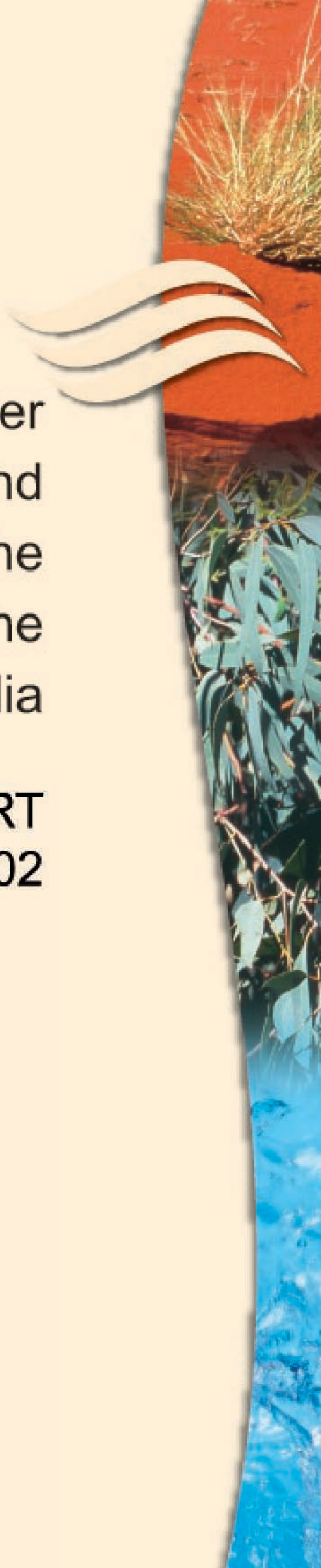
Review of groundwater resource condition and management principles for the Tertiary Limestone Aquifer in the South East of South Australia

DWLBC REPORT 2006/02



Government of South Australia

Department of Water, Land and Biodiversity Conservation

Review of groundwater resource condition and management principles for the Tertiary Limestone Aquifer in the South East of South Australia

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Resource Allocation Division
Department of Water, Land and Biodiversity Conservation

February 2006

Report DWLBC 2006/02

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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

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The Department of Water, Land and Biodiversity Conservation was requested by the SE Catchment Water Management Board to undertake a comprehensive review of the groundwater resource condition and management framework for the Tertiary Limestone Aquifer in the South East region of South Australia. This region comprises three Prescribed Wells Areas (PWAs): Lower Limestone Coast (formerly Lacepede-Kongorong, Naracoorte Ranges and Comaum-Caroline), Padthaway and Tatiara. The timing of this review aligns with a statutory requirement of the *Natural Resources Management Act, 2004* to review Water Allocation Plans (WAPs) every five years.

RESOURCE CONDITION

Trigger levels were adopted to flag areas of the PWAs where rates of groundwater level decline or salinity increase exceed -0.1 m/yr or 10 mg/L/yr, respectively. By analysing water level and salinity trends from the Department's observation well database, seven 'hotspot' areas were identified across the South East where water level and/or salinity triggers have been exceeded. Most water level hydrographs from these hotspot areas demonstrate a strong correlation with annual rainfall, making it difficult to differentiate the relative impacts of climate variability, land-use change or excessive extraction. The link between rainfall and hydrograph response can be either direct (below average rainfall resulting in reduced recharge) or indirect (below average rainfall resulting in greater demand for irrigation water). Because water allocation in the South East is currently based on theoretical crop water requirements rather than volumetric extraction, it was not possible to isolate the dominant cause of water level decline or salinity rise in each management area. Nevertheless, the hotspot areas and proposed reasons for exceeding trigger levels (in addition to climatic influences) are:

- **Management areas 1–3 (Padthaway PWA)** – Water level declines, probably caused by excessive groundwater pumping in Management Area 1. Contributions of salt to management areas 2 and 3 from local recycling and influx from the adjacent Ranges (i.e. Management Area 4).
- **Stirling, Willalooka and Wirrega management areas (Tatiara PWA)** – Water levels are declining and groundwater salinity is rising. Rising salinity levels are most likely due to a combination of irrigation recycling and geological controls. Water levels are declining because current use exceeds both the existing and proposed Permissible Annual Volumes for these areas. Current allocations also exceed the existing and proposed Permissible Annual Volumes for these areas.
- **Frances, Joanna and Zone 5A management areas (Lower Limestone Coast PWA)** – Declining water levels since the early 1990s, likely due to a combination of climate variability and intensive extraction for irrigation on both the South Australian and Victorian sides of the border. Salinity trends inconclusive.
- **Glenburnie, Myora and Zone 2A management areas (Lower Limestone Coast PWA)** – Declining water levels for the last thirty years, no consistent salinity trend. Direct evidence of forest impacts on groundwater in Nangwarry observation wells (e.g., NAN009) after Ash Wednesday bush fires. In addition the level of stock and domestic water use around Mount Gambier is estimated to be high.

- **Kongorong and MacDonnell management areas (Lower Limestone Coast PWA)** – Declining water levels during the 1990s, most likely caused by intensive groundwater pumping for irrigation.
- **Marcollat, Peacock and Woolumbool management areas (Lower Limestone Coast PWA)** – Abrupt drops in mean annual water level towards the end of the 1990s, possibly coinciding with (and driven by) the construction of deep groundwater drains in the area.
- **Northern half of Zone 3A management area** – high rates of salinity increase, possibly due to irrigation recycling.

GROUNDWATER RECHARGE AND USE

The best available dataset for regional hydrogeological investigations across the South East is the water level observation network. Accordingly, the most robust method for estimating recharge rates for all management areas should incorporate this data set. This review therefore deemed the Water Table Fluctuation (WTF) method as being the most satisfactory approach for revising recharge rates. Some areas within the PWAs were not appropriate for application of the WTF method. In these cases the recharge rate was estimated by either weighting existing recharge rates based on soil and land use type (Border Designated Area Zones 2A to 6A) or weighting soil related recharge rates from Allison and Hughes, 1978 (lower South East management areas). For management areas where none of these approaches could be used to improve current estimates of recharge rates, the rate was left at the existing value.

A new approach was used to determine the total available recharge (TAR) for allocation in each management area. Forestry impacts are now considered on the “use” side of the water budget ledger, reflecting regulations under the *NRM Act 2004* that acknowledge commercial forestry as a ‘water affecting activity’. Under this scheme, the only component of the water budget that is incorporated into the TAR determination is that for Environmental Water Requirements (EWRs). The EWRs were set at a nominal 10% of the total vertical recharge assuming (a) no forested areas and (b) zero recharge beneath lakes and native vegetation. This component provides water for Groundwater Dependent Ecosystems (GDEs) and an allowance for lateral throughflow in the aquifer.

Current water “use” was determined as the sum of four components:

- Forest recharge debits (83 % of recharge for softwood and 77 % for hardwood, applied over agreed threshold areas). These figures were determined from the best scientific research conducted to date, and incorporate changes in canopy cover throughout the growth cycle of the forest.
- Forest water use (2.59 ML/ha/yr for softwood and 2.34 ML/ha/yr for hardwood, applied over current forested estate areas). These figures were also determined from the best scientific research conducted to date, and incorporate changes in groundwater extraction throughout the growth cycle of the forest.
- Total allocations (incorporating licensed extractions for irrigation, industrial and town water supplies).
- Stock and domestic water use (as per the 2001 WAPs).

PERMISSIBLE ANNUAL VOLUMES

In this review, the PAV for each management area has been revised to the new total available recharge (TAR) values. There are four categories of management areas that need to be considered for future management purposes:

- Management areas identified as hotspots having total use greater than total available recharge: Padthaway Management Area 2, Stirling, Wirrega, Zones 2A and 3A. Current studies in Padthaway, the Hundred of Stirling and the Border Designated Area will provide improved understanding of the impacts of different land uses, which will help to inform future management decisions for these areas.

- Management areas identified as hotspots but having total use less than the revised total available recharge: Glenburnie, Kongorong, MacDonnell, Marcollat, Peacock and Woolumbool.

  Glenburnie, Kongorong and MacDonnell were determined to be under-allocated based on revised recharge rates, however, these recharge rates apply to upper units of the TLA rather than the deeper Camelback Member where the majority of extraction occurs. The revised recharge rates are higher than those in the current WAPs but actual volumetric extractions for irrigation are likely to exceed the current allocation volumes, which are based on the hectare IE allocation rates.

  Marcollat, Peacock, and Woolumbool were identified through the hotspot analysis due to the impacts of deep drains rather than excessive volumetric extraction for irrigation.

- Management areas not identified as hotspots but having total use greater than total available recharge: Beamma, Coles, Hindmarsh, Hynam East, Mount Benson, Shaugh, Short and Tatiara.

  The Hindmarsh management area supplies the majority of groundwater used by Kimberly Clark Australia Pty Ltd., which does not have a licensed allocation under the current WAP.

  The remaining management areas are over-allocated either due to potential impacts of plantation forests or large areas of native vegetation that were previously unaccounted for in PAV determinations.

- The 39 of 73 management areas having total use less than total available recharge. These were not identified as hotspots.

  It is important as a basic principle for sustainability to ensure sufficient lateral throughflow occurs in areas characterised by highly variable groundwater salinity to mitigate potential water quality threats.

In recognition of the potential uncertainties associated with estimating recharge rates, stock and domestic water requirements and current allocations based on the irrigation equivalent system, all management areas that were not identified as hotpots but having current use within ±20% of the TAR are considered to be in balance.

OTHER CONSIDERATIONS

This review also considered current provisions of the WAPs to protect GDEs, and made recommendations to the Board as to what (if any) changes are required for management area boundaries, hydrogeological assessment methods and resource monitoring systems.

1. INTRODUCTION

1.1 BACKGROUND AND SCOPE OF WORK

At the request of the South East Catchment Water Management Board (SECWMB), the Department of Water Land and Biodiversity Conservation (DWLBC) has undertaken a review of the current Permissible Annual Volume (PAV) and level of use for the Tertiary Limestone Aquifer (TLA) in three of the Prescribed Wells Areas (PWAs) of south-eastern South Australia. In undertaking the review, the Department agreed to assess the condition of the TLA groundwater resource, to review the methodology used to derive the PAV, to include an environmental component in the PAV, and to account for potential forestry impacts in the groundwater allocation process.

Results of the study are contained within this document and meet the statutory requirements under the *Natural Resource Management Act 2004* to review the Water Allocation Plan (WAP) for each PWA every 5 years, next due at the end of June 2006. Water allocation plans form the statutory and policy frameworks for groundwater allocation and management in each PWA. The WAPs must include an assessment of the capacity of the resource to meet the demands for water, and provide for the allocation and use of water so that:

- An equitable balance is achieved between the social, economic and environmental needs for water; and
- The rate of use of the water is sustainable.

The following PWAs were included in this study (Fig. 1):

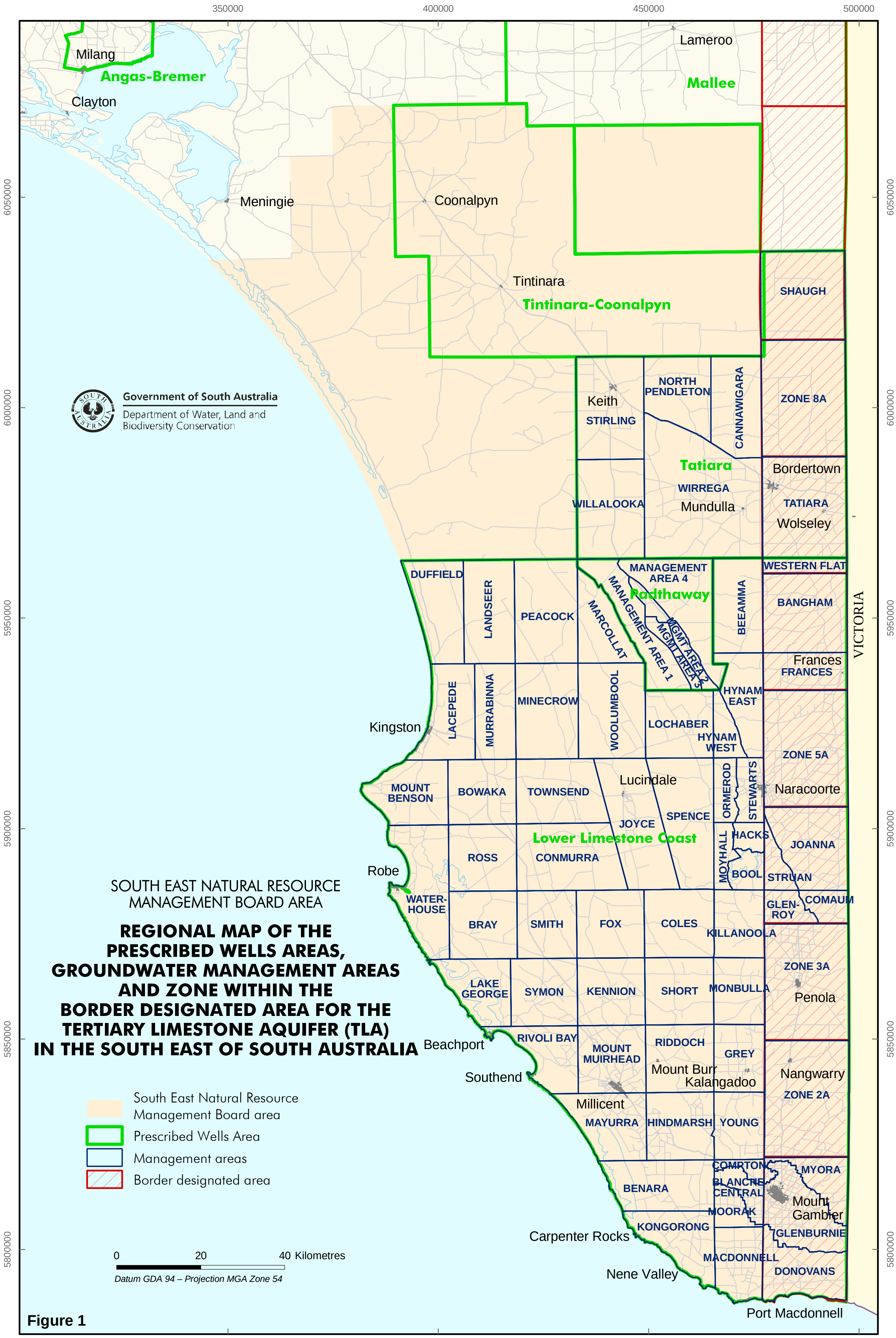
- Lower Limestone Coast
  (formerly Lacepede-Kongorong, Comaum-Caroline & Naracoorte Ranges)
- Padthaway
- Tatiara

This review does not include results from the ongoing Volumetric Conversion Project undertaken by DWLBC. Until reliable groundwater extraction figures have been published, the estimates of Total Available Recharge (i.e. recommended PAV) presented herein can only be compared against current licensed allocations, potential forestry impacts and stock/domestic water requirements. Nevertheless, this comparison reveals areas that are apparently over-allocated and/or over-used, which can then be associated with observed water level and salinity trends.

1.2 OBJECTIVES

The main objectives and approaches of the review were:

- **Objective 1.** Assess the current condition of the groundwater resources in order to determine the capacity of the unconfined aquifer in each PWA to meet the demands for water on a continuing basis.



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Approach: Temporal trends in groundwater levels and salinity of the unconfined aquifer were assessed for each observation well in the DWLBC network over the last 5 years, 10 years and entire monitoring record. Observation wells with trends that exceeded an adopted water level or salinity trigger value were then examined to determine the likely cause(s). For completeness, trends were also calculated and mapped for the confined aquifer.

- **Objective 2.** Examine and recommend an appropriate methodology for determining groundwater recharge to the unconfined aquifer for the purposes of better estimating the PAV.

  Approach: The Water Table Fluctuation method for determining mean annual recharge was reviewed and applied to appropriate management areas. For all other areas, recharge was either left unchanged or weighted spatially according to soil and land-use coverage.

- **Objective 3.** Assess the current water allocation and use from the groundwater resource from all extractive users, considering that the basis of water allocation is to change from net water use to total extraction through the conversion to volumetric allocations.

  Approach: Revised estimates of Total Available Recharge (TAR, as opposed to PAV) were compared with current allocations/demand for each management area. Estimates of forest water requirements including both recharge interception and direct extraction were calculated, and stock and domestic use was estimated and added to total allocations as reported by DWLBC Licensing South East.

- **Objective 4.** Determine whether the capacity of the resource is sufficient to meet the demand identified on a continuing basis in each management area, and the reasons for the determination.

  Approach: Future demand for groundwater was assumed to be approximately equal to current allocations/demand, and does not consider volumetric irrigation requirements as this information is being compiled through the Volumetric Conversion Project.

- **Objective 5.** Recommend a methodology to protect the needs of Groundwater Dependent Ecosystems (GDEs).

  Approach: Methodologies to protect Groundwater Dependent Ecosystems have been identified and are currently under review.

- **Objective 6.** Assess the implications of changing the boundaries of the TLA management areas.

  Approach: The merits of amalgamating management areas are discussed in terms of the impacts on the resource.

- **Objective 7.** Evaluate the adequacy of the current hydrogeological assessment methods for groundwater license transfers.

  Approach: Hydrogeological assessments for groundwater licence transfers for both the unconfined and confined aquifers were reviewed to determine if they were adequate to meet current allocation issues.

- **Objective 8.** Evaluate the adequacy of current groundwater resource monitoring systems.

  Approach: The current groundwater-level and salinity monitoring networks in the South East were compared with requirements based on current and future demands of the resource.

1.3 HYDROGEOLOGICAL AND CLIMATIC SETTING

The hydrogeology and hydrostratigraphic nomenclature of the South East region is well documented (e.g., see Bradley et al, 1995 and Brown et al, 2001). The groundwater resource is managed as two distinct groundwater systems, an upper unconfined aquifer referred to as the Tertiary Limestone Aquifer (TLA) and a confined aquifer referred to as the Tertiary Confined Sand Aquifer (TCSA).

Groundwater flow is generally from east to west originating from the Dundas Plateau in south-western Victoria for both aquifers. This is demonstrated in the water table and potentiometric contours shown in Figures 2 and 3. The two sets of water table contours on Figure 2 show the seasonal variability in water table distribution.

The climate of the South East region is typified by hot, dry summers and cool, wet winters. Annual rainfall ranges from more than 800 mm in the south to approximately 450 mm in the north. Potential annual evapotranspiration increases from ~1400 mm in the south to ~1800 mm in the north. Analysis of climatic trends in the lower South East has revealed a general drying trend since the early 1950s (McInnes et. al., 2003). This is reflected in most groundwater hydrographs and was highlighted by Brown et al. (2001) which demonstrated a strong relationship between decreases in average annual rainfall and declining water levels measured in observation wells for both the confined and unconfined aquifers over the last 40 years.

Average maximum temperature has increased by 0.17^{o}C per decade in South Australia since 1950, with the minimum increasing by 0.18^{o}C per decade, and overall, the average temperature by 0.17^{o}C per decade (McInnes et al., 2003). The trends in annual rainfall since 1910 show an overall decline in rainfall in South Australia compared with other parts of the continent.

Projected changes in climatic condition from modelling results indicate an increase in future annual average temperatures, as well as variations in the seasonal temperature and rainfall across the State (McInnes et al, 2003). In the South East region climate modelling has indicated a significant variation from the current weather pattern. Predicted changes include a continuation of the increasing temperature trend and an overall decreasing annual rainfall trend most significantly occurring in the spring. Annual decreases in rainfall of up to 15% are predicted for 2030 and up to 60% by 2070 (McInnes et al., 2003). The close relationship between climate and groundwater levels in the aquifers, will in-turn, continue to have a negative impact on the groundwater resources of the South East.

