthaway PWA comprises improved pastures for sheep and cattle grazing. Irrigated agriculture and horticulture are the other major land uses, with a gross annual production estimated to be in excess of $36 million. Irrigation totalled 7059 Ha during the 1994/95 season, with vines, pastures, grass seed and coriander accounting for over two thirds of the crop area. The irrigation is concentrated on the interdunal flat, along the main Keith – Naracoorte road due to the combination of suitable soil types, good quality shallow groundwater and high well yields.



SALT ACCESSIONS TO THE PADTHAWAY IRRIGATION AREA

PADTHAWAY PRESCRIBED WELLS AREA REGIONAL GEOLOGY

June 2004

Figure 2

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3. GEOLOGY AND HYDROGEOLOGY

3.1 REGIONAL GEOLOGY

The Padthaway PWA lies within the Tertiary Gambier Basin, near its northern margin with the Murray Basin. The northern margin of the Gambier Basin is defined by the outcropping granitic basement of the Padthaway Ridge, and the eastern margin consists of the Dundas Plateau (Fig. 2).

Sedimentation in the Gambier Basin commenced in the Late Palaeocene to Middle Eocene and has occurred under varying degrees of marine influence. The paralic Wangerrip Group, consisting of the Pebble Point Formation, the Pember Mudstone and the Dilwyn Formation was deposited in low-energy, interdistributary bay and deltaic environments (Blake, 1980; Holdgate, 1982; Gravestock et al., 1986; White, 1995). The onset of a major marine transgression caused the deposition of the marginal marine Nirranda Group across the Gambier Basin, including the Mepunga Formation, a beach barrier sand and the Narrawaturk Marl, probably deposited in a middle shelf environment (Blake, 1980; White, 1995). The Narrawaturk Marl grades upwards into the lithologically similar basal member of the Gambier Limestone.

Further marine transgression caused the deposition of the marine Heytesbury Group, consisting of the Gambier Limestone and the Gellibrand Marl. The Gambier Limestone, deposited in an open marine shelf environment, is a major fossiliferous carbonate, varying in thickness up to 400 m offshore. Deposition of the Gambier Limestone ended in the early Middle Miocene during a global eustatic fall in sea level (Haq et al., 1987) and uplift of the southern Australian continental margin. During the remainder of the Miocene, the formation was exposed to extensive karstic weathering and erosion, which has continued intermittently to the present day. The Gellibrand Marl has only been identified in one drillhole in South Australia, Katnook 2, near Penola, where it consists of 7 m of Early Oligocene brown, shelly marl, and immediately underlies the Camelback Member of the Gambier Limestone.

Quaternary sedimentation in the South East was dominated by high energy swell from the Southern Ocean and prevailing onshore westerly winds. This resulted in deposition of comminute bioclastic beach, barrier and transgressive dune complexes. Repeated marine transgressions have resulted in construction, destruction and reworking of these complexes and the formation of the Coomandook and Bridgewater Formations. The marine transgression extended to the Kanawinka Fault at Naracoorte and crossed the Padthaway Ridge north of Coonalpyn. This resulted in extensive reworking of the underlying Pliocene sands and Miocene limestone, forming the sandy limestone, calcareous sandstones and shelly sandstone and clay lithologies of the Coomandook Formation.

The series of major coastal barriers that were constructed intermittently throughout the Pleistocene as subparallel topographic ridges across the coastal plain and on the continental shelf is referred to as the Bridgewater Formation. This is the main unconfined aquifer in the Naracoorte Ranges and comprises skeletal calcarenite and marl deposited in shallow subtidal, littoral and dune environments. The shallow subtidal facies of the Bridgewater Formation consist of seaward dipping, coarse carbonate sands with abundant broken shells of marine gastropods and bivalves together with foraminifera and coralline algae. These occur as the basal transgressive phase. The sediments of the littoral zone are well-sorted, medium to coarse-grained, quartzose and skeletal carbonate sands deposited as shoestring sand bodies subparallel to the present coastline. The beach deposits, up to 3 m thick, extend into the core of the ranges as distinctive bi-directional cross-bedded strata. The bulk of the visible ranges are formed by the transgressive dune or aeolianite facies, comprising weakly cemented, fine to medium-grained well-sorted and rounded skeletal sand. The dune facies interfinger with, or overlie sediments of the lagoonal Padthaway Formation in the interdunal corridors. The Padthaway Formation, the main aquifer on the Padthaway flats, consists of dense, white, calcitic and dolomitic mudstone typically 1 to 2 m thick. Interbedded greenish clay and clayey quartz sand is also common.

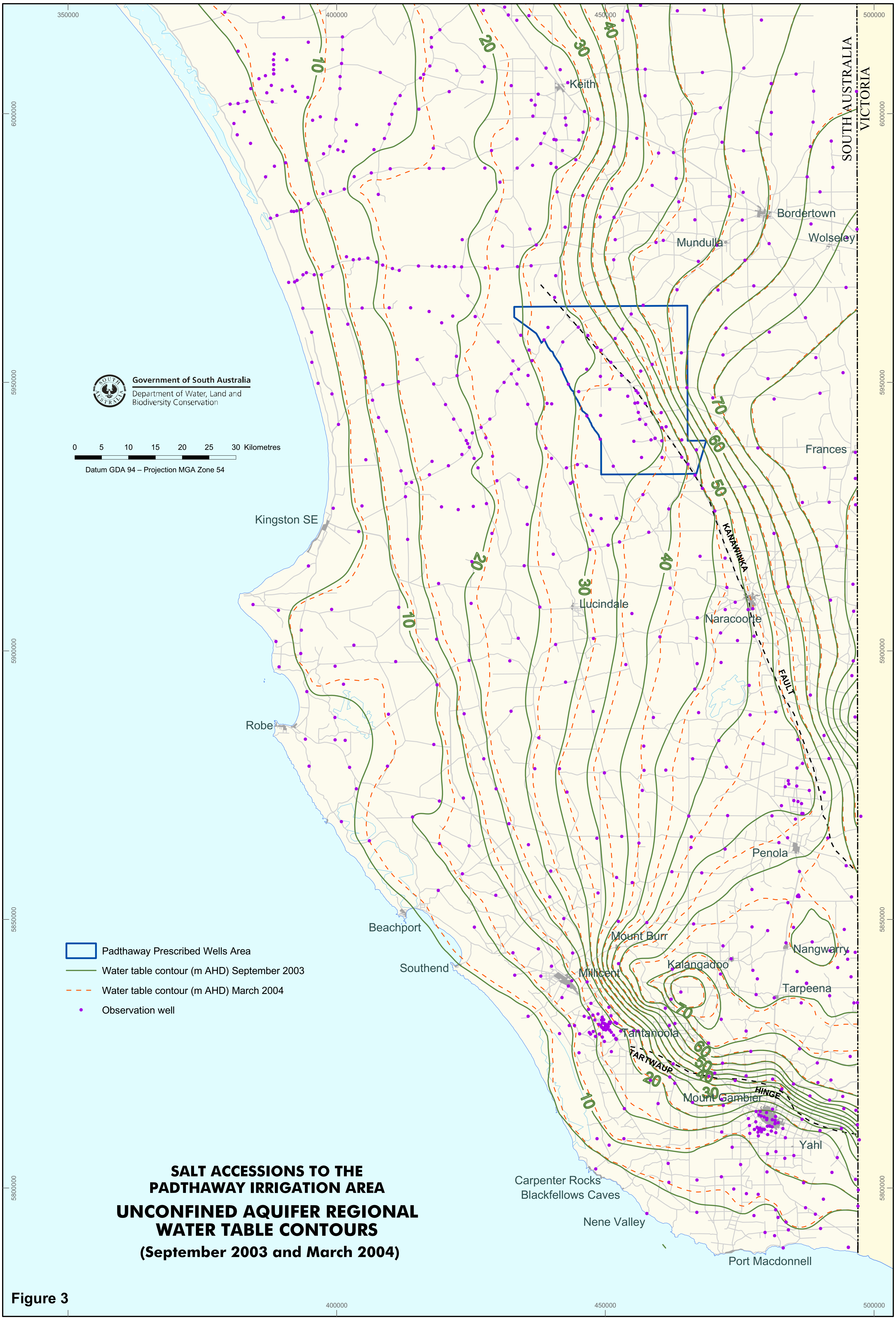
The structures of the south-eastern basins are thought to be controlled by reactivation of Palaeozoic structures of the Tasman Fold Belt System (Gravestock et al., 1986). However, major structures in the underlying Cretaceous Otway Basin have produced only minor warping or faulting in the Tertiary units. Sprigg (1952) described gentle folding in Gambier Limestone, which he related to faulting in the underlying basement units. A gentle anticline in Tertiary sediments in Allen's Quarry, near Mount Gambier, is related to the nearby Tartwaup Fault and minor Tertiary movement has also occurred along the Kanawinka Fault, which runs through the Padthaway PWA. Seismic sections indicate that many faults also displace the Gambier Limestone.

3.2 REGIONAL HYDROGEOLOGY

Groundwater in the South East flows through two major aquifer systems: the regionally unconfined limestone aquifer system, consisting of the late Tertiary – Quaternary Gambier Limestone, Coomandook, Bridgewater and Padthaway formations and the regionally confined sand aquifer system consisting of the early Tertiary Dilwyn Formation. Lateral flow in both the confined and unconfined aquifers is from the topographic high of the Dundas Plateau in western Victoria, from which it flows radially west and south towards the coast (Fig. 3). Although groundwater flow velocities are dependent on local aquifer characteristics, higher rates of flow are generally evident in the unconfined aquifer where secondary porosity has developed. The confined and unconfined aquifer systems are separated by a low permeability aquitard, comprising a dark brown carbonaceous clay. There is hydraulic connection between the two aquifers but the degree of interconnectivity is yet to be quantified and is currently being reviewed.

Two major faults in the area, the north-west trending Kanawinka Fault and the west-north-west trending Tartwaup Fault may impact on groundwater flow, as indicated by a steepening of the potentiometric surface immediately up hydraulic gradient of each fault. However, this impact and the mechanisms leading to it are poorly understood.

Groundwater salinity in the unconfined aquifer ranges between approximately 500 mg/L in the south and 7000 mg/L in the north. Groundwater salinity in the confined aquifer system is typically below 500 mg/L in the south, around Mount Gambier, but increases to over 10 000 mg/L as the aquifer thins to the north of Kingston.



SALT ACCESSIONS TO THE PADTHAWAY IRRIGATION AREA

UNCONFINED AQUIFER REGIONAL WATER TABLE CONTOURS

(September 2003 and March 2004)

Figure 3

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3.3 LOCAL HYDROGEOLOGY

Groundwater in the Padthaway region is sourced from the shallow unconfined limestone aquifer comprising the geological units and aquifers of the Bridgewater and Padthaway formations (Fig. 4). Groundwater flow in the unconfined aquifer is generally south-westerly to the east of the Kanawinka Fault, changing to north-westerly, commensurate with the slope of topography, on the inter-dunal flat (Fig. 5). The hydraulic gradient immediately east of the Fault is steep, and is possibly due to the low transmissivity of the Bridgewater Formation or, more likely, an indication that flow across the Fault is restricted (Cobb and Brown, 2000). The hydraulic gradient becomes flatter to the west of the fault due to the high transmissivity of the Padthaway Formation. Brown (1998a and b) and Cobb and Brown (2000) conducted drilling and hydrogeological appraisals of the unconfined aquifer of the Padthaway area, obtaining the following information about the local hydrogeology:

- The unconfined aquifer in the Naracoorte Ranges consists of the Bridgewater Formation. This is overlain on the plains (i.e. the main irrigation area) by the Padthaway Formation (Fig. 4).
- Both the Padthaway and Bridgewater Formation aquifers have similar salinity and hydrogeological characteristics.
- Due to poor cementation and large spatial variability in hydraulic conductivity of the Bridgewater Formation in some areas, this unit has limited potential as an aquifer in the Naracoorte Ranges. A high proportion of fine sand is produced from some pumped wells.
- The highly transmissive Padthaway Formation is the dominant aquifer in the main irrigation area and provides high well yields.
- With the exception of the main irrigation area, where the two aquifers are in good hydraulic connection, the Keppoch Clay member separates the Padthaway and Bridgewater Formations. Where present this clay acts as a confining unit.
- The Keppoch Clay is present in the east of the irrigation area, where groundwater quality in the Bridgewater Formation is slightly better than in the Padthaway Formation. However, the permeability of the Bridgewater Formation in this area is significantly lower than in the main irrigation area.

Depths to water in bores below the inter-dunal flat range between approximately 3 m and 4.5 m (Fig. 6). Depth to water is more variable in the Naracoorte Ranges due to the undulating topography there, ranging between approximately 5 m and 30 m below ground level (Fig. 6). The water table in the unconfined aquifer in the Naracoorte Ranges is rising by between 2 cm/y and 12 cm/y, but is fairly static on the inter-dunal flat. The increase is believed to be due to increased recharge resulting from clearance of native vegetation and the failure of lucerne crops in the mid-1970s. Groundwater Total Dissolved Solids (TDS) in the Naracoorte Ranges vary between approximately 860 mg/L and 1700 mg/L, with increases of up to 20 mg/L/y being observed (Fig. 7). On the inter-dunal flat, groundwater is more saline, ranging between 1000 mg/L and 1900 mg/L, increasing by up to 44 mg/L/y. Recorded bore yields are highly variable, ranging between 0.2 L/s and 300 L/s (DWLBC, 2004).

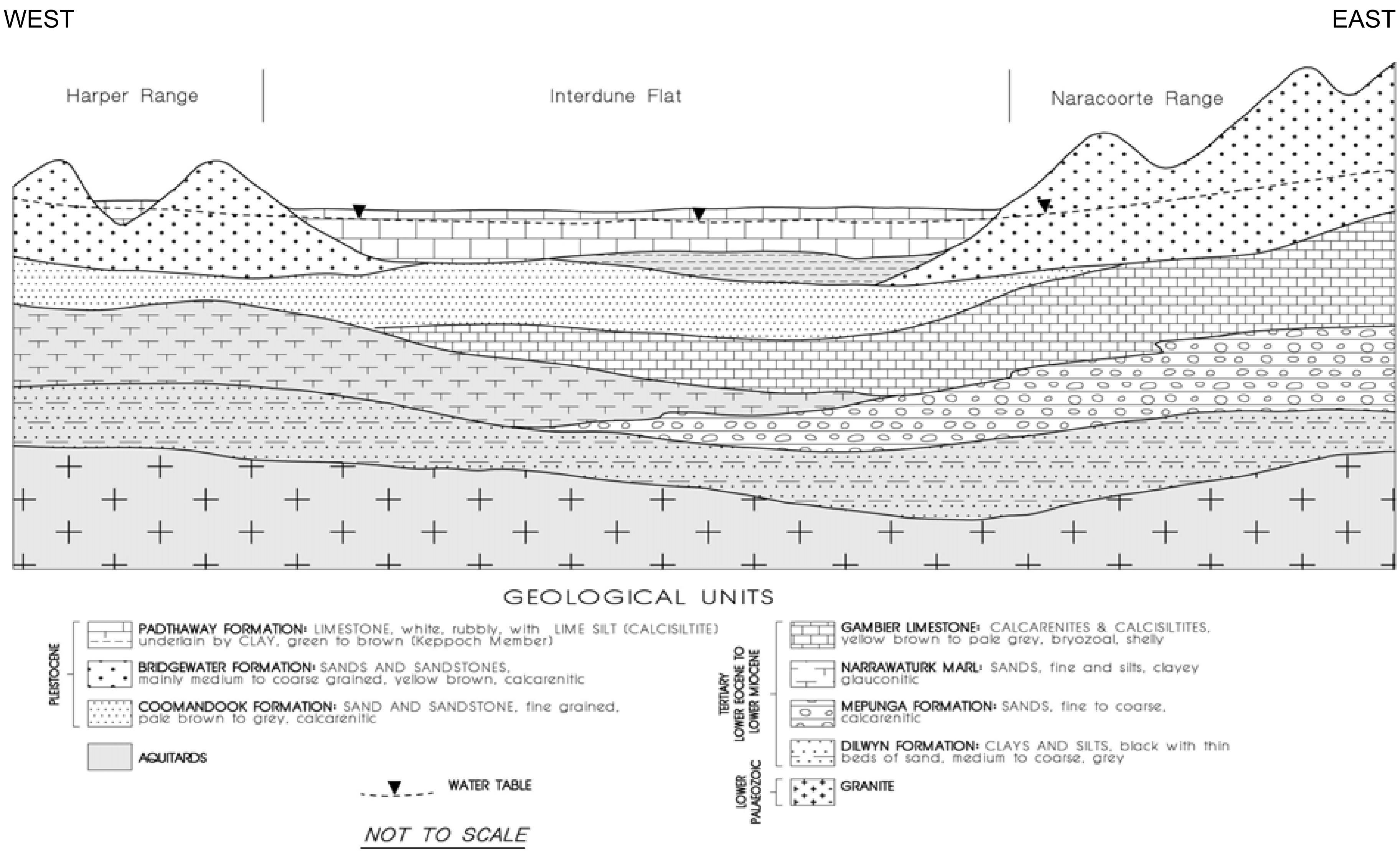
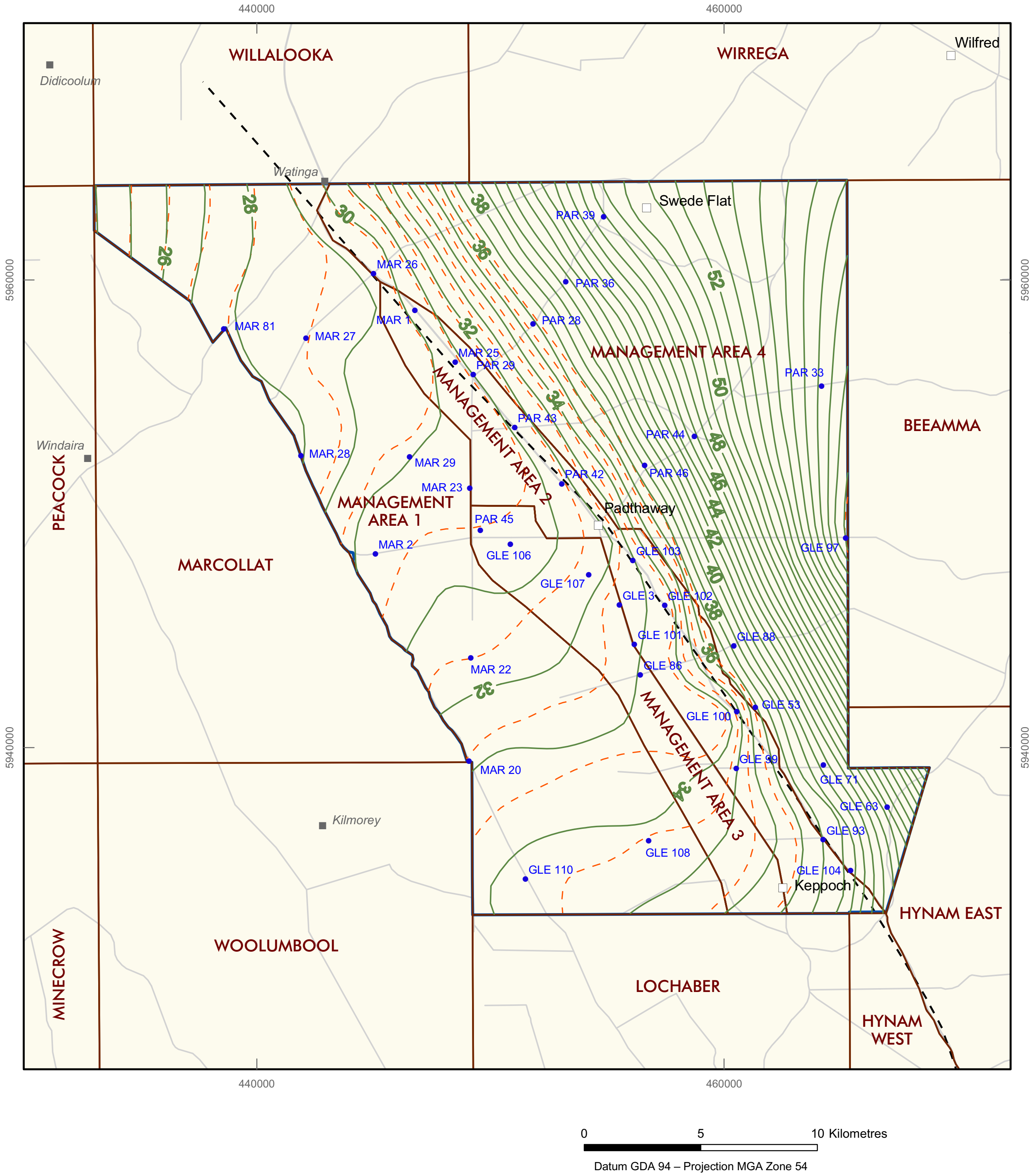