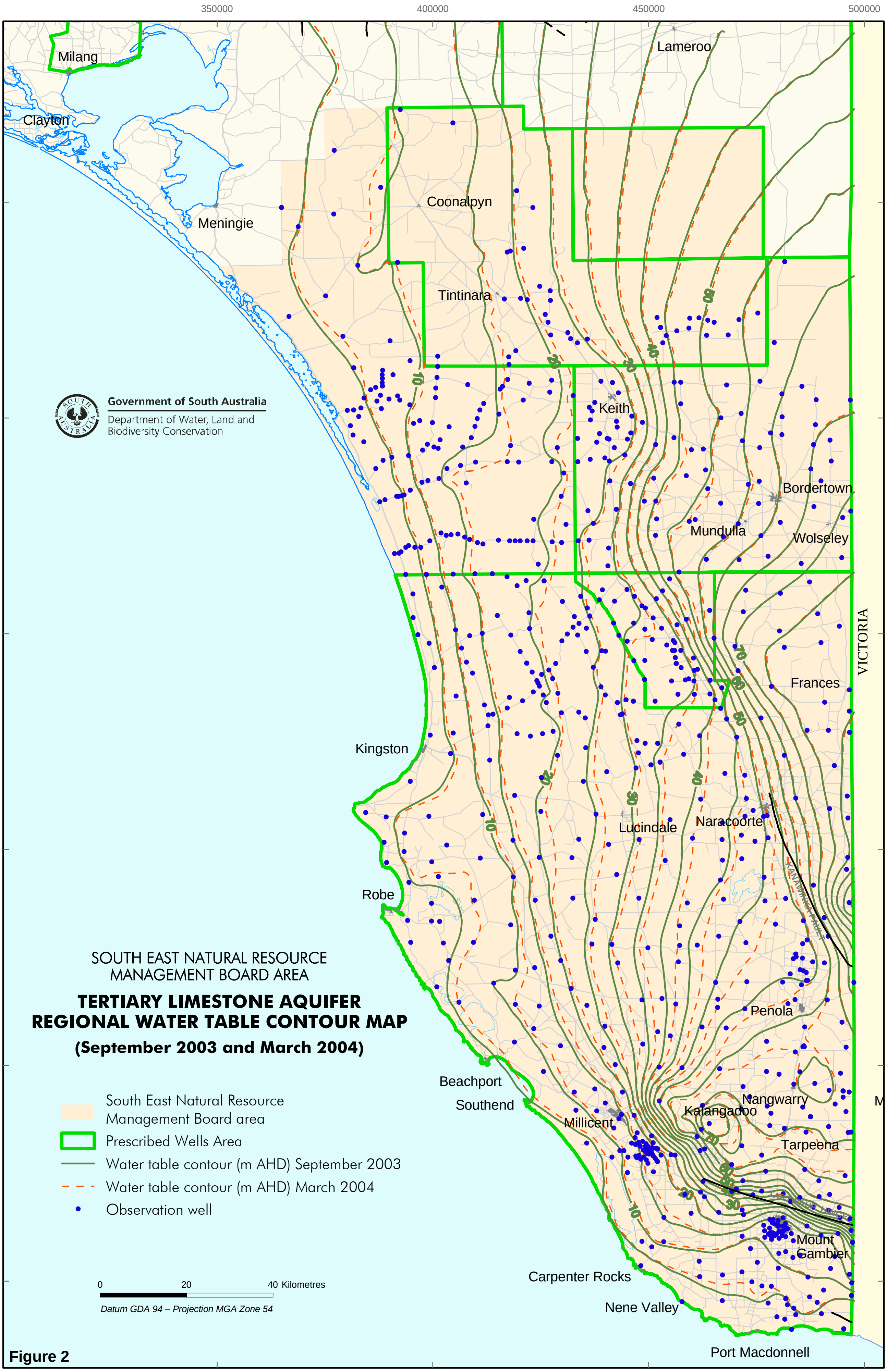

Figure 2

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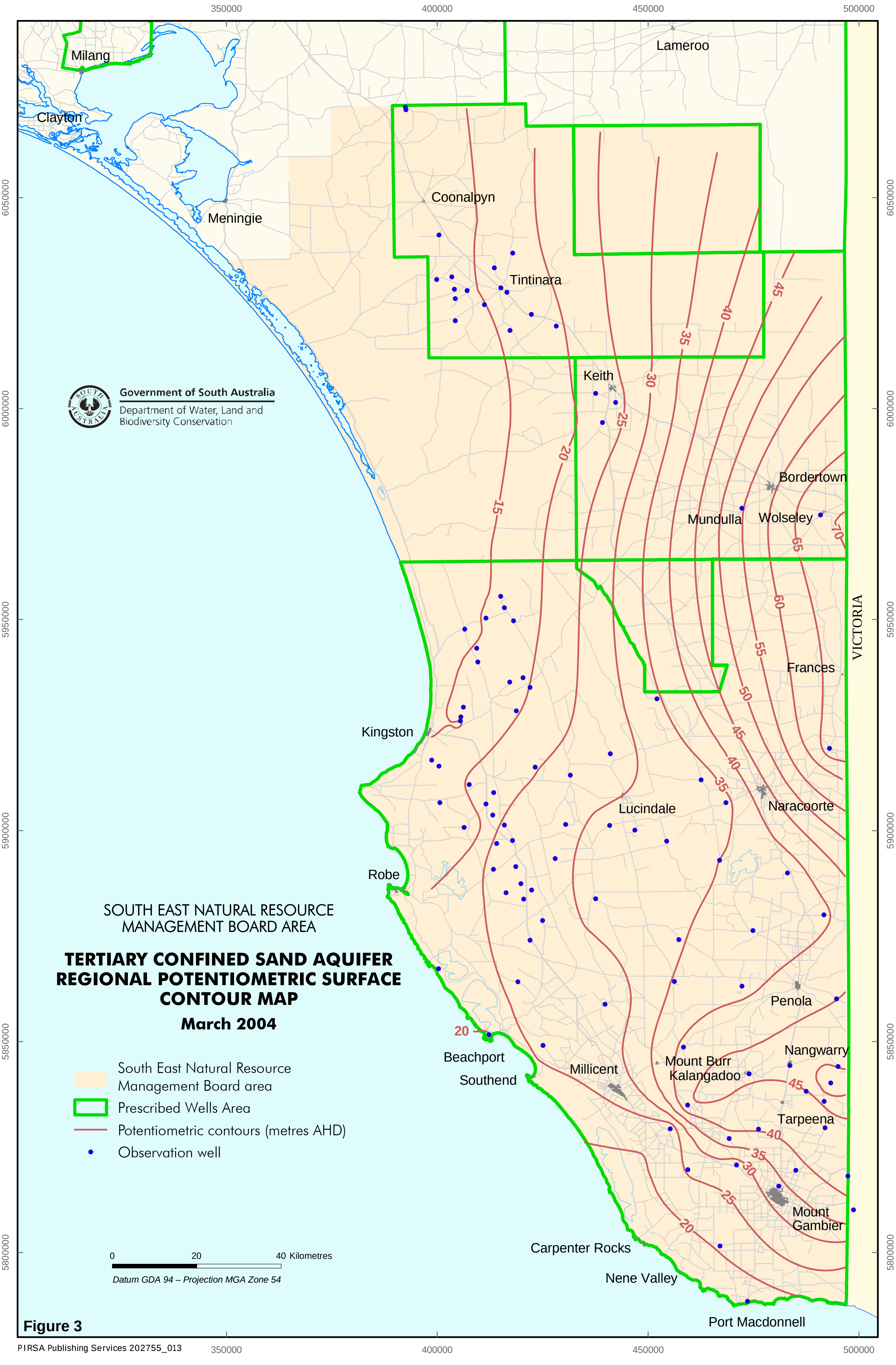

TERTIARY CONFINED SAND AQUIFER REGIONAL POTENTIOMETRIC SURFACE CONTOUR MAP

March 2004

Figure 3

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2. GROUNDWATER RESOURCE EVALUATION

Objective 1. *Assess the current condition of the groundwater resources in order to determine the capacity of the unconfined aquifer in each PWA to meet the demands for water on a continuing basis.*

2.1 GROUNDWATER RESOURCE CONDITION TRIGGERS

The groundwater resource condition “triggers” specified in the current WAPs are designed to protect the resource from degradation by preventing further allocation where a trigger is currently being exceeded, or where the granting and subsequent use of a new allocation is likely to cause the triggers to be exceeded. Both water level and salinity triggers are specified for the TLA (below). These trigger levels also enable flagging of stressed areas when reviewing the condition of the resource.

2.1.1 RESOURCE CONDITION TRIGGERS FOR PWA’S

With the exception of the Tatiara PWA, the South East Catchment Water Management Board’s WAPs state that the taking and use of water from either the TLA or TCSA shall not cause, or be likely to cause (Table 1):

- *A mean (arithmetic) decrease in underground water levels within the vicinity of the point of taking (including neighbouring properties and the nearest underground water level monitoring wells), or within the relevant management area of greater than 0.1 metres per year (measured over the preceding 5 years, except where the taking and use of water is for the purposes of industry or energy generation).*

- *A decline in underground water levels over a period of greater than 3 years within the vicinity of the point of taking (including neighbouring properties and the nearest underground water level monitoring wells), or within the relevant management area, before a new stable equilibrium water level is achieved, were the taking and use of water is for the purposes of industry or energy generation.*

- *And for the TLA only, a mean (arithmetic) increase in salinity of the underground water resource of greater than 10 mg/L (measured over the preceding 5 years) within the vicinity of the point of use (including neighbouring properties and the nearest salinity monitoring wells), or within the relevant management area.*

The current WAP for the Tatiara PWA specifies different salinity trigger levels from the other PWAs to reflect the significantly higher groundwater salinities observed in that area. The annual rate of salinity increase for the TLA is set at 50 mg/L/yr in the Stirling Management Area and 25 mg/L/yr in the Hundred of Pendleton, both of which are calculated over the preceding five-year period.

Table 1. Groundwater Resource Condition Triggers

	Aquifer	WAP Trigger Value	BORDER DESIGNATED AREA		‘Approaching’ Trigger (50% of WAP Trigger value)
			SA Zone No.	Permissible rate of potentiometric lowering	
Water Level Drawdown (m/yr)	TLA	0.1	1–5	0.25	0.05
			6–8	0.05	
			9–11	0.65	
	TCSA	0.1	1–6	0.5	0.05
			7–11	0.25	
Salinity (TDS) increase (mg/L/yr)	TLA	10	All	N/A	5
	TCSA	N/A	All	N/A	N/A

2.1.2 RESOURCE CONDITION TRIGGERS FOR THE BORDER DESIGNATED AREA

Under the *Groundwater (Border Agreement) Act 1985* the permissible rate of potentiometric surface lowering is the maximum rate of water level decline allowed in each management area of the Border Designated Area. The average change in groundwater level over the preceding five-year period is calculated from selected observation wells in both aquifers for each management area and compared with a permissible rate of change of 0.05 m/yr.

In June 2004 the Nineteenth Annual report by the SA-Victoria Border Groundwaters Agreement Review Committee stated different trigger levels for different Zones within the Border Designated Area (Table 1):

- 0.25 m/yr for Zones 1A to 5A, to account for observed rates of decline, but will be reviewed in the next 5 year Management Review by the Border Groundwaters Agreement Review Committee.
- 0.05 m/year for Zones 6A, 7A and 8A.
- 0.65 m/year for Zones 9A to 11A, to account for the confined nature of the TLA in this region.

2.2 APPROACH

Water level and salinity trend analysis was undertaken for the current study using time-series data extracted from the State’s groundwater monitoring database (called *Obswell,* https://info.pir.sa.gov.au/obswell/new/obsWell/MainMenu/menu). Trend lines were determined by linear regression of measured data for the last five years, ten years and for the entire monitoring record. Entire monitoring record trends were calculated for observation wells with at least 15 years of continuous record, and therefore can reflect long-term trends for between 15 and ~32 years. Maps representing the water level and salinity trend for each reliable observation well were then prepared for spatial comparison and analysis.

To assess the condition of the groundwater resource in both aquifers, uniform trigger levels were adopted for all management areas within the three PWAs, including those in the Border Designated Area. The adopted water level and salinity triggers were -0.1 m/yr and +10 mg/L/yr, both calculated over the previous ten years instead of the five-year period specified in the WAPs (discussed below). Trends that exceeded the adopted trigger values for either water level or salinity were used to identify stressed or ‘hotspot’ areas. These areas were then studied in detail to identify possible reasons for the observed trends.

2.2.1 COMPARISON OF TEMPORAL TRENDS

The choice of a most representative timescale for analysing water level and salinity trends was based on a compromise between using as much data as possible (i.e. the entire monitoring record) and needing to reflect recent short-term changes in water level. For this review, ten year trends were considered most appropriate for water level analysis, and for consistency this period was also adopted for salinity trend analysis.

It is suggested that for future resource condition assessments, the most appropriate time period over which to conduct trend analysis be reviewed to account for recent climatic trends. This should be reflected in the new Water Allocation Plans.

2.3 RESULTS: TERTIARY LIMESTONE AQUIFER

2.3.1 WATER LEVEL TRENDS

The five year (Fig. 4), ten year (Fig. 5) and entire monitoring record (Fig. 6) maps reveal management areas where water-level trends are approaching or have exceeded the adopted trigger level. A summary of the number of wells used in the regional analysis and that have either exceeded or are approaching the trigger level is summarised in Table 2.

Table 2. Summary of TLA wells exceeding or approaching water level triggers

TIME SERIES	NUMBER OF WELLS	EXCEED TRIGGERS (< -0.1 m/yr)	APPROACH TRIGGERS (-0.1 to -0.05 m/yr)
Five Year Trend	556	108 Wells (19%)	65 wells (12%)
Ten Year Trend	484	158 wells (33%)	77 wells (16%)
Entire Trend	434	56 wells (13%)	76 wells (18%)

The most obvious features in Figure 5 are:

- Declining water levels of between -0.1 to -0.4 m/yr in management areas of the Border Designated Area, Padthaway PWA and Tatiara PWA.
- Negligible changes in water levels over most of the remaining Lower Limestone Coast PWA.

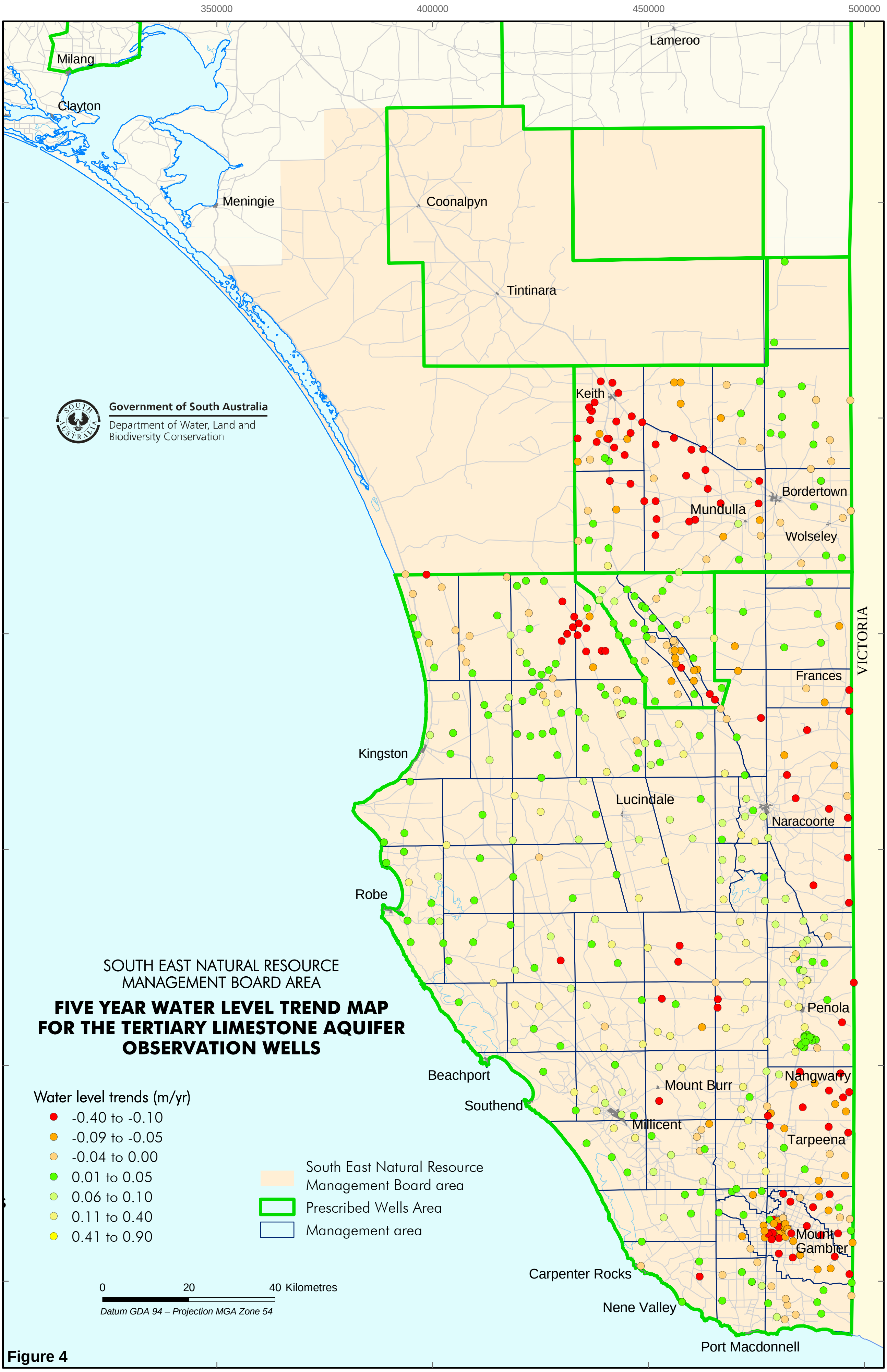

Figure 4

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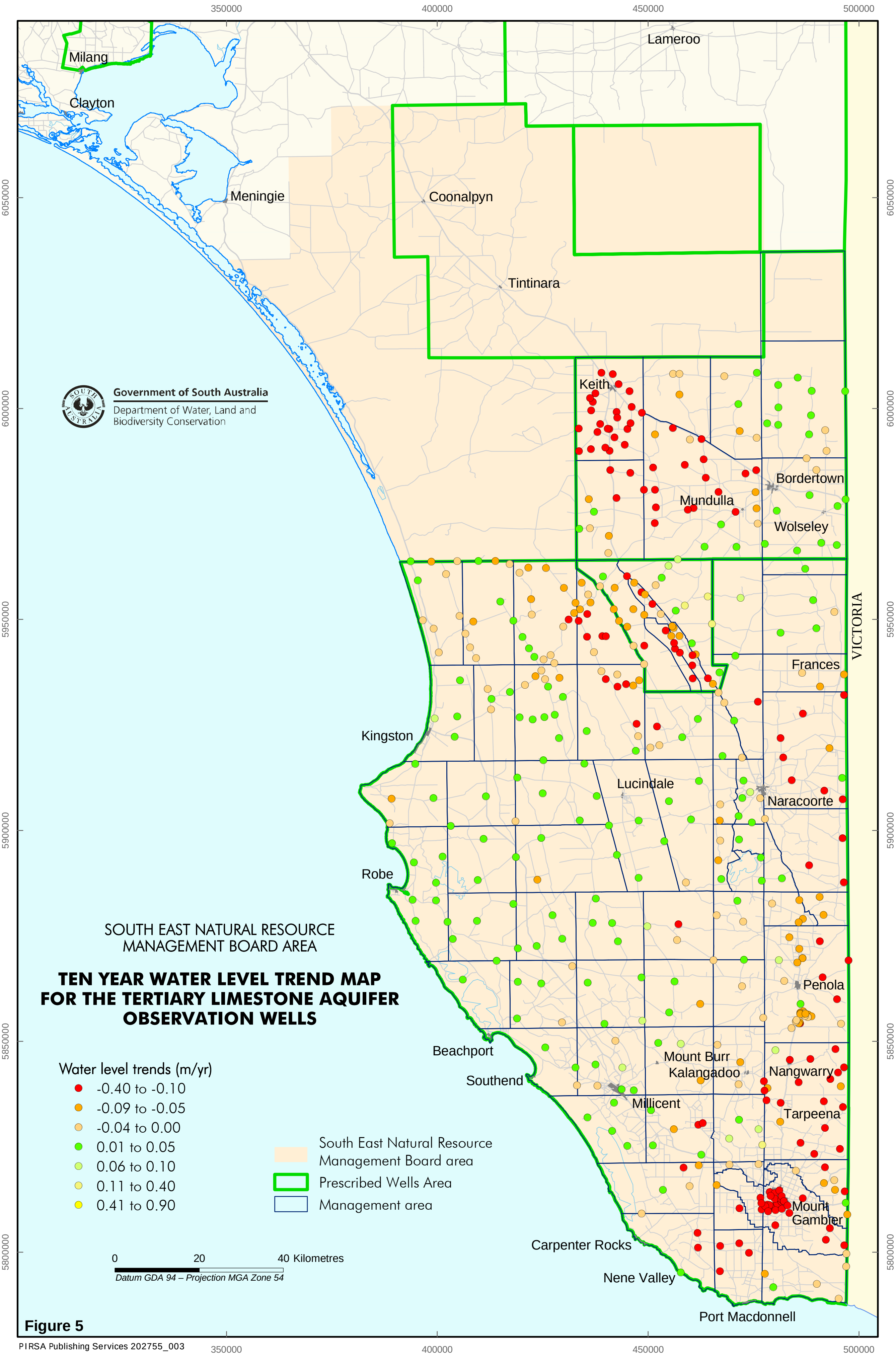
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Coonalpyn
Tintinara
Keith
Bordertown
Mundulla
Wolseley
VICTORIA
Frances
Kingston
Lucindale
Naracoorte
Robe
Penola
Beachport
Mount Burr
Kalangadoo
Nangwarry
Southend
Millicent
Tarpeena
Mount Gambier
Carpenter Rocks
Nene Valley
Port Macdonnell
Government of South Australia
Department of Water, Land and Biodiversity Conservation
SOUTH EAST NATURAL RESOURCE MANAGEMENT BOARD AREA
TEN YEAR WATER LEVEL TREND MAP FOR THE TERTIARY LIMESTONE AQUIFER OBSERVATION WELLS
Water level trends (m/yr)
-0.40 to -0.10
-0.09 to -0.05
-0.04 to 0.00
0.01 to 0.05
0.06 to 0.10
0.11 to 0.40
0.41 to 0.90
South East Natural Resource Management Board area
Prescribed Wells Area
Management area
0
20
40 Kilometres
Datum GDA 94 – Projection MGA Zone 54
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Figure 5

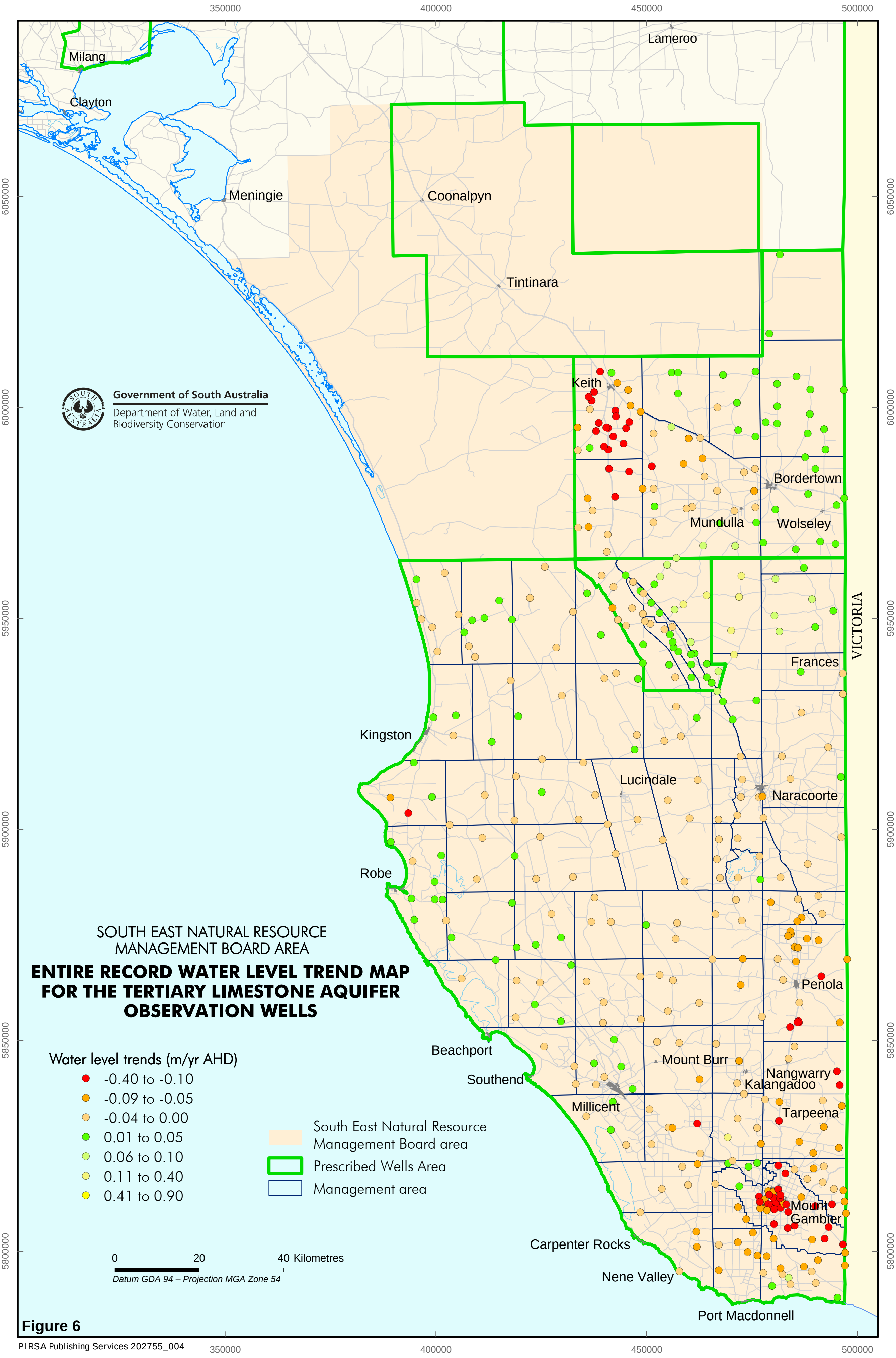

Figure 6

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Table 3. TLA wells exceeding or approaching water level triggers in each management area

Management Area	Number of Wells	10 Year Water Level Trend Exceeding (< -0.1 m/yr), Approaching (-0.1 to -0.05 m/yr)
BANGHAM SUB AREA	4	
BEEAMMA SUB AREA	1	
BENARA	4	1 Exceed, 1 Approaching
BLANCHE CENTRAL	3	3 Exceed, 1 Approaching
BOOL	2	
BOWAKA	2	
BRAY	3	
CANNAWIGARA	5	1 Approaching
COLES	3	1 Exceeds
COMAUM	2	2 Approaching
COMPTON	2	
CONMURRA	4	1 Approaching
DONOVANS	5	1 Approaching
DUFFIELD	9	1 Approaching
FOX	4	
FRANCES	3	2 Approaching
GLENBURNIE	40	40 Exceed
GLENROY	4	3 Approaching
GREY	4	1 Exceed, 1 Approaching
HACKS	1	
HINDMARSH	6	2 Exceed, 1 Approaching
HYNAM EAST	4	1 Exceeds
HYNAM WEST	3	
JOANNA	3	3 Exceed
JOYCE	3	
KENNION	4	
KILLANOOLA	3	
KONGORONG	4	2 Exceed
LACEPEDE	4	
LAKE GEORGE	2	
LANDSEER	8	2 Approaching
LOCHABER	5	1 Exceed
MACDONNELL	4	4 Exceed
MGMT AREA 1	10	1 Exceed, 5 Approaching
MGMT AREA 2	12	6 Exceed, 5 Approaching
MGMT AREA 3	5	4 Exceed , 1 Approaching
MGMT AREA 4	11	1 Exceed, 2 Approaching
MARCOLLAT	10	5 Exceed, 3 Approaching
MAYURRA	4	
MINECROW	13	2 Approaching
MONBULLA	4	
MOORAK	1	1 Exceeding

Management Area	Number of Wells	10 Year Water Level Trend Exceeding (< -0.1 m/yr), Approaching (-0.1 to -0.05 m/yr)
MOUNT BENSON	4	1 Approaching
MOUNT MUIRHEAD	6	
MOYHALL	3	1 Approaching
MURRABINNA	4	
MYORA	7	2 Exceed, 2 Approaching
NORTH PENDLETON	3	1 Approaching
ORMEROD	2	1 Approaching
PEACOCK	16	1 Exceed, 6 approaching
RIDDOCH	3	1 Approaching
RIVOLI BAY	3	
ROSS	2	
SHAUGH	0	
SHORT	3	1 approaching
SMITH	4	
SPENCE	4	
STEWARTS	6	
STIRLING	25	25 Exceed
STRUAN	2	
SYMON	5	
TATIARA	10	
TOWNSEND	6	
WATERHOUSE	8	
WESTERN FLAT S/A	1	
WILLALOOKA	9	3 Exceed, 2 Approaching
WIRREGA	25	16 Exceed, 3 Approaching
WOOLUMBOOL	11	4 Exceed, 2 approaching
YOUNG	4	
ZONE 2A	21	17 exceed, 3 Approaching
ZONE 3A	31	5 Exceed, 15 Approaching
ZONE 5A	9	7 Exceed, 1 Approaching
ZONE 8A	11	

The number of wells in used in each management area and that have either exceeded or are approaching the trigger level are presented in Table 3. From this analysis, six areas were identified as ‘hotspot’ areas, where there is a concentration of wells exhibiting significant water level declines in excess of trigger levels. These areas are:

- Management Areas 1, 2 and 3 (Padthaway PWA)
- Stirling, Willalooka and Wirrega Management Areas (Tatiara PWA)
- Frances, Joanna and Zone 5A Management Areas (Lower Limestone Coast PWA)
- Glenburnie, Myora & Zone 2A Management Areas (Lower Limestone Coast PWA)
- Kongorong & MacDonnell Management Areas (Lower Limestone Coast PWA)
- Marcollat, Peacock & Woolumbool Management Areas (Lower Limestone Coast PWA).

2.3.2 SALINITY TRENDS

A summary of the number of wells used in the regional salinity analysis and that have either exceeded or are approaching the adopted trigger level is provided in Table 4. Figures 7, 8 and 9 are the mapped salinity trends for the five year, ten year and entire monitoring record periods.

Table 4. Summary of TLA wells exceeding or approaching salinity triggers

TIME SERIES	NUMBER OF WELLS	EXCEED TRIGGERS (> 10 mg/L/yr)	APROACH TRIGGERS (5 to 10 mg/L/yr)
Five Year Trend	229	82 Wells (36%)	29 wells (13%)
Ten Year Trend	175	62 wells (35%)	22 wells (13%)
Entire Trend	183	66 wells (36%)	29 wells (16%)

General observations from these maps are:

- All three maps show similar salinity trends.
- Trends of increasing salinity are most evident in Tatiara and Padthaway PWAs, which partly reflect the high density of observation wells in these areas. These areas were identified as water level hotspots and can also be considered as salinity hotspots as there are many wells that have trends exceeding the adopted 10 mg/L/yr trigger value.
- Wells located in the management areas between the townships of Naracoorte and Penola, including Zone 3A, commonly exceed the salinity trigger value. Therefore this general area is considered a seventh stressed or ‘hotspot’ area.
- The ten-year trend map shows declining trends dispersed amongst increasing trends (e.g., Padthaway PWA).
- More than one-third of all evaluated observation wells show increasing salinity levels in excess of 10 mg/L/yr for the ten-year map.

The number of wells in used in each management area and that have either exceeded or are approaching the adopted salinity trigger level are presented in Table 5.

2.4 RESULTS: TERTIARY CONFINED SAND AQUIFER

2.4.1 WATER LEVEL TRENDS

The five year, ten year and entire monitoring record water-level trends for the TCSA are presented in Figures 10, 11 and 12. Note there are significantly fewer wells available for trend analysis in the TCSA compared with the TLA, this reflects both a smaller number of confined aquifer wells and few with adequate temporal datasets. General trends from the ten year map (Fig. 11) are:

- Recovery of +0.1 to +0.9 m/yr in the Kingston artesian irrigation district (east of Kingston-Robe).
- Declines of -0.1 to -0.4 m/yr in the Stirling management area and throughout the lower South East (Hindmarsh, Young, Benara, Nangwarry, Grey and Mingbool management areas).

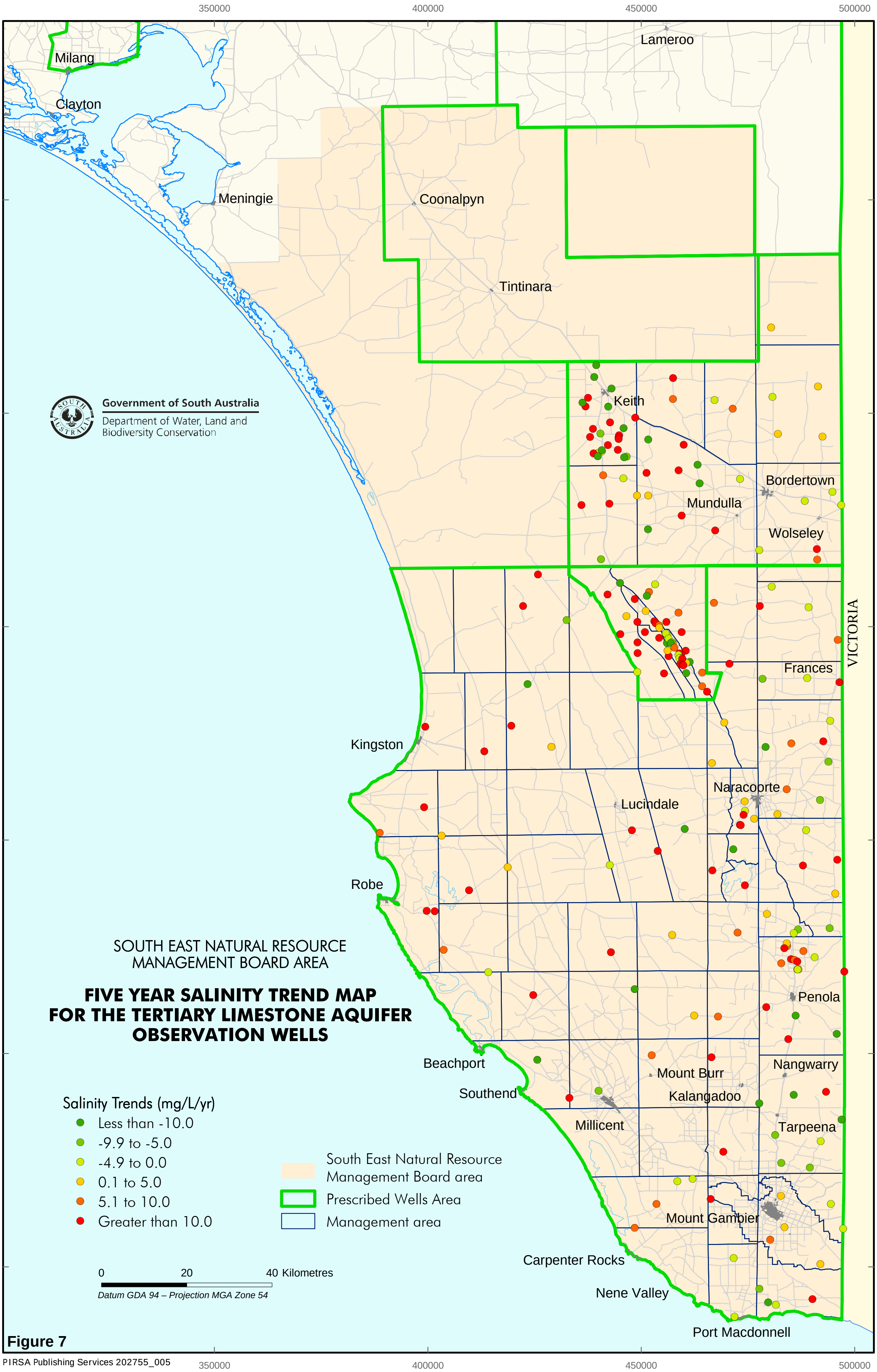

Figure 7

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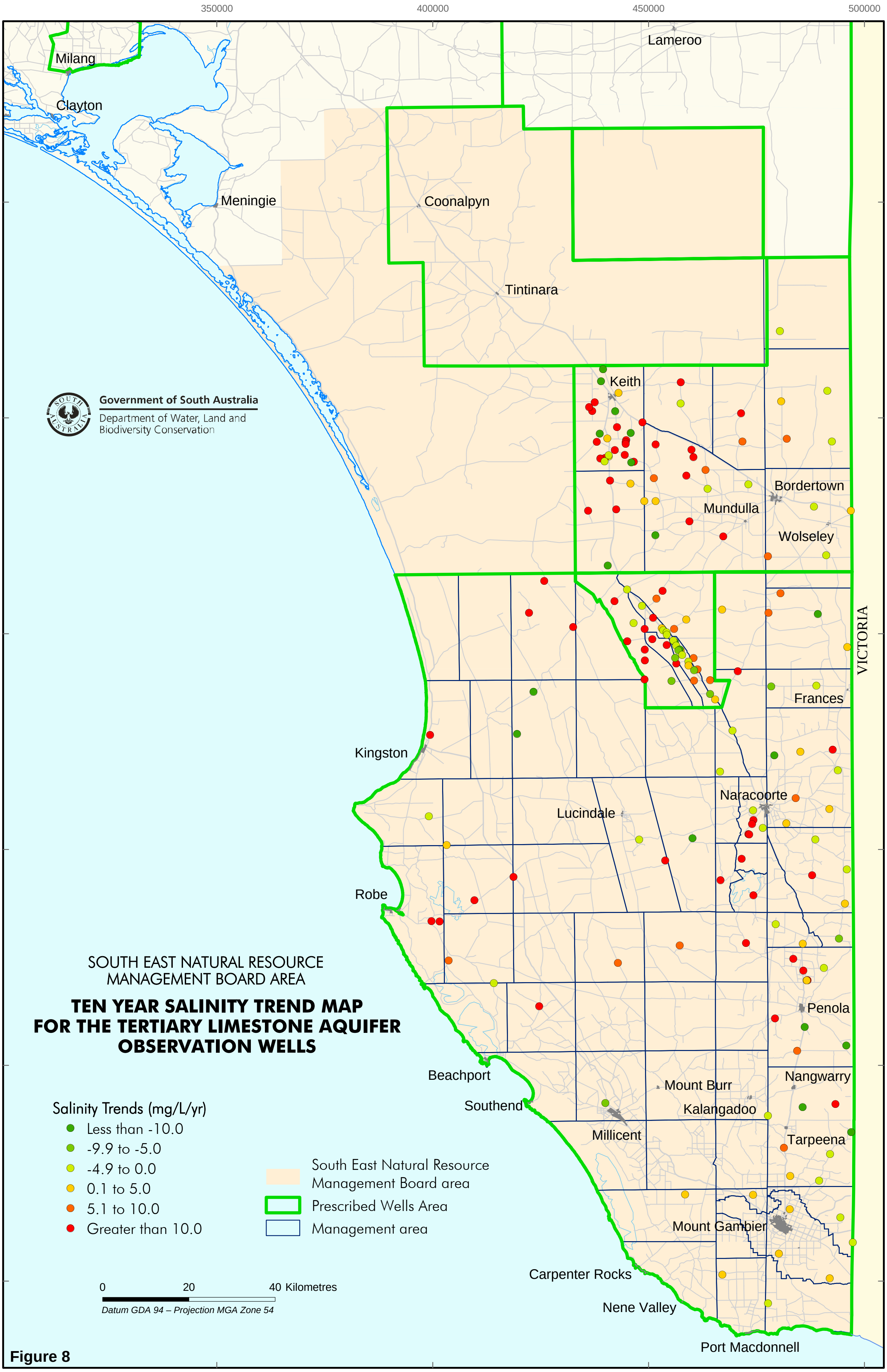

Figure 8

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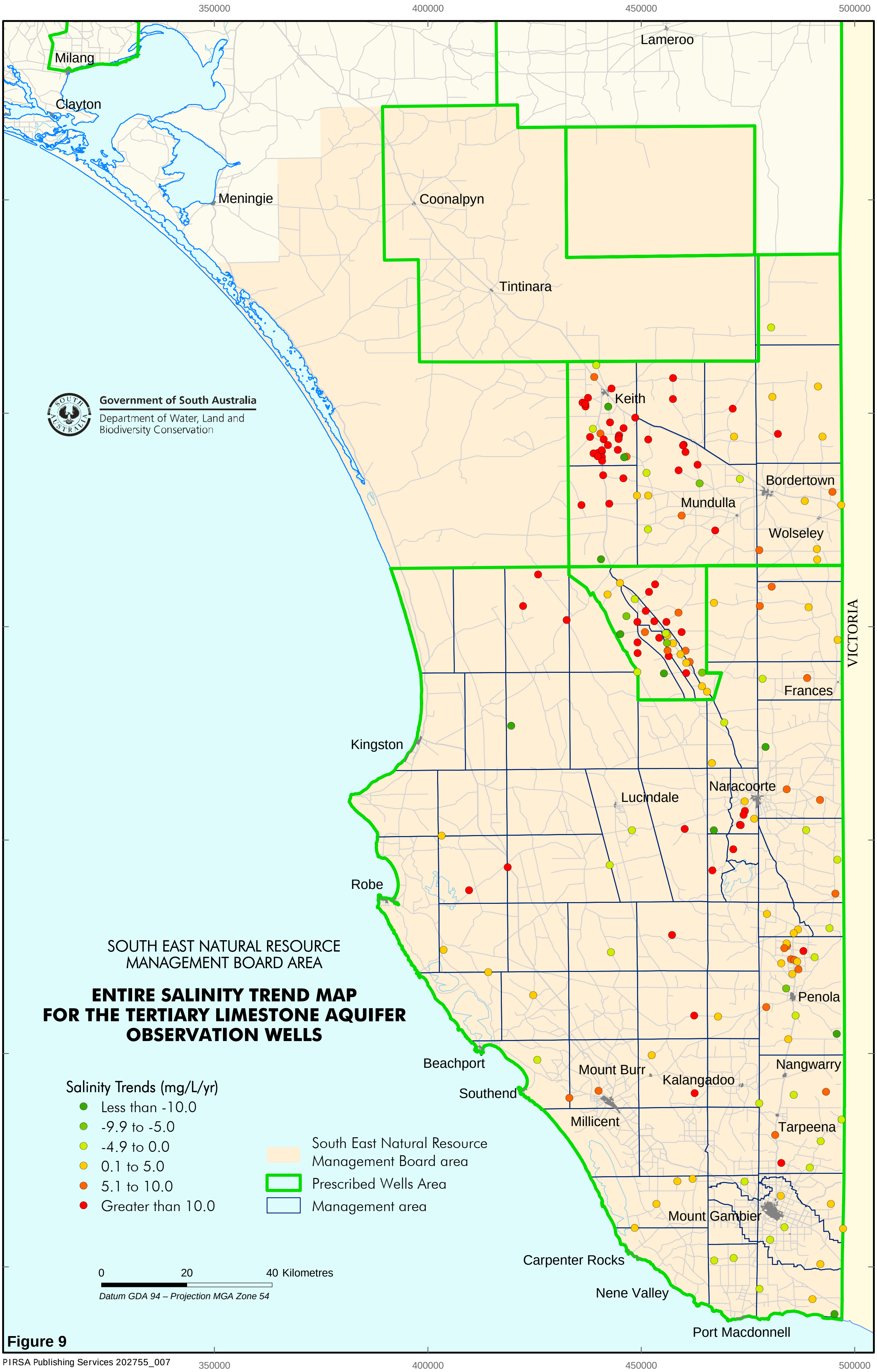

Figure 9

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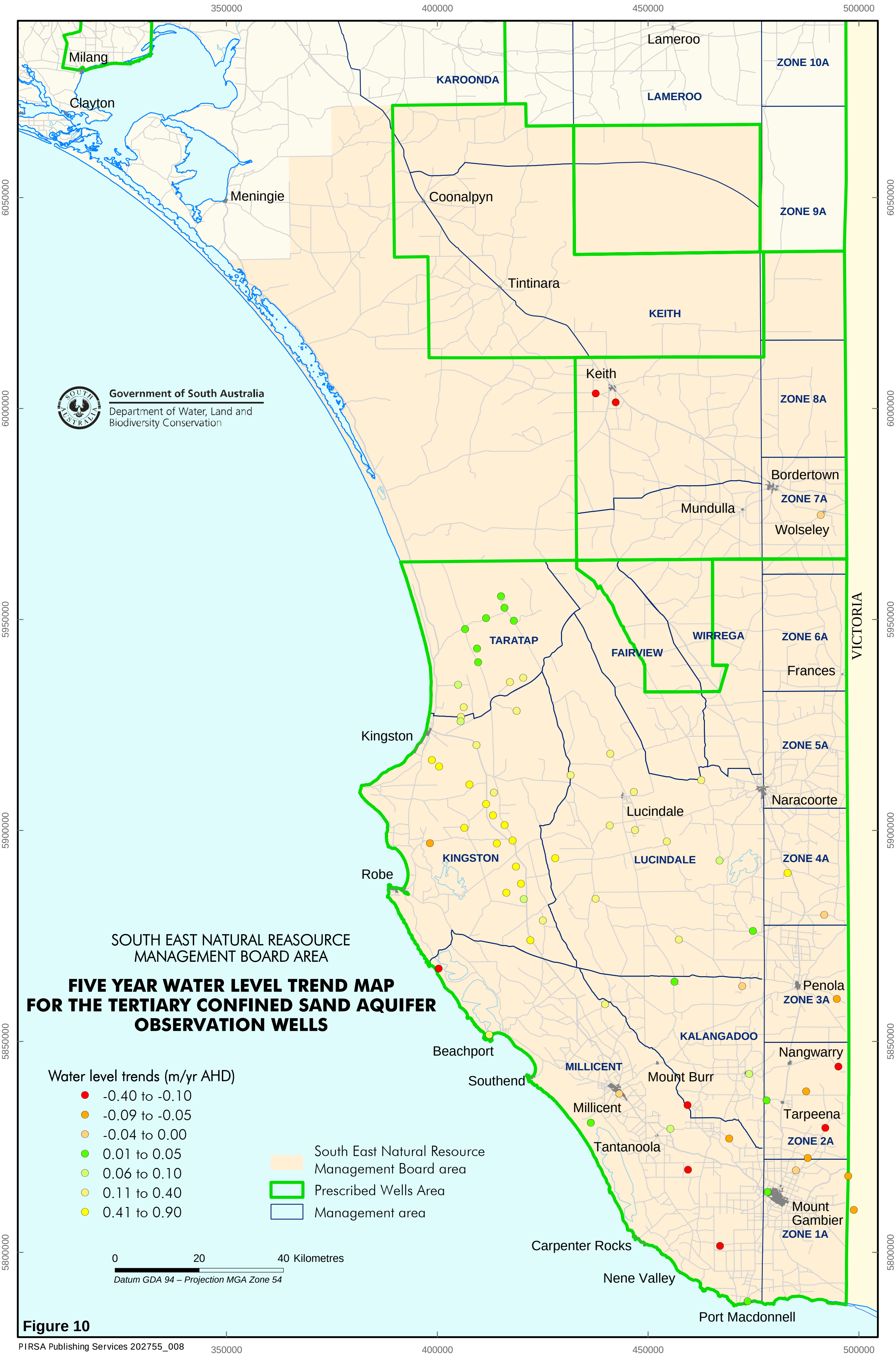

FIVE YEAR WATER LEVEL TREND MAP FOR THE TERTIARY CONFINED SAND AQUIFER OBSERVATION WELLS

Figure 10

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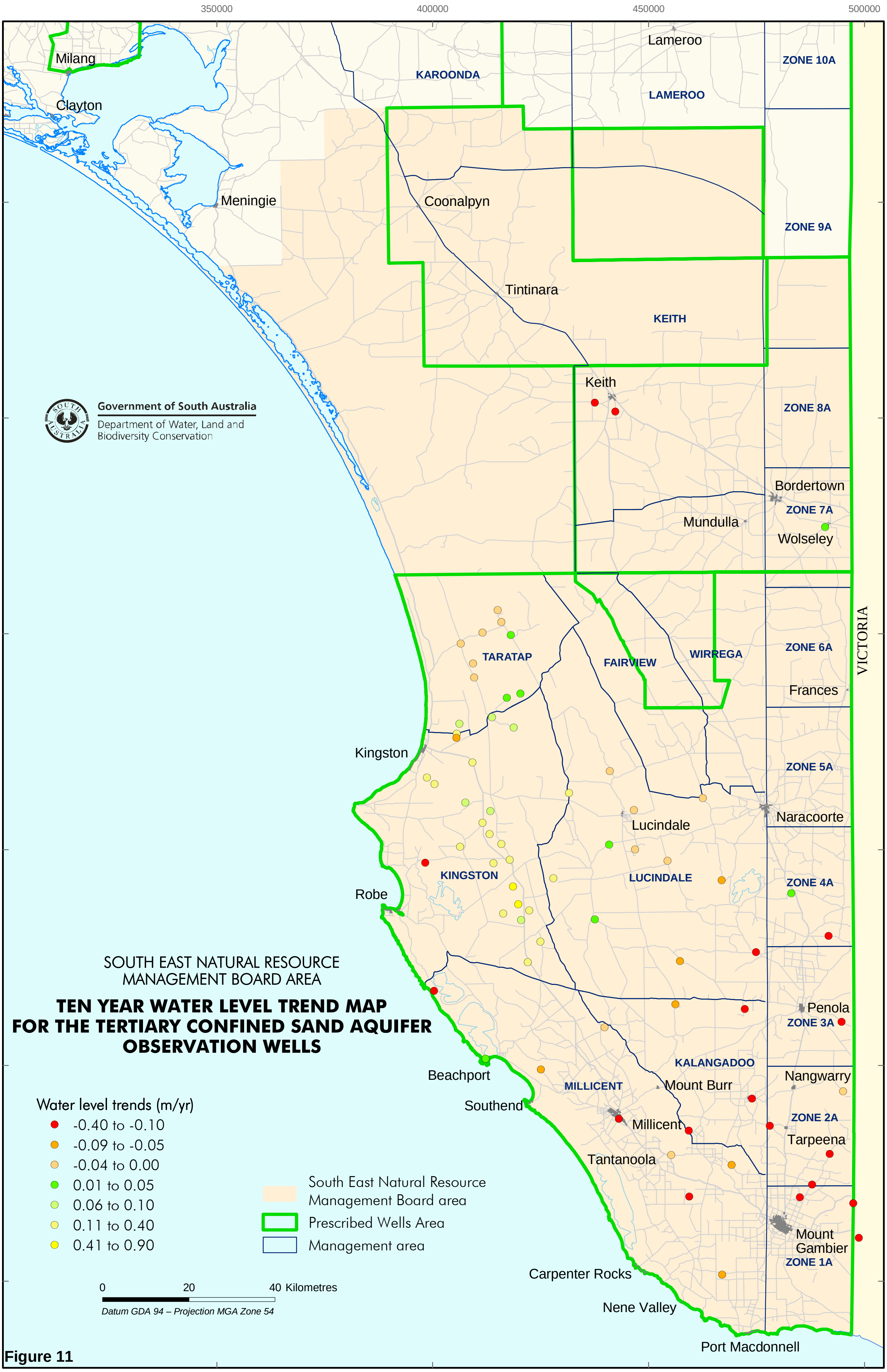