Figure 4. Local hydrogeology



- Padthaway Prescribed Wells Area
- Unconfined groundwater management zone
- Kanawinka Fault
- Water level contour (m AHD) September 2003
- Water table contour (m AHD) March 2004
- Current water level observation bore and number (GLE 78)

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SALT ACCESSIONS TO THE PADTHAWAY IRRIGATION AREA

UNCONFINED AQUIFER WATER TABLE CONTOURS

(September 2003 and March 2004)

Figure 5

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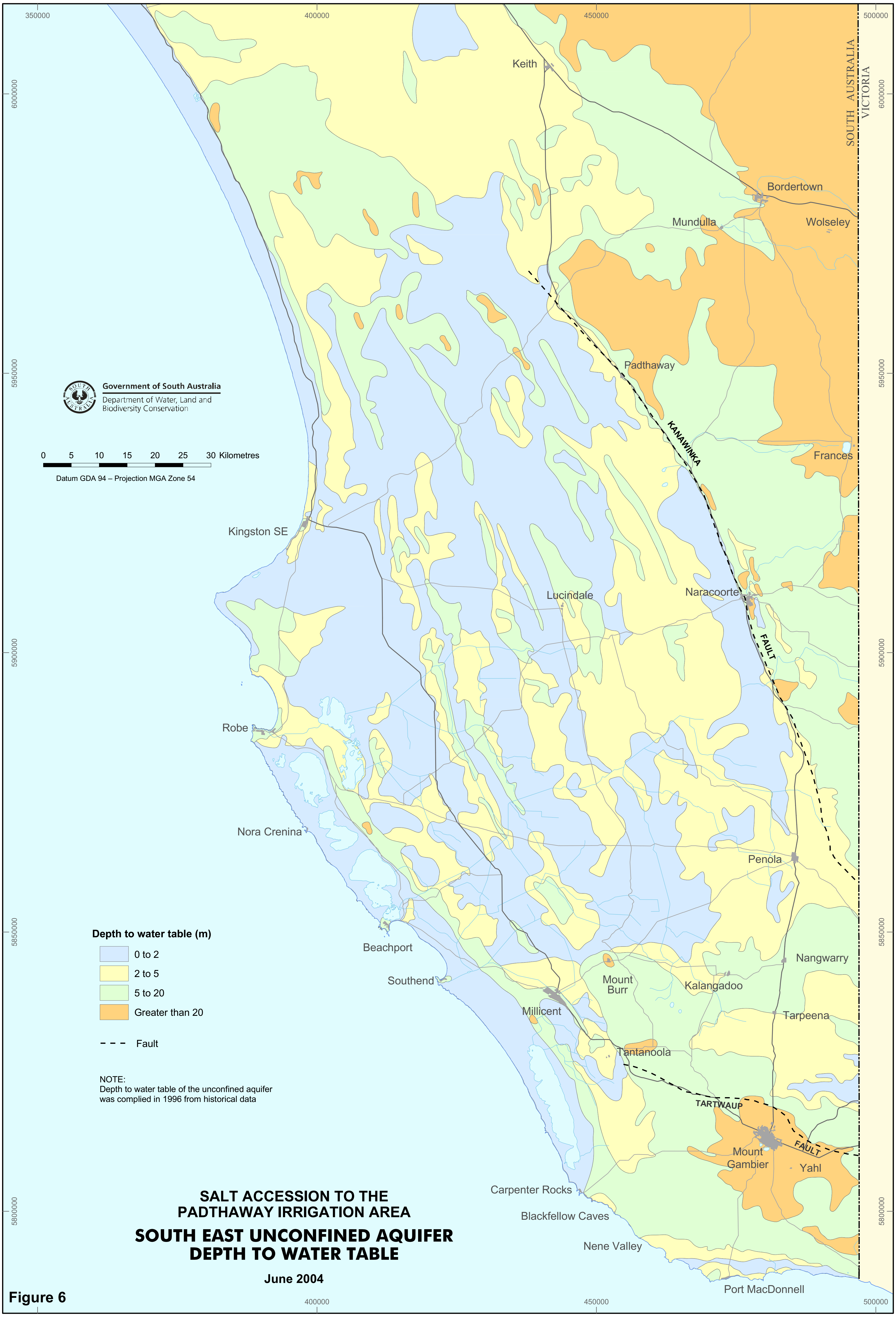

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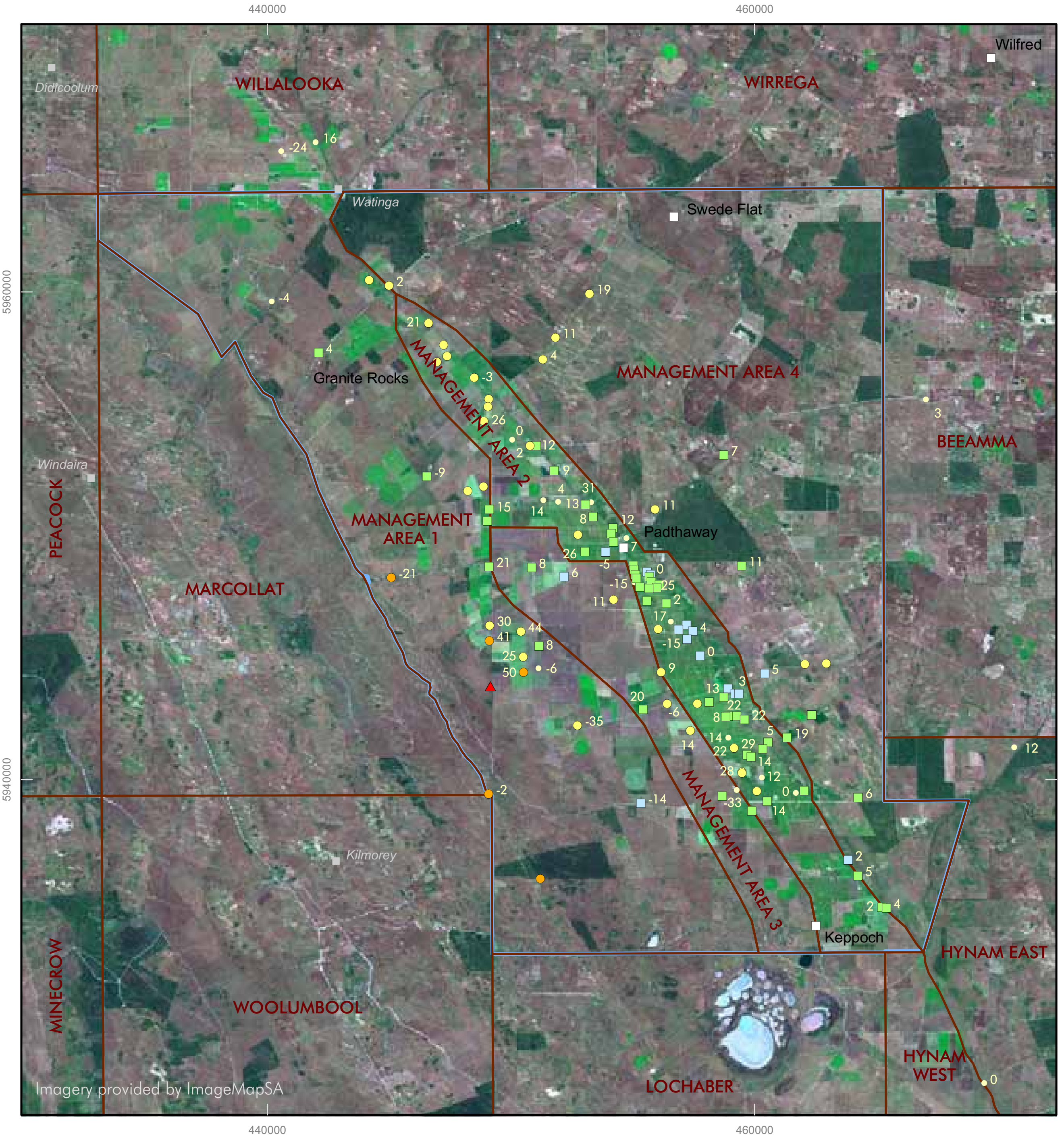

Salinity (mg/L)

- Less than 500
- 500 to 1000
- 1000 to 1500
- 1500 to 3000
- 3000 to 7000
- 7000 to14 000
- Greater than 14 000

11 Salinity trend (mg/L/yr)

Padthaway Prescribed Wells Area

Unconfined groundwater management zone

0 5 10 Kilometres

Datum GDA 94 – Projection MGA Zone 54

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SALT ACCESSIONS TO THE PADTHAWAY IRRIGATION AREA

UNCONFINED AQUIFER LATEST SALINITY AND TREND

(Salinity trend to September 2003)

PIRSA Publishing Services 202561_007

Figure 7

3.4 SOILS

Soils in the Padthaway area were first mapped by Blackburn (1964) as part of a general survey of the central South East region. Subsequently a more detailed survey of the Plain was conducted by Wetherby and Armstrong (1978).

There are two main soil types which dominate the Padthaway area: sandy dune soils on the slopes; and shallow loamy red (terra rossa) and black soils that overly calcrete representing the top of the Padthaway Formation (Fig. 8).

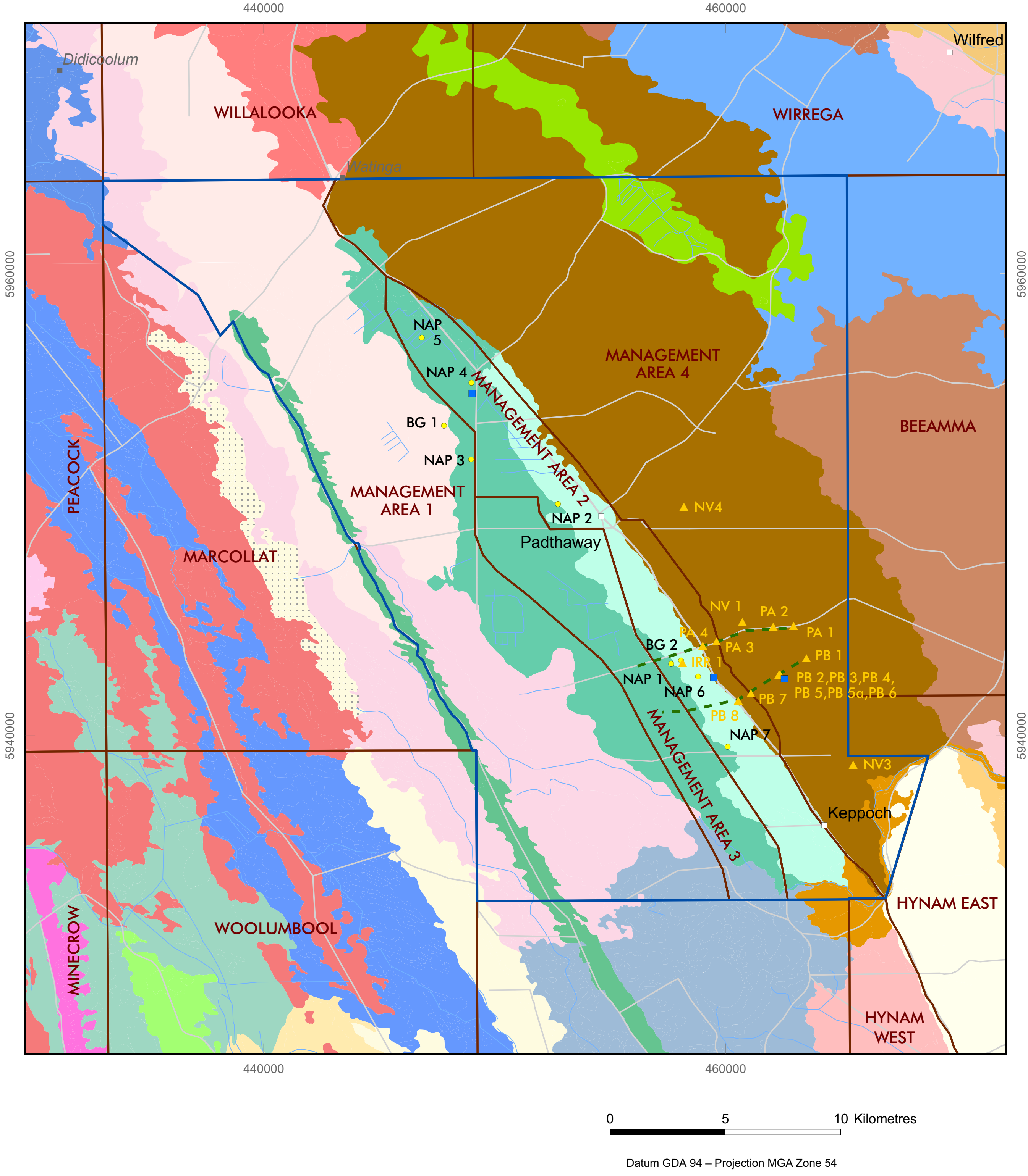
Deep sandy soils (>1 m) overlaying red to yellow clay cover the western slope of the Naracoorte Ranges. Towards the west of the Riddoch Highway, the soil unit consists of sand over clay duplex soils at the base of the range (Wetherby and Armstrong,1978). The clay is usually mottled with a predominately olive grey colour and occurs at a depth of 10 to 30 cm (Wetherby and Armstrong,1978).

The largest unit comprises of a red or Terra Rossa soil which lies between the Riddoch Highway and Grubb Road. Instrumentation sites NAP 6 and 7 are situated within this unit. The profile generally consists of duplex brown sand to loam, overlying a red brown clay at a depth of 20 to 40 cm. Generally, soft marly limestone exists below this depth, with hard rubblier limestone becoming present towards the west. Soils along the east of Grubb Road (NAP 1) and south west of the Padthaway Township are generally duplex with a mottled grey-brown medium clay sub soil (Wetherby and Armstrong,1978). The topsoil is generally 30 cm deep and overlays a hard calcrete topped limestone. Towards the northwest (in the vicinity of NAP 3, 4 and 5) soils become shallower (< 30 cm deep), consisting of a sandy loam to light clay at the surface, followed by a dark brown to black clay over a rubbly calcrete topped limestone. The calcrete layer is the dominant controlling factor limiting the suitability of the soil for irrigation purposes. Soil logs from drill holes and excavation pits for each site are presented in Appendix One.

3.5 GROUNDWATER USE AND CURRENT GROUNDWATER MANAGEMENT

The Padthaway PWA was proclaimed in 1976 following concerns that increased irrigation activity may lower the water table. The original water licenses were issued on the basis of established irrigation activity or proposed development. As there was no assessment of sustainable water use in the Padthaway PWA, allocations were simply capped at 35 083 ML.

Five water management areas (Management Areas 1, 2a, 2b, 3 and 4) were created within the Padthaway PWA following the introduction of water transfer policy in 1994, but these were never formally recognised. Management areas 2A and 2B were eventually combined to form groundwater management zones that have been formally adopted for the PWA (Fig. 5). The capacity of the groundwater resource to meet demands has historically been evaluated by calculating Permissible Annual Volumes (PAVs) and Volumes for Licensed Allocation (VLAs) for each of these Management Zones. These are outlined in the Water Allocation Plan for the Padthaway Prescribed Wells Area (2001) and are described below:



Padthaway Prescribed Wells Area

Unconfined groundwater management zone

NAP and CSIRO sites

Drillholes

Geophysical transect

Rain gauge – stable isotopes

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SALT ACCESSIONS TO THE PADTHAWAY IRRIGATION AREA

SOIL TYPE AND INSTRUMENT LOCATION PLAN

June 2004

Figure 8

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- PAVs are estimated based on average annual vertical recharge to the aquifer, i.e.

  PAV for a management area (ML/y) = (sum of (A_n x R_n)) x S_f

  Where:

  - A_n is the land area (km^2) of a defined recharge region within the management area.
  - R_n is the annual average vertical recharge rate (mm/y) of the defined recharge region A_n.
  - S_f is the salinity factor adopted for the management area. This factor is a proportional reduction applied to recharge, where extraction of 100% of recharge would lead to unacceptable salinity impacts.
- The VLA for the unconfined aquifer in each management area is calculated as follows:

  VLA (ML/y) = PAV – (provisions for the effects of forestry on recharge and stock, domestic and environmental demands) – (10% buffer in areas that are not fully allocated and do not become fully allocated as a result of the buffer).

The average annual recharge rate below cleared agricultural land was estimated for each management area by the (then) Department for Water Resources in 1994. Each management area was classified according to soil type, morphology and hydrogeological conditions. These recharge zones were further subdivided according to soil depth, depth to water and vegetation cover. The upper and lower recharge limits for these recharge zones were determined from various seasonal hydrograph responses. The lower limits were adopted for the PAVs for each management area. The upper and lower recharge limits for each management area are shown in Table 1 and the PAVs and VLAs estimated based on the lower values are compared with the total licensed allocations at 2001 in Table 2.

Table 1. Estimated upper and lower limits for vertical recharge for each management area in the Padthaway PWA

Recharge Rate (mm/y)	Management Area 1	Management Area 2A	Management Area 2B	Management Area 3	Management Area 4
Lower Limit	66	90	50	58	21
Upper Limit	90	105	62	66	35

Table 2. PAVs, VLAs and Total Licensed Allocations for the unconfined aquifer in each management area of the Padthaway PWA

Management Area	PAV (ML/y)	VLA (ML/y)	Total Licenced Allocation (2001)
1	15 774	14 019	12 415
2	5 960	5 960	15 675
3	2 900	2 859	3 807
4	6 678	5 774	3 216
Total	31 312	28 613	35 113

Table 2 shows that, in 2001, total licensed allocations exceeded both the VLA and PAV for the Padthaway PWA, with the over allocated areas being management areas 2 and 3. However, as the PAVs and VLAs have been estimated based on minimal understanding of the hydrogeology of the unconfined aquifer in the PWA and the mechanisms of salt movement through the groundwater system, this needs to be revised.

4. APPROACH

4.1 PROJECT COMPONENTS

The project was divided into five components as described below. For planning purposes, these are being undertaken in two phases, with each phase incorporating work on the five components as appropriate. The Phases are:

- Phase 1 (January 2003 to April 2004): Includes work under Components 1–3 and involves the establishment of sites for field trials including drilling, installation of instrumentation and the commencement of data collection from the beginning of the 2003–2004 irrigation season. This report describes the results of Phase 1, which will then be used to refine the methodology for Phase 2.
- Phase 2 (July 2004 to September 2005): Continued data collection from sites established during Phase 1 and completion of Components 1–3. Additional sites may be added, depending on the results from Phase 1. Results of Components 1–3 will be combined into salt and water budgets for the region (Component 4) and used to assess groundwater resource sustainability, formulate water management options and establish long term monitoring requirements (Component 5).

4.1.1 COMPONENT 1: MAGNITUDES AND TIME SCALES OF SALT ACCESSIONS FROM THE NARACOORTE RANGES

- Quantify the amount of salt stored in the Naracoorte Ranges.
- Quantify recharge rates in the Naracoorte Ranges under the various land-uses that occur there.
- Determine the potential for increased movement of salt to the water table due to increased recharge under cleared and irrigated areas.
- Determine the flowpaths and time scales for this salt to move from the Naracoorte Ranges to the main Padthaway Irrigation Area.
- Completion report due September 2005.

4.1.2 COMPONENT 2: ESTIMATION OF DEEP DRAINAGE OF MOISTURE AND SALT BELOW IRRIGATED VINEYARDS AT PADTHAWAY

- This component is being carried out under a Consultancy Agreement with CSIRO. The following details are derived from the Services Specification provided to DWLBC by CSIRO.
- Point measurement of water and salt fluxes beneath the root zone at 2 vineyard sites where there is less variation in soil type across the vineyard. Within each vineyard, a sensor will be placed beneath the vine-row and in the inter-row.
- Direct measurements of vineyard-scale evapotranspiration (water use) at 3–4 vineyard sites, using a mobile flux station.

- Calibrated and validated models of vineyard and crop evapotranspiration to enable the above measurements to be extrapolated across the Padthaway region using meteorological data acquired from 4 climate stations.
- Quantified estimates of the water use efficiency of the irrigated vineyards – especially how much water is lost through evaporation and drainage.
- Completion September 2005.

4.1.3 COMPONENT 3: ESTIMATION OF DEEP DRAINAGE OF MOISTURE AND SALT UNDER VARIOUS IRRIGATION AND SOIL TYPES AT PADTHAWAY

- Follows on from Component 2 by expanding the study of water and salt fluxes below vineyards to other types of irrigation practices in the area.
- Estimate crop water use and salt / water balances below different irrigation and crop types, including flood and centre pivot irrigated seed crops and drip irrigated grapevines on different soil types.
- Measurement of water application rates and patterns via flow meters installed on bores and using surface hydrological techniques (for flood irrigation).
- Estimation of evapotranspiration and hence drainage of salt and water to the water table using a combination of soil tensiometers, capacitance probes, neutron moisture meters, salinity probes and piezometers installed just below the water table.
- The utilization of a combination of instruments at each site provides for comparison between techniques and a higher level of confidence in the estimates of drainage fluxes to the water table.
- Location of a piezometer and suction lysimeters at two of the vineyard sites allows correlation between data collected using the methodology for Component 4 and that applied at the other irrigated sites.
- Completion September 2005.

4.1.4 COMPONENT 4: DEVELOPMENT OF WATER AND SALT BALANCES FOR THE PADTHAWAY IRRIGATION AREA

- Incorporation of the information gained from Components 1–3 above into a salt and water balance for the shallow groundwater system at Padthaway. This will culminate in the development of an analytical or numerical groundwater model capable of predicting the impacts of proposed management scenarios on groundwater quality and availability. This will be addressed in Volume Three: Conceptual Models.
- Completion September 2005.

4.1.5 COMPONENT 5: DEVELOPMENT OF MANAGEMENT POLICIES

- Use of the model to assist with determining the sustainable extraction limit for the areas of concentrated irrigation activity and the region as a whole. The sustainable extraction limit should result in stable groundwater salinity in the long-term, and allow unimpeded aquifer throughflow.

- Identification of management options for the region and prediction of the impacts of these management options on groundwater levels and salinity.
- Evaluation of the current monitoring network to ensure that it meets future requirements.
- This component was originally due to be completed in September, 2005. However, whilst recommendations for management options will be made by this date, a three-dimensional numerical model will be developed following completion of this project, with results and further recommendations due in October, 2006.

5. METHODOLOGY

5.1 COMPONENT 1: MAGNITUDES AND TIME SCALES OF SALT ACCESSIONS FROM THE NARACOORTE RANGES

5.1.1 BACKGROUND AND APPROACH

Rainfall recharge to water table aquifers in the semi-arid regions of south east Australia prior to European settlement was negligible (<0.2 mm/year), (Allison and Hughes, 1983; Allison et al., 1990). This was due in the main to a dry climate and the high water requirements of the predominantly deep-rooted native vegetation. Whilst rainfall has been relatively low over the past 20 000 years, small quantities of salt present in rainfall can over time accumulate in the unsaturated zone such that the salt store is in excess of seawater concentrations (Leaney and Herczeg, 1999). Following the clearance of native vegetation ~100 years ago recharge to the aquifer has increased between one and two orders of magnitude. The salt load once stored in the soil profile is now in the process of draining through the unsaturated zone (or may have already reached the water table) due to the increased recharge. The rate at which the salt moves vertically through the unsaturated zone depends on the hydraulic properties of the zone and rainfall.

5.1.2 MODELLING OF THE CHLORIDE FRONT IN THE UNSATURATED ZONE TO ESTIMATE RECHARGE

Drill cores taken from the unsaturated zone beneath different types of land use and soil type were used to locate the chloride (salt) peak. Chloride, a dissolved anion of salt, is preferred as a measure of salinity as it behaves conservatively within the groundwater system. A mathematical model is then applied to the profile to predict how long it will take for the chloride peak to reach the water table. These results can then be applied to soil clay maps to produce a spatial picture of changes in groundwater salinity in the aquifer over time.

5.1.3 SITE SELECTION

The first phase of drilling in the Naracoorte Ranges was carried out in March, 2003. Drilling at the irrigated site IRR2 was carried out in June 2003 to minimise the inconvenience to the owner. Sites for unsaturated zone soil profile sampling and piezometer installation were chosen to include the range of soil types and land uses that occur in the Naracoorte Ranges. The land uses include:

- Native vegetation (representing conservation areas, as well as providing information on initial (pre-clearing) conditions).
- Cleared dryland agriculture.
- Irrigated lucerne.
- Pine plantations.

The soil types that occur in the Naracoorte Ranges are shown in Figure 8. In order to properly investigate groundwater salinisation along flow paths, the sites were orientated along two flow lines from the Ranges towards the main Padthaway Irrigation Area. These are designated Transect A and Transect B (Fig. 8).

Unsaturated zone soil profile samples were collected, and one piezometer installed with a screen 1–2 m below the water table at each of the sites. These screen depths were selected as the effects of groundwater salinisation are expected to be most obvious just below the water table.

As the development of comprehensive water and salt balances and reliable groundwater flow and solute transport models require information on groundwater salinity and flow at different depths in the aquifer, it was proposed to drill one hole throughout each of (a) the Bridgewater Formation below the Naracoorte Ranges and (b) the Padthaway Formation below the main irrigation area. These holes were left open to allow tests such as borehole geophysics, tracer profiling and point dilution to be carried out, providing valuable information on preferential groundwater flow through the carbonaceous aquifers.

5.1.4 SOIL SAMPLING / CORE COLLECTION, PIEZOMETER INSTALLATION, AND METHOD OF ANALYSIS

Soil cores were collected throughout the unsaturated zone and just below the water table at each site, using hollow augers and a split-tube wire line recovery technique mounted on an Investigator rig. It was necessary to collect the samples without the use of air or any other drilling fluids to prevent drying of the samples or addition of water, which would affect the water contents and pore water chloride results. Drilling was contracted to Drilling Solutions (SA) Pty Ltd. and a DWLBC employee was on-site at all to recover samples.

The core samples were split length-wise, with one half being well-mixed and placed in 500 ml screw top glass food jars for soil physical properties and pore water chloride analyses and the other half was retained as a continuous core sample. Samples were collected at 0.5 m intervals to a depth of 10 m and at 1 m intervals below this. On a few occasions (i.e. sites PA3, PB7 and NV1), sampling was stopped at the maximum depth limit for the hollow augers (~26 m), despite the fact that the water table had not yet been reached, and drilling continued to the water table using air.

5.1.4.1 Saturated zone core collection

As the Bridgewater Formation consists predominantly of unconsolidated sands it would be impossible to leave a drillhole open in that aquifer. It was therefore decided to construct a nest of piezometers (piezometers PB2, PB3, PB4, PB5 and PB6; see Fig. 8), sampling groundwater at various depths, as an alternative to the open hole in the Naracoorte Ranges. One hole (site PB5) was continuously cored to 50 m depth into the Gambier Limestone aquifer. Unsaturated zone soil samples were collected to a depth of 16 m as described above. Diamond coring with mud was then used to retrieve continuous core throughout the saturated zone of the shallow unconfined aquifer and into the underlying Gambier Limestone. The lithostratigraphic log of this core, in conjunction with geophysical logs (natural gamma and neutron), was then used as a basis for selecting the screen depths of the nested piezometers at this site.

5.1.4.2 Piezometer installation

Piezometers were installed 1–2 m below the water table in the cored holes at each of the unsaturated zone sampling sites. In some cases, the holes required additional air drilling to the correct depths as they had partially collapsed, or the water table was below the depth limit of the hollow augers, as described above.

The nest of piezometers (PB2, PB3, PB4, PB5, PB6) was installed by rotary mud drilling adjacent the location of the deep core collected throughout the shallow unconfined aquifer (site PB5). The original deep hole had collapsed too much to allow proper installation of a piezometer, so a new deep hole (PB5a) was mud-drilled 40 m up-gradient and both holes were geophysically logged (gamma and neutron) to compare lithology between the two sites. The screen depths of the shallower piezometers (PB2, PB3, PB4, PB6) were then selected based on the geological and geophysical logs of the two deep holes.

All piezometers were constructed using 50 mm Class 12 PVC pipe with slotted screens across the desired depth intervals. The areas around the screens were packed with 3 mm gravel and bentonite seals were added above this, before the holes were backfilled with drill cuttings (see geological logs in App. A). With the exception of the topmost hole, the holes for the nested piezometers were additionally grouted with a layer of cement at least 5 m thick above the bentonite before being backfilled to prevent cross contamination via dissolution features in the carbonaceous aquifer. For the cored holes, filter sock was placed around the piezometer screens to prevent the entry of fine sand.

An 8” diameter hole (IRR1) was air-drilled throughout the Padthaway Formation in the main irrigation area and was able to be left open with only a small amount of collapse (see Fig. 8 for location).

Drillhole locations and construction details are summarised in Table 3.

5.1.4.3 Method of analysis for soil physical properties

The unsaturated zone soil samples were analysed for gravimetric water content, particle size, matric suction and pore water chloride concentration at the CSIRO Land and Water, Adelaide laboratory.

The water contents of the samples were obtained gravimetrically by oven drying the samples overnight at 105°C and measuring the wet and dry weights.

Chloride analyses of the sediment pore water samples were carried out on solutions of 10 g of sediment in 50 g of deionised water. These were analysed by a first-derivative potentiometric endpoint titration with $AgNO_3$ using an ORION Model 960 Autotitrator. The $AgNO_3$ titrant was standardised with a 1000 ppm chloride standard solution and the sample volume used was 1 ml. Uncertainty for this method determined by replicating standards is ± 3%. Chloride measurements were then corrected for the dilution factor and water content.

Particle size analyses were carried out on selected sediment samples following the method of Lewis (1983).

Table 3. Piezometer locations and construction details

Obs. no.	Permit no.	Description	Easting	Northing	Ground Elev (m AHD)	Geological unit	Final depth (m)	Production zone (m)
PA1	61229	Cleared valley. Some trees	462942	5944764	51.461	Bridgewater	12.0	9.5–11.5
PA2	61285		462068	5944738	51.038	Bridgewater	15.0	11.6–13.6
PA3	61233		459614	5944090	74.068	Bridgewater	50.0	44.0–46.0
PA4	61234		459021	5943906	49.614	Bridgewater	21.5	17.75–19.75
PB1	61230	Cleared valley. No trees. Pines nearby	463504	5943355	50.981	Bridgewater	12.5	9.0–12.0
PB2	61240		462360	5942661	57.199	Bridgewater	40.0	37.0–39.0
PB3	61239		462364	5942657	56.707	Bridgewater	35.0	26.5–29.5
PB4	61237		462355	5942652	56.669	Bridgewater	22.0	19.0–21.0
PB5	61235		462294	5942630	56.037	Gambier	50.0	41.0–44.0
PB5a	61232		462337	5942646	55.053	Gambier	48.0	41.0–44.0
PB6	61236		462342	5942654	55.997	Bridgewater	20.0	16.0–18.0
PB7	61231		461108	5941845	68.43	Bridgewater	45.0	35.0–37.0
PB8	61241		460552	5941536	45.813	Bridgewater	16.0	12.5–14.5
NV1	64243	Uncleared native vegetation	460736	5944934	64.541	Bridgewater	30.0	25.0–27.0
IRR1	61242	Irrigated vineyard on flats	458137	5943169	-	Padthaway	23.0	Open hole
NV 3	106184	Uncleared native vegetation	465526	5938756	-	Bridgewater	24	Backfilled
NV 4	106183	Uncleared native vegetation	458203	5949925	-	Bridgewater	16	Backfilled

5.1.5 GROUNDWATER SAMPLING AND METHOD OF ANALYSIS

5.1.5.1 Sample collection

Groundwater samples were collected from the newly installed piezometers and a range of existing observation wells in April 2003, using a Grundfos MP1 submersibile pump. Water levels were measured using a water level meter prior to pumping. The piezometers / observation wells were then pumped until 3 bore volumes had been purged and readings of pH, temperature and EC had become stable.

Analyses of the groundwater samples for electrical conductivity (EC), pH, temperature, dissolved oxygen content and redox potential were carried out in the field using a portable TPS 90 FLMV temperature-pH-salinity meter (T.P.S. Pty Ltd). Field measurements of alkalinity were made using a hach® field titration kit, using 1.6 m H_2SO_4 to a pH 4.3 fixed end-point. 125 ml aliquots of water for major cation and anion analyses were filtered through a 0.45 μm membrane and pre-filter and those for cation analysis were acidified with HNO_3 before being stored in 50 or 100 ml polyethylene bottles. Separate, un-filtered samples were taken for δ^2H and δ^{18}O analysis and stored upside-down in 30 ml glass McCartney bottles with rubber sealed caps.

5.1.5.2 Method of major ion analysis

Major ion analyses of groundwater samples were carried out at the ALS, Melbourne laboratory. Here, Na, K, Mg, Ca and S were analysed by ICP-ES with a precision of ± 2% and Br was analysed by ion chromatography using a UV detector with a precision of ± 5%.

5.1.5.3 Method of stable isotopes, δ^2H AND δ^{18}O analysis

Groundwater samples for δ^2H and δ^{18}O analyses were analysed using a Europa Scientific Ltd. GEO 20-20 dual inlet gas ratio mass spectrometer. Water samples for oxygen-18 analyses were first equilibrated with CO_2 of known isotopic composition (Socki et al., 1992) and δ^{18}O‰ was determined by mass spectrometry of the equilibrated CO_2 gas with a precision of ± 0.1‰. Results are expressed as δ^{18}O (^{18}O/^{16}O) in 'per mil' (‰) as a deviation from the standard, Vienna Standard Mean Ocean Water (V-SMOW), where:

$$\delta^{18}O‰ = \frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{V\text{-}SMOW}}{(^{18}O/^{16}O)_{V\text{-}SMOW}} \times 1000$$

For analysis of δ^2H, 20 μL of sample was reduced to hydrogen gas by circulating it as vapour across hot uranium at 810°C. This was then introduced into the mass spectrometer. Results are expressed as δ^2H (^{2}H/^{1}H) in 'per mil' (‰) relative to V-SMOW, where:

$$\delta^2H‰ = \frac{(^2H/H)_{sample} - (^2H/H)_{V\text{-}SMOW}}{(^2H/H)_{V\text{-}SMOW}} \times 1000$$

Including errors induced by the azeotropic distillation, the overall precision of the oxygen-18 and deuterium analyses are ± 0.1 ‰ and ± 1 ‰ respectively.

5.1.6 BOREHOLE LOGGING AND SURFACE GEOPHYSICS

Geophysical logging surveys were carried out on the two deep holes at the nested piezometer site (PB5 and PB5a) and on the open hole in the main irrigation area (IRR1). As the holes at PB5 and PB5a needed to be cased immediately after drilling to prevent collapse, only natural gamma and neutron logs were carried out on these. A full suite of logs was carried out on the open hole, IRR1, including: caliper, natural gamma, neutron, density, induction, point resistance, spontaneous potential, temperature, pH, EC and borehole TV.

During June 2004 Zonge Engineering conducted a NanoTEM survey to map groundwater across the fault. Two transects (5.4 km each) were carried out from the Naracoorte Ranges down onto the Padthaway flat (Fig. 8). The data will be corrected for height elevation to provide a profile of the water table and its conductance (salinity) at varying depths across the fault.

5.2 COMPONENT 2: ESTIMATION OF DEEP DRAINAGE OF MOISTURE AND SALT BELOW IRRIGATED VINEYARDS AT PADTHAWAY

5.2.1 BACKGROUND AND APPROACH

The soil zone in the main irrigation area is relatively thin ranging between ~0.3 to ~2 m. While the soil thickness varies, it generally thins from east to west, forming a wedge shaped profile between the base of the Ranges and Grubb Road. The soils overlie the Padthaway Formation that commonly has a hard 2–5 cm thick calcrete surface. This surface has been ‘ripped’ beneath a number of the vineyards to increase drainage to the aquifer. Given the shallow and variable thickness of the soil zone, and the heterogenous properties of the underlying geology, the best method to estimate recharge beneath the vines was therefore considered to be by applying a one-dimensional mass balance model to the water and salt budgets. The Atmospheric Research Branch of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), were engaged to accurately measure the micrometeorology at each of the viticulture sites. The locations of the four viticulture sites are displayed on Figure 9.

The major advantage of using this particular approach to estimate the water balance was that it was calculated on a vineyard scale. It therefore does not have the limitations of techniques such as lysimeters that adopt a point scale approach to estimate deep drainage. Point scale methods inevitably lead to increased uncertainty during the scaling up process.