Figure 11

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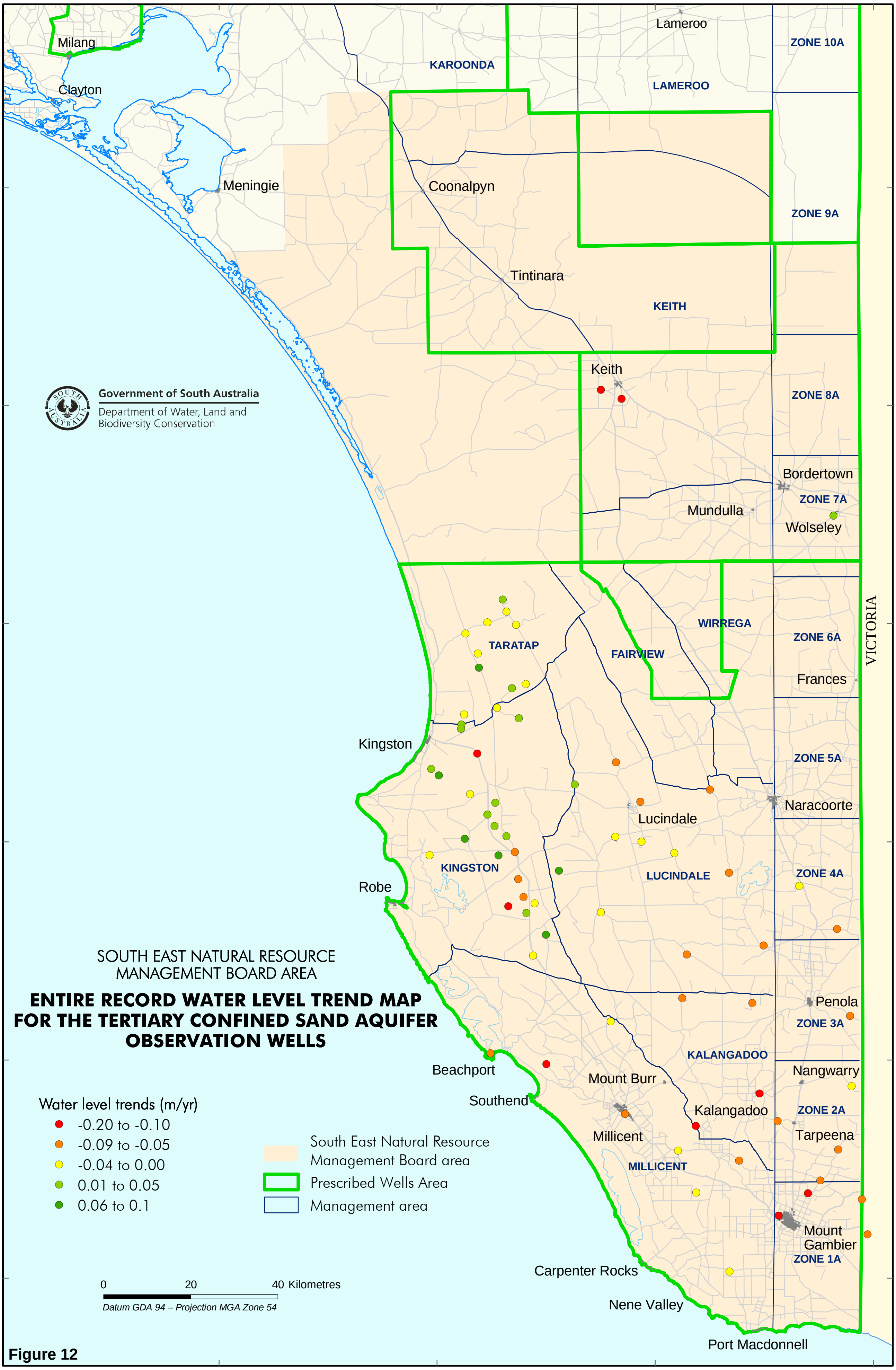

Figure 12

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Table 5. TLA wells exceeding or approaching salinity trigger levels in each management area

Management Area	Number of Wells	10 Year Salinity Trend Exceeding (> 10 mg/L/yr), Approaching (5 to 10 mg/L/yr)
BANGHAM SUB AREA	4	2 Approaching
BEEAMMA SUB AREA	1	
BENARA	1	
BLANCHE CENTRAL	0	
BOOL	1	1 Exceed
BOWAKA	1	
BRAY	1	1 Approaching
CANNAWIGARA	2	1 Exceed, 1 Approaching
COLES	1	1 Approaching
COMAUM	1	
COMPTON	1	
CONMURRA	1	1 Exceed
DONOVANS	1	
DUFFIELD	0	
FOX	1	1 Approaching
FRANCES	2	
GLENBURNIE	3	
GLENROY	2	
GREY	1	
HACKS	1	1 Exceed
HINDMARSH	0	
HYNAM EAST	2	1 Exceed
HYNAM WEST	1	
JOANNA	4	1 Exceed, 1 Approaching
JOYCE	2	1 Exceed
KENNION	0	
KILLANOOLA	1	1 Exceed
KONGORONG	0	
LACEPEDE	1	1 Exceed
LAKE GEORGE	1	
LANDSEER	0	
LOCHABER	0	
MACDONNELL	1	
MGMT AREA 1	8	6 Exceed
MGMT AREA 2	19	1 Exceed, 1 Approaching
MGMT AREA 3	3	3 Exceed
MGMT AREA 4	8	1 Exceed, 5 Approaching
MARCOLLAT	0	
MAYURRA	0	
MINECROW	2	
MONBULLA	0	
MOORAK	0	

Management Area	Number of Wells	10 Year Salinity Trend Exceeding (> 10 mg/L/yr), Approaching (5 to 10 mg/L/yr)
MOUNT BENSON	1	1 Approaching
MOUNT MUIRHEAD	1	
MOYHALL	1	1 Exceed
MURRABINNA	0	
MYORA	2	
NORTH PENDLETON	2	1 Exceed
ORMEROD	0	
PEACOCK	3	3 Exceed
RIDDOCH	0	
RIVOLI BAY	0	
ROSS	1	1 Exceed
SHAUGH	1	
SHORT	0	
SMITH	0	
SPENCE	1	
STEWARTS	6	4 Exceed
STIRLING	25	14 Exceed, 1 Approaching
STRUAN	0	
SYMON	0	
TATIARA	4	1 Approaching
TOWNSEND	0	
WATERHOUSE	2	2 Exceed
WESTERN FLAT S/A	0	
WILLALOOKA	5	3 Exceed
WIRREGA	13	6 Exceed, 2 Approaching
WOOLUMBOOL	0	
YOUNG	0	
ZONE 2A	7	1 Exceed, 1 Approaching
ZONE 3A	10	4 Exceed, 2 Approaching
ZONE 5A	7	1 Exceed, 1 Approaching
ZONE 8A	4	1 Exceed

The recovery of water levels in the Kingston artesian irrigation district is most obvious on the five year map (Fig. 10) and likely reflects recent well rehabilitation work undertaken as part of the South East Confined Aquifer Well Rehabilitation Scheme (SECAWRS).

Table 6 summarises the number of wells used in the regional analysis and that have either exceeded or are approaching the adopted trigger levels.

Table 6. Summary of TCSA wells exceeding or approaching water level triggers

TIME SERIES	NUMBER OF WELLS	EXCEED TRIGGERS (< -0.1 m/yr)	APROACH TRIGGERS (-0.05 to -0.1 m/yr)
Five Year Trend	74	8 Wells (11%)	8 wells (11%)
Ten Year Trend	72	19 wells (26%)	8 wells (11%)
Entire Trend	71	9 wells (13%)	22 wells (31%)

2.4.2 SALINITY TRENDS

The distributions of salinity trends for the TCSA are similar for the five year and ten year periods (Figs 13 and 14). The greatest concentration of wells on these maps is in the Kingston irrigation area because these are the only long term salinity observation wells. Generally there has been no significant change in salinity over the monitoring record.

2.5 ANALYSIS OF STRESSED OR 'HOT SPOT' AREAS

2.5.1 TERTIARY LIMESTONE AQUIFER

Results from the previous section identified seven 'hotspot' areas that had experienced either a decline in groundwater level or a salinity increase that exceeded the adopted trigger levels. The areas identified were located in:

- Padthaway Management Areas 1, 2 and 3 (Padthaway PWA);
- Stirling, Willalooka and Wirrega Management Areas (Tatiara PWA);
- Frances, Joanna, and Zone 5A Management Areas (Lower Limestone Coast PWA);
- Glenburnie, Myora and Zone 2A Management Areas (Lower Limestone Coast PWA);
- Kongorong and MacDonnell management areas (Lower Limestone Coast PWA);
- Marcollat-Peacock-Woolumbool management areas (Lower Limestone Coast PWA) and
- northern part of Zone 3A (Lower Limestone Coast PWA).

Each of these areas are now examined more closely to identify reasons for exceeded trigger levels. The cumulative deviation of annual rainfall from the mean was determined for each hotspot area from nearby rainfall-gauging stations. The rainfall record from 1970 was used to coincide with the commencement of the observation well networks in the South East.

2.5.1.1 Management Areas 1, 2 and 3 (Padthaway PWA)

Hydrographs from observation wells beginning around 1970 have a sinuous long-term trend and show little overall change in water level in the last 35 years (for example Well GLE017, Fig. 15). The figure also highlights the strong relationship between cumulative deviation of annual rainfall from the mean and changes in groundwater level. There are two explanations why rainfall would dominate the hydrograph signature:

- A direct response; above or below average rainfall corresponds with a rise or fall in water table.
- An indirect response whereby to compensate for below average rainfall, increased groundwater extraction has occurred.

As irrigation allocations are based on the average water use requirements of a specific crop type it is not possible to determine whether extraction was increased to make up for a deficit in rainfall.

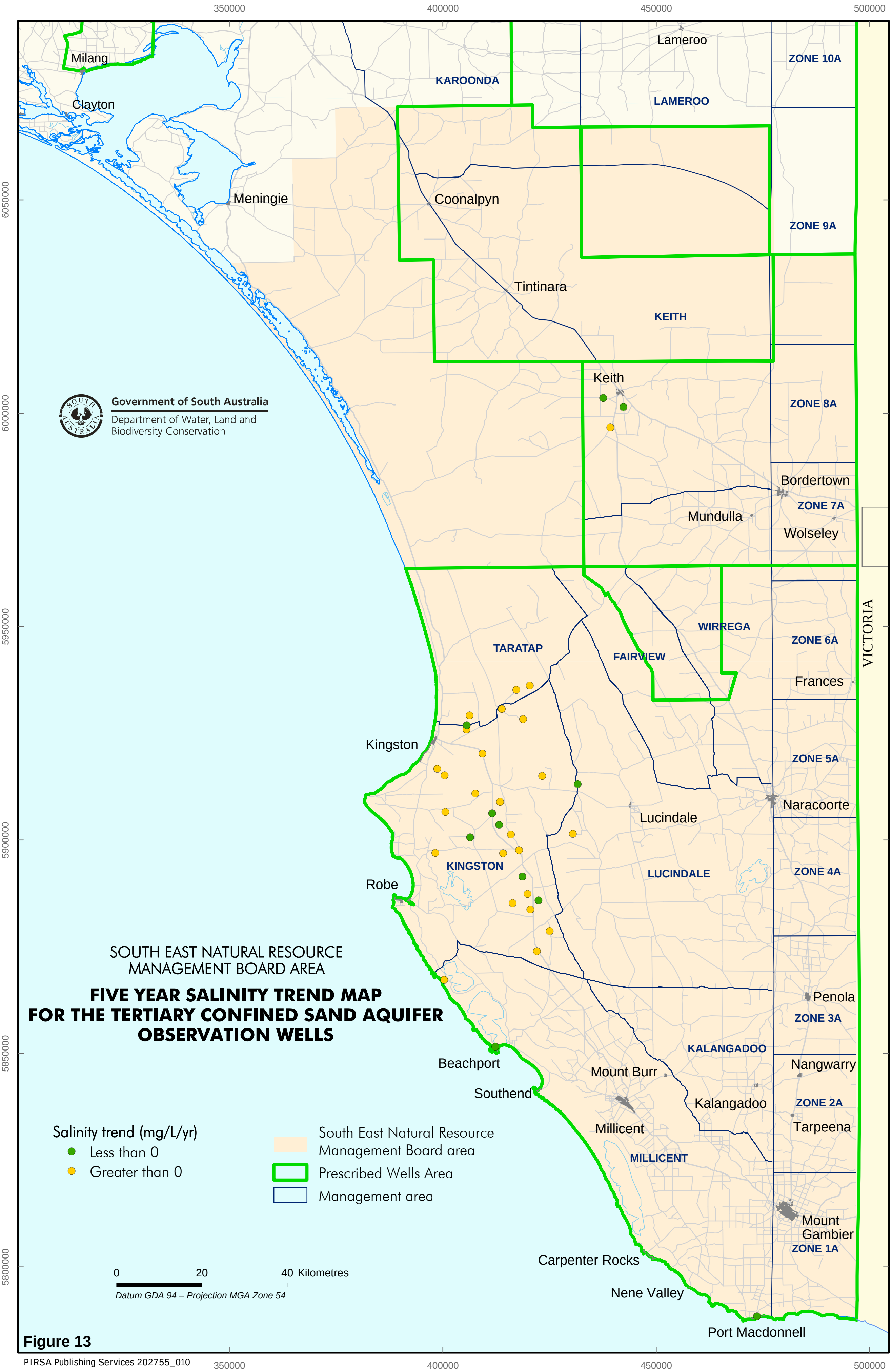

Figure 13

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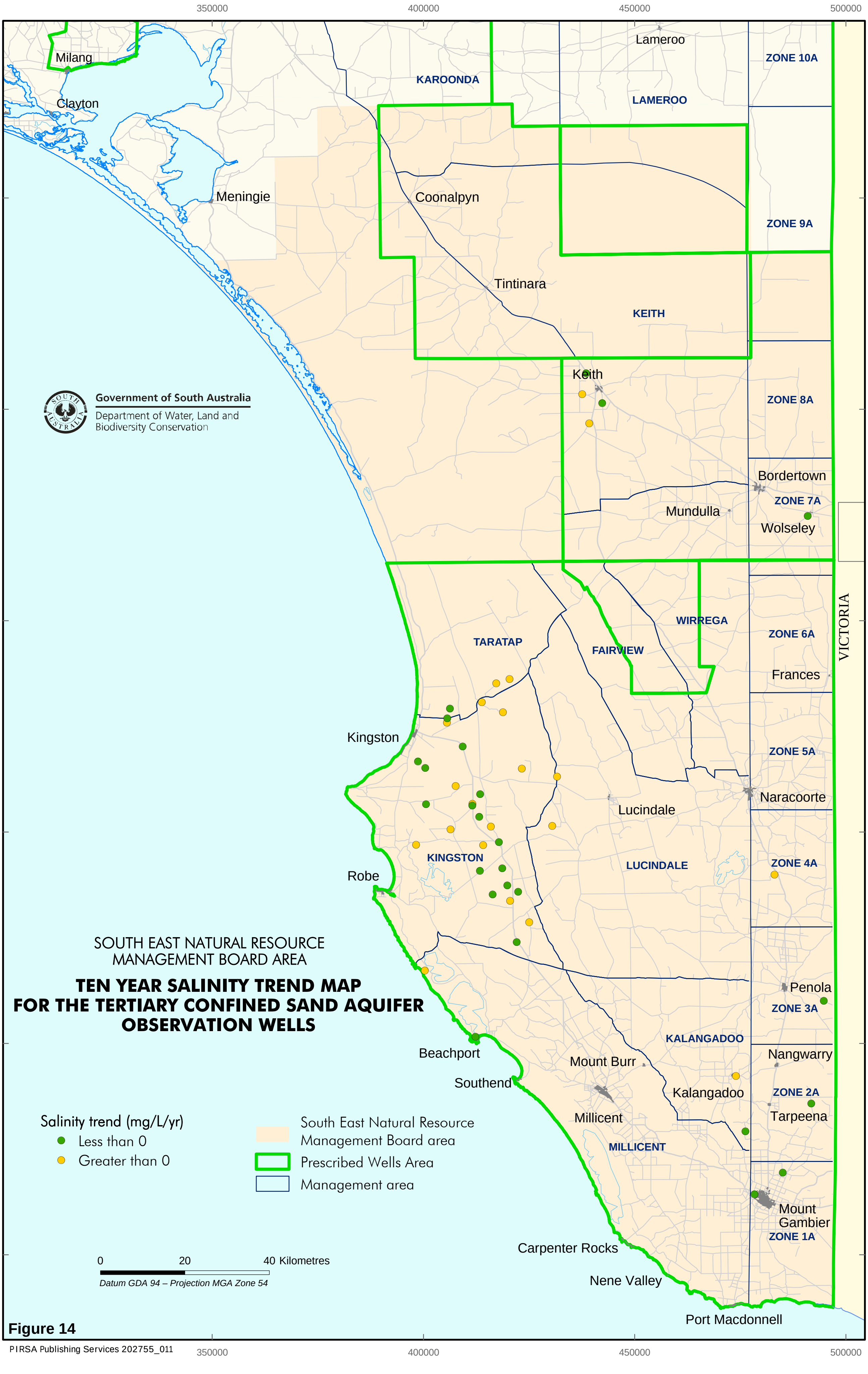

Figure 14

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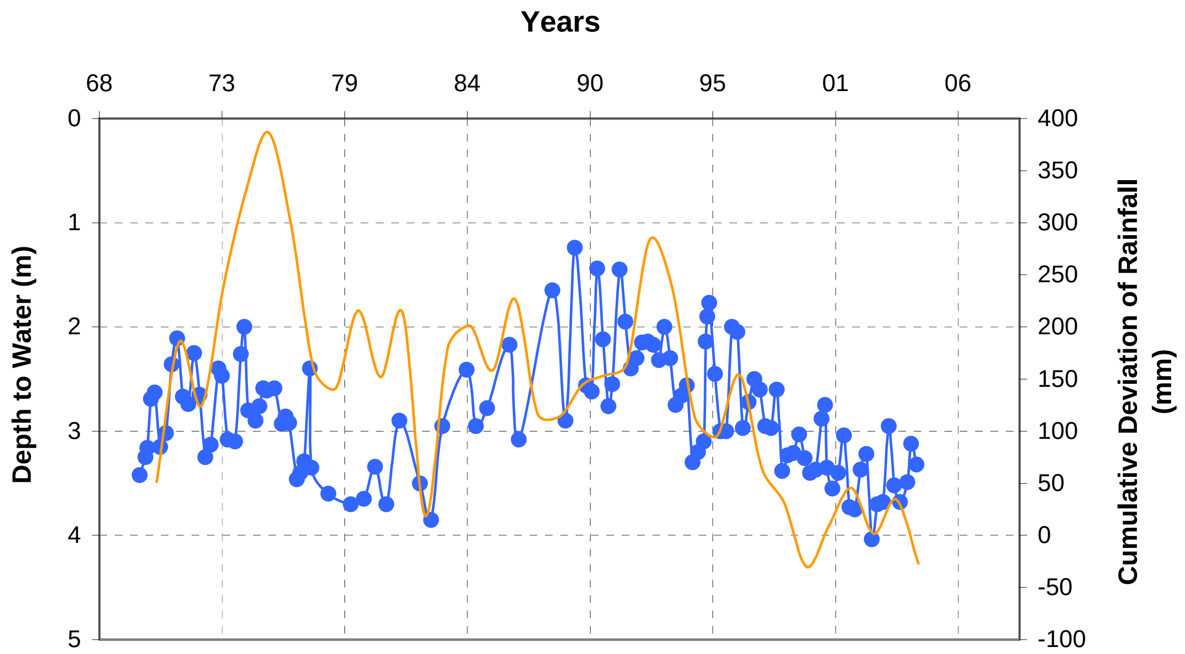


Figure 15. Hydrograph of Observation Well GLE017 (Padthaway Management Area 2) and cumulative deviation from mean annual rainfall

The salinity-time monitoring record from observation wells in the Padthaway PWA is shorter and more fragmented than that of the water level record. Confidence in interpreting the trends is therefore reduced. However, groundwater salinity on the Plain generally increased during the 1980s and early part of the 1990s. Since then the groundwater salinity has stabilised and in some areas decreased.

The observed salinity trends have previously been attributed to irrigation recycling in the main viticultural belt (Management Area 2). Preliminary results from the *Padthaway Salt Accession Investigations and Determination of Sustainable Extraction Limits (PAV)* study will be available at the end of October 2005. The primary objective of this study was to quantify and compare salt accession under different land use practices in the Naracoorte Ranges and on the Plain.

A significant increase in groundwater salinity has been observed in well MAR022 located in Management Area 1 since the mid-1990s (Fig. 16). Similar increases are observed in nearby wells and may be caused by local extraction for irrigation to the east, drawing in high salinity groundwater from the west.