A second method of estimating deep drainage was by using drainage meters. A drainage meter is an in-situ tool used to monitor sub-surface soil water potential, hydraulic gradient and deep drainage. It is discussed further in the Drainage Measurements section.

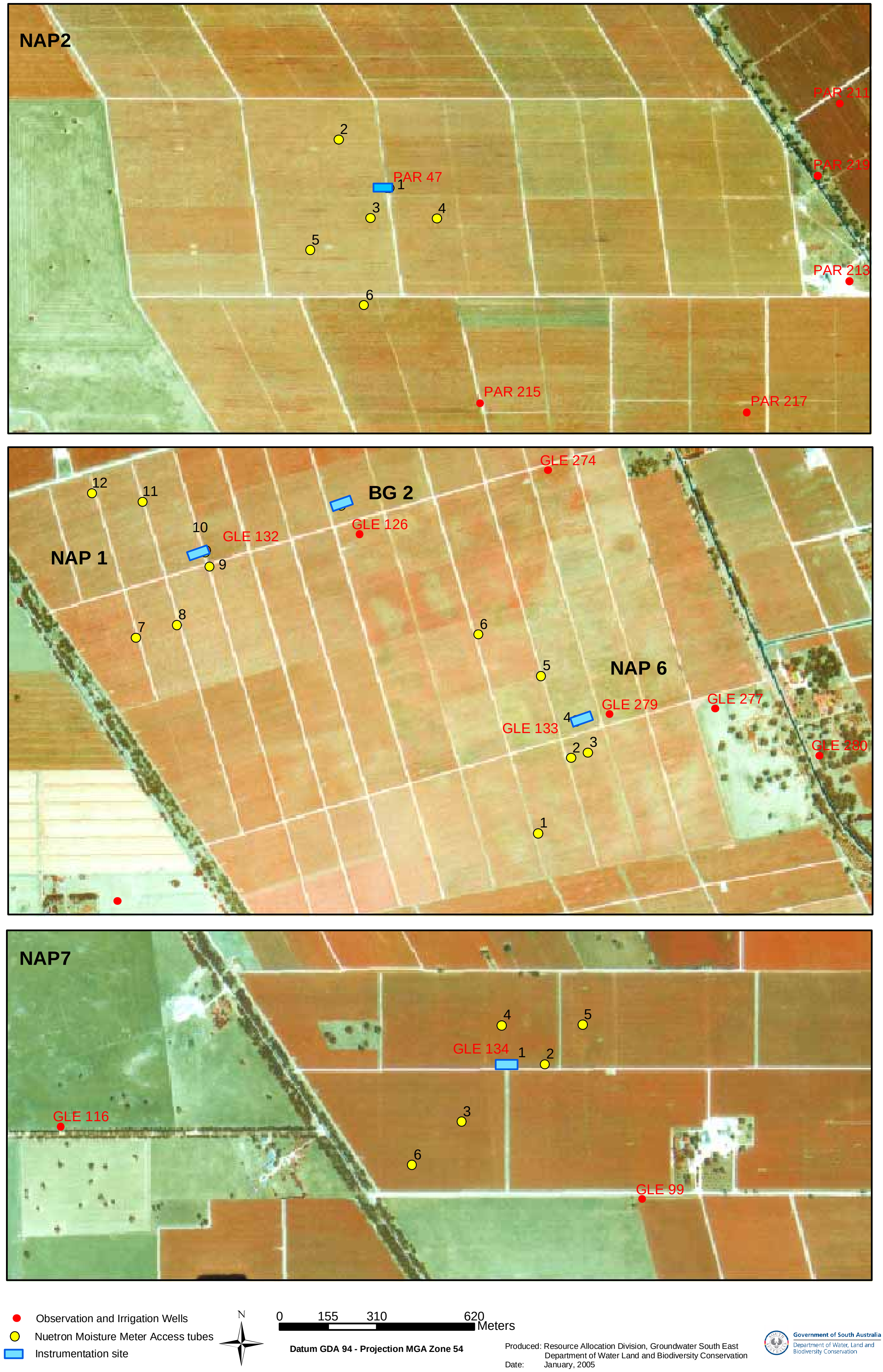


Figure 9. Site Plan at Vineyard Sites

5.2.2 WATER AND SALT BALANCE TO ESTIMATE RECHARGE

The components that make up the water and salt mass balances are as follows:

Water Mass Balance $P + I = ET + D + \Delta S$

Where *P* (rainfall) and *I* (irrigation) are the input components of the water balance, *ET* is the water lost via evapotranspiration from the soil and plants. *ΔS* is the change in stored soil water in the root zone. All are measurable allowing the drainage flux *D* to be estimated as a residual.

When each of these components is multiplied by a concentration C of salt that it contains it is possible to determine the salt balance in the same way.

Salt Mass Balance $C_pP + C_iI = C_{et}ET + C_dD + C_{\Delta S}\Delta S$

In the absence of measurements of *ΔS*, a daily soil water balance can also be calculated using theoretical values for available soil moisture storage following the *Penman-Grindley* approach (Penman, 1948, 1949, 1950; Grindley 1967, 1969). Here drainage is viewed as a function of effective rainfall and irrigation (P + I – ET) and recharge takes place only when the soil moisture deficit (SMD) is zero (Rushton and Redshaw 1979). In a heterogeneous environment, such as the soils at Padthaway, drainage may occur when SMD > 0 through preferential flow. Therefore, applying the Penman-Grindley method to a heterogenous soil profile may lead to an underestimation of drainage.

5.2.2.1 Site selection and micrometerological measurements

The largest output component in the water balance is evapotranspiration. A flux station and 4 automatic weather stations (AWS) were constructed from April – June, 2003 and installed at Padthaway from July 3 – July 5, 2003 to provide accurate spatially averaged evaporation data (Fig. 10). The sites used were as follows:

NAP 2 (Reisling):	AWS 1
NAP 6 (Shiraz):	AWS 2
NAP 1 (Reisling/chardonnay):	AWS 3 and Flux Station
NAP 7:	AWS 4

In addition to rainfall, temperature, humidity and wind measurements, two of the AWS sites (NAP 1 and NAP 7) have been equipped with sensors to record irrigation events (time on/ time off); and soil moisture content (EnviroSMART sensors) in the vine row and mid-row. The soil sensors and pressure switches were installed in August 2003 and are logged on the AWS datalogger.

All AWS data are telemetered to CSIROs Pye Laboratory daily; quality-checked and archived. A system to facilitate access to these data by the project partners (DWLBC, PGGA, SEWCMB) is currently being developed.


(a)


(b)

Figure 10. (a) CSIRO Climate station at NAP 1, NAP 2, NAP 6 and NAP 7; (b) CSIRO Flux Station at NAP 6 (2003–04) and NAP 6 (2004–05)

5.2.2.2 Soil moisture measurements – neutron moisture meter

Changes in soil moisture (*ΔS*) in the unsaturated zone were measured using a neutron moisture meter (NMM). DWLBC staff supervised the drilling of 48 neutron holes during July 2003 at vineyard sites NAP 1, 2, 6 and 7. Twelve 75 mm diameter holes to the depth of 4 m were drilled at each site, 6 directly under the vine row and 6 in the inter row. CSIRO installed 50 mm diameter aluminium access tubes during August 2003. The presence of a gap between the soil and the neutron probe access tube, filled with either air or water, inevitably introduces a systematic error in neutron probe readings. To avoid this, a 'slurry' mixture consisting of kaolin, cement and water was poured down the hole before the tubes were inserted. The cavity volume of each hole varied, with some holes requiring more slurry than others.

The locations of the neutron access tubes are shown on Figure 9. Bulk soil samples were taken and analysed by PIRSA-Rural Solutions for soil moisture salinity and pH. These are read fortnightly (by DWLBC staff) between bud-burst and leaf-fall and monthly during winter. These data will provide high precision estimations of changes in the volumetric water content (*ΔS*) in the root zone that are needed for interpretation of the water balance.

5.2.3 DRAINAGE METER APPROACH TO ESTIMATE RECHARGE

5.2.3.1 Drainage measurements

Installation of drainage meters was delayed until the second year of the project, as a result of the analyses of the NMM data from Orlando Wyndham (NAP 7) that showed evidence of root activity at 1 m. The data from BRL Hardy (NAP 6 and NAP 1) – although more noisy – also showed large seasonal changes in soil water content at 1 m depth that can only be explained by root activity. The NMM data from the 2003–04 growing season (2003–04) was analysed to determine more precisely the extent of the root zone before the drainage meters are installed.

During December 2004, two drainage meters were installed at NAP 6 (Fig. 11) and NAP 7 (1 in the vine row and 1 in the inter row). The drainage meters were installed in uniform marly clay (Padthaway Formation) at an interval of 2 to 3 m below the ground surface. Once drainage (*D*) is calculated samples taken from the meter and lysimeters are analysed for salt content (*C*) and a salt flux is determined as follows:

Salt Flux $$M_c = C_d D + \frac{dc}{dz} D$$

Where M_c is the salt flux to the water table, D is deep drainage, C_d is the soil moisture concentration below the root zone, dc/dz is any change in concentration in salt load in the profile over the sample period.

Drainage measurements obtained from the drainage meter will be compared to the drainage value determined from the water and salt mass balance approach.

Figure 11. Installation of a drainage meter at NAP 6

5.3 COMPONENT 3: ESTIMATION OF DEEP DRAINAGE OF MOISTURE AND SALT UNDER VARIOUS IRRIGATION AND SOIL TYPES AT PADTHAWAY

5.3.1 BACKGROUND AND APPROACH

A similar approach used to determine the water and salt mass balance under drip irrigation for the grape vines was adopted to estimate deep drainage under flood and center pivot irrigation. Chloride mass balance and stable isotopes δ^2H and δ^{18}O, will also be used to estimate drainage and evaporation under a number of irrigation practices (flood, drip and centre pivot). The drainage and evaporation values will be compared to those measured via the above methods and will be used in the water balance.

5.3.2 CHLORIDE AND STABLE ISOTOPES δ^2H AND δ^{18}O MASS BALANCE TO ESTIMATE RECHARGE

The chloride mass balance method uses the change in concentration of chloride in the soil profile over time to estimate deep drainage that ultimately leads to recharge. Chloride is dissolved anion of salt and is concentrated in the soil profile due to evaporation. The change in concentration of chloride (*Cl*) input through rainfall and irrigation equals the amount chloride reaching the water table plus the addition of chloride contributed from the evaporation process (and possibly from chloride stored in the soil profile). For the method to be valid the system must be in steady state, otherwise a transient model such as SODICS of Rose *et al* 1979 should be considered.

The following equations can therefore be used to estimate deep drainage:

$$C_t = (P_{cp} + I_{ci}) / (P + I)$$

$$D = (P+I) X C_t / C_c$$

Where C_t is the average chloride concentration of precipitation (P_{cp}) and irrigation (I_{ci}) and C_c is the average chloride concentration of soil water below the root zone.

The comparison of the stable isotopic composition of precipitation, irrigation and soil moisture can be used to estimate evaporation rates. Measurement of changes in the stable isotopic signature of water is one technique that has been successfully used in the quantification of evaporation in a number of settings (Gat 1981 and Simpson *et al.,* 1992). Evaporation leads to an enrichment in water molecules with heavier isotopes (δ^2H and δ^{18}O) because of preferential loss to the atmosphere of water molecules consisting of only lighter isotopes (δ^1H and δ^{16}O). In contrast, transpiration does not result in any fractionation, allowing the two processes to be separated out in the water balance. By monitoring the changes in isotopic signature and corresponding chloride concentration (as a proxy for salinity) of irrigation water and return flow (soil water) at different stages during the irrigation delivery, we can gain an understanding of the amount of irrigation water evaporated.

The above methods involve the chemical sampling of precipitation, irrigation water, soil water and groundwater for chloride and stable isotopes δ^2H and δ^{18}O throughout the year.

5.3.3 SITE SELECTION

Seven sites have been established with detailed monitoring equipment in the main Padthaway Flats irrigation area to determine salt accession through the soil profile under different irrigation practices and soil types (see Fig. 8 for locations). These consist of one centre pivot site (NAP 3), two flood irrigation sites (NAP 4 and 5), and four irrigated vineyard sites (NAP 1, 2, 6 and 7). In addition, two background sites, BG 1 and BG 2, were sited in cleared, non-irrigated areas near NAP 3 and NAP 5 (see Fig. 8 for locations). A summary of the instrumentation located at each site is presented in Table 4. Figures 9 and 12 show the location of the instrumentation at the vineyard, centre pivot and flood irrigation study areas and Figure 13 displays an established vineyard and flood instrumentation site.

5.3.4 SAMPLING / CORE COLLECTION AND PIEZOMETER INSTALLATION

5.3.4.1 Piezometer installation and soil sample collection

Piezometers were installed at each site during June 2003. At the centre pivot and flood irrigation sites, holes were drilled with hollow augers mounted on an Investigator rig. A split-tube wire line recovery technique was used to collect core samples for water content, particle size and pore water chloride analyses, as described for Component 1 above. At the four vineyard sites, piezometers were installed directly under the vine row, as shown in Figure 9, using rotary hammer with air circulation. No core samples were collected at these sites due to inaccessibility of the vine rows to the Investigator rig. All holes were completed with 50 mm class 12 PVC piezometers screened just below the water table at depths ranging from 3 m to 10 m. Gravel was packed around the screened interval, and overlayed with a bentonite seal, before being cemented to the surface. Well construction reports and geological logs are presented in Appendix A. A continuous groundwater level recorder has been installed in each piezometer, and is connected directly to the Agrilink telemetry units.

Groundwater samples are being pumped from the piezometers at all sites and analysed for chloride monthly and HCO_3, Ca, K, Mg, Na, S, Br and NO_3 at random time intervals during the year.

5.3.4.2 Precipitation and irrigation application measurements

Agrilink Holdings Pty Ltd installed rain gauges at all sites during June 2003. Irrigation sites NAP 3 (centre pivot), NAP 2 and NAP 6 are equipped with 2 rain gauges per site. At irrigation site NAP 3 two rain gauges are used to measure sprinkler discharge from each rotation of the centre pivot (Fig. 14a) and at irrigation sites NAP 2 and NAP 6 a rain gauge has been placed under the dripper line to measure discharge.

Rain capturing devices were installed near NAP 6, NAP 4 and in the Naracoorte Ranges (refer to Fig. 8 for locations). The rain gauges are sampled monthly for δ^2H and $\delta^{18}O$ and chloride. To reduce evaporation, 200 ml of paraffin wax is added to the capturing container each time a sample is collected.

Shaft encoders to measure actual flows onto the flood irrigation bays at the two flood irrigation sites (NAP 4 and 5) were installed by DWLBC staff during September 2003. At both sites, a concrete base and small “flow straightening” walls were constructed immediately upstream and downstream of the sluice gate (Fig. 14b). The water level is then measured via a float well and shaft encoder with data being fed into the existing Agrilink telemetry network. Field gauging was undertaken in November 2003 to establish a relationship between the water level and the corresponding discharge.

Irrigators are obtaining water samples from irrigation bores at all sites monthly throughout the irrigation season. Water samples are being analysed for Cl, Br, P, K, Na, Mg N, SO_4 and HCO_3.