Whilst not constituting a hotspot, hydrographs from observation wells in the Padthaway Ranges (i.e. Management Area 4) show long-term groundwater level rises of between 0.04 and 0.18 m/yr over the monitoring record. The majority of these hydrographs indicate the water table has reached or is approaching a new state of equilibrium (e.g., Well PAR044, Fig. 17). Groundwater salinity in this area has also increased on average ~3 mg/L/yr since

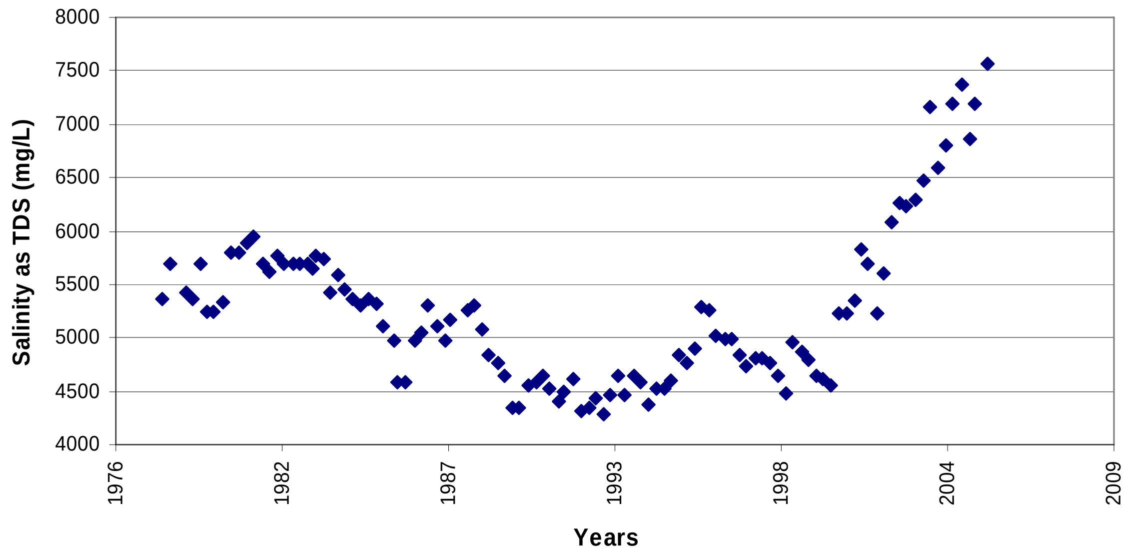


Figure 16. Salinity of Observation Well MAR022 (Padthaway Management Area 1)

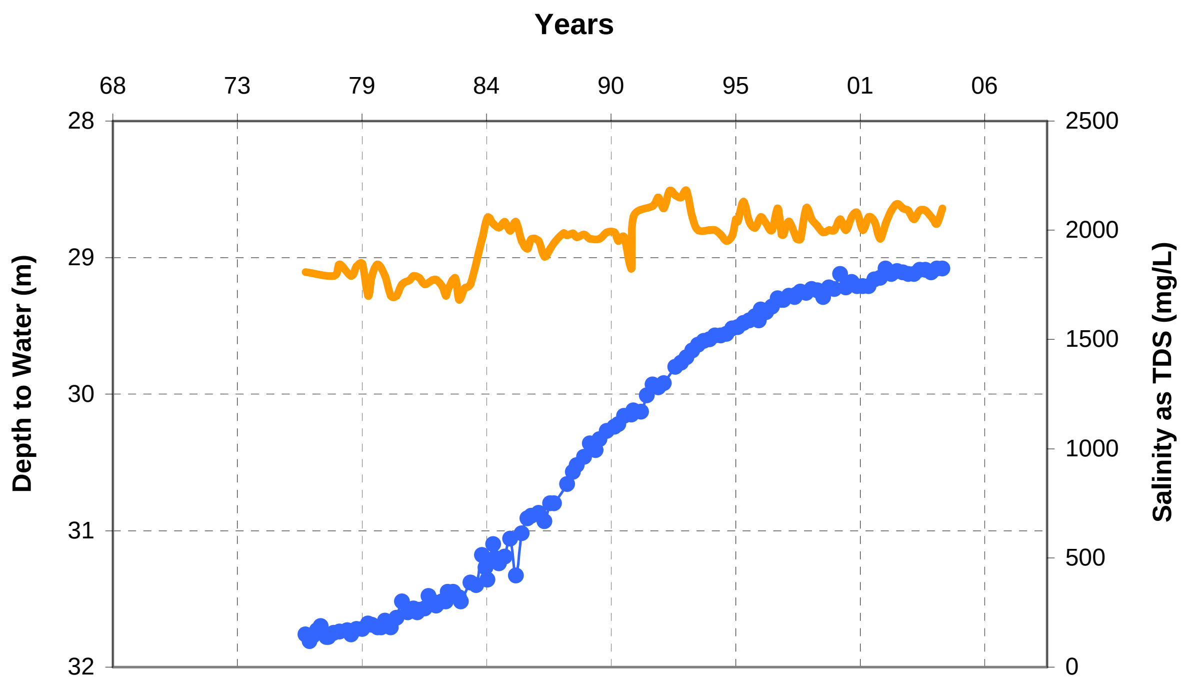


Figure 17. Hydrograph and Salinity of Observation Well PAR044 (Padthaway Management Area 4) and cumulative deviation from mean annual rainfall

1984/1985. The overriding influence on both hydrograph and salinity-time graph data is considered to be land use change (i.e., clearing of native vegetation) (Bradley et al., 1995). It is recommended that future WAPs acknowledge groundwater level rises in excess of 0.1 m/yr to be a groundwater resource condition trigger.

2.5.1.2 Stirling, Willalooka and Wirrega Management Areas (Tatiara PWA)

Groundwater levels have been monitored in the Tatiara PWA since 1975. Water levels are declining in the majority of the western and central water management areas (Stirling, Willalooka and Wirrega). The most significant declines are observed in Stirling where a decrease in the water table of three metres over the last 30 years is evident. A nominal 35% reduction of allocations during 1997/1998 in the Stirling Management Area appears to have had no measurable impact on the declining water level trend.

There is a strong correlation between water level and cumulative deviation of annual rainfall from the mean in most observation wells (e.g. well STR012, Fig. 18). The reasons for this are most likely similar to those attributed to the trends observed in the Padthaway Management Areas 1-3 (above).

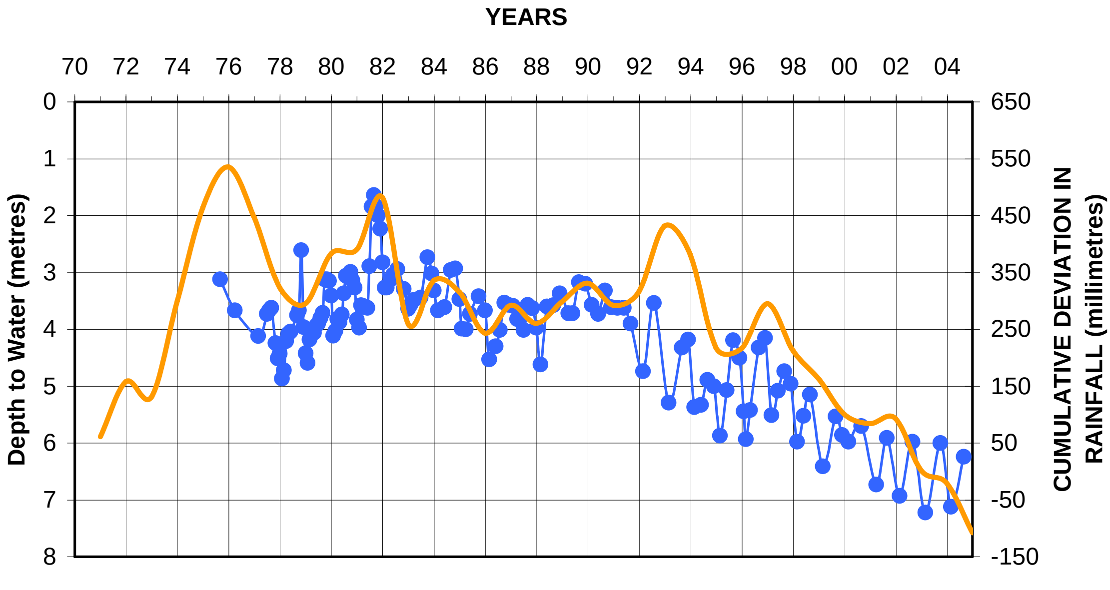


Figure 18. Hydrograph of Observation Well STR012 (Stirling Management Area) and cumulative deviation from mean annual rainfall

The highest groundwater salinity for the Tatiara PWA occurs in the Stirling Management Area where values of more than 8000 mg/L are common. Salinity trend analysis shows significant increases over the entire record in the management areas of Stirling, Willalooka and Wirrega. There are at least two mechanisms for increasing groundwater salinity in this area: concentration of irrigation water by evapotranspiration and subsequent recycling of irrigation drainage water, and geological controls on groundwater flow out of the area (i.e. a basement high immediately west of the Tatiara PWA).

2.5.1.3 Frances, Joanna and Zone 5A Management Areas (Lower Limestone Coast PWA)

From the early 1990s significant declining water levels have been observed in the Frances, Joanna and Zone 5A Management Areas. While the trends are most obvious in the ten year water level trend map (Fig. 5), the entire water level trend map (Fig. 6) shows negligible long-term declines. As observed in the Padthaway and Tatiara PWAs, the relationship between average annual rainfall and changes in groundwater level also applies for these Management Areas (e.g., well BIN007, Fig. 19).

Salinity trends are inconclusive; there are examples of increasing, stable and declining trends over the entire length of the monitoring record. It is not possible to comment on the relationship between water level decline and irrigation activity for the reasons outlined previously.

2.5.1.4 Glenburnie, Myora and Zone 2A Management Areas (Lower Limestone Coast PWA)

A representative hydrograph for the Glenburnie and Myora Areas is shown in Figure 20 (well GAM029). Over a thirty-year period the water table has declined by more than three metres. However this decline has not been linear; the first twenty years (i.e. 1975–1995) showed an overall decline of not more than 1.5 m, followed by a further decline of 2 to 2.5 m in the last ten years. Despite above-average rainfall in 1996, 2000, 2001 and 2003, the water level has continued to decline. This is due in part to the deep water table, and therefore a delayed and subdued response to vertical rainfall recharge. This observation is not unique to the area and reveals a much weaker relationship between rainfall and water level than observed in other parts of the South East. A continuing decline in water levels may be due to a combination of reduced recharge as a result of the plantation industry, the high concentration of stock and domestic wells in these areas or increased extraction for irrigation.

Previous attempts to derive a detailed water balance for this area have not been successful; this may be due to the apparent compartmentalisation of groundwater flow adjacent to the Tartwaup Fault.

The hydrograph for well NAN009 (Fig. 21) is more representative of groundwater levels in Zone 2A. Between the early 1970s and 1983, water levels gradually declined. The Ash Wednesday bush fires in February 1983 decimated softwood plantations in the area, which lead to partial recovery of water levels via enhanced recharge and possibly the cessation of direct groundwater extraction by the trees. Since then, forests have been replanted and as result groundwater levels have returned to a declining trend.

The adopted salinity trigger value has not been exceeded in these management areas.

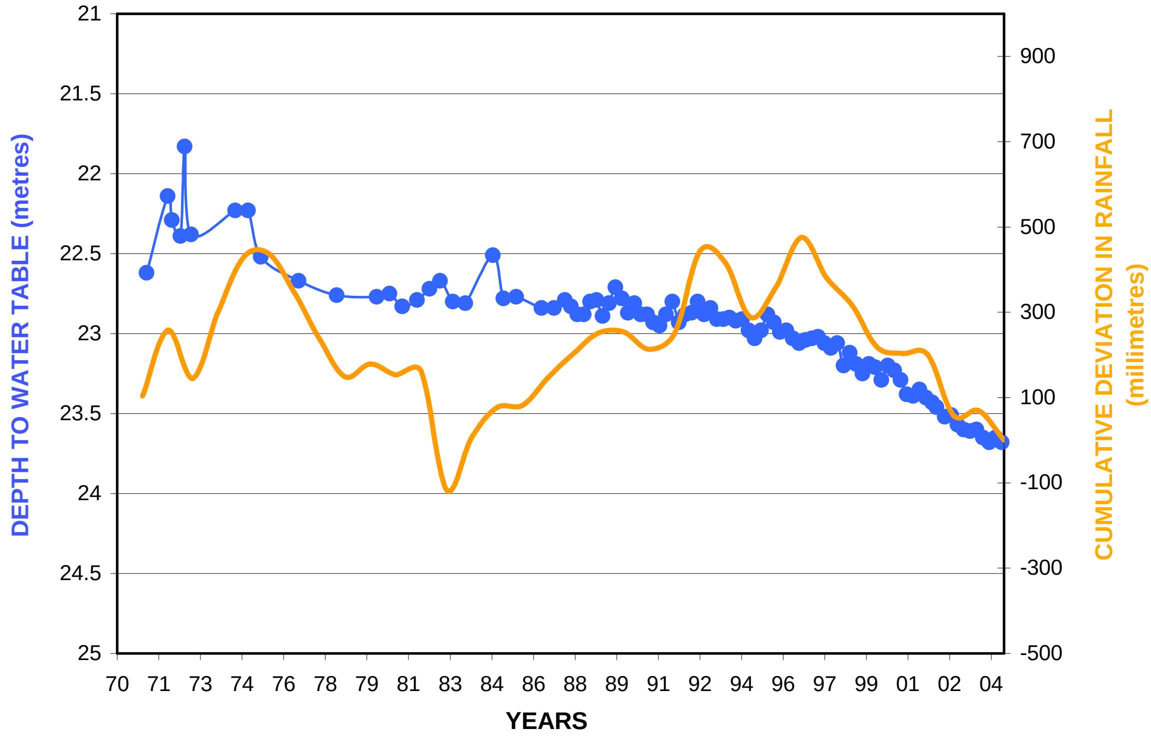


Figure 19. Hydrograph of Observation Well BIN007 (Frances management Area) and cumulative deviation from mean annual rainfall

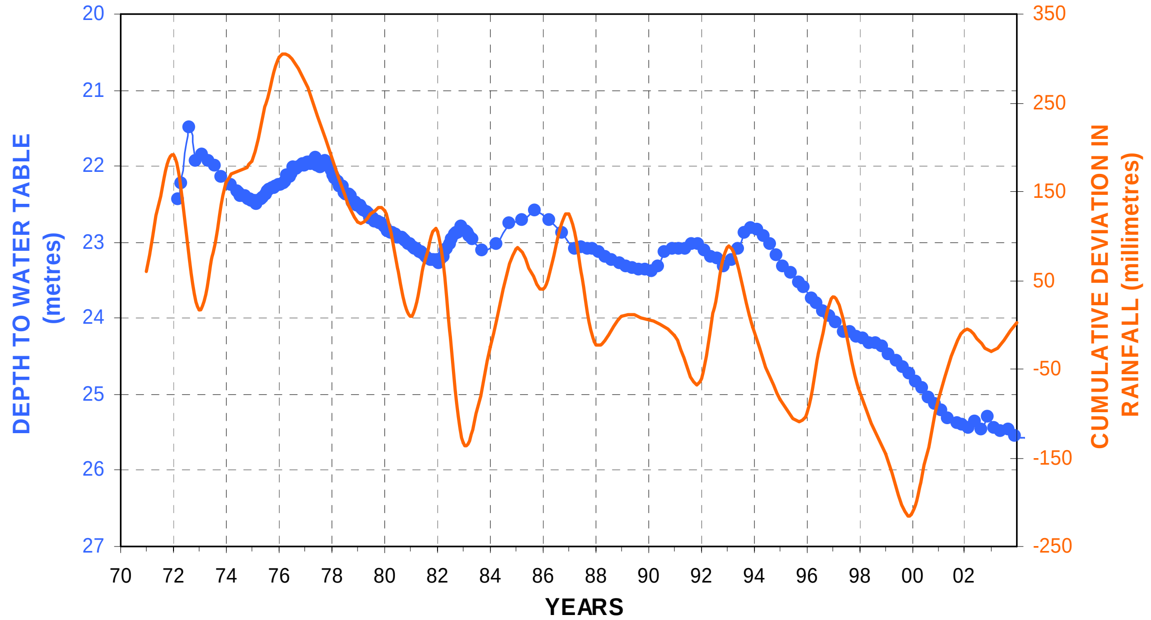


Figure 20. Hydrograph of Observation Well GAM029 (Glenburnie Management Area) and cumulative deviation from mean annual rainfall

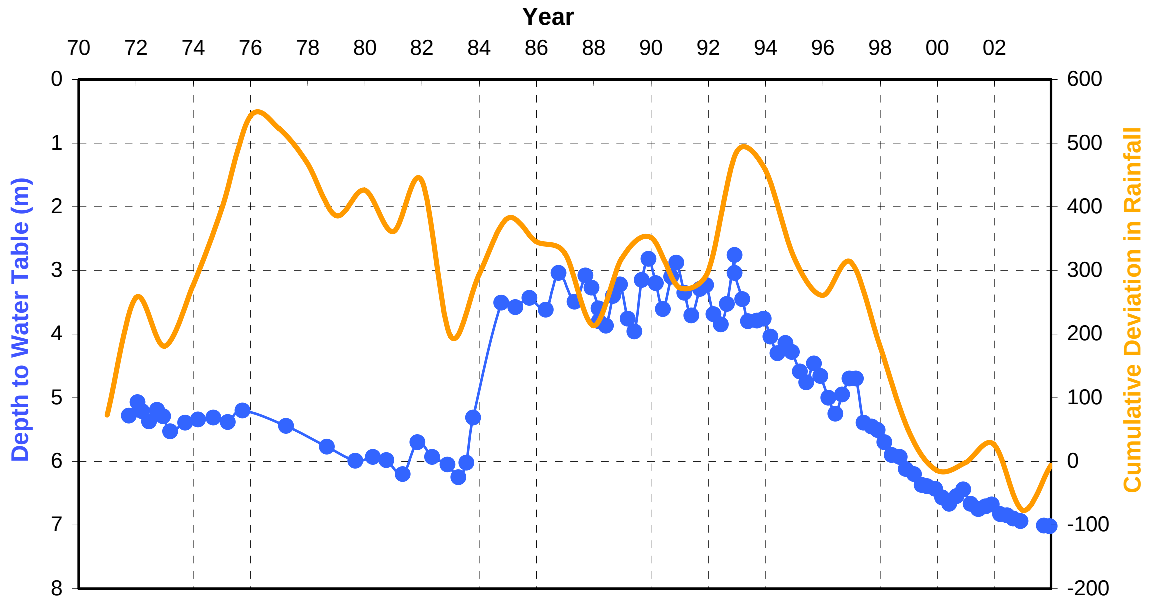


Figure 21. Hydrograph of Observation Well NAN009 (Zone 2A Management Area) and cumulative deviation from mean annual rainfall

2.5.1.5 Kongorong and MacDonnell Management Areas (Lower Limestone Coast PWA)

A representative hydrograph for this area is shown in Figure 22 (well MAC046). Water levels were approximately stable until the early 1990s, before declining until 2000 when the region received above-average rainfall. During the last four to five years the water level has remained relatively stable, and therefore it is the preceding five years that has influenced the 10-year trends.

In this area most groundwater is sourced from the deep, Camelback Member of the Gambier Limestone. However water level monitoring is focussed primarily on the uppermost hydrostratigraphic units. Therefore the current observation wells do not adequately reflect the behaviour of the deeper units of the TLA. It is suggested that changes be made to the monitoring network to confirm resource monitoring trends and allocation limits.

2.5.1.6 Marcollat, Peacock and Woolumbool Management Areas (Lower Limestone Coast PWA)

Several hydrographs from this area exhibit an abrupt fall in water level at the end of 1999/ early 2000 (e.g., well PEC064, Fig. 23). The timing of this drop in water level coincides approximately with the construction of deep groundwater drains in the area. If the hydrographs are reflecting the presence of the drains, then further work is required to establish the regional impacts of these features on the groundwater resources.

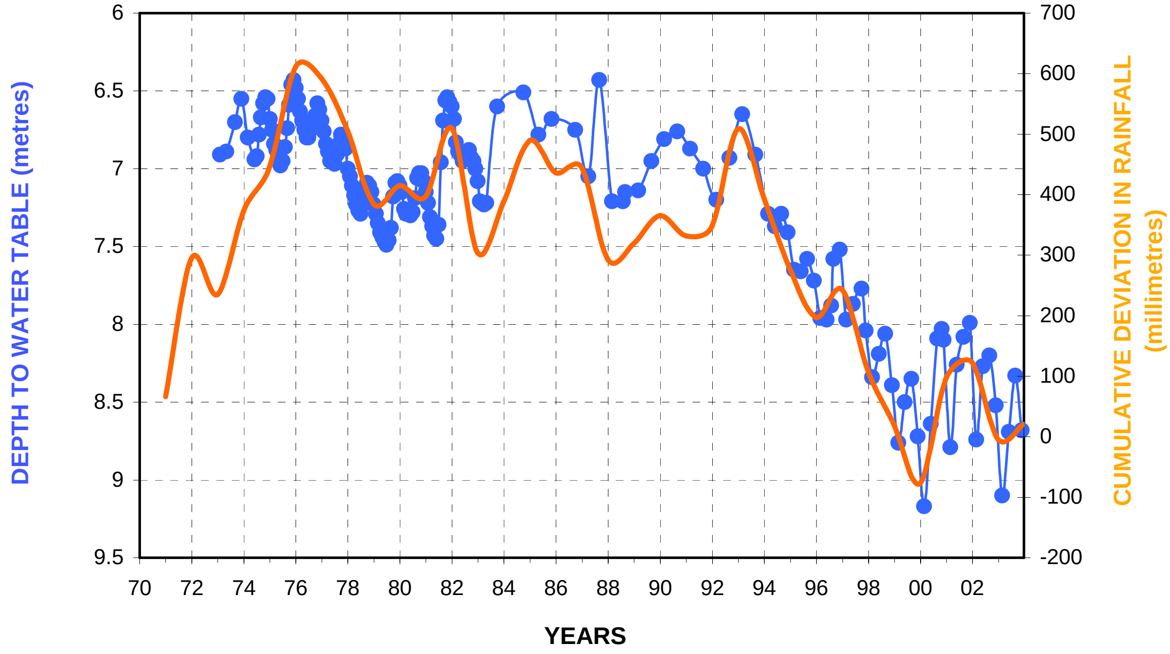


Figure 22. Hydrograph of Observation Well MAC046 (MacDonnell Management Area) and cumulative deviation from mean annual rainfall

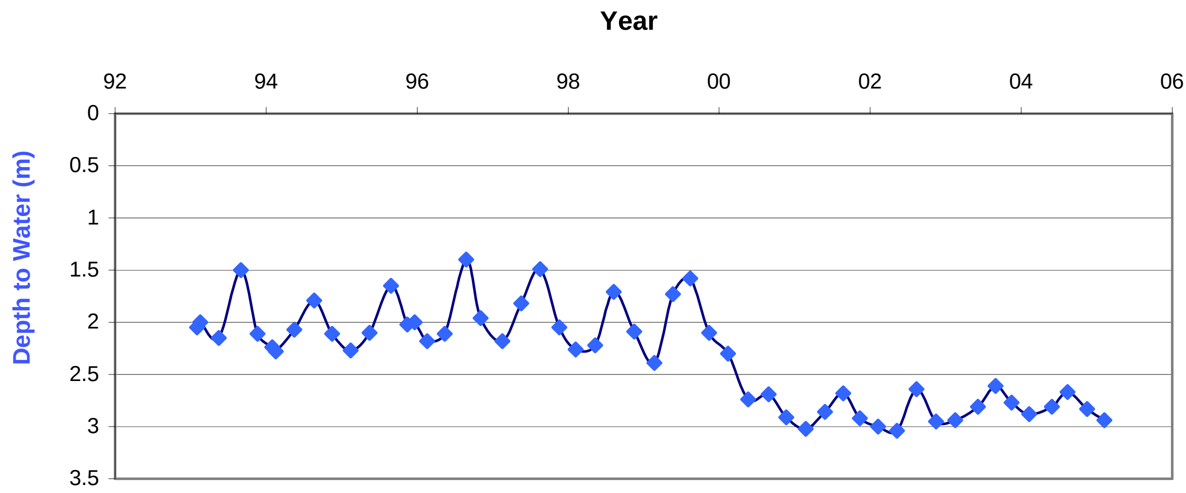


Figure 23. Hydrograph of Observation Well PEC064 (Peacock management Area)

2.5.1.7 Northern part of Zone 3A (Lower Limestone Coast PWA)

Both five year and ten year salinity trend maps (Figs 7 and 8) reveal numerous observation wells in the area around Coonawarra and northwards towards Naracoorte that exceed the adopted trigger value. The processes responsible for these trends are yet to be determined and will be the focus of a forthcoming study.

2.5.2 TERTIARY CONFINED SAND AQUIFER

Most observation wells for the TCSA in the lower South East display water level trends that exceed the recommended trigger levels (Fig. 11). The majority of these have similar water level trends:

- Pre-1992 stable,
- Decline since end of 1992,
- Stable from the end of 1999 / beginning of 2000, and
- Possible pumping affects post 2000.

The post 1992 decline is consistent with a decline in total annual rainfall since the end of 1992 / beginning 1993 (Brown et al, 2001). Brown et al. (2001) showed a strong relationship between rainfall and declining water level trends in both unconfined and confined aquifers between 1979 and 1999. It is unlikely, except in the Nangwarry area and along the Gambier axis, that the confined aquifer is receiving direct recharge. Therefore the relationship between rainfall and hydrographs is probably an indirect response due to increased extraction from the aquifer.