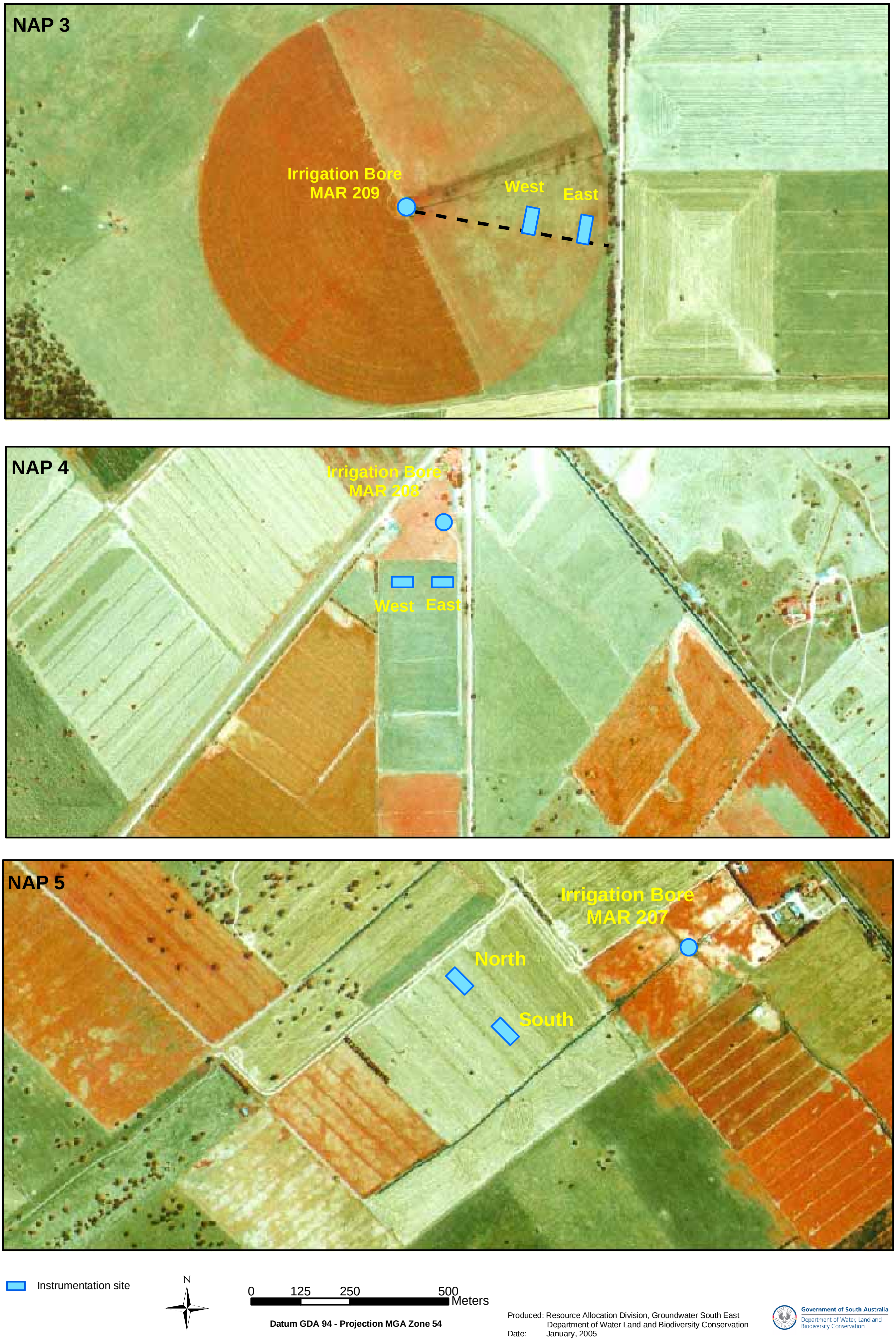
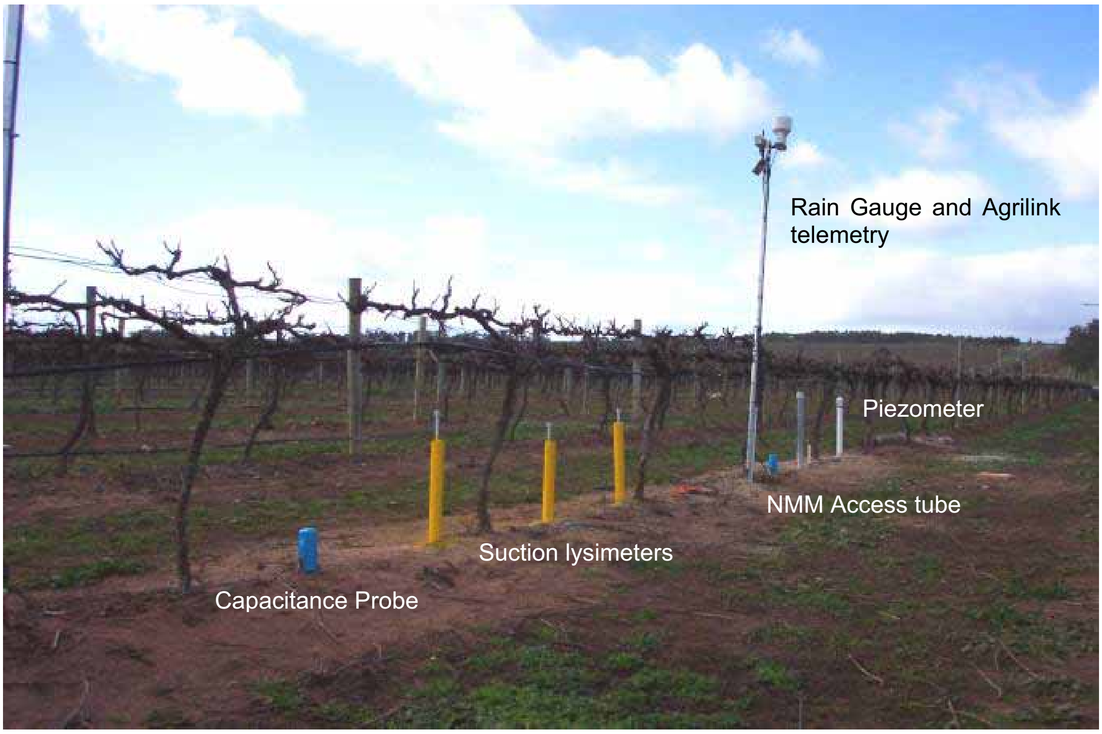
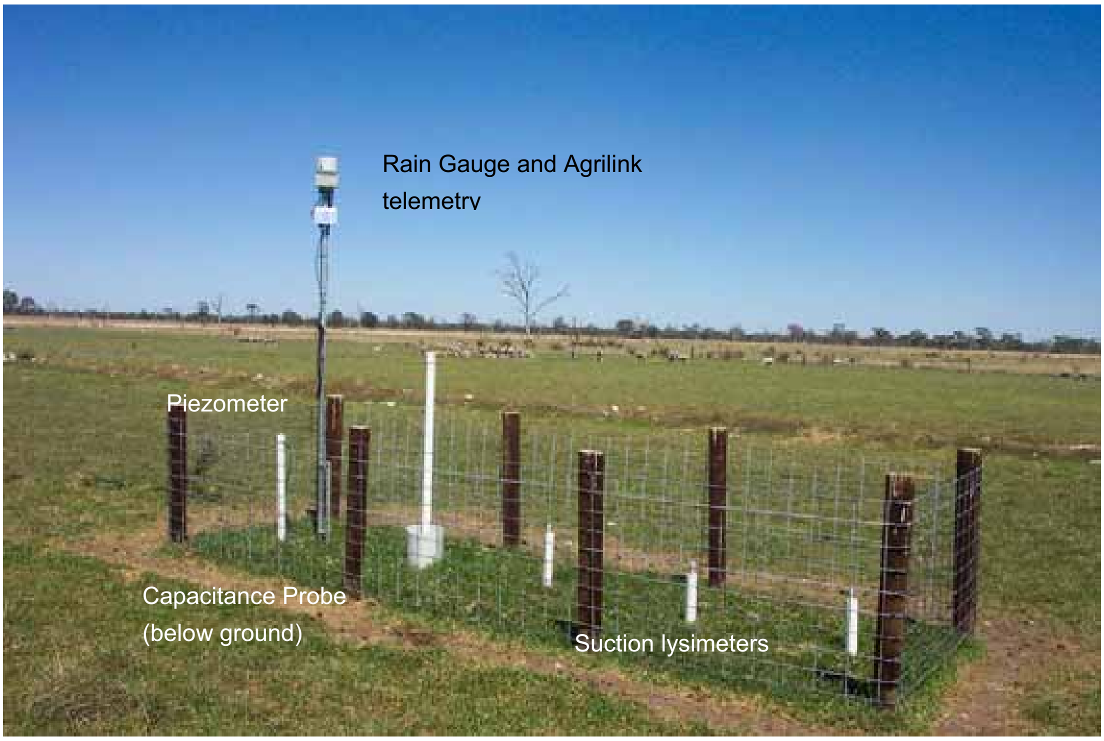


Figure 12: Site Plan at Center Pivot and Flood Sites

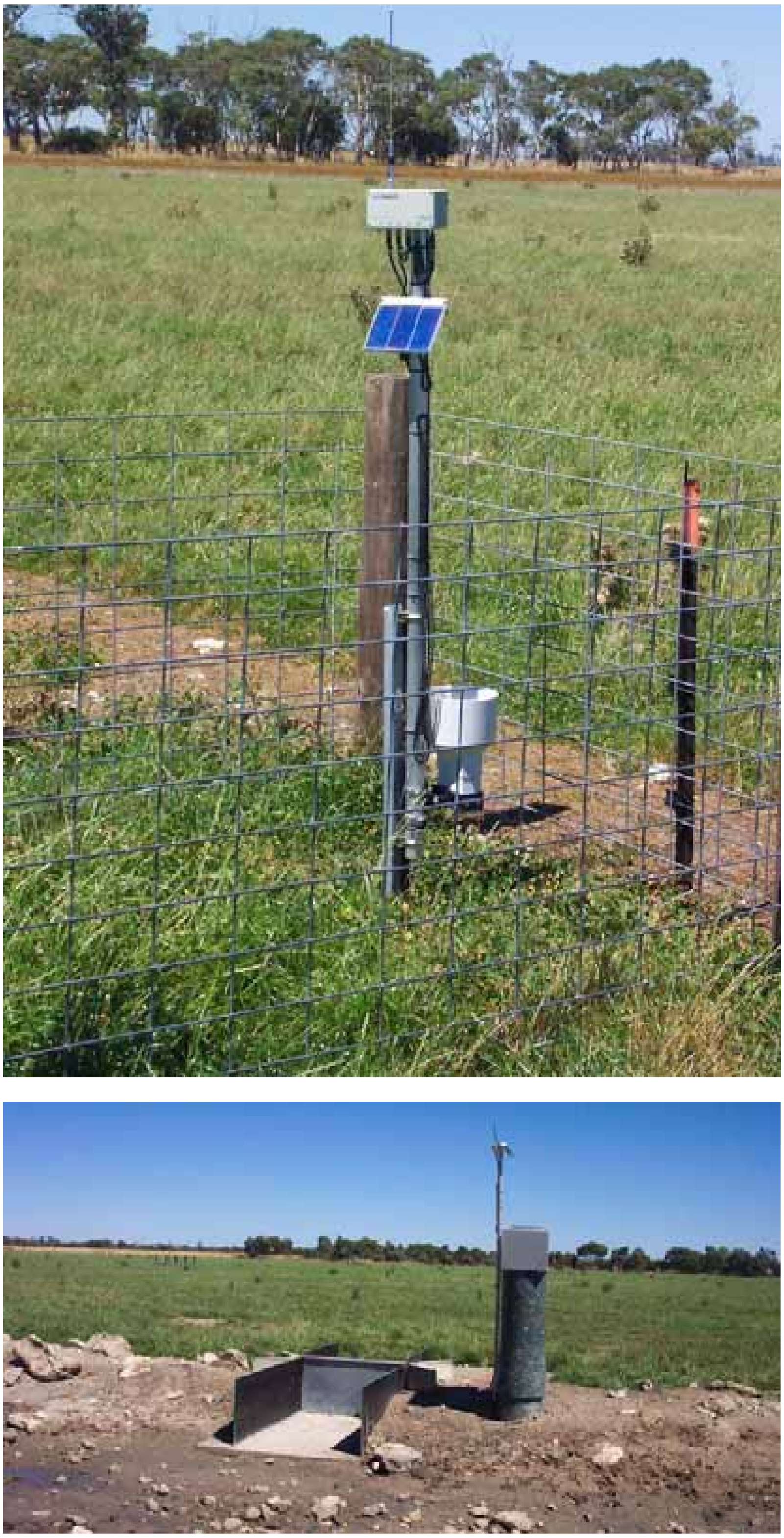


(a)



(b)

Figure 13. (a) Instrumentation at Vineyard site NAP 6 and (b) Instrumentation at Flood and Centre Pivot Sites NAP 3, 4 and 5



(a)

(b)

Figure 14 Irrigation application: (a) measured via a rain gauge at NAP 3, (b) measured via a shaft encoder at NAP 4 and NAP 5

Table 4. Instrumentation summary

Site	NAP 1	NAP 2	NAP 3		NAP 4		NAP 5		NAP 6	NAP 7	BG 1	BG 2
Irrigation	Drip	Drip	Pivot		Flood		Flood		Drip	Drip	Dryland	Dryland
Crop	Vines	Vines	Lucerne		Pasture		Pasture		Vines	Vines	Pasture	
Site Location	CS4	CS1	West	East	East	West	North	South	CS5	CS6		Near CS5
Easting	457645	452713	448872	448989	449047	448991	446847	446956	458763	460056	447813	458081
Northing	5943075	5950023	5952025	5951971	5955304	5955298	5957247	5957135	5942505	5939546	5953437	5943262
CSIRO Instrumentation												
Flux Station									1			
Weather Stn (AWS)	1	1							1	1		
Enviroscan									2	2		
Drainage Meter									2	2		
NAP Instrumentation												
Piezometer	1	1	1		1			1	1	1		
Screen depth (m)	3.9-9.9	3.5-9.5	3.25-9.25		3.85-9.85			3.2-9.2	4-10	4.35-10.35		
SWL (m)	3.9	3.5	2.3		3.0			2.75	5	3.95		
Lysimeters												
Depth 1	1.4	1.4	0.9	0.9	1.4	1.4	1.4	1.4	1.55	1.4	1.4	1.4
Depth 2	2.4	2.4	1.4	1.4	2.4	2.4	2.4	2.4	2.55	2.4	2.4	2.4
Depth 3	3.4	3.4	2.4	2.4	3.4	3.4	2.9	2.9	3.55	3.4	3.2	3.4
Climate Station												
*C-probe**		2	1	1	1	1	1	1	2		1	1
Rain Gauge	1	1	2	1	1			1	2	1		
NMM Access Tubes	12	12							12	12		
Flow Meters			1		1		1					
Shaft Encoders					1		1					

5.3.4.3 Evapotranspiration

Estimates of crop water use (Eto) at the centre pivot and flood irrigation sites will be calculated from Class A Pan Evaporation (Epan) provided by the Bureau of Meteorology. Eto can be calculated using the following expression:

ETo = Epan.Cp.Kc

Where Epan is assumed to be linearly related to the potential evaporation via the pan coefficient (Cp) and Kc is the crop coefficient, which varies from 0.6 to 1.0 during the growing stages of lucerne and pasture. Monthly values can be sourced from Desmier (1992).

The limitation in calculating ET at the flood irrigation sites is that the above equation only accounts for crop water use (T) and not the surface evaporation of irrigation water when it is applied, therefore underestimating the actual water loss by evapotranspiration.

As mentioned above, this can be overcome by the sampling of stable isotopes $\delta^{2}H$ and $\delta^{18}O$ in irrigation and soil water, which will provide a direct indication of evaporation losses independent of transpiration.

5.3.4.4 Groundwater extraction

To measure groundwater extraction, flow meters were installed on the irrigation wells at sites NAP3 (MAR 209), NAP4 (MAR 208) and NAP5 (MAR 207). The flow meters are equipped with telemetry and record the flow rate (L/s), daily volume (kL) and total (accumulated) volume (ML) extracted out of the irrigation well.

5.3.4.5 Soil moisture measurements - capacitance probes

Capacitance probes measure the dielectric constant of a soil and hence its water content by the capacitance method. The instruments are not calibrated, however, they are able to produce a soil moisture profile at depth and therefore will be useful to determine lag times and the extent that soil moisture moves down the profile after irrigation and rainfall events.

The installation of capacitance probes (C-Probes) was carried out by Agrilink in June 2003. Two C-Probes were installed at NAP sites 2, 3, 4, 5 and 6, and one C-probe at each of the 2 background sites. C-Probes were installed directly under the vine row at investigation sites 2 and 6. Based on the soil type and root system, sensors were set at depths of 10, 20, 30, 50, 100, 150, 200, 250 and 300 cm. The C-Probe utilises the telemetry system to log and transmit data.

5.3.4.6 Soil moisture samples - backhoe excavation

To enable in situ collection of soil moisture samples, DWLBC along with the assistance of staff from Stonehaven, Orlando and Southcorp excavated backhoe pits in September 2004, within the vine rows down to depths of 2 m at each of the sites. In addition, two pits were excavated during October 2004 at NAP 1 and 6 with a larger excavator capable of digging down to 4 to 5 m.

Soil samples were collected at various intervals and have been sent to CSIRO for analysis on EC, Cl, porosity, bulk density and soil moisture content. The soil moisture Cl results will compliment and verify samples collected from the suction lysimeters.

5.3.4.7 Salinity drainage measurements

To quantify a salt flux to the water table, suction lysimeters were installed to measure soil moisture salinity (chloride) within the vadose zone. At each of the seven irrigation sites and two background sites, three 100 mm diameter holes were drilled within the unsaturated zone at nominal depths of 1, 2 and 3 m and equipped with suction lysimeters (see Table 5 for installation depths). The lysimeters were constructed by attaching a 15 cm porous ceramic cup to the end of 16 mm diameter PVC conduit. These were placed in the hole, with the ceramic cup surrounded by diatomaceous earth to provide a good contact with the surrounding soil. A bentonite seal was placed above the diatomaceous earth and the hole was cemented to the surface. Two groups of three lysimeters were installed at each of the centre pivot (NAP 3) and the two flood (NAP 4 and 5) irrigation sites to achieve average readings across the bay (Fig. 12). Within the four vineyard sites (NAP 1, 2, 6, and 7) each lysimeter was installed directly under the vine row (Fig. 13a).

Table 5. Lysimeter sites and installation depths

Padthaway salt accession sites	Depth below GL			Total Tube Length		
Site No.	*SL1*	*SL2*	*SL3*	*SL1*	*SL2*	*SL3*
NAP 1	1.01	2.04	3.01	1.40	2.40	3.40
NAP 2	1.04	2.03	3.03	1.40	2.40	3.40
NAP 3 West	0.52	1.15	2.02	0.90	1.40	2.40
NAP 3 East	0.50	0.94	2.00	0.90	1.40	2.40
NAP 4 West	1.06	2.03	3.05	1.40	2.40	3.40
NAP 4 East	1.13	2.01	2.92	1.40	2.40	3.40
NAP 5 North	1.04	2.01	2.51	1.40	2.40	2.90
NAP 5 South	0.97	2.02	2.52	1.40	2.40	2.90
NAP 6	0.95	2.00	2.90	1.55	2.55	3.55
NAP 7	1.00	2.01	2.96	1.40	2.40	3.40
BG 1	0.99	2.05	2.87	1.40	2.40	3.20
BG 2	0.90	1.97	3.05	1.40	2.40	3.40

The suction lysimeters are sampled monthly by DWLBC staff. Sampling is carried out by applying a constant negative pressure to the ceramic cup, using a vacuum pump (Fig. 15). This draws pore water through the porus cup and pore water samples are brought to the surface through a 5 mm tube using a syringe. Samples are analysed for EC and Chloride monthly, and have also been analysed for HCO_3, Ca, K, Mg, Na, S, Br and NO_3.

Additional sampling of suction lysimeters will be carried out at NAP 3, 4 and 5 throughout the irrigation season to measure the δ^2H and δ^{18}O composition of the soil water at depth.

Figure 15. Sampling of suction lysimeters at background site BG 2

APPENDICES

A. WELL CONSTRUCTION DETAILS AND GEOLOGICAL LOGS

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61242

UNIT No. IRR 1.

Hundred: **Sec:**

Coordinates: E 458137 N 5943169 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	6.8		2	16.1				1446	623131

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**1.0**		**SAND**	**Fine-grained, dark grey/brown, minor white sandstone fragments.**	Topsoil				
1.0	**1.5**		**CLAY**	**Brown.**	Padthaway Fm				
1.5 4.0	**5.0**		**LIMESTONE**	**White to cream, hard, with fine sand, well-cemented.** Becoming white to off white / grey limestone, hard, with minor white – cream clay.	Padthaway Fm				
5.0	**6.0**		**CLAY and SAND**	**Off-white / grey with off-white / grey limestone.**	Padthaway Fm				
6.0	**14.0**		**LIMESTONE and CLAY**	**Off-white to grey sticky clay with some limestone.**	Padthaway Fm				
14.0	**15.0**		**CLAY**	**Grey.**	Padthaway Fm				
15.0	**16.0**		**SANDSTONE**	**Med. – coarse grained, partially cemented.**	Bridgewater Fm				
16.0	**17.0**			**LOST SAMPLE**					
17.0	**18.0**		**SAND**	**Brown**	Bridgewater Fm				
18.0	**19.0**		**CLAY**	**Black, lignitic.**	Dilwyn Fm?				
19.0	**23.0**		**SAND**	**Brown, minor black lignitic clay.** **END OF HOLE 23 m.**	Dilwyn Fm?				

REMARKS: Hole drilled to 23 m but collapsed back to 16.1 m.

DRILL TYPE: 8" rotary air	COMPLETED: Pre-collar to 2 m, then open hole to 16.1 m.
DRILL FLUID: Air & water	LOGGED BY: D. Wohling
DATE 16/3/03	SHEET 1 OF 1

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation NAP3

PERMIT No.

UNIT No. NAP 3

Hundred: **Sec:**

Coordinates: E 448872 N 5952025 El. Surface(m) El. Ref. Point(m)

Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	3.5	2.3	3.25	9.25					

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**0.15**		**Clayey SAND**	**Fine-med. grained, approx. 5% clay, dark brown. Roots to 0.1 m.**	**Topsoil**				
0.15 0.15 1.7 2.9	**9.0**		**LIMESTONE**	**Cream, crystalline, sandy, layered with sand and clayey sand.** Crystalline limestone fragments retrieved only. Becoming sandier (fine-coarse sand , cream coloured). Fine-coarse grained cream sand, 5-10% clay, with limestone chunks. Drillers noted variable resistance suggesting layering.	**Padthaway Fm**				
				End of Hole 9 m.					

REMARKS: **Note: Core samples collected at 0.5 m intervals to 4 m.**	DRILL TYPE: Hollow auger	COMPLETED 50 mm PVC piezometer
	DRILL FLUID: None	LOGGED BY: N. Howes
	DATE 24/6/03	SHEET 1 OF 1

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation NAP4

PERMIT No.

UNIT No. NAP 4.

Hundred: Sec:

Coordinates: E N El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	3.5	3.0	3.85	9.85					

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**0.2**		**Loamy SAND**	**Fine-med. grained, approx. 5% clay, dark brown. Roots to 0.1 m.**	**Topsoil**				
0.2 0.7 1.6	**1.9**		**LIMESTONE**	**Cream, crystalline, sandy, layered with sand and clayey sand.** Crystalline limestone fragments retrieved only (low sample recovery). Becoming sandier (medium-grained sand , cream coloured).	**Padthaway Fm**				
1.9 2.5 2.7 3.0	**3.6**		**Clayey SAND**	**Medium-grained, cream and orange, 5-10% clay.** Some chunks of calcrete. More orange in colour. Decreasing clay and increasing limestone chunks.	**Padthaway Fm**				

3.6 4.5 6.5 8	**10.5** 4.6		**LIMESTONE**	**Cream, crystalline, layered with sand (poorly sorted, fine-coarse grained) and clayey sand. Cuttings sticky and "plaster like".** Layer of medium-coarse cream sand. Formation became "softer", according to driller. Thin hard layer, becoming softer again.	**Padthaway Fm**				
				End of Hole 10.5 m.					

REMARKS: **Note: Core samples collected at 0.5 m intervals to 5 m.** Gravel pack from 9.85 m to 2.2 m. Bentonite seal 2.2 m to 1.6 m. Cement to surface.	DRILL TYPE: Hollow auger	COMPLETED 50 mm PVC piezometer
	DRILL FLUID: None	LOGGED BY: N. Howes
	DATE 24/6/03	SHEET 2 OF 2

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation NAP5

PERMIT No.

UNIT No. NAP 5.

Coordinates: E 446956 N 5957135 El. Surface(m) El. Ref. Point(m)

Datum:

Hundred: **Sec:**

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	2.5 - 3	2.75	3.2	9.2					

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**0.3**		**Clayey SAND**	**Fine-med. grained, approx. 5% clay, dark brown. Roots to 0.1 m. Moist.**	**Topsoil**				
0.3	**9.2**		**LIMESTONE**	**Cream, crystalline, sandy, layered with sand and clayey sand.**	**Padthaway Fm**				
				End of Hole 9.2 m.					

REMARKS: **Note: Core samples collected at 0.5 m intervals to 4.5 m.**

Gravel pack from 9.2 m to 1.5 m.
Bentonite seal 1.5 m to 0.8 m.
Cement to surface.

DRILL TYPE: Hollow auger	COMPLETED 50 mm PVC piezometer
DRILL FLUID: None	LOGGED BY: N. Howes
DATE 23/6/03	SHEET 1 OF 1

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61243

UNIT No. NV 1

Hundred: Glen Roy **Sec: 299**

Coordinates: E 460736 N 5944934 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	24		25.0	27.0	< 0.1	25 mins	Airlift	-	-

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**0.5**		**SAND**	**Fine – med. grained, brown, moist, friable.**	Topsoil				
0.5	**1.25**		**Clayey SAND**	**Fine – med. grained, red, moist, friable.**	Bridgewater Formation				
1.25 6.0	**6.5**		**SAND and SANDSTONE**	**Fine grained, cream, dry sand interlayered with fine – med. grained calcareous sandstone.** Becoming coarser (fine – med. grained)	Bridgewater Formation				
6.5 7.1	**7.4**		**SAND**	**Fine – med. grained, light brown, dry.** Becoming orange / red coloured and more moist.	Bridgewater Formation				
7.4	**13.5**		**SAND and SANDSTONE**	**Fine grained, cream, dry sand interlayered with fine – med. grained calcareous sandstone. Sandstone dominates above 8.5 m, with sand increasing below 8.5 m.**	Bridgewater Formation				
13.5	**14.4**		**SAND**	**Fine – med. grained light brown sand, soft, dry, minor calcareous lumps.**	Bridgewater Formation				
14.4 15.4 16.5 18.0	**18.5**		**SAND and SANDSTONE**	**Fine grained, cream, dry sand interlayered with fine – med. grained calcareous sandstone.** Becoming moist. Dry sand as above with small calcareous lumps. Becoming moist	Bridgewater Formation				

REMARKS:

Gravel Pack: ~ 24 – 27 m
Bentonite Seal

DRILL TYPE: Hollow auger, continuous core.	COMPLETED: 50 mm PVC, slotted screen 25 – 27 m.
DRILL FLUID: None	LOGGED BY: N. Howes
DATE 12/3/03	SHEET 1 OF 2

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG
CONTINUATION SHEET

PROJECT:
PERMIT No.
UNIT No.
Hundred: **Sec:**

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
18.5	**19.0**		**SAND**	**Fine – med. grained light brown sand, soft, moist at the bottom.**	Bridgewater Formation				
19.0 19.5	**20.0**		**SAND and SANDSTONE**	**Fine grained, cream, dry sand interlayered with fine – med. grained calcareous sandstone.** Becoming fine – med. grained orange / cream sand, soft, moist, with only small lumps of calcareous sandstone.	Bridgewater Formation				
20.0	**20.7**		**Sandy CLAY**	**Fine – med. grained, red / brown, becoming yellow / cream, stiff, increasing sand below 20.5 m.**	Bridgewater Formation				
20.7 21.5 23.0 24.0	**27.0** 22.0 23.5		**SAND**	**Fine – med. grained, yellow, moist, becoming wet at 24 m.** Minor hard sub-angular to sub-rounded calcareous lumps ≤ 5 cm diam. Some gravelly sand layers a few cm thick. Becoming med. – coarse grained. END OF HOLE 27 m.	Bridgewater Formation				

GROUNDWATER PROGRAM

WATER WELL LOG

The Department of Water, Land and Biodiversity Conservation

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 106184

UNIT No. NV 3

Hundred: Glen Roy **Allotment: 1**

Coordinates: E 0465526 N 5938756 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	22							-	-

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**1**		**SAND**	**Fine – med. grained, brown top sand**	Topsoil				
1	**2**		**SAND**	**Fine – med. Grained orange sand**	Bridgewater Formation				
2	**4**		**SAND**	**Fine grained partly consolidated light brown sand**	Bridgewater Formation				
4	**8**		**SAND**	**Fine-grained orange silty sand to sandy clay. Red to orange clay at 7m**	Bridgewater Formation				
8	**8.5**		**LIMESTONE**	**Cream unconsolidated limestone**	Bridgewater Formation				
8.5	**12**		**SANDSTONE**	**Fine – med. grained Light brown to orange, cemented calcareous sandstone. Becoming lighter in colour at 12m**	Bridgewater Formation				
12	**13**		**LIMESTONE**	**Cream to light brown unconsolidated limestone. Some sand present.**	Bridgewater Formation				
15	**16**		**SAND**	**Fine grained orange to light brown sand**					
16	**17**		**SAND**	**Medium - coarse grained cream to light brown sand**					

REMARKS:

Hole was backfilled.
50mm cores were retrieved down to a depth of 10m and 1m cores from 10 to 24m

DRILL TYPE: Hollow auger, continuous core.	COMPLETED: Backfilled
DRILL FLUID: None	LOGGED BY: J van den Akker
DATE 31/3/05	SHEET 1 OF 2

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG
CONTINUATION SHEET

PROJECT:

PERMIT No.

UNIT No.

Hundred: **Sec:**

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
17	**18**		**SAND** Sandstone	**Fine grained yellow partly cemented-calcrete present**	Bridgewater Formation				
18	**19**		**SAND**	**Fine – med. grained cream unconsolidated calcareous sand**	Bridgewater Formation				
19	**22**		**SAND**	**Cream to yellow fine grained sand. Calcareous sand at 22m**	Bridgewater Formation				
22	**23.5**		**SAND**	**Light brown to yellow fine grained sand**	Bridgewater Formation				

The Department of Water, Land and Biodiversity Conservation	GROUNDWATER PROGRAM **WATER WELL LOG**	**PROJECT: Padthaway Salt Accession Investigation**
		PERMIT No. 106183
		UNIT No. NV 4
	Coordinates: E 0458203 N 5949925 El. Surface(m) El. Ref. Point(m) Datum:	**Hundred: Parsons Sec: 136**

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m) From	INTERVAL (m) To	SUPPLY L/sec	SUPPLY Test length	SUPPLY Method	TOTAL DISSOLVED SOLIDS mg/L	TOTAL DISSOLVED SOLIDS Analysis No.
	10.50							-	-

DEPTH (m) From	DEPTH (m) To	GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING Dia (mm)	CASING From (m)	CASING To (m)
0	**1.5**		**SAND**	**Fine – med. grained blight brown top sand**	Topsoil				
1.5 5.5 5.5 7.0 9.0	**11.5** 5.5 7.0 9.0 11.5		**SAND** Clay Sand Sand Sand	**Fine – med. Grained orange sand to silty sand** Brown / Orange clay Interlayered light grey fine to medium grained calcareous sand Bands of Consolidated / cemented sand, med. grained Light brown sand, becoming coarser, interlayered with light grey calcareous sand	Bridgewater Formation				
11.5	**13**		**SAND**	**Fine yellow silty sand**	Bridgewater Formation				
13	**14**		**SAND**	**Med. – Coarse brown sand**	Bridgewater Formation				

REMARKS:		
Hole was backfilled. 50mm cores were retrieved down to a depth of 12m and 1m cores from 12 to 14m Total Depth = 16m	DRILL TYPE: Hollow auger, continuous core.	COMPLETED: Backfilled
	DRILL FLUID: None	LOGGED BY: J van den Akker
	DATE 30/3/05	SHEET 1 OF 1

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61229

UNIT No. PA 1.

Hundred: Glen Roy **Sec: adj. 389**

Coordinates: E 462942 N 5944764 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	8.2 – 8.5 m		9.5	11.5	0.2	20 mins	Airlift	1698	623136

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**0.4**		**SAND**	**Fine-med. grained, light brown, with sticks, leaves, roots.**	Topsoil				
0.4 2.0 3.5 4.0	**4.5**		**SAND / Clayey SAND**	**Orange fine-med. grained sand with clayey lumps and red zones, moist, friable.** Increasing partially cemented (calcareous) orange/red layers. Softer (less cemented), yellow. Red / orange clayey sand (containing red, orange and cream zones).	Bridgewater Fm				
4.5	**6.0**		**SAND**	**Med. grained, well-sorted, red and yellow bands, moist, friable.**	Bridgewater Fm				
6.0 7.0 7.1 7.2 8.0	**11.5** 7.1 7.2		**Clayey SAND**	**Med.-coarse grained, soft, red and yellow banded.** Orange Pink Becoming fine-med. grained, coarsening downwards. Fine-coarse-grained. END OF HOLE 11.5 m.	Bridgewater Fm				

REMARKS:		
Gravel pack: 6 – 11.5 m Bentonite seal	DRILL TYPE: Hollow auger, continuous core.	COMPLETED: 50 mm PVC with slotted screen 9.5 – 11.5 m.
	DRILL FLUID: None	LOGGED BY: N. Howes
	DATE: 12/3/03	SHEET 1 OF 1

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61285

UNIT No. PA 2.

Coordinates: E 462068 N 5944738 El. Surface(m) El. Ref. Point(m) Datum:

Hundred: Glen Roy **Sec: 299**

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	10.6 – 10.8		11.6	13.6	< 0.1	25 mins	Airlift	1664	623137

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**0.7**		**SAND**	**Fine, grey.**	Topsoil				
0.7	**2.4**		**SAND**	**Fine, yellow, becoming orange.**	Bridgewater Fm				
2.4 5.0	**5.2**		**Clayey SAND**	**Fine, yellow/orange to brown/orange, minor pink/grey bands.** Med. grained.	Bridgewater Fm				
5.2	**9.0**		**Sandy CLAY**	**Orange/brown.**	Bridgewater Fm				
9.0	**11.4**		**Clayey SAND**	**Orange/brown**	Bridgewater Fm				
11.4	**12.5**		**SAND**	**Fine, grey, becoming coarse, brown/orange.** END OF HOLE 12.5 m.	Bridgewater Fm				

REMARKS:

Gravel pack 10 – 13.6 m
Bentonite seal

DRILL TYPE: Hollow auger, continuous core.	COMPLETED: 50 mm PVC, slotted casing 11.6 – 13.6 m.
DRILL FLUID: None	LOGGED BY: D. Wohling
DATE: 16/3/03	SHEET 1 OF 1

The Department of Water, Land and Biodiversity Conservation	GROUNDWATER PROGRAM **WATER WELL LOG** Coordinates: E 459614 N 5944090 El. Surface(m) El. Ref. Point(m) Datum:	**PROJECT: Padthaway Salt Accession Investigation** **PERMIT No. 61233** **UNIT No. PA 3.** **Hundred: Glen Roy Sec: adj 310**

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m) From	INTERVAL (m) To	SUPPLY L/sec	SUPPLY Test length	SUPPLY Method	TOTAL DISSOLVED SOLIDS mg/L	TOTAL DISSOLVED SOLIDS Analysis No.
	Approx. 40 m	38 m	44.0	46.0	< 0.1	20 mins	Airlift	-	-

DEPTH (m) From	DEPTH (m) To	GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING Dia (mm)	CASING From (m)	CASING To (m)
0	**1.9**		**SAND**	**Fine grained, grey becoming light brown.**	Topsoil				
1.9	**3.3**		**Clayey SAND to Sandy CLAY**	**Red/orange, fine-grained clayey sand, becoming sandy clay at 2.0 m**	Bridgewater Formation				
3.3	**22.9**		**SAND and SANDSTONE**	**Fine grained, red / brown sand with well-cemented calcareous sandstone.**	Bridgewater Formation				
7.5				Sand becomes fine to med. grained.					
8.0				Sandstone is medium to poorly cemented.					
9.4				Sand becomes fine grained, red.					
10.5				Sand becoming pale orange / brown.					
22.9	**24.0**		**CLAY**	**Red / brown.**	Bridgewater Fm				
24.0	**25.9**		**SAND**	**Pale orange, fine grained, minor sandstone**	Bridgewater Fm				
25.9	**26.0**		**Sandy CLAY**	**Red.**	Bridgewater Fm				
26.0	**50.0**		**SAND, Sandy CLAY and SANDSTONE**	**No core sample. Alternating layers, as above.** **END OF HOLE 50.0 m**	Bridgewater Fm				

REMARKS:		
Gravel pack: ~ 43 – 46 m Bentonite seal	DRILL TYPE: Hollow auger, continuous core to 26 m, then rotary air.	COMPLETED: 50 mm PVC, slotted screen 44 – 46 m.
	DRILL FLUID: None to 26 m, then air / water.	LOGGED BY: D. Wohling
	DATE: 13/3/03	SHEET 1 OF 1

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61234

UNIT No. PA 4.

Hundred: Glen Roy **Sec: adj. 310**

Coordinates: E 459021 N 5943906 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	16.5		17.75	19.75	0	30 mins	Airlift	-	-

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**0.9**		**SAND**	**Fine grained, grey.**	Topsoil				
0.9 2.0 3.5 4.0	**6.4**		**Sandy CLAY**	**Red/brown to orange/brown.** Increasing grey colouring. Red/brown grading to red/orange/brown. Becoming dark red.	Bridgewater Formation				
6.4 8.0 11.0 13.0	**14.0** 14.0		**SAND and SANDSTONE**	**Light brown fine sand and well-cemented light brown sandstone, minor clay.** Sandstone is less well-cemented (well to medium cemented). Sandstone becomes medium to poorly cemented. Brown sand and minor well-cemented sandstone.	Bridgewater Formation				
14.0 14.0 14.5 15.5 18.0 19.0	**19.5** 14.5 15.5 18.0 19.0 21.5		**Clayey SAND to CLAY**	**Orange / brown to red.** Orange/brown to red clayey sand. Dark red/brown clay, minor grey clay. Brown sandy clay, minor black sandy clay. Becoming coarser. Coarse brown sandy clay to coarse brown/orange sand with black/brown clayey sand. Med. brown/orange sand, minor clay. END OF HOLE 21.5 m	Bridgewater Formation				

REMARKS:		
Gravel pack: ~ 16.5 – 19.75 m Bentonite seal	DRILL TYPE: Hollow auger, continuous core	COMPLETED: 50 mm PVC, slotted screen 17.75 – 19.75 m.
	DRILL FLUID: None	LOGGED BY: D. Wohling
	DATE: 15/3/03	SHEET 1 OF 1

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61230

UNIT No. PB 1.

Hundred: Glen Roy **Sec: adj 387**

Coordinates: E 463504 N 5943355 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	5.5-6.0	5.8	9.0	12.0				-	-

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**0.5**		**SAND**	**Grey/brown, fine grained.**	Topsoil				
0.5	**1.0**		**SAND**	**Orange, fine-med. grained.**	Bridgewater Fm				
1.0	**9.5**		**Clayey SAND**	**Orange, fine-med. grained.**	Bridgewater Fm				
2.0				Increasing red bands, becoming orange to reddish-orange.					
4.0				Sand increasing in grain size, becoming med.–coarse.					
5.0				Becoming coarse red/orange clayey sand, grey zone somewhere between 6.5-7.0 m.					
7.0				Back to fine-med. grained clayey sand, grey to orange.					
8.0				Orange-brown.					
8.5				Increasing clay content, with clay lens 8.8-9.0 m.					
9.0	9.5			Grey to orange colour.					
9.5	**12.5**		**SAND**	**Orange, fine to coarse grained.**	Bridgewater Fm				
10.0	10.5			Fine-med. grained, weakly cemented.					
10.5	11.0			Fine-med. grained, orange.					
11.0	12.5			No sample collected, so unconfirmed lithology.					
				END OF HOLE 12.5 m					

REMARKS:

Gravel pack: ~ 8 – 12 m
Bentonite seal

DRILL TYPE: hollow auger, continuous core	COMPLETED: 50 mm PVC with slotted screen 9.0 – 12.0 m.
DRILL FLUID: None	LOGGED BY: D. Wohling
DATE: 9/3/03	SHEET 1 OF 1

GROUNDWATER PROGRAM
WATER WELL LOG

The Department of Water, Land and Biodiversity Conservation

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61240

UNIT No. PB 2.