It is also possible that a reduction in overburden pressure resulting from the climate-induced decline in head in the overlying water table aquifer is affecting the head in the confined aquifer. Significant declines in water level have been observed in the unconfined aquifer in these areas over the last ten years.

The lower South East is hydrogeologically complex with numerous deep faults that incise both the unconfined and confined aquifers and further work is required to increase our understanding of the interconnectivity between the unconfined and confined aquifers.

3. METHODS FOR DETERMINING GROUNDWATER RECHARGE

Objective 2. *Examine and recommend an appropriate methodology for determining groundwater recharge to the unconfined aquifer for the purposes of better estimating the PAV.*

3.1 BACKGROUND

The basic management principle used to define Permissible Annual Volumes (PAVs) for the TLA is that groundwater allocation shall not exceed the mean annual vertical recharge rate in each management area. This approach assumes that lateral throughflow is maintained in the aquifer, thereby allowing salts that have accumulated during recharge to be flushed down gradient.

3.2 REVIEW OF RECHARGE ESTIMATION TECHNIQUES

Recharge is therefore the fundamental component of the water balance for resource allocation in the South East. However, it is also arguably the most difficult to measure. Numerous techniques have been developed that have proved to be suitable for estimating direct recharge to water table aquifers in semi-arid regions of Australia. These methods include residual water balance, water table fluctuation, lysimeters and environmental tracers (e.g., chloride mass balance). With the exception of lysimeters, all of these methods infer recharge or potential recharge by relating it in some way to rainfall. Lysimeters provide the only direct measurement but they are limited in their application due to introduced error associated with up-scaling from a point measurement. There is also a time component associated with this technique, as most lysimeters require two to three years to settle after ground disturbance before meaningful figures can be used.

It is difficult to directly compare one recharge estimation technique with another because of the different spatial and temporal scales associated with each. Hence, it is generally recommended that more than one technique be applied to improve confidence in recharge rates.

3.3 WATER TABLE FLUCTUATION METHOD

Many groundwater recharge studies have demonstrated a strong, linear relationship between rainfall amount and change in groundwater levels (e.g., Armstrong and Smith 1974; Stadter, 1989; Brown et al. 2001). The two latter studies were undertaken in the South East region. This relationship allows the estimation of recharge rates from seasonal fluctuations in water levels. This method of recharge estimation, known as the Water Table Fluctuation (WTF) method, assumes that a rise in the water table as measured in a piezometer or observation well is due to rainfall recharge. The measured seasonal rise in water table elevation is then multiplied by the specific yield of the aquifer to obtain an annual recharge rate. It is an indirect approach for determining recharge, but is related to a physical measurement of the aquifer. The WTF method is particularly effective in areas with high winter rainfall and shallow water tables (Armstrong and Narayan, 1998), and is therefore an ideal method for determining recharge rates in the South East. A recent review of recharge techniques across Australia has also concluded that the WTF method is possibly the most robust approach, particularly where long term observation data exists (Petheram et al, 2000). On the basis of this, the WTF method is considered the most suitable method for the South East given the current observation well database.

There are a number of advantages in using the water table fluctuation method:

- The hydrograph response is a summation of the processes occurring in the unsaturated zone at a paddock to catchment scale. The inferred recharge therefore accounts for both diffuse and preferential flow. The larger scale of the method means that it is not subject to the same spatial variability as other techniques that rely on point scale measurement.
- The length of record contained in hydrographs is usually much longer than other studies that commonly last two to three seasons. Therefore the record removes error associated with limited temporal information.
- As mentioned it is an actual physical measurement of the response of the aquifer. It is therefore real and not derived from numerical, analytical or stochastic modelling.

Limitations to the application of this method include:

- Pumping. The change in water level in a well can be influenced by external factors such as extraction and changes in atmospheric pressure.
- Excessive depth to water tables. The water table response to rainfall experiences a lag time and therefore the fluctuations are muted.
- Monitoring frequency. There is potential for missing seasonal peaks and troughs of the water table fluctuation, however DWLBC with over thirty years of monitoring experience, has adjusted the monitoring times to measure the water table at the peaks and troughs.
- The approach requires an accurate estimate of specific yield at the location of the observation well that is seldom available and difficult to determine.

3.4 APPLICATION OF THE WTF METHOD TO THE SOUTH EAST

The WTF method was applied to each management area to provide improved estimates of vertical recharge rates. For simplicity a specific yield of 0.1 was used for all management areas. Whilst it is recognised that specific yield can vary significantly in limestone aquifers, the value of 0.1 is considered conservative and representative of limestone aquifers (Domenico and Schwartz, 1988).

Observation wells with consistent, seasonal water level fluctuations across at least several years of record were selected for analysis. Periods of significant declining or increasing water levels, or where there was evidence of groundwater extraction were excluded from the calculations. The number of wells used for each management area varied considerably (from one to eleven) reflecting the varying density and data quality of the observation wells.

The relationship between depth to water and magnitude of water table fluctuation is shown in Figure 24 for all observation wells that exhibited usable fluctuation data. This plot demonstrates that in areas where the depth to water is greater than ten metres, seasonal water table fluctuations are significantly muted. Thus, application of the WTF method is conservative in areas such as the Naracoorte and Padthaway Ranges, and to the south of Mount Gambier. In these areas, an alternative approach for obtaining refined estimates of recharge rates had to be adopted.

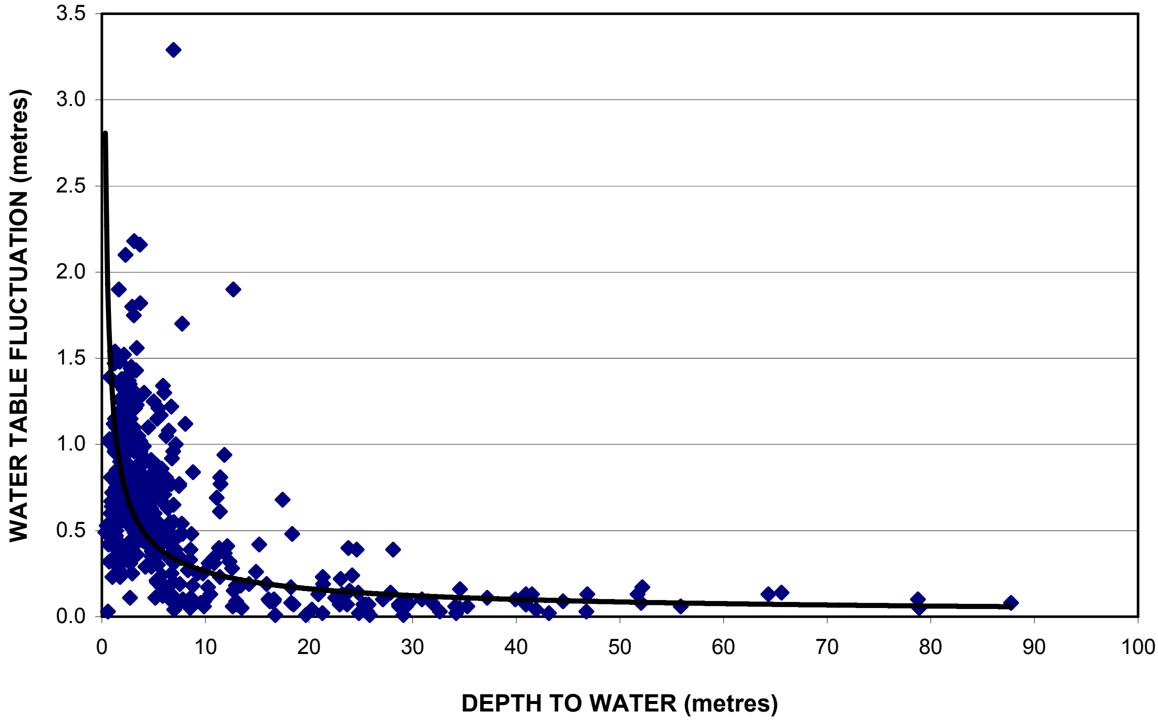


Figure 24. Depth to water against mean annual water table fluctuation in all observation wells used for estimating recharge by the WTF method

Previous estimates of recharge rates for the Border Designated Area management zones were determined for different soil and land-use types (Bradley et al., 1995). Each management area had several different recharge rates rather than a single number as adopted for the Lacepede-Kongorong PWA and forested areas were assigned a lower recharge rate than non-forested areas with the same soil type.

In the current study, the impacts of forestry are explicitly incorporated into the groundwater assessment process (discussed further in section 4) and a single recharge rate is applied for each management area. The latter was achieved by area weighting the different existing soil-related recharge rates, assuming recharge below forested areas was no different to that for unimproved pasture over the same soil unit.

There were also a number of areas outside the Border Designated Area where the WTF method proved to be inappropriate. For example, parts of the Tatiara PWA where irrigation has affected the hydrographs; south of Mount Gambier where the seasonal fluctuations have been altered by declining water levels; and areas of the Naracoorte Ranges where rising water tables have masked seasonal fluctuations. In the case of the area around and to the south of Mount Gambier, mean annual recharge rates were determined through area-weighting rates that Allison and Hughes (1978) had determined for different surficial geologies. For all other cases the previous recharge rate (as published in the current WAPs) was adopted.

A summary of the recharge estimation technique applied to each management area is provided on a map in Appendix 1.

3.5 RESULTS

Recharge rates determined by the WTF method or one of the alternatives discussed above range from 15–200 mm/yr (Table 7 and App. 1). The recharge rates are an optimum value (i.e. they are for unimproved pasture). Areas that are covered by lakes, native vegetation and plantation forestry will have lower recharge rates and will be dealt with in the following section.

Previous recharge rates that were used for the current WAPs are also provided in Table 7 for comparison and reveal some significant differences:

- The WTF method generally provided higher recharge rates than previous estimates.
- The previous recharge rate for management areas in the Designated Border Area have been calculated by area-weighting the different soil/land-use types.
- In Zones 2A and 3A the higher recharge rates reflect exclusion of the forested areas that previously had an associated reduced recharge rate.
- Recharge rates for the area around and to the south of Mount Gambier were determined using the results of Allison and Hughes (1978) and are generally higher than previous estimates for this area.

Table 7. Revised mean annual recharge rate for each management area compared with previous recharge rates. For areas where the WTF method was not appropriate (see text) an alternative approach was used

Management Area	Water Table Fluctuation (m/yr)	Calculated Recharge (mm/yr)	Previous Recharge (mm/yr)	Adopted Recharge R_V (mm/yr)	Comments
BANGHAM SUB AREA			17	20	WTF not valid (deep water tables), Border Zone Weighted Average
BEEAMMA SUB AREA			20	20	WTF not valid (deep, increasing, no seasonal fluctuation), Previous rate adopted
BENARA			75	170	Recharge by weighting values from Allison & Hughes (1978) as per soil/surface geology
BLANCHE CENTRAL			50	175	Recharge by weighting values from Allison & Hughes (1978) as per soil/surface geology
BOOL	1.05	105	75	105	WTF from 3 wells (ROB006, 009, 010)
BOWAKA	0.85	85	50	85	WTF from 2 wells (BOW004 & 006)
BRAY	0.9	90	50	90	WTF method
CANNAWIGARA			15	15	WTF not valid (deep water tables), Previous rate adopted
COLES	1.2	120	100	120	WTF method from 3 wells (CLS004, 006, 009)
COMAUM			35	60	WTF not valid (deep water tables), Border Zone Weighted Average, Forested area change 20 to 70 mm
COMPTON			50	175	Recharge by weighting values from Allison & Hughes (1978) as per soil/surface geology
CONMURRA	0.95	95	75	95	WTF method from 4 wells
DONOVANS	0.25	25	52	175	WTF not valid (deep water tables), Allison & Hughes (1978) approach
DUFFIELD	0.5	50	25	50	WTF from 8 wells
FOX	1	100	100	100	WTF from 4 wells
FRANCES			26	30	WTF not valid (declining & deep water tables, muted flucs), Border Zone Weighted Average
GLENBURNIE			44	150	WTF not valid (no seasonal fluctuations), Allison & Hughes (1978) approach
GLENROY			98	100	Border Zone Weighted Average for consistency
GREY	1.5	150	75	150	WTF method - 1 well (GRY001)
HACKS	1.23	123	75	125	One good well (ROB002) for WTF method
HINDMARSH	0.95	0.95	75	150	Recharge by weighting values from Allison & Hughes (1978) as per soil/surface geology
HYNAM EAST	0.44	44	25	25	WTF not valid (no representative wells for range)
HYNAM WEST	0.8	80	50	80	WTF method - 1 well (HYN015)
JOANNA			47	50	WTF not valid (declining & deep water tables), Border Zone Weighted Average
JOYCE	1.2	120	50	120	WTF method

Management Area	Water Table Fluctuation (m/yr)	Calculated Recharge (mm/yr)	Previous Recharge (mm/yr)	Adopted Recharge R_V (mm/yr)	Comments
KENNION	1.2	120	100	120	WTF from 6 wells
KILLANOOLA	1.43	143	100	145	WTF method 3 wells (KIL 002, 004, 005)
KONGORONG	0.5	50	75	170	Recharge by weighting values from Allison & Hughes (1978) as per soil/surface geology
LACEPEDE	1	100	50	100	WTF from 2 wells
LAKE GEORGE			75	75	No reliable data for WTF
LANDSEER	0.45	45	25	45	WTF fom 6 wells
LOCHABER	0.9	90	50	90	WTF from 5 wells
MACDONNELL	0.75	75	75	150	Recharge by weighting values from Allison & Hughes (1978) as per soil/surface geology
MGMT AREA 1			75	75	Pumping effect hinders estimation. Use previous rate.
MGMT AREA 2			75	75	Pumping effect hinders estimation. Use previous rate.
MGMT AREA 3			75	75	Pumping effect hinders estimation. Use previous rate.
MGMT AREA 4			25	25	Use previous rate.
MARCOLLAT	0.75	75	25	75	WTF from 4 wells
MAYURRA	1.1	110	75	110	WTF from 2 wells
MINECROW	0.73	73	50	75	WTF from 3 wells
MONBULLA	1.8	180	100	180	WTF from 4 wells
MOORAK			50	175	Recharge by weighting values from Allison & Hughes (1978) as per soil/surface geology
MOUNT BENSON	0.6	60	50	60	WTF from 3 wells
MOUNT MUIRHEAD	1.1	110	100	110	WTF from 4 wells
MOYHALL	1.05	105	75	105	WTF from 3 wells (ROB001, 004, 008)
MURRABINNA	0.9	90	50	90	WTF from 1 well
MYORA			40	160	Recharge by weighting values from Allison & Hughes (1978) as per soil/surface geology
NORTH PENDLETON			30	30	WTF method not appropriate (no representative hydrographs), Previous rate adopted
ORMEROD	1.2	120	75	120	WTF from 1 dodgy well (NAR049)
PEACOCK	0.66	66	25	70	WTF from 11 wells
RIDDOCH	1.3	130	75	130	WTF from 3 wells
RIVOLI BAY	1	100	75	100	WTF from 2 wells
ROSS	1.1	110	50	110	WTF from 1 well (ROS009)

Management Area	Water Table Fluctuation (m/yr)	Calculated Recharge (mm/yr)	Previous Recharge (mm/yr)	Adopted Recharge R_V (mm/yr)	Comments
SHAUGH			*15*	*15*	Border Zone Weighted Average for consistency (only one value for one unconfined area)
SHORT	1.5	150	100	150	WTF from 3 wells
SMITH	1	100	75	100	WTF from 2 wells (SMT005 & 006)
SPENCE	1.15	115	50	115	WTF from 2 wells
STEWARTS	1.42	142	75	145	WTF from 3 wells
STIRLING			50	50	WTF method not appropriate (no representative hydrographs), Previous rate adopted
STRUAN			95	95	Border Zone Weighted Average for consistency
SYMON	1.1	110	75	110	WTF from 2 wells (SYM004 & 015)
TATIARA			13	15	Border Zone Weighted Average for consistency
TOWNSEND	0.85	85	50	85	WTF from 3 wells
WATERHOUSE	0.8	80	50	80	WTF from 2 wells
WESTERN FLAT S/A			18	20	Border Zone Weighted Average for consistency
WILLALOOKA			40	40	WTF method not appropriate (no representative hydrographs), Previous rate adopted
WIRREGA			30	30	WTF method not appropriate (no representative hydrographs), Previous rate adopted
WOOLUMBOOL	0.86	86	50	90	WTF from 5 wells
YOUNG	2.3	230	75	200	Recharge by weighting values from Allison & Hughes (1978) as per soil/surface geology
ZONE 2A			66	95	Border Zone Weighted Average for consistency, Forested area change 5 to 60 mm and 45 to 130 mm
ZONE 3A			79	100	Border Zone Weighted Average for consistency, Forested area change 20 to 70 mm and 45 to 130 mm
ZONE 5A			37	40	Border Zone Weighted Average for consistency
ZONE 8A			15	15	Border Zone Weighted Average for consistency

4. TOTAL AVAILABLE RECHARGE AND CURRENT USE

Objective 3. *Assess the current water allocation and use from the groundwater resource from all extractive users, considering that the basis of water allocation is to change from net water use to total extraction through the conversion to volumetric allocations.*

4.1 MANAGEMENT PRESCRIPTION

The Permissible Annual Volume (PAV) for each management area is based on allocating all vertical recharge after providing some allowances for environmental water requirements and for maintaining lateral throughflow throughout the TLA to manage groundwater salinity. The approach for setting PAV is not consistent across all management areas. Furthermore, estimates of the PAV have considered the impacts of forestry by assigning a recharge rate of zero to all forested areas, except in the Border Designated Area where variable rates were adopted for forested areas (Bradley et al., 1995).

This review suggests that forestry now be considered on the "use" side of the water budget ledger. Under this scheme, the only component of the water budget that will be incorporated into the PAV determination is that for Environmental Water Requirements (EWRs). The EWRs for Groundwater Dependent Ecosystems (GDEs) will be set at a nominal 10% of the total vertical recharge assuming (a) no forested areas and (b) zero recharge beneath lakes and native vegetation. This environmental component could also be used to allow for a degree of lateral throughflow throughout the aquifer system, however this has not been considered explicitly in the current study.

Groundwater "uses" include forestry impacts; licensed extractions for irrigation, industrial and town water supplies; and stock and domestic water use.

The forestry impacts include recharge debits, which have come about through consultation between the forestry industry and the SA Government, and amount to an agreed 83% reduction underneath softwood plantations and 77% reduction underneath hardwood plantations (App. 2). These figures incorporate characteristics of the growing cycle of the forests and associated variations in canopy cover over time. Recent work undertaken by CSIRO Forestry (Benyon and Doody, 2004) has determined that both softwood and hardwood plantations can also extract groundwater when the depth to water table is less than about seven metres. To assess the implications of direct extraction of groundwater by forest plantations, water use figures for softwood and hardwood of 2.6 ML/ha/yr and 2.3 ML/ha/yr have been adopted for this study. These estimates are based on conservative rates of potential use (from Benyon and Doody, 2004) considering the growth cycles of the plantations (App. 2).

Stock and domestic water use figures were previously determined by Cobb and Brown (2000 a-c) using census data from the Bureau of Statistics and average consumption volumes supplied by the NSW Department of Agriculture. These figures were adopted for the current WAPs and remain unchanged for this study.

4.2 METHODS

The mean annual vertical recharge rate (R_V) was calculated for each management area using either the WTF method or a suitable alternative (Section 3.4 and Table 7). To determine the Total Available Recharge (TAR) that can be allocated in each management area, the following calculations were applied.

Total land area (A_T) of each management area was determined using GIS. Recharge beneath major lakes (area A_L) and native vegetation (area A_{NV}) was assumed to be zero. To account for this, a Net area (A_N) was determined for each management area:

$$A_N = A_T - (A_{NV} + A_L).$$

To determine the net volume of recharge (V_{VR}) for each management area, the net area was multiplied by the average recharge rate:

$$V_{VR} = A_N \times R_V$$

Because the EWRs of GDEs are yet to be quantified, an environmental allowance (V_E) of 10% of V_{VR} was adopted for each management area:

$$V_E = V_{VR} \times 0.1$$

The TAR for allocation in each management area is then given by

$$TAR = V_{VR} - V_E$$

The environmental allowance (V_E) could be increased above 10% in future to allow for an additional component of lateral throughflow in each management area.

TAR is the component of recharge available for allocation after accounting for environmental needs. The use of TAR instead of PAV has been adopted to distinguish between what level of development the resource can support in a sustainable manner (i.e. TAR) and what satisfies social and economic requirements from the resource (i.e. PAV). Recommendations for how PAVs should be adjusted towards the new TAR values are provided in Chapter 5.

The following discussion describes how the components that make up total groundwater "use" were calculated. These components are forestry, licensed allocations for irrigation, industry and public water supply; and stock and domestic water use.

A model has been developed to estimate the net recharge reductions under plantation forestry, incorporating changes in recharge rate through the growth cycle of different forest types. Under an agreement between the State Government and the forestry industry, threshold areas for forestry development were established for both Softwood (A_{ST}) and Hardwood (A_{HT}) in each management area (Table 8). These threshold areas were derived from estimated forest area, planned expansion in 2002 and a portion of the Strategic Reserve promised for offsetting future forestry development. The threshold figures are the maximum areas that can be planted in each management area without having to obtain an offsetting water allocation.

The threshold areas were used in this study to calculate the loss of recharge due to forest recharge interception. Discussions between the State Government and the forestry industry resulted in an agreement that, over the growth cycle of the forests, an average of 17% (Softwood) and 23% (Hardwood) of the mean annual recharge would be maintained (App. 2).

Table 8. Current and threshold areas (June 2004) for softwood and hardwood forest in each TLA management area

Management Area	SOFTWOOD		HARDWOOD	
	Threshold Area (Ha)	Current Area (Ha)	Threshold Area (Ha)	Current Area (Ha)
BENARA	5430	3558	185	32
BLANCHE CENTRAL	2842	2413	307	21
BOOL	0	0	299	3
BOWAKA	318	0	0	21
BRAY	1681	699	600	0
COLES	610	0	13934	12302
COMAUM	2477	2231	3	5
COMPTON	794	672	0	0
CONMURRA	1730	0	350	1419
DONOVANS	3756	3560	106	39
FOX	1740	556	4012	1352
GLENBURNIE	8497	7912	512	89
GLENROY	0	0	0	0
GREY	86	77	129	11
HACKS	0	0	63	0
HINDMARSH	11241	10204	436	147
JOANNA	1611	1417	0	4
JOYCE	533	0	263	3162
KENNION	3009	1984	3723	117
KILLANOOLA	366	0	1395	536
KONGORONG	6573	5630	0	0
LAKE GEORGE	623	177	0	0
MACDONNELL	3	0	0	0
MAYURRA	780	15	52	6
MONBULLA	828	0	4568	1929
MOORAK	141	52	15	1
MOUNT BENSON	5247	4746	0	0
MOUNT MUIRHEAD	2946	1978	633	30
MOYHALL	0	0	0	1
MYORA	8005	7633	269	24
RIDDOCH	7895	6551	3545	286
RIVOLI BAY	757	207	0	0
ROSS	464	0	600	0
SHORT	627	683	11479	9645
SMITH	664	548	0	0
SPENCE	548	0	1998	2148
STEWARTS	60	0	0	0
STRUAN	59	0	0	0
SYMON	3155	1722	1719	56
TOWNSEND	552	0	275	0
WATERHOUSE	852	423	0	2
YOUNG	4670	3810	1318	226
ZONE 2A	22103	20105	3074	989
ZONE 3A	12839	11696	184	187
ZONE 5A (JESSIE)	15	0	0	8
TOTAL	**127128**	**101259**	**56045**	**34799**

The “total recharge debits” (V_{ST} + V_{HT}) under softwood and hardwood is then:

$V_{ST} = A_{ST} \times (R_V \times 0.83)$, and

$V_{HT} = A_{HT} \times (R_V \times 0.77)$.