Hundred: Glen Roy **Sec: 387**

Coordinates: E 462360 N 5942661 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	NA		37.0	39.0				1328	623139

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**?**		**SAND**	**Fine – med. grained, grey / brown.**	Topsoil				
?	**15.5**		**SAND / Clayey SAND**	**Orange / yellow, fine – med. grained, becoming more red/orange at 6 m. Coarse sand layer at approx. 15 m.**	Bridgewater Fm				
15.5	**40.0**		**SAND and SANDSTONE**	**Interlayered sand and calcrete cemented sandstone layers.** END OF HOLE 40.0 m	Bridgewater Fm				
40.0				**Bridgewater Fm / Gambier Limestone boundary.**					

REMARKS:

Gravel pack: 34.5 – 39 m
Bentonite seal 32.8 – 34.5 m
Cement plug

DRILL TYPE: Rotary mud	COMPLETED: 50 mm PVC, slotted screen 37.0 – 39.0 m.
DRILL FLUID: mud	LOGGED BY: N. Howes
DATE: 30/3/03	SHEET 1 OF 1

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61239

UNIT No. PB 3

Hundred: Glen Roy **Sec: 387**

Coordinates: E 462364 N 5942657 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	NA	16.215	26.5	29.5				1110	623135

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**?**		**SAND**	**Fine – med. grained, grey / brown.**	Topsoil				
?	**11.0**		**SAND / Clayey SAND**	**Orange / yellow, fine – med. grained, becoming more red/orange at 6 m.**	Bridgewater Fm				
11.0 14.5	**35.0** 15.0		**SAND and SANDSTONE**	**Interlayered sand and calcrete cemented sandstone layers.** Coarse sand. END OF HOLE 35.0 m	Bridgewater Fm				

REMARKS:		
Gravel Pack: ~ 25.5 – 29.5 m Bentonite seal Cement plug	DRILL TYPE: Rotary mud	COMPLETED: 50 mm PVC, slotted screen 26.5 – 29.5 m.
	DRILL FLUID: mud	LOGGED BY: N. Howes
	DATE: 29/3/03	SHEET 1 OF 1

GROUNDWATER PROGRAM
WATER WELL LOG

The Department of Water, Land and Biodiversity Conservation

PROJECT: Padthaway Salt Accession Investigation	
PERMIT No. 61237	
UNIT No. PB 4.	
Hundred: Glen Roy	**Sec: 387**

Coordinates: E 462355 | N 5942652 | El. Surface(m) | El. Ref. Point(m) | Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	NA	15.62	19.0	21.0				944	623138

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**?**		**SAND**	**Fine – med. grained, grey / brown.**	Topsoil				
?	**14.0**		**SAND / Clayey SAND**	**Orange / yellow, fine – med. grained, becoming more red/orange at 6 m.**	Bridgewater Fm				
14.0	**22.0**		**SAND and SANDSTONE**	**Interlayered sand and calcrete cemented sandstone layers.** END OF HOLE 22.0 m	Bridgewater Fm				

REMARKS:		
Gravel pack: 17 – 21 m Bentonite seal Cement plug	DRILL TYPE: Rotary mud	COMPLETED: 50 mm PVC, slotted screen 19 – 21 m.
	DRILL FLUID: mud	LOGGED BY: N. Howes
	DATE: 29/3/03	SHEET 1 OF 1

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61235

UNIT No. PB 5.

Hundred: Glen Roy Sec: 387

Coordinates: E 462294 N 5942630 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m) From	INTERVAL (m) To	SUPPLY L/sec	SUPPLY Test length	SUPPLY Method	TOTAL DISSOLVED SOLIDS mg/L	TOTAL DISSOLVED SOLIDS Analysis No.
	15.6	14.7	41	44				-	-

DEPTH (m) From	DEPTH (m) To	GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING Dia (mm)	CASING From (m)	CASING To (m)
0	**0.5**		**SAND**	**Grey/brown, fine-med. grained, dry.**	Topsoil				
0.5 1.1 1.5 3.5 4.0	**6.0**		**SAND**	**Orange/brown, fine-med. grained, moist, friable.** Flecks of black organic matter. Less organic matter. Increasing orange zones. Many orange, ferruginous zones (non-cemented).	Bridgewater Formation				
6.0 7.5 8.9 9.7 10.3	**11.0** 9.8		**Clayey SAND**	**Red-orange, fine-med. grained, non-calcareous, ~ 10% clay, moist, friable.** Becoming lighter in colour, less ferruginous, less clayey. Increasing clay content and red-orange colouring. Sandier zone. Higher clay content (~ 20%), cream coloured.	Bridgewater Formation				
11.0 12.9 13.0	**13.1**		**SAND**	**Med. – coarse grained, red, minor clay.** Some cream coloured grains. Becoming lighter in colour (cream & orange).	Bridgewater Formation				
13.1	**15.1**		**SAND and CALCRETE**	**Interlayered sand and calcrete.**	Bridgewater Formation				

REMARKS: Hole collapsed so gravel became stuck around casing and filled hole to surface. No bentonite seal could be added.

DRILL TYPE: Hollow auger to 20 m, then diamond core.	COMPLETED 50 mm PVC, slotted screen 41-44m.
DRILL FLUID: None above 20.0 m, then mud/polymer.	LOGGED BY: N. Howes
DATE 8/3/03	SHEET 1 OF 2

The Department of Water, Land and Biodiversity Conservation	GROUNDWATER PROGRAM **WATER WELL LOG** CONTINUATION SHEET	**PROJECT: Padthaway Salt Accession Investigation** **PERMIT No. 61235** **UNIT No.** **Hundred: Glen Roy Sec: 387**

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
15.1	**15.9**		**SANDSTONE**	**Sand cemented with calcrete.**	Bridgewater Formation				
16.0	**16.6**		**SAND**	**Med. – coarse, brown.**	Bridgewater Formation				
16.6 17.8	**19.5**		**SAND and SANDSTONE**	**Med. – coarse grained, brown, sandstone is sand cemented with calcrete** Possible cavity, although collapse may have occurred higher up (e.g. sandy zone 16-17 m).	Bridgewater Formation				
19.5	**21.8**		**Clayey SAND**	**Orange-brown, fine – med. grained.**	Bridgewater Formation				
21.8 27.6 31.3 34.0 34.9 35.0	**36.0** 36.0		**SAND and SANDSTONE**	**Alternating sand (fine-med. grained sand) and calcrete cemented sandstone. Sandstone pieces were sub-angular to sub-rounded with small dissolution features.** Sand becoming more clayey. Sand becomes non-clayey. Some orange zones. Sand is orange, fine-med. grained with minor coarse sand. Includes cavity approximately 60 cm wide.	Bridgewater Formation				
36.0	**38.0**		**SANDSTONE and Silty CLAY**	**Sandstone is fine-grained, orange and white. Silty clay is grey-green.**	Gambier Limestone				
38.0	**38.2**		**LIMESTONE**	**Grey-green, bryozoal.**	Gambier Limestone				
38.2	**40.0**		**SANDSTONE and Silty CLAY**	**Sandstone is fine-grained, orange and white. Silty clay is grey-green.**	Gambier Limestone				
40.0	**40.8**		**LIMESTONE**	**Grey-green, glauconitic, minor bryozoa.**	Gambier Limestone				
40.8 46.2	**48.5** 47.0		**SAND**	**Grey-green, fine-med. grained, partially cemented, calcareous, minor bryozoa and glauconite.** More grey, fine-grained and clayey.	Gambier Limestone				
48.5	**50.0**		**LIMESTONE**	**Grey-green, sandy (fine-med. grained), bryozoal.** **END OF HOLE 50.0 m**	Gambier Limestone				

GROUNDWATER PROGRAM

WATER WELL LOG

The Department of Water, Land and Biodiversity Conservation

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61232

UNIT No.

Hundred: Glen Roy **Sec: 387**

Coordinates: E 462337 N 5942646 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m) From	INTERVAL (m) To	SUPPLY L/sec	SUPPLY Test length	SUPPLY Method	TOTAL DISSOLVED SOLIDS mg/L	TOTAL DISSOLVED SOLIDS Analysis No.
	NA	15.29	41.0	44.0				1446	623133

DEPTH (m) From	DEPTH (m) To	GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING Dia (mm)	CASING From (m)	CASING To (m)
0	**0.5**		**SAND**	**Fine – med. grained, grey / brown.**	Topsoil				
0.5	**12.5**		**SAND / Clayey SAND**	**Orange / yellow, fine – med. grained.**	Bridgewater Fm				
12.5 21.0	**36.0**		**SAND and SANDSTONE**	**Interlayered sand and calcrete cemented sandstone layers.** Coarse sand layer ~ 0.5 m thick.	Bridgewater Fm				
36.0	**45.0**		**Silty CLAY / SAND / LIMESTONE**	**Grey – green, bryozoal.** END OF HOLE 45 m	Gambier Limestone				

REMARKS:

Gravel pack: 38 – 44 m
Bentonite seal
Cement plug.

DRILL TYPE: Rotary mud	COMPLETED: 50 mm PVC, slotted screen 41 – 44 m.
DRILL FLUID: mud	LOGGED BY: N. Howes
DATE: 27/3/03	SHEET 1 OF 1

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM

WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61236

UNIT No. PB 6.

Hundred: Glen Roy Sec: 387

Coordinates: E 462342 N 5942654 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY

DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
		From	To	L/sec	Test length	Method	mg/L	Analysis No.
NA	15.62	16.0	18.0				1043	623132

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**5**		**SAND**	**Fine – med. grained, grey / brown.**	Topsoil				
5	**11.0**		**SAND / Clayey SAND**	**Orange / yellow, fine – med. grained.**	Bridgewater Fm				
11.0	**20.0**		**SAND and SANDSTONE**	**Interlayered sand and calcrete cemented sandstone layers.** END OF HOLE 20.0 m	Bridgewater Fm				

REMARKS:

Gravel pack: 15 – 18 m
Bentonite seal

DRILL TYPE: Rotary mud	COMPLETED: 50 mm PVC, slotted screen 16 – 18 m.
DRILL FLUID: mud	LOGGED BY: N. Howes
DATE: 28/3/03	SHEET 1 OF 1

GROUNDWATER PROGRAM

WATER WELL LOG

The Department of Water, Land and Biodiversity Conservation

PROJECT: Padthaway Salt Accession Investigation	
PERMIT No. 61231	
UNIT No. PB 7.	
Hundred: Glen Roy	**Sec: 387**

Coordinates: E 461108 N 5941845 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m) From	INTERVAL (m) To	SUPPLY L/sec	SUPPLY Test length	SUPPLY Method	TOTAL DISSOLVED SOLIDS mg/L	TOTAL DISSOLVED SOLIDS Analysis No.
	32		35.0	37.0	< 0.1	25 mins	Airlift	-	-

DEPTH (m) From	DEPTH (m) To	GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING Dia (mm)	CASING From (m)	CASING To (m)
0	**2.2**		**SAND**	**Fine grained, grey to yellow/orange, becoming dark orange/brown.**	Topsoil				
2.2	**3.0**		**Sandy CLAY**	**Fine grained, dark orange / brown with red bands.**	Bridgewater Formation				
3.0	**14.1**		**SAND and SANDSTONE**	**Fine grained brown sand (minor clay), dry, interlayered with well-cemented calcareous sandstone, fine – med. grained, white to red/brown.**	Bridgewater Formation				
5.5	6.0			Sand becomes fine – med. grained, red-brown.					
6.2				Increasing clay content (to clayey sand), becoming moist.					
7.0	7.3			Sand becoming red-brown fine – med. grained sand, minor clay, dry.					
7.3				Sand becoming fine grained, cream coloured, dry.					
8.9				Becoming moist.					
14.1	**14.3**		**Clayey SAND**	**Fine – med. grained, red, moist.**	Bridgewater Formation				
14.3	**20.5**		**SAND and SANDSTONE**	**Fine – med. grained sand, red / orange, interlayered with hard well – cemented calcareous sandstone, fine – med. grained, white to red/brown.**	Bridgewater Formation				
16.0				Clay and moisture contents increase slightly.					
20.5	**22.0**		**Clayey SAND**	**Fine – med. grained, red, clay content increasing to 5-10 % towards bottom.**	Bridgewater Formation				
22.0	**26.5**		**SAND and SANDSTONE**	**Fine – med. grained sand, interlayered with hard well – cemented calcareous sandstone, fine – med. grained, white to red/brown.**	Bridgewater Formation				
24.9	25.0			Red fine – med. grained clayey sand layer.					
				END OF CORE 26.5 m.					

REMARKS: Gravel pack: ~ 34 – 37 m Bentonite seal	DRILL TYPE: Hollow auger, continuous core to 26.5 m then rotary air.	COMPLETED: 50 mm PVC, slotted screen 35 – 37 m.
	DRILL FLUID: None above 26.5 m, then air/foam.	LOGGED BY: D. Wohling / N. Howes
	DATE: 10/3/03	SHEET 1 OF 2

GROUNDWATER PROGRAM

WATER WELL LOG

CONTINUATION SHEET

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61235

UNIT No.

Hundred: Glen Roy **Sec: 387**

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
26.5	**45.0**			**Air drilled below 26.5 m. Geology probably similar to above, but no cuttings retrieved to confirm. Drillers noted many large cavities.** END OF HOLE 45 m	Bridgewater Formation				

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61241

UNIT No. PB 8.

Hundred: Glen Roy **Sec: adj. 316**

Coordinates: E 460552 N 5941536 El. Surface(m) El. Ref. Point(m) Datum:

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	11.4		12.5	14.5	0.1	25 mins	Airlift	1105	623134

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
0	**1.2**		**SAND**	**Fine-med. grained, dark brown, moist, friable, roots in top 20 cm.**	Topsoil				
1.2 2.4 3.3	**3.5** 3.4		**Sandy CLAY**	**Red/orange-brown, with red/orange zones, sand fine-med. grained, moist, friable.** Decreasing sand content. Includes calcareous lump 5 cm thick.	Bridgewater Formation				
3.5	**5.0**		**SANDSTONE and SAND**	**Interlayered calcareous sandstone (fine-med. grained, cream / orange) and fine sand, cream/orange, dry.**	Bridgewater Formation				
5.0 5.0 6.0 6.4 6.5 7.0	**9.5** 6.0 6.4 6.5 7.0 9.5		**SANDSTONE and CLAY/Clayey SAND**	**Interlayered pink calcareous sandstone and clay - clayey sand.** Sandstone interlayered with red clayey sand. Red sandy clay, dry-moist, crumbly. Pink calcareous sandstone. Lost sample, but included rock layers. Hard sandstone layers with red/brown sandy clay, decreasing clay content below 9.4 m	Bridgewater Formation				

REMARKS:		
Gravel pack: ~ 11.5 – 14.5 m Bentonite seal	DRILL TYPE: Hollow auger, continuous core.	COMPLETED: 50 mm pvc with slotted casing 12.5 – 14.5 m.
	DRILL FLUID: None	LOGGED BY: N. Howes
	DATE: 11/3/03	SHEET 1 OF 2

GROUNDWATER PROGRAM
WATER WELL LOG
CONTINUATION SHEET

The Department of Water, Land and Biodiversity Conservation

PROJECT: Padthaway Salt Accession Investigation

PERMIT No. 61241

UNIT No.

Hundred: Glen Roy **Sec: adj. 316**

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
9.5	**12.0**		**SAND**	**Red/brown, fine-med. grained, minor clay with calcareous lumps up to 5 cm diameter.**					
11.0	12.0			Increasing calcareous sandstone, slightly coarser.					
12.0	**16.0**		**SAND and SANDSTONE**	**Med. – coarse sand, cream coloured with sandstone. Coarsening downward below 13.0 m.**					
14.5	14.6			Hard rock layer.					
14.6				Fine-med. sand, cream, with chunks of sandstone.					
15.5				Becoming more orange.					
				END OF HOLE 16.0 m.					

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	356 or 366 days	time interval

δD	hydrogen isotope composition
$\delta^{18}O$	oxygen isotope composition
^{14}C	carbon-14 isotope (percent modern carbon)
CFC	chlorofluorocarbon (parts per trillion volume)
EC	electrical conductivity (µS/cm)
pH	acidity
ppm	parts per million
ppb	parts per billion
TDS	total dissolved solids (mg/L)

GLOSSARY

Act (the). In this document, refers to The *Natural Resources Management Act* (South Australia) 2004.

Adaptive management. A management approach, often used in natural resource management, where there is little information and/or a lot of complexity and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Algal bloom. A rapid accumulation of algal biomass (living organic matter) which can result in deterioration in water quality when the algae die and break down consuming the dissolved oxygen and releasing toxins.

Ambient. The background level of an environmental parameter (e.g. a background water quality like salinity).

Anabranch. A branch of a river that leaves the main stream.

Annual adjusted catchment yield. Annual catchment yield with the impact of dams removed.

Aquifer. An underground layer of rock or sediment which holds water and allows water to percolate through.

Aquifer, confined. Aquifer in which the upper surface is impervious and the water is held at greater than atmospheric pressure. Water in a penetrating well will rise above the surface of the aquifer.

Aquifer, storage and recovery (ASR). The process of recharging water into an aquifer for the purpose of storage and subsequent withdrawal.

Aquifer test. A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resource available for development from the well.

Aquifer, unconfined. Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

Aquitard. A layer in the geological profile that separates two aquifers and restricts the flow between them.

Arid lands. In South Australia arid lands are usually considered to be areas with an average rainfall of less than 250 mm and support pastoral activities instead of broad acre cropping.

Artesian. Under pressure such that when wells penetrate the aquifer water will rise to the ground surface without the need for pumping.

Artificial recharge. The process of artificially diverting water from the surface to an aquifer. Artificial recharge can reduce evaporation losses and increase aquifer yield. *(See recharge, natural recharge, aquifer.)*

Barrage. Specifically any of the five low weirs at the mouth of the River Murray constructed to exclude seawater from the Lower Lakes.

Baseflow. The water in a stream that results from groundwater discharge to the stream. (This discharge often maintains flows during seasonal dry periods and has important ecological functions.)

Basin. The area drained by a major river and its tributaries.

Benchmark condition. Points of reference from which change can be measured.

Biological diversity (biodiversity). The variety of life forms: the different life forms including plants, animals and micro-organisms, the genes they contain and the *ecosystems (see below)* they form. It is usually considered at three levels — genetic diversity, species diversity and ecosystem diversity.

Biota. All of the organisms at a particular locality.

Bore. *See well.*

Buffer zone. A neutral area that separates and minimises interactions between zones whose management objectives are significantly different or in conflict (e.g. a vegetated riparian zone can act as a buffer to protect the water quality and streams from adjacent land uses).

Catchment. A catchment is that area of land determined by topographic features within which rainfall will contribute to runoff at a particular point.

Catchment water management board. A statutory body established under Part 6, Division 3, s. 53 of the Act whose prime function under Division 2, s. 61 is to implement a catchment water management plan for its area.

Catchment water management plan. The plan prepared by a CWMB and adopted by the Minister in accordance with Part 7, Division 2 of the Water Resources Act 1997.

Codes of practice. Standards of management developed by industry and government, promoting techniques or methods of environmental management by which environmental objectives may be achieved.

Cone of depression. An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction which exceeds the rate of recharge. Continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality.

Conjunctive use. The utilisation of more than one source of water to satisfy a single demand.

Council of Australian Governments (COAG). A council of the Prime Minister, State Premiers, Territory Chief Ministers and the President of the Australian Local Government Association which exists to set national policy directions for Australia.

CWMB. Catchment Water Management Board.

Dams, off-stream dam. A dam, wall or other structure that is not constructed across a watercourse or drainage path and is designed to hold water diverted, or pumped, from a watercourse, a drainage path, an aquifer or from another source. Off-stream dams may capture a limited volume of surface water from the catchment above the dam.

Dams, on-stream dam. A dam, wall or other structure placed or constructed on, in or across a watercourse or drainage path for the purpose of holding and storing the natural flow of that watercourse or the surface water.