Recent studies conducted in southeast SA and southwest Victoria have measured rates of direct groundwater extraction by forest plantations over shallow water tables (Benyon and Doody, 2004). Using the results from these study sites, an average rate of groundwater use of 2.6 ML/ha/yr for Softwood and 2.3 ML/ha/yr for Hardwood has been estimated (App. 2) for areas where the depth to water table is less than seven metres. These groundwater use figures were applied in the current study to existing areas of forestry based on 2002 land use for softwood (area A_{S7}) and 2004 land use for hardwood (area AH7) (App. 3). Plantation forestry in areas where the depth to water table is more than seven metres is considered to not use groundwater. The total volume of groundwater potentially used by softwood (V_{SWU}) and hardwood (V_{HWU}) is then given by

$V_{SWU} = A_{S7} \times 2.6$

$V_{HWU} = A_{H7} \times 2.3$

Irrigation, industrial and town water allocations (V_{TA}) for each management area were sourced from DWLBC records for the 2003-2004 irrigation period (Kelly and McIntyre, 2004) and are based on the current hectare IE system for irrigation allocations.

Estimates of stock and domestic water use (V_{SD}) were taken from the existing WAPs which reflect the work of Cobb and Brown (2000 a-c).

The Total Volume of Use (V_{TU}) for each management area is:

$V_{TU} = (V_{ST} + V_{HT}) + (V_{SWU} + V_{HWU}) + V_{TA} + V_{SD}$

The difference (ΔV) between inputs (TAR) and outputs (V_{TU}) provides an indication of the degree to which estimated use (NB: use for irrigation equates to current allocations – see above) differs from the TAR for each management area:

$\Delta V = TAR - V_{TU}$

The current hectare IE system for irrigation allocations does not account for a delivery component, i.e. the amount of additional water required to overcome irrigation system losses (e.g. drainage, leakage, evaporation). Therefore existing allocations are not an accurate estimate of the volume of water extracted from the resource. Hence, some management areas may be closer to being (or more) over-allocated.

4.3 RESULTS AND DISCUSSION

All components for the TAR calculation are provided in Table 9 along with a comparison of current PAVs for each management area. Note that the components of the PAV calculation have changed and therefore a direct comparison between current PAVs and recommended TARs may be misleading. Nevertheless there are a few areas where significant differences exist between TAR and current PAV. These include a reduction (i.e. TAR<PAV) for Hynam East and Shaugh management areas, and large increases (i.e. TAR>PAV) for Benara, Blanche Central, Compton, Donovans, Glenburnie, Hindmarsh, Joyce, Kongorong, Marcollat, Moorak, Myora, Peacock and Young management areas.

Table 9. Calculation of Total Available Recharge (TAR) for allocation.

Note: the net recharge volume for Wirrega Management Area also includes 2300 ML/yr direct recharge from run-away holes

TLA Management Area	Total Area (Ha) A_T	Area less Lakes & Native Veg. (Ha) A_N	Adopted Recharge Rate (mm/yr) R_V	Net Recharge Volume (ML/yr) V_{VR}	Total Available Recharge (ML/yr) TAR	Existing PAV (ML/yr)	% Difference
BANGHAM SUB AREA	37507	30044	20	6009	5408	4170	30%
BEEAMMA SUB AREA	26784	22907	20	4581	4123	5000	-18%
BENARA	29850	24672	170	41943	37749	16100	134%
BLANCHE CENTRAL	7712	7708	175	13489	12140	2300	428%
BOOL	7355	4675	105	4908	4417	3200	38%
BOWAKA	24902	21055	85	17896	16107	11200	44%
BRAY	25921	21133	90	19020	17118	10800	59%
CANNAWIGARA	28189	25178	15	3777	3399	4200	-19%
COLES	26873	23359	120	28031	25228	23400	8%
COMAUM	7737	6275	60	3765	3388	1750	94%
COMPTON	3775	3759	175	6579	5921	1700	248%
CONMURRA	38902	34812	95	33071	29764	26300	13%
DONOVANS	24180	21837	175	38215	34394	12600	173%
DUFFIELD	27444	20499	50	10250	9225	5900	56%
FOX	25997	22634	100	22634	20370	22400	-9%
FRANCES	17943	16271	30	4881	4393	4680	-6%
GLENBURNIE	27676	27251	150	40876	36789	12300	199%
GLENROY	8238	8174	100	8174	7357	4550	62%
GREY	19522	18551	150	27827	25044	13300	88%
HACKS	4847	4648	125	5810	5229	3700	41%
HINDMARSH	25807	23168	150	34751	31276	9000	248%
HYNAM EAST	20090	15895	25	3974	3576	5000	-28%
HYNAM WEST	7951	7951	80	6361	5725	4000	43%
JOANNA	32183	28567	50	14284	12855	10000	29%
JOYCE	38868	35351	120	42422	38180	17900	113%
KENNION	25788	23399	120	28079	25271	21600	17%
KILLANOOLA	19271	17119	145	24823	22340	17400	28%
KONGORONG	24208	21357	170	36307	32676	11700	179%
LACEPEDE	26283	20015	100	20015	18014	11400	58%
LAKE GEORGE	21962	11814	75	8861	7975	8600	-7%
LANDSEER	29804	18829	45	8473	7626	5800	31%
LOCHABER	25956	23353	90	21018	18916	12500	51%
MACDONNELL	19109	18081	150	27122	24410	13300	84%
MGMT AREA 1	24746	22455	75	16841	15157	15774	-4%
MGMT AREA 2	8514	8477	75	6358	5722	5960	-4%
MGMT AREA 3	5375	5268	75	3951	3556	2900	23%
MGMT AREA 4	32201	26378	25	6594	5935	6678	-11%

TOTAL AVAILABLE RECHARGE AND CURRENT USE

TLA Management Area	Total Area (Ha) A_T	Area less Lakes & Native Veg. (Ha) A_N	Adopted Recharge Rate (mm/yr) R_V	Net Recharge Volume (ML/yr) V_{VR}	Total Available Recharge (ML/yr) TAR	Existing PAV (ML/yr)	% Difference
MARCOLLAT	21007	19647	75	14735	13262	5000	165%
MAYURRA	26325	19626	110	21588	19430	13500	44%
MINECROW	33845	27240	75	20430	18387	15300	20%
MONBULLA	19284	16476	180	29657	26692	16600	61%
MOORAK	7388	7088	175	12404	11164	3200	249%
MOUNT BENSON	25858	23963	60	14378	12940	10000	29%
MOUNT MUIRHEAD	25971	25319	110	27851	25066	23500	7%
MOYHALL	6918	5889	105	6183	5565	4800	16%
MURRABINNA	21945	17184	90	15466	13919	9400	48%
MYORA	14602	14344	160	22950	20655	6000	244%
NORTH PENDLETON	26459	24809	30	7443	6699	7400	-9%
ORMEROD	8420	8242	120	9890	8901	6095	46%
PEACOCK	36932	31217	70	21852	19666	8400	134%
RIDDOCH	26004	24472	130	31814	28633	13800	107%
RIVOLI BAY	20306	15588	100	15588	14029	12000	17%
ROSS	25578	20745	110	22820	20538	11300	82%
SHAUGH	40861	26646	15	3997	3597	7760	-54%
SHORT	25986	22665	150	33997	30597	21700	41%
SMITH	22801	19060	100	19060	17154	14100	22%
SPENCE	37695	31539	115	36270	32643	17000	92%
STEWARTS	9964	9293	145	13475	12128	7140	70%
STIRLING	39380	37838	50	18919	17027	19260	-12%
STRUAN	7287	7189	95	6830	6147	3700	66%
SYMON	25389	22726	110	24998	22498	16200	39%
TATIARA	47956	45812	15	6872	6185	6548	-6%
TOWNSEND	31197	27412	85	23300	20970	14100	49%
WATERHOUSE	34778	22364	80	17891	16102	11400	41%
WESTERN FLAT S/A	7472	6409	20	1282	1154	952	21%
WILLALOOKA	38010	36311	40	14524	13072	10000	31%
WIRREGA	79771	74340	30	24602	24442	28120	-13%
WOOLUMBOOL	36255	31089	90	27980	25182	16500	53%
YOUNG	19296	16818	200	33636	30273	9500	219%
ZONE 2A	55600	52393	95	49774	44796	25000*	79%
ZONE 3A	55600	50146	100	50146	45132	24000*	88%
ZONE 5A	55600	52168	40	20867	18780	18500*	2%
ZONE 8A	55600	53418	15	8013	7211	7700*	-6%

* Existing PAV is the Allowable Annual Volume (AAV) for the TLA as set by the Border Groundwaters Agreement Review Committee for licensed water allocations.

The primary reasons for major changes in TAR from the current PAV include:

- Improved estimates of average recharge rates (WTF method or alternatives);
- More accurate determination of land areas through GIS (including management areas, native vegetation and forested areas);
- Allowances for Environmental Water Requirements are now explicitly included in the TAR determination;
- Forestry recharge debits now considered a "use" and therefore not included in the TAR.

All components of total groundwater use (V_{TU}) have been calculated and are provided in Table 10. The ΔV and "ΔV as a % of TAR" columns provide insight to the level of under- or over-allocation of the groundwater resource under the recommended management system. Of the 73 management areas, a total of 21 (i.e. 29%) are over-allocated by up to 183% (Padthaway Management Area 2).

Many of the management areas that are apparently over-allocated have significant components of potential forest groundwater extraction in the total "use" estimate (e.g., Coles, Hindmarsh, Mount Benson, Short, Zones 2A and 3A). Other reasons for the over-allocated (and under-allocated) management area are provided in the next Chapter 5.

The total Gazetted volume of water currently held for Strategic Reserve by the Government appears in the right-most column of Table 10. Varying proportions of these volumes have already been nominated to offset future forestry development. The remaining volume (not tabulated) is unallocated.

Table 10. Comparison between Total Groundwater Use (V_{TU}) and Total Available Recharge (TAR)

Note: the total allocations for Hindmarsh and Mayurra management areas now incorporate previously-unlicensed extractions by Kimberley Clark Australia Pty Ltd. of 16653 ML/yr and 1647 ML/yr, respectively

Management Area	Total Forestry Recharge Debits (V_{ST} + V_{HT}) (ML/yr)	Current Forest Water Use (V_{SWU} + V_{HWU}) (ML/yr)	2004 Total Allocation V_{TA} (ML/yr)	Stock & Domestic V_{SD} (ML/yr)	Total Use V_{TU} (ML)	Total Available Recharge TAR (ML/yr)	delta V (ML)	delta V as % TAR	Gazetted Strategic reserve (ML)
BANGHAM SUB AREA	0	0	4100	155	4255	5408	1153	21%	0
BEEAMMA SUB AREA	0	0	6136	105	6241	4123	-2118	-51%	0
BENARA	7904	2927	10972	279	22082	37749	15667	42%	1369
BLANCHE CENTRAL	4542	0	2172	263	6977	12140	5163	43%	238
BOOL	242	0	1617	76	1935	4417	2483	56%	484
BOWAKA	224	0	7938	238	8400	16107	7706	48%	774
BRAY	1672	398	6575	219	8864	17118	8254	48%	1694
CANNAWIGARA	0	0	3665	285	3950	3399	-551	-16%	0
COLES	13483	28787	6276	222	48768	25228	-23540	-93%	1192
COMAUM	1235	12	2008	30	3285	3388	104	3%	0
COMPTON	1153	0	772	191	2116	5921	3805	64%	238
CONMURRA	1620	2223	17298	400	21541	29764	8223	28%	3555
DONOVANS	5598	0	12507	645	18750	34394	15643	45%	0
DUFFIELD	0	0	1429	185	1614	9225	7611	83%	0
FOX	4533	4091	13551	249	22424	20370	-2054	-10%	2918
FRANCES	0	0	4657	140	4797	4393	-404	-9%	0
GLENBURNIE	11170	0	15742	2530	29442	36789	7346	20%	0
GLENROY	0	0	5735	65	5800	7357	1557	21%	0
GREY	256	225	16331	286	17098	25044	7946	32%	0
HACKS	61	0	3474	78	3613	5229	1616	31%	0
HINDMARSH	14499	8196	22820	492	46007	31276	-14730	-47%	759
HYNAM EAST	0	0	4958	140	5098	3576	-1522	-43%	0
HYNAM WEST	0	0	3809	70	3879	5725	1846	32%	0
JOANNA	669	141	10119	330	11259	12855	1597	12%	0
JOYCE	774	6737	13043	243	20797	38180	17383	46%	487
KENNION	6437	5413	13663	288	25801	25271	-530	-2%	3418
KILLANOOLA	1998	1253	9943	209	13403	22340	8937	40%	2429
KONGORONG	9275	531	8519	394	18719	32676	13957	43%	239
LACEPEDE	0	0	5869	162	6031	18014	11983	67%	0
LAKE GEORGE	388	33	4562	166	5149	7975	2826	35%	1337
LANDSEER	0	0	4258	14	4272	7626	3354	44%	0
LOCHABER	0	0	7394	84	7478	18916	11438	60%	1968
MACDONNELL	4	0	14472	381	14857	24410	9553	39%	0
MGMT AREA 1	0	0	13635	461	14096	15157	1061	7%	0
MGMT AREA 2	0	0	16022	172	16194	5722	-10472	-183%	0

TOTAL AVAILABLE RECHARGE AND CURRENT USE

Management Area	Total Forestry Recharge Debits (V_{ST} + V_{HT}) (ML/yr)	Current Forest Water Use (V_{SWU} + V_{HWU}) (ML/yr)	2004 Total Allocation V_{TA} (ML/yr)	Stock & Domestic V_{SD} (ML/yr)	Total Use V_{TU} (ML)	Total Available Recharge TAR (ML/yr)	delta V (ML)	delta V as % TAR	Gazetted Strategic reserve (ML)
MGMT AREA 3	0	0	3807	107	3914	3556	-358	-10%	0
MGMT AREA 4	0	0	1706	196	1902	5935	4033	68%	0
MARCOLLAT	0	0	1631	36	1667	13262	11595	87%	0
MAYURRA	756	0	9890	234	10880	19430	8549	44%	3794
MINECROW	0	0	7757	54	7811	18387	10576	58%	0
MONBULLA	7568	4514	9337	207	21627	26692	5065	19%	1881
MOORAK	225	0	2417	95	2737	11164	8427	75%	0
MOUNT BENSON	2613	10443	7074	98	20228	12940	-7289	-56%	588
MOUNT MUIRHEAD	3226	2159	13625	40	19050	25066	6016	24%	3633
MOYHALL	0	0	2171	83	2254	5565	3311	59%	0
MURRABINNA	0	0	5788	40	5828	13919	8091	58%	0
MYORA	10962	6760	3714	725	22161	20655	-1507	-7%	0
NORTH PENDLETON	0	0	6542	170	6712	6699	-13	0%	0
ORMEROD	0	0	350	85	435	8901	8466	95%	0
PEACOCK	0	0	3951	240	4191	19666	15475	79%	0
RIDDOCH	12067	305	8544	267	21183	28633	7449	26%	1656
RIVOLI BAY	628	112	5513	423	6677	14029	7352	52%	1846
ROSS	932	0	7245	175	8352	20538	12186	59%	1460
SHAUGH	0	0	5308	170	5478	3597	-1881	-52%	0
SHORT	14039	24338	8633	245	47255	30597	-16657	-54%	112
SMITH	551	1419	10653	213	12836	17154	4318	25%	18
SPENCE	2292	5025	8174	301	15793	32643	16850	52%	2444
STEWARTS	72	0	13837	85	13994	12128	-1867	-15%	0
STIRLING	0	0	20938	285	21223	17027	-4196	-25%	0
STRUAN	47	0	4036	70	4153	6147	1994	32%	0
SYMON	4337	3344	9847	259	17787	22498	4712	21%	2543
TATIARA	0	0	7280	250	7530	6185	-1345	-22%	0
TOWNSEND	569	0	8654	294	9517	20970	11452	55%	2164
WATERHOUSE	566	1087	8058	466	10177	16102	5925	37%	788
WESTERN FLAT S/A	0	0	964	30	994	1154	160	14%	0
WILLALOOKA	0	0	10589	340	10929	13072	2143	16%	0
WIRREGA	0	0	32187	590	32777	24442	-8335	-34%	0
WOOLUMBOOL	0	0	7270	238	7508	25182	17674	70%	0
YOUNG	9782	1721	5151	355	17009	30273	13264	44%	835
ZONE 2A	19677	46392	20057	857	86983	44796	-42186	-94%	1385
ZONE 3A	10798	30139	24049	505	65491	45132	-20359	-45%	0
ZONE 5A	5	0	18999	505	19509	18780	-729	-4%	0
ZONE 8A	0	0	4854	280	5134	7211	2077	29%	0

5. PERMISSIBLE ANNUAL VOLUMES

Objective 4. *Determine whether the capacity of the resource is sufficient to meet the demand identified on a continuing basis in each management area, and the reasons for the determination.*

5.1 INTRODUCTION

Previous determinations of the Permissible Annual Volume (PAV) were based on what is now termed the Total Available Recharge (TAR) for each management area. If an area was under stress, either through water level decline, salinity increase or current allocations exceeding TAR, then the PAV was adjusted to compensate for these trends or to match existing levels of use.

5.2 REVISION OF PAVS

In this review, the PAV for each management area outside the Border Designated Area (BDA) has been revised to the new TAR values. The PAVs for TLA management areas within the BDA have been retained at the Allowable Annual Volumes (AAV) set by the Border Groundwaters Agreement Review Committee (AAVs set for the TLA and TCSA are added to calculate the PAV for each management area).

There are four categories of management areas that need to be considered for future management purposes:

- Management areas that were identified as hotspots and have total use greater than total available recharge (i.e. $\Delta V<0$).
- Management areas that were not identified as hotspots but have total use greater than total available recharge (i.e. $\Delta V<0$).
- Management areas that were identified as hotspots but have total use less than total available recharge (i.e. $\Delta V>0$).
- Management areas that were not identified as hotspots and have total use less than total available recharge (i.e. $\Delta V>0$).

In recognition of the potential errors associated with estimating recharge rates, forestry impacts on groundwater, stock and domestic water requirements and current extraction for irrigation, all management areas that were not identified as hotpots but have ΔV within ±20% of the TAR were considered to be in balance.

5.2.1 MANAGEMENT AREAS THAT ARE HOTSPOTS WITH $\Delta V<0$

Padthaway Management Area 2, Stirling, Wirrega, Zone 2A and Zone 3A management areas were all identified as hotspots and have an estimated total use that exceeds the total available recharge by more than 20%. For the first three of these areas, the current irrigation allocation component of the total use value also exceeds the total available recharge.

Current studies into salt accession processes in Padthaway, the Hundred of Stirling and Border Designated Area will provide additional information on the relative impacts of different land uses, which in turn will provide direction for making accurate management adjustments.

The Zone 2A management area has a total use that exceeds total available recharge by almost 100% due to the estimate for forest plantation water use (i.e. direct extraction) component, which accounts entirely for this deficit. The long-term effects of forest plantations on the groundwater resource is uncertain and therefore requires further technical investigation to help provide direction about future management settings in these areas. In addition, the recharge rate for Zone 2A (i.e., 95 mm/yr cf. 200 mm/yr in the adjacent Young Management Area) is likely to be an underestimate because recharge rates for the Border Zones 2A – 9A were not changed in this review.

Zone 3A also has total estimated use exceeding recharge, and was identified as a hotspot based on salinity trends in the northern part of the management area exceeding the 10 mg/L/yr trigger value. The processes responsible for these trends are the subject of a forthcoming comprehensive study and the results of this study will provide direction for future management settings.

5.2.2 MANAGEMENT AREAS NOT HOTSPOTS WITH ΔV<0

Beamma, Coles, Hindmarsh, Hynam East, Mount Benson, Shaugh, Short and Tatiara management areas were not identified as hotspots but have current estimated use exceeding total annual recharge by more than 20%;

- Hindmarsh management area encompasses the majority of groundwater use by Kimberly Clark Australia Pty Ltd., which was previously not a licensed allocation and thus not accounted for in PAV assessments.
- Coles, Mount Benson and Short management areas have extensive forest plantations over shallow water tables and therefore a significant estimated forest water use (i.e. direct extraction) component.
- Beamma and Hynam East management areas both contain approximately 4000 Ha of native vegetation that was previously not considered in the recharge estimation.
- Shaugh and Tatiara management areas both have low average annual recharge rates (i.e. 15 mm/yr) and large areas of native vegetation that were previously not considered in recharge estimations.

5.2.3 MANAGEMENT AREAS THAT ARE HOTSPOTS WITH ΔV>0

Six management areas were identified as hotspots where current levels of estimated use are more than 20% below total available recharge. These are Glenburnie, Kongorong and MacDonnell in the Lower South East and Marcollat, Peacock and Woolumbool in the Upper South East.

Marcollat, Peacock and Woolumbool were identified through the hotspot analysis due to abrupt declines in groundwater levels toward the end of the 1990s that are likely to be associated with the construction of deep drains in the area. The difference of 70–90% between total annual recharge and total use may be leaving the area via discharge into the drains.

Whilst estimates of vertical recharge are based upon the best available science in each part of the South East region, the new (higher) values adopted for Glenburnie, Kongorong and MacDonnell management areas may not be appropriate given the observed water level and salinity trends. In areas of intensive irrigation use, actual volumetric extractions may exceed the allocation volume based on the hectare IE allocation rates.

5.2.4 MANAGEMENT AREAS NOT HOTSPOTS WITH ΔV>0

Thirty nine of the seventy three management areas have water level and salinity trends below trigger levels and also an estimated total groundwater use less than total available recharge. This situation is ideal as it suggests that current use is within the capacity of the resource. In areas characterised by highly-variable salinity there is a need to ensure sufficient lateral through-flow to mitigate potential salinity impacts.

6. PROTECTION OF GROUNDWATER DEPENDENT ECOSYSTEMS (GDES)

Objective 5. *Recommend a methodology to protect the needs of Groundwater Dependent Ecosystems (GDEs).*

6.1 INTRODUCTION

This section identifies and discusses the merits of a number of approaches that may be used to protect Groundwater Dependent Ecosystems (GDEs) in the South East region. Not considered was a methodology for identifying individual GDEs or an approach for determining the degree to which GDEs are groundwater dependent. Both are part of a separate study currently being undertaken by Resource and Environmental Management (REM) consultants.

Two methodologies to protect GDEs were considered appropriate for the South East region; they are protection zones and the issuing of ‘phantom’ licences. These methods would be in addition to the 10% of total annual recharge allocated for each management area.

6.2 PROTECTION ZONES

A protection (or buffer) zone is placed around a GDE to preserve the environmental condition of the ecosystem and prevent impacts from nearby groundwater extraction. The extent of the protection zone could be either fixed (e.g. 200 m radius) for all GDEs or variable, i.e. an appropriate zone set for individual GDEs. Extraction of groundwater from within the protection zone either through pumping for irrigation or forestry impacts may be restricted depending on potential impacts on the GDE. A fixed protection zone relies on an arbitrary or ‘best-guess’ estimate as to the size of a protection zone required for all GDEs. Alternatively, the size of the protection zone could vary proportionally to the size of the GDE.

A variable protection zone requires some estimation of the extent or radius of influence that the GDE has on the groundwater system. This is generally not known for a number of reasons, including that it is a relatively new area of scientific research. The following two mathematical equations are commonly used in hydrogeology and have potential to be used to estimate the extent of a protection zone. A GDE with measurable surface discharge can be conceptualised as being analogous to a large pumping well. That is, the shape of the water table around a GDE is similar to a drawdown cone around a pumping well. Approximating the geometric shape of the pumping well could therefore be used to estimate the extent of the protection zone.