Dams, turkey nest dam. An off-stream dam that does not capture any surface water from the catchment above the dam.

Diffuse source pollution. Pollution from sources such as an eroding paddock, urban or suburban lands and forests; spread out, and often not easily identified or managed.

District Plan. (District Soil Conservation Plan) An approved soil conservation plan under the repealed *Soil Conservation Act 1989*. These plans are taken to form part of the relevant regional NRM plans under the transitional provisions of the *Natural Resources Management Act 2004* (Schedule 4 – subclause 53[4] until regional NRM plans are prepared under Chapter 4, Part 2 of the Act.

Domestic purpose. The taking of water for ordinary household purposes and includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares.

Domestic wastewater. Water used in the disposal of human waste, for personal washing, washing clothes or dishes, and swimming pools.

DSS (decision support system). A system of logic or a set of rules derived from experts, to assist decision making. Typically they are constructed as computer programs.

DSS. Dissolved suspended solids.

DWLBC. Department of Water, Land and Biodiversity Conservation. Government of South Australia.

EC. Abbreviation for electrical conductivity. 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25 degrees Celsius. Commonly used to indicate the salinity of water.

Ecological processes. All biological, physical or chemical processes that maintain an ecosystem.

Ecological values. The habitats, the natural ecological processes and the biodiversity of ecosystems.

Ecologically sustainable development (ESD). Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased.

Ecology. The study of the relationships between living organisms and their environment.

Ecosystem. Any system in which there is an interdependence upon and interaction between living organisms and their immediate physical, chemical and biological environment.

Ecosystem Services. All biological, physical or chemical processes that maintain ecosystems and biodiversity and provide inputs and waste treatment services that support human activities.

Effluent. Domestic wastewater and industrial wastewater.

EIP. Environment improvement program.

EMLR. Eastern Mount Lofty Ranges.

Entitlement flows. Minimum monthly River Murray flows to South Australia agreed in the Murray-Darling Basin Agreement 1992.

Environmental values. The uses of the environment that are recognised as of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

Environmental water provisions. Those parts of environmental water requirements that can be met, at any given time. This is what can be provided at that time with consideration of existing users' rights, social and economic impacts.

Environmental water requirements. The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk.

EP. Eyre Peninsula.

EPA. Environment Protection Agency.

Ephemeral streams / wetlands. Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

Erosion. Natural breakdown and movement of soil and rock by water, wind or ice. The process may be accelerated by human activities.

ESD. Ecologically sustainable development *(see above for definition)*.

Estuaries. Semi-enclosed waterbodies at the lower end of a freshwater stream that are subject to marine, freshwater and terrestrial influences and experience periodic fluctuations and gradients in salinity.

Eutrophication. Degradation of water quality due to enrichment by nutrients (primarily nitrogen and phosphorus), causing excessive plant growth and decay. *(See algal bloom).*

Evapotranspiration. The total loss of water as a result of transpiration from plants and evaporation from land, and surface waterbodies.

Fishway. A generic term describing all mechanisms that allow the passage of fish along a waterway. Specific structures include fish ladders (gentle sloping channels with baffles that reduce the velocity of water and provide resting places for fish as they 'climb' over a weir) and fishlifts (chambers, rather like lift-wells, that are flooded and emptied to enable fish to move across a barrier).

Floodplain. Of a watercourse means: (a) the floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under Part 7 of the Water Resources Act 1997; or (b) where paragraph (a) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the Development Act 1993, or (c) where neither paragraph (a) nor paragraph (b) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse.

Flow bands. Flows of different frequency, volume and duration.

GAB. Great Artesian Basin.

Gigalitre (GL). One thousand million litres (1 000 000 000).

GIS (geographic information system). Computer software allows for the linking of geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

GL. *See gigalitre.*

Greenhouse effect. The balance of incoming and outgoing solar radiation which regulates our climate. Changes to the composition of the atmosphere such as the addition of carbon dioxide through human activities, have the potential to alter the radiation balance and to effect changes to the climate. Scientists suggest that changes would include global warming, a rise in sea level and shifts in rainfall patterns.

Geological features. Include geological monuments, landscape amenity and the substrate of land systems and ecosystems.

Greywater. Household wastewater excluding sewage effluent. Wastewater from kitchen, laundry and bathroom.

Groundwater. *See underground water.*

Habitat. The natural place or type of site in which an animal or plant, or communities of plants and animals, lives.

Heavy metal. Any metal with a high atomic weight (usually, although not exclusively, greater than 100), for example mercury, lead and chromium. Heavy metals have a widespread industrial use, and many are released into the biosphere via air, water and solids pollution. Usually these metals are toxic at low concentrations to most plant and animal life.

Hydrogeology. The study of groundwater, which includes its occurrence, recharge and discharge processes and the properties of aquifers. *(See hydrology.)*

Hydrography. The discipline related to the measurement and recording of parameters associated with the hydrological cycle, both historic and real time.

Hydrology. The study of the characteristics, occurrence, movement and utilisation of water on and below the earth's surface and within its atmosphere. *(See hydrogeology.)*

Hyporheic zone. The wetted zone among sediments below and alongside rivers. It is a refuge for some aquatic fauna.

Indigenous species. A species that occurs naturally in a region.

Industrial wastewater. Water (not being domestic wastewater) that has been used in the course of carrying on a business (including water used in the watering of irrigation of plants) that has been allowed to run to waste or has been disposed of or has been collected for disposal.

Infrastructure. Artificial lakes; or dams or reservoirs; or embankments, walls, channels or other works; or buildings or structures; or pipes, machinery or other equipment.

Integrated catchment management. Natural resources management that considers in an integrated manner the total long-term effect of land and water management practices on a catchment basis, from production and environmental viewpoints.

Intensive farming. A method of keeping animals in the course of carrying on the business of primary production in which the animals are confined to a small space or area and are usually fed by hand or by mechanical means.

Irrigation. Watering land by any means for the purpose of growing plants.

Irrigation season. The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May.

Lake. A natural lake, pond, lagoon, wetland or spring (whether modified or not) and includes: part of a lake; and a body of water declared by regulation to be a lake; a reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

Land. Whether under water or not and includes an interest in land and any building or structure fixed to the land.

Land capability. The ability of the land to accept a type and intensity of use without sustaining long-term damage.

Leaching. Removal of material in solution such as minerals, nutrients and salts through soil.

Licence. A licence to take water in accordance with the Water Resources Act 1997. *(See water licence.)*

Licensee. A person who holds a water licence.

Local water management plan. A plan prepared by a council and adopted by the Minister in accordance with Part 7, Division 4 of the Act.

Macro-invertebrates. Animals without backbones that are typically of a size that is visible to the naked eye. They are a major component of aquatic ecosystem biodiversity and fundamental in food webs.

MDBC. Murray-Darling Basin Commission.

Megalitre (ML). One million litres (1 000 000).

ML. *See megalitre.*

MLR. Mount Lofty Ranges.

Model. A conceptual or mathematical means of understanding elements of the real world which allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change.

Mount Lofty Ranges Watershed. The area prescribed by Schedule 1 of the regulations.

Natural recharge. The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc.) *(See recharge area, artificial recharge.)*

NHMRC. National Health and Medical Research Council.

NHT. Natural Heritage Trust.

Natural Resources. Soil; water resources; geological features and landscapes; native vegetation, native animals and other native organisms; ecosystems.

Natural Resources Management (NRM). All activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively.

Occupier of land. A person who has, or is entitled to, possession or control of the land.

Owner of land. In relation to land alienated from the Crown by grant in fee simple — the holder of the fee simple; in relation to dedicated land within the meaning of the *Crown Lands Act 1929* that has not been granted in fee simple but which is under the care, control and management of a Minister, body or other person — the Minister, body or other person; in relation to land held under Crown lease or licence — the lessee or licensee; in relation to land held under an agreement to purchase from the Crown — the person entitled to the benefit of the agreement; in relation to any other land — the Minister who is responsible for the care, control and management of the land or, if no Minister is responsible for the land, the Minister for Environment and Heritage.

Palaeochannels. Ancient buried river channels in arid areas of the state. Aquifers in palaeochannels can yield useful quantities of groundwater or be suitable for ASR.

Pasture. Grassland used for the production of grazing animals such as sheep and cattle.

Percentile. A way of describing sets of data by ranking the data set and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

Permeability. A measure of the ease with which water flows through an aquifer or aquitard.

Personal property. All forms of property other than real property. For example, shares or a water licence.

Phreaphytic vegetation. Vegetation that exists in a climate more arid than its normal range by virtue of its access to groundwater.

Phytoplankton. The plant constituent of organisms inhabiting the surface layer of a lake; mainly single-cell algae.

PIRSA. (Department of) Primary Industries and Resources South Australia.

Pollution, diffuse source. Pollution from sources that are spread out and not easily identified or managed (e.g. an eroding paddock, urban or suburban lands and forests).

Pollution, point source. A localised source of pollution.

Potable water. Water suitable for human consumption.

Potentiometric head. The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer.

Precautionary principle. Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

Prescribed area, surface water. Part of the State declared to be a surface water prescribed area under the Water Resources Act 1997.

Prescribed lake. A lake declared to be a prescribed lake under the Water Resources Act 1997.

Prescribed water resource. A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed watercourse. A watercourse declared to be a prescribed watercourse under the Water Resources Act 1997.

Prescribed well. A well declared to be a prescribed well under the Water Resources Act 1997.

Property right. A right of ownership or some other right to property, whether real property or personal property.

Proponent. The person or persons (who may be a body corporate) seeking approval to take water from prescribed water.

PWA. Prescribed Wells Area.

PWCA. Prescribed Watercourse Area.

PWRA. Prescribed Water Resources Area.

Ramsar Convention. This is an international treaty on wetlands titled The Convention on Wetlands of International Importance Especially as Waterfowl Habitat. It is administered by the International Union for Conservation of Nature and Natural Resources. It was signed in the town of Ramsar, Iran in 1971, hence its common name. The Convention includes a list of wetlands of international importance and protocols regarding the management of these wetlands. Australia became a signatory in 1974.

Recharge area. The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. *(See artificial recharge, natural recharge.)*

Reclaimed water. Treated effluent of a quality suitable for the designated purpose.

Rehabilitation (of waterbodies). Actions that improve the ecological health of a waterbody by reinstating important elements of the environment that existed prior to European settlement.

Remediation (of waterbodies). Actions that improve the ecological condition of a waterbody without necessarily reinstating elements of the environment that existed prior to European settlement.

Restoration (of waterbodies). Actions that reinstate the pre-European condition of a waterbody.

Reticulated water. Water supplied through a piped distribution system.

Riffles. Shallow stream section with fast and turbulent flow.

Riparian landholder. A person whose property abuts a watercourse or through whose property a watercourse runs.

Riparian rights. These were old common law rights of access to, and use of water. These common law rights were abolished with the enactment of the Water Resources Act 1997, which now includes similar rights under s. 7. Riparian rights are therefore now statutory rights under the Act. Where the resource is not prescribed (Water Resources Act 1997, s. 8) or subject to restrictions (Water Resources Act 1997, s. 16), riparian landholders may take any amount of water from watercourses, lakes or wells without consideration to downstream landholders, if it is to be used for stock or domestic purposes. If the capture of water from watercourses and groundwater is to be used for any other purpose then the right of downstream landholders must be protected. Landholders may take any amount of surface water for any purpose without regard to other landholders, unless the surface water is prescribed or subject to restrictions.

Riparian zone. That part of the landscape adjacent to a water body, that influences and is influenced by watercourse processes. This can include landform, hydrological or vegetation definitions. It is commonly used to include the in-stream habitats, bed, banks and sometimes floodplains of watercourses.

Seasonal watercourses or wetlands. Those watercourses and wetlands that contain water on a seasonal basis, usually over the winter/spring period, although there may be some flow or standing water at other times.

State water plan. The plan prepared by the Minister under Part 7, Division 1, s. 90 of the Act.

Stock Use. The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act).

Stormwater. Runoff in an urban area.

Surface water. (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir.

Taxa. General term for a group identified by taxonomy — which is the science of describing, naming and classifying organisms.

To take water. From a water resource includes (a) to take water by pumping or syphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water in a watercourse from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir.

Total kjeldhal nitrogen (TKN). The sum of aqueous ammonia and organic nitrogen. Used as a measure of probable sewage pollution.

Transfer. A transfer of a licence (including its water allocation) to another person, or the whole or part of the water allocation of a licence to another licensee or the Minister under Part 5, Division 3, s. 38 of the Act. The transfer may be absolute or for a limited period.

Underground water (groundwater). Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground.

Volumetric allocation. An allocation of water expressed on a water licence as a volume (e.g. kilolitres) to be used over a specified period of time, usually per water use year (as distinct from any other sort of allocation).

Wastewater. *See domestic wastewater, industrial wastewater.*

Water affecting activities. Activities referred to in Part 4, Division 1, s. 9 of the Act.

Water allocation. (a) in respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (b) in respect of water taken pursuant to an authorisation under s. 11 means the maximum quantity of water that can be taken and used pursuant to the authorisation.

Water allocation, area based. An allocation of water that entitles the licensee to irrigate a specified area of land for a specified period of time usually per water use year.

Water allocation plan (WAP). A plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with Division 3 of Part 7 of the Act.

Water licence. A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area. This grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water. A water licence confers a property right on the holder of the licence and this right is separate from land title.

Water plans. The State Water Plan, catchment water management plans, water allocation plans and local water management plans prepared under Part 7 of the Act.

Water service provider. A person or corporate body that supplies water for domestic, industrial or irrigation purposes or manages wastewater.

Waterbody. Waterbodies include watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers.

Watercourse. A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; and a lake through which water flows; and a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse.

Water-dependent ecosystems. Those parts of the environment, the species composition and natural ecological processes, which are determined by the permanent or temporary presence of flowing or standing water, above or below ground. The in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems.

Water-use year. The period between 1 July in any given calendar year and 30 June the following calendar year. This is also called a licensing year.

Well. (a) an opening in the ground excavated for the purpose of obtaining access to underground water; (b) an opening in the ground excavated for some other purpose but that gives access to underground water; (c) a natural opening in the ground that gives access to underground water.

Wetlands. Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic/intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tides does not exceed six metres.

REFERENCES

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 1998. Crop Evapotranspiration; Guidelines for Computing Crop Water Requirements, FAO Irrigation and Drainage Paper, 56, Food and Agriculture Organization of the United Nations, Rome.

Allison, G.B. and Hughes, M.W., 1983, The use of natural tracers as indicators of soilwater movement in a temperate semi-arid region. J. Hydrol., 60:157-173.

Allison, G.B., Cook, P.G., Barnett, S.R., Jolly, I.D. and Hughes, M.W., 1990, Land clearance and river salinisation in the Western Murray Basin, Australia. J. Hydrol., 119:1-20.

Blackburn, G., 1964, The soils of Counties MacDonnell and Robe, South Australia. CSIRO Division of Soils, Soils and Land Use Series No. 45.

Blake, W.J.R., 1980, Geology and hydrogeology of the Early Tertiary sediments of the Otway Basin., La Trobe University (Victoria). MSc. thesis (unpublished).

Brown, K., 1998a, Groundwater Quality Investigations, Padthaway Irrigation Area - Hydrogeological Appraisal of Management Plan Option One: Sourcing Groundwater from the Naracoorte Ranges., Dept. of Mines and Energy Report Book 98/4.

Brown, K., 1998b, Padthaway Irrigation Area, South East, South Australia - Groundwater Quality Investigation Drilling Program, December 1996-January 1997., Dept. of Mines and Energy Report Book 98/5.

Cobb, M. and Brown, K., 2000, Water Resource Assessment: Padthaway Prescribed Wells Area for the South East Catchment Water Management Board., PIRSA Report Book 2000/00031.

Desmier, R.E., 1992, Estimation of the water requirements of irrigated crops in the Padthaway Proclaimed Region, South Australia.

DWLBC, 2004, Obswell Groundwater Well Database, https://info.pir.sa.gov.au/obswell/new/obs

Well/MainMenu/menu, January, 2004.

Gat, J.R., Lakes, in Stable isotope Hydrology, Deuterium and Oxygen-18 in the water cycle, edited by J.R Gat and R. Gonfiantini, Tech Rep. Ser. No. 210, pp. 203-221, Int. At. Energy Agency, Vienna, 1981.

Gravestock, D.I., Hill, A.J. and Morton, J.G.G., 1986, A review of the structure, geology, and hydrocarbon potential of the Otway Basin in South Australia., South Australia. Dept. of Mines and Energy Report Book, 86/77.

Grindley, J., 1967, The estimation of soil moisture deficits. Meteorol. Mag., 96 (1137): 97-108.

Grindley, J., 1969, The calculation of actual evaporation and soil moisture deficits over specified catchment areas. Meteorol. Off. Bracknell, Hydrol. Mem., No. 38.

Haq, B.U., Hardenbol, J. and Vail, P.R., 1987, Chronology of fluctuating sea levels since the Triassic., Science, 235(4793): 1156-1167.

Holdgate, G.R., 1982, Stratigraphy, sedimentology and hydrocarbon prospects of the Dilwyn Formation, in the central Otway Basin of southeastern Australia., Royal Society of Victoria, Proceedings, 93:129-148.

Leaney, F.W.J. and Herczeg, A.L., 1999, The origin of fresh groundwater in the SW Murray Basin and its potential for salinisation. CSIRO Land and Water Technical Report 7/99.

Lewis, D.W., 1983, Practical Sedimentology. Hutchinson Ross, Pennsylvania.

Penman, H.L., 1948, Natural evaporation from open water, bare soil and grass. Proc. R. Soc. London, Ser A, 193: 120-146

Penman, H.L., 1949, The dependence of transpiration on weather and soil conditions. J.Soil Sci., 1:74-89

Penman, H.L., 1950, The water balance of the Stour catchment area. J Inst. Water Eng., 4:457-469

Rose, C.D., Dayananda, P.W.A,, Nielson, and D.R, Biggar J.W., 1979, Longterm solute dynamics and hydrology in irrigated slowly permeable soils Irrig Sci 1:77

Simpson, H.J., Herczeg, A.I., and Meyer, W.S. Stable Isotope Ratios In Irrigation Water Can Estimate Rice Crop Evaporation, Geophysical Research letters. 19: 377-380, 1992

Socki, R.A., Karlsson, H.R. and Gibson, E.K. Jr., 1992, Extraction techniques for the determination of oxygen-18 in water using preevacuated glass vials., Anal. Chem., 64, pp 829-831.

Sprigg, R.C., 1952, The geology of the South-East provinces, South Australia, with special reference to Quaternary coast-line migrations and modern beach developments. South Australia. Geological Survey. Bulletin, 29.

Stadter, F., Bradley, J., DeSilva, J., Foley, G. and Robinson, M., 1995, Five Year Technical Review 1991-1995 Border (Groundwater Agreement) Act, 1985.

Wetherby, K.G. and Armstrong, D.W., 1978, Soils of the Padthaway Irrigation Area, South Australia. South Australia. Department of Agriculture and Fisheries.

White, M.R., 1995, Micropalaeontological analysis of 26 petroleum wells in the Gambier Basin, South Australia. South Australia. Dept. of Mines and Energy, Report Book, 95/6.