The first mathematical approach for estimating the extent of the protection zone is obtained by rearranging the one-dimensional, variable-saturated-depth equations of groundwater flow (either linear or radial). Groundwater flow in an aquifer of variable saturated thickness and a constant hydraulic conductivity is calculated from Darcy’s law:

$$Q = -Kwh\frac{dh}{dx}$$

where Q can be equated to the volumetric flow rate out of a GDE [L/T], K is the hydraulic conductivity [L/T], w is the width [L] of aquifer through which flow is occurring (e.g. length of stream or perimeter of discharge feature receiving groundwater), h is the saturated thickness of aquifer [L] and dh/dx is the hydraulic gradient [-]. The analytical solutions to this equation for one-dimensional and radial flow are:

$$L = \frac{Kw(h_1^{\,2} - h_0^{\,2})}{2Q}$$

$$\ln r_0 = \frac{\pi K(h_1^{\,2} - h_0^{\,2})}{Q} + \ln r_w$$

where L or r_0 are the length or radius of influence [L], h_1 is the head at the edge of the drawdown cone [L], h_0 is the head at the GDE [L], and r_w is the radius of the GDE [L]. The advantages of this approach are that linear and circular GDEs can be represented and it is suitable for unconfined aquifers. A disadvantage is that Q would need to be estimated for either equation.

The second mathematical approach calculates a radius of influence from a theoretical pumping well located some distance away from the GDE (i.e. the radius of zero drawdown from an extraction well). By rearranging the Jacob straight-line solution for a confined aquifer, the radius of zero drawdown (R) can be calculated using the following equation:

$$R = 1.5\sqrt{\frac{Tt}{S}}$$

where T is the transmissivity [L^2/T], t is time and S is storage [-]. An advantage of this method is that no flow rate, is required. The main disadvantage is that the buffer zone may be overestimated because it assumes transient flow and confined aquifer conditions and therefore steady state flow cannot be simulated.

For GDEs that have no surface discharge, the buffer zone could be approximated using a reverse approach to the above methods. That is, the distance that a pumping well should be placed away from a GDE can be estimated for known pumping rates.

The use of a mathematical approach to determine the extent of protection zones for GDEs is questionable as is the applicability of each individual model. However without comprehensive research, possibly integrating hydrochemical data, there is no other obvious method.

6.3 ‘PHANTOM’ LICENSING

This method assigns a ‘phantom’ licence or allocation to each GDE. This allocation would be taken into consideration in any hydrogeological assessment for transfer into the immediate area. To function successfully this method would require a reasonably accurate calculation of the groundwater requirement for the GDE. At this point such information is not available for GDEs in the South East.

If a GDE was located within the area of a proposed extraction well then a possible solution is to allow the following. The construction of an extraction well is permitted providing that there is no deleterious impact on the GDE. Wells should therefore be completed in such a way that portion of the aquifer in direct influence with the GDE is isolated from the point of extraction. For example it would be possible to complete wells in deeper, unconnected parts of the aquifer. Another disadvantage of this approach is that it does not deal with existing groundwater extraction. If the groundwater extraction already occurs at shallow depth near a GDE then an alternative solution is required.

6.4 RECOMMENDATIONS

From current knowledge it is recommended that the protection zone approach be adopted to manage GDEs in the South East region. The method is conceptually simple and transparent. The appropriate mathematical model to delineate a zone requires further consideration, as does whether to go for a fixed or variable approach to determine the width of the zone.

Specific water entitlements for GDEs may be determined from a number of priority wetlands throughout the South East via a comprehensive study that is currently underway.

7. GROUNDWATER MANAGEMENT AREA BOUNDARIES

Objective 6. *Assess the implications of changing the boundaries of the TLA management areas in relation to the potential hydrogeological impacts.*

7.1 BACKGROUND

Each of the three PWAs (Lower Limestone Coast, Padthaway and Tatiara) are subdivided into smaller groundwater management areas such that there are currently 73 management areas for the TLA (Fig. 1). The boundaries of these management areas generally conform to Hundred administrative boundaries, although there are a few exceptions:

- along the South Australian-Victorian Border the 20 kilometre-wide groundwater management zones of the Border Designated Area have been adopted;
- some Hundreds and Border Designated Area Zones have been further subdivided to be consistent with hydrogeological boundaries or for the purposes of zoning areas of high-density irrigation.

This section discusses the merits of changing some of the management area boundaries in the SE PWAs, either through amalgamating current management areas or constructing new management areas based on physical attributes of the groundwater resource. It should be recognised throughout this process that groundwater is not transferable - unlike most surface water bodies, groundwater has very long residence times (typically between $10^1 – 10^5$ years). Therefore it is not physically possible to take a groundwater body from one area and move it to another. However for flexibility, and to meet COAG principles, the transfer of a water licence is currently permitted within a management area.

7.2 DIFFERENT OPTIONS AND ADVANTAGES/DISADVANTAGES FOR CHANGE

One option for changing TLA management area boundaries is to form new areas that reflect the underlying hydrogeology rather than Hundred boundaries. The 17 groundwater management areas currently used to manage the TCSA (e.g. Fig. 10) were formed on this basis. Whilst the boundaries of Zones 1A to 9A are fixed under the Groundwater (Border Agreement) Act 1985, all other management area boundaries can be changed by the SECWMB after successful community consultation. One approach is to construct a series of new management area boundaries that extend westward along inferred groundwater flow lines from the north and south boundaries of the Border Designated Area Zones. These new management areas would require further east-west discretization based on a combination of topography, geological characteristics and water quality trends.

The most significant impact of increasing the size of individual management areas is that it will allow the transfer of water licences over a much greater area. A change to larger management areas is seen by some sections of the community as positive as it will potentially 'free-up' water licences that are currently restricted by the smaller management boundaries. It is hoped that in doing so it will have a knock-on effect and stimulate the water trading market in the region.

From a resource management perspective, the current management areas are the first 'line of defence' that prevent over-concentration of groundwater extraction in small areas. The second 'line of defence' is the 4 km by 4 km square test (discussed in next section). This method is not a rigorous hydrogeological assessment. There is concern that that if the size of the management areas were to be increased, then the 4 km x 4 km square test would, on its own, be unable to adequately prevent a concentration of irrigation activity in areas of high water availability and good water quality. In these instances, additional rules for transfer may need to be developed (e.g. transfers only allowed from areas of better to poorer groundwater quality).

7.3 RECOMMENDATIONS

If management areas were to be amalgamated or enlarged, then a new hydrogeological assessment method would be required to avoid localised pressure on the groundwater resource. From a resource management and administration perspective it is recommended that the current management boundaries be retained for the 2006 Water Allocation Plans.

One exception to retaining the current management area boundaries that the SECWMB may wish to consider is in the Padthaway PWA. Recent results from the Padthaway Salt Accession Project indicate that the primary source of groundwater salinity beneath the Plains is by leaching of pre-clearing salt from the unsaturated zone in the adjacent Naracoorte Ranges. Groundwater chemistry trends, coupled with numerical modelling results and salinity observations in wells at the base of the Ranges suggest that most of this remnant salt has now been flushed from the Ranges and relatively fresh groundwater in now entering the Plains. Whilst the potential impacts of salt accumulation beneath different irrigation activities on the Plains is still to be quantified, the project results released to date suggest that maintaining the lateral inflow of fresh groundwater from the Ranges is crucial for ensuring the long-term sustainability of irrigation development in this area. Therefore careful planning of management settings is required for Management Area 4 (i.e. the Ranges). One way of reducing the degree of over-allocation currently occurring on the Plains (i.e. Management Areas 1-3) is to merge these three relatively small management areas.

8. HYDROGEOLOGICAL ASSESSMENT METHODS

Objective 7. *Evaluate the adequacy of the current hydrogeological assessment methods for groundwater licence transfers.*

8.1 HYDROGEOLOGICAL ASSESSMENT FOR THE TLA

There are two primary criteria used to assess applications for new allocations or transfers of water taking licences in the TLA. The first utilises the trigger values for rates of groundwater level decline and salinity increase specified in the current Water Allocation Plans (WAPs). Where a trigger is currently being exceeded in a nearby observation well, or where the granting and subsequent use of a new allocation is likely to cause the one of triggers to be exceeded, the application to transfer will generally be refused.

The second assessment criteria is the 4 km x 4 km square test, which was originally designed to prevent concentrated groundwater extraction in localised areas that could lead to degradation of the resource. The 4 km x 4 km square test calculates the total volume of recharge within a 4 km x 4 km square using the adopted recharge rate for the management area. The square is centred on the point of proposed taking, unless the precise point is not specified in which case the square is centred on the centremost point of the nominated land section. The application to transfer is granted if the sum of the proposed transfer allocation and existing allocations is not more than 25% above the total volumetric recharge within the 4 km x 4 km square. The additional 25% allows for uncertainty in the recharge estimate and to not be overly restrictive in the transfer process.

8.2 HYDROGEOLOGICAL ASSESSMENT FOR THE TCSA

The method of hydrogeological assessment for administering transfers of water taking licences for the TCSA is the 2 m @ 2 km test. A Theis (1935) theoretical drawdown curve is used to determine the drawdown at a distance of 2 km from the proposed extraction well. If the predicted drawdown is less than two metres then the licence transfer is granted. The assessment is theoretical only and requires specific hydrogeological information such as hydraulic conductivity, aquifer thickness and storativity. These parameters are seldom known and therefore the assessment is often undertaken using generalised information and/or data obtained some distance from the proposed well site.

A major disadvantage of the 2m @ 2 km test is that it does not consider cumulative drawdown effects; it is solely to test the effect of a single proposed application. Therefore it does not assess the potential impacts of well interference or if the extraction rate is sustainable. One way to address this issue is to establish minimum well separation distances (section 8.4).

8.3 RECOMMENDATIONS FOR TLA HYDROGEOLOGICAL ASSESSMENTS

The current TLA hydrogeological assessment process could be improved via incorporating the following changes in the 2006 WAPs.

- The 4 km x 4 km square test does not stipulate the orientation of the square. By rotating the square it is possible to obtain different results. It is recommended the test be changed from a square to a circle with a radius of 2.25 km. The area of this circle is 16 km^2, thereby maintaining continuity between past and future hydrogeological tests.
- Because the intention of the 4 km x 4 km square test is to prevent adverse water level and salinity trends in localised areas, the square (or circle if the previous change is implemented) should be centred on the centroid of the area of application.

8.4 RECOMMENDATIONS FOR TCSA HYDROGEOLOGICAL ASSESSMENTS

The existing 2 m @ 2 km test for the TCSA does not protect against the cumulative effects from well interference. It is recommended that the following options be considered for incorporation into the TCSA hydrogeological assessment.

- An additional well interference component (e.g., not more than a certain proportion of the total pressure head above the top of the aquifer, or not more than a specified combined interference would be permitted).
- An additional minimum well separation distance.
- Restriction on total annual extraction from a single well or in a given area.
- Include an assessment of the potential impact from excessive drawdown that could result in the aquifer changing from confined to unconfined conditions or for the possibility of reversing the hydraulic gradient between the unconfined and confined aquifers.

Each of the above recommendations would require detailed technical interpretation and modelling in order to set quantitative assessment criteria; such work is beyond the scope of the current study.

9. GROUNDWATER RESOURCE MONITORING SYSTEMS

Objective 8. *Evaluate the adequacy of current groundwater resource monitoring systems.*

9.1 INTRODUCTION

DWLBC is currently undertaking a comprehensive review of its groundwater level and salinity monitoring networks across the South East. This exercise is running in parallel to a major review of water quality monitoring systems in the region as part of the State Water Monitoring Review. Nevertheless, the following important monitoring considerations have arisen through the current review of resource condition and revision of recharge rates. There are also a number of other ongoing groundwater investigations that will feed important monitoring data into the database.

9.2 UNCONFINED AQUIFER

During the last five to ten years, the regional monitoring network for the TLA has continually changed in an effort to maintain currency with ongoing land use change and emerging environmental issues. Examples include:

- monitoring of wells near and removed from high-density irrigation areas, for both water level and salinity trend analysis;
- installation of wells for Salt Accession Projects in the Padthaway and Tatiara PWAs;
- drilling new wells for hydrostratigraphic assessment in the Lower South East;
- additional wells to monitor water table responses under Blue Gums and other forest plantations.

Only observation wells with five or more years worth of data were assessed for trend analysis in this study. A greater number of observation wells will be available for future assessment as there are currently a significant number of wells with 3-4 years data for both water levels and salinity.

There are number of areas and issues that will ultimately require changes to be made to the existing monitoring networks; these include

- Recharge estimation by the WTF and chloride mass balance (CMB) methods. Ideally one or two representative observation wells should be set up in each management area. The location of the wells should be such that there are no impacts from pumping/irrigation/fertilisation on the hydrographs or groundwater chemistry (especially chloride). To further enhance the accuracy of the CMB method, several of these representative hydrograph sites should also be instrumented with rainfall-chemistry sampling devices.
- There is little monitoring occurring in the heavily-utilized Camelback Formation (a deep sub-aquifer within the TLA) to the south of Mount Gambier, due to a lack of suitable monitoring wells.

- The monitoring networks in the Coonawarra area are currently being reviewed as part of a major investigation into the potential impacts of climate and land-use change on the local wine industry. It is likely that more wells will be drilled in the coming years to facilitate hydrochemical and isotopic sampling from the shallow aquifer.
- Spatial coverage of the monitoring network for the TLA is generally good. However, the salinity coverage could be improved in the following management areas: Bowaka, Compton, Conmurra, Duffield, Hindmarsh, Kennion, Kongorong, Lake George, Landseer, Lochaber, Marcollat, Mayurra, Moorak, Smith, Struan, Townsend, Western flat and Woolumbool. In particular, there is a large gap in the salinity trend map for the TLA (Fig. 5) in the Woolumbool and Lochaber management areas. There are salinity observation wells in the general area, but they have not been measured consistently and as a result no trends are apparent.
- Seawater intrusion in coastal areas due to irrigation activity requires further investigation. An observation well drilled two years ago into the Camelback formation about one kilometre from the coast has shown summer declines in water level. These declines likely reflect pumping activity in the area, which may lead to further intrusion of the salt-water interface. The first line of wells from the coast that are utilised for centre pivots are now being monitored routinely for any adverse salinity changes.
- Generally four measurements a year are taken in most of the southeast monitoring networks. While this is adequate for medium to long-term monitoring, the frequency of measurement may be insufficient to observe the peak and trough of each season that is most important for application of the WTF method. It is recommended therefore that selected wells in all management areas be installed with continuous water level loggers.
- All observation wells should be completed in a single hydrostratigraphic unit and if possible a specific yield for each observation well determined. Observation wells should also be related to the overlying dominant soil type.
- Large industrial groundwater users such as Kimberly Clark Australia should continue to have their annual use closely monitored against water level trends.

A major finding of the current study and DWLBC's more-thorough review of the monitoring networks is that rationalization is required. That is, there are many examples across the SE region where either too many or otherwise unnecessary wells are being monitored more frequently than necessary. For these areas, as well as the areas identified above as requiring additional monitoring, it is recommended that some existing wells be equipped with continuous logging devices. Particular examples where this would be beneficial include:

- Areas of deeper water tables where rainfall-recharge events appear as delayed and muted responses in the water level. The only way to monitor these events is with continuous water level loggers. DWLBC has recently installed two loggers in deeper water table areas around Mount Gambier.
- Some wells with loggers should be connected to telemetry to optimize the timing of manual water level monitoring in the area. This approach would provide more accurate hydrographs for recharge determination by the WTF method.

9.3 TERTIARY CONFINED SAND AQUIFER

The confined aquifer requires additional wells to monitor both water levels and salinity. Specific areas requiring attention are:

- Around the Tartwaup fault where the degree of inter-connection between the unconfined and confined aquifers is unknown. At the fault the head difference between the unconfined and the confined aquifers changes from negative to positive (from north to south). The geology also changes in the TCSA from mainly clay with occasional sand beds on the south side of the fault, to mainly sand with occasional clay beds on the northern side.
- Outside of the Kingston irrigation area where the confined observation well network is sparse. New sites have recently been added to the network but have not resulted in adequate data for the evaluation of trends yet. Some private wells are used but the majority of wells are Government owned. It is recommended that a number of private confined domestic and irrigation wells be airlifted and purged to provide improved spatial coverage.
- The Renmark Group Aquifer (confined aquifer in the Murray Basin) in the northern parts of the study area.

10. SUMMARY AND RECOMMENDATIONS

This study has reviewed the groundwater resource condition and management framework for the South East region of South Australia. Each of the following dot points provides an overview of the approach and major findings from each of the preceding chapters.

- **Groundwater Resource Evaluation**: For consistency trigger levels of -0.1 m/yr and +10 mg/L/yr were chosen for water level and salinity trend analysis of the Tertiary Limestone Aquifer. Seven 'hotspot' areas were identified across the South East where the adopted water level and/or salinity triggers were being exceeded. Each of the hotspot areas were investigated to identify reasons why the triggers were being exceeded, (i.e., by excessive pumping for irrigation, land use change or climate variability). Most hydrographs showed a strong correlation with annual rainfall, which meant it was often not possible to differentiate between the various mechanisms. It was concluded that the link between rainfall and hydrograph response could be either direct (below average rainfall resulted in declining water levels) or indirect (below average annual rainfall resulted in increased extraction which contributed to declining water levels). Because water allocation in the South East is based on theoretical crop water requirements and not total volumetric extractions it was not possible to isolate the dominant cause of water level decline or salinity increase in each management area. However the analysis of the hotspot areas, and proposed reasons for exceeding triggers additional to climatic influences, are considered to be:
    - **Management areas 1–3 (Padthaway PWA)**
    - Possible impacts from excessive groundwater extraction in Management Area 1.
    - Competing contributions of salt to Management Areas 2 and 3 from local recycling of irrigation drainage water and influx from the adjacent Ranges (i.e. Management Area 4).
    - **Stirling, Willalooka and Wirrega management areas (Tatiara PWA)**
    - Water levels are declining and salinity is rising.
    - Water levels declining because current use exceeds both the existing and proposed PAVs for these areas. Allocations also exceed both the existing and proposed PAVs for these areas.
    - Salinity trends likely due to a combination of recycling irrigation drainage water and geological controls.
    - **Frances, Joanna and Zone 5A management areas (Lower Limestone Coast PWA)**
    - Declining water levels since the early 1990s, salinity trends inconclusive.
    - Possibly due to a combination of climate variability, expansion of plantation forestry areas and intensive extraction (exceeding allocation) both on the South Australian and Victorian sides of the border.
    - **Glenburnie, Myora and Zone 2A management areas (Lower Limestone Coast PWA)**
    - Declining water levels for the last thirty years, no consistent salinity trends.
    - Possible direct forest impacts (evident from observation wells after Ash Wednesday bush fires) and high intensity stock and domestic water use in these areas.

- **Kongorong and MacDonnell management areas (Lower Limestone Coast PWA)**
- Declining water levels during the 1990s.
- Likely due to intensive extraction (exceeding allocation), particularly from the Camelback Member of the TLA where most of the groundwater is extracted.
- **Marcollat, Peacock and Woolumbool management areas (Lower Limestone Coast PWA)**
- Abrupt drops in mean annual water level towards the end of the 1990s, possibly coinciding with (and driven by) the construction of deep groundwater drains in the area. It is recommended that the impact of drains, both existing and proposed, on groundwater levels be further investigated.

- **Methods for Determining Groundwater Recharge**: The best available dataset for regional hydrogeological investigations across the South East is the water level observation network. Accordingly, the most robust method for estimating recharge to all the management areas should incorporate this data set. Hence the water table fluctuation method was deemed most satisfactory for revising recharge rates. Some areas within the PWAs were not appropriate for application of the WTF method. In these cases the recharge rate was estimated by either weighting existing recharge rates based on soil and land use type (Border zones 2A to 6A), weighting soil related recharge rates from Allison and Hughes (1978) (lower South East management areas), or left at the existing rate (App. 1 summarises the spatial variability of recharge estimation techniques and rates).

- **Total Available Recharge and Current Use**: A new approach was used to determine the total available recharge (TAR) for allocation in each management area. This review recommended that forestry now be considered on the “use” side of the water budget ledger. Under this scheme, the only component of the water budget that will be incorporated into the TAR determination is that for Environmental Water Requirements (EWRs). The EWRs for Groundwater Dependent Ecosystems (GDEs) will be set at a nominal 10% of the total vertical recharge assuming (a) no forested areas and (b) zero recharge beneath lakes and native vegetation. The current total volume of groundwater use was estimated as the sum of:

  - Forest recharge debits (83 % of the recharge rate for softwood and 77 % of the recharge rate for hardwood, applied over Threshold Areas).
  - Forest water use (2.59 ML/ha/yr for softwood and 2.34 ML/ha/yr for hardwood, applied over current forested estate areas that have depth to water table less that 7 metres).
  - Total allocations (incorporating licensed extractions for irrigation, industrial and town water supplies).
  - Stock and domestic water use.

- **Permissible Annual Volumes**: In this review, the PAVs were revised to the new TAR values. Four categories were developed to represent levels of allocation and hotspot status in each management area:

  - Management areas identified as hotspots where total use is greater than total available recharge: Padthaway Management Area 2, Stirling, Wirrega, Zones 2A and 3A. Current studies underway in Padthaway, the Hundred of Stirling and the Border Designated Area will provide the necessary scientific information to inform management decisions for these areas.

  - Management areas identified as hotspots where total use is less than total available recharge: Glenburnie, Kongorong, MacDonnell, Marcollat, Peacock and Woolumbool.
  - Glenburnie, Kongorong and MacDonnell were determined to be “under-allocated” as the revised recharge rates for these areas are higher than those in the current WAPs. These rates, however, apply to upper units of the TLA rather than the Camelback Member where the majority of extraction occurs. The revised TAR values, therefore, may be too high and should be investigated by comparing recharge rates to the water table with rates of deeper circulation between individual TLA units.
  - Actual volumetric extractions for irrigation in this area are likely to be higher than current allocations based on the hectare IE allocation rates, which would also decrease the degree of under-allocation.
  - Peacock, Marcollat and Woolumbool were identified through the hotspot analysis due to the impacts of deep drains rather than excessive volumetric extraction for irrigation.
  - Management areas not identified as hotspots where total use is greater than total available recharge: Beamma, Coles, Hindmarsh, Hynam East, Mount Benson, Shaugh, Short and Tatiara. Hindmarsh management area is now over-allocated because this review has accounted for currently unlicensed use by Kimberly Clarke Australia Pty Ltd. Other areas are over-allocated because of previously unaccounted areas of native vegetation beneath which zero recharge is assumed or potential impacts of plantation forests.
  - Management areas not identified as hotspots where total use is less than total available recharge (i.e., ideal situation): 39 of the 73 management areas. It is important as a basic principle for sustainability to ensure sufficient lateral throughflow in areas characterised by highly-variable groundwater salinity to mitigate potential water quality threats.
- **Protection of Groundwater Dependent Ecosystems (GDEs)**: Two methodologies were proposed; Protection zones and ‘Phantom’ licences. The former of these two methodologies included the use of fixed or variable protection zones. It was recommended that the variable approach be adopted even though it requires a choice of mathematical approach and characterisation of individual GDEs. It was further recommended that any decision on an appropriate method to protect GDEs wait on the outcomes of the detailed review of GDE requirements currently undertaken by REM consultants.

- **Groundwater Management Area Boundaries**: The merits of changing management area boundaries were discussed. From a resource management and administrative perspective it was recommended that the current management boundaries be retained for the 2006 Water Allocation Plans, except possibly in the Padthaway PWA. If management areas were to be amalgamated or changed, then a new hydrogeological assessment method would be required to avoid localised pressure on the groundwater resource.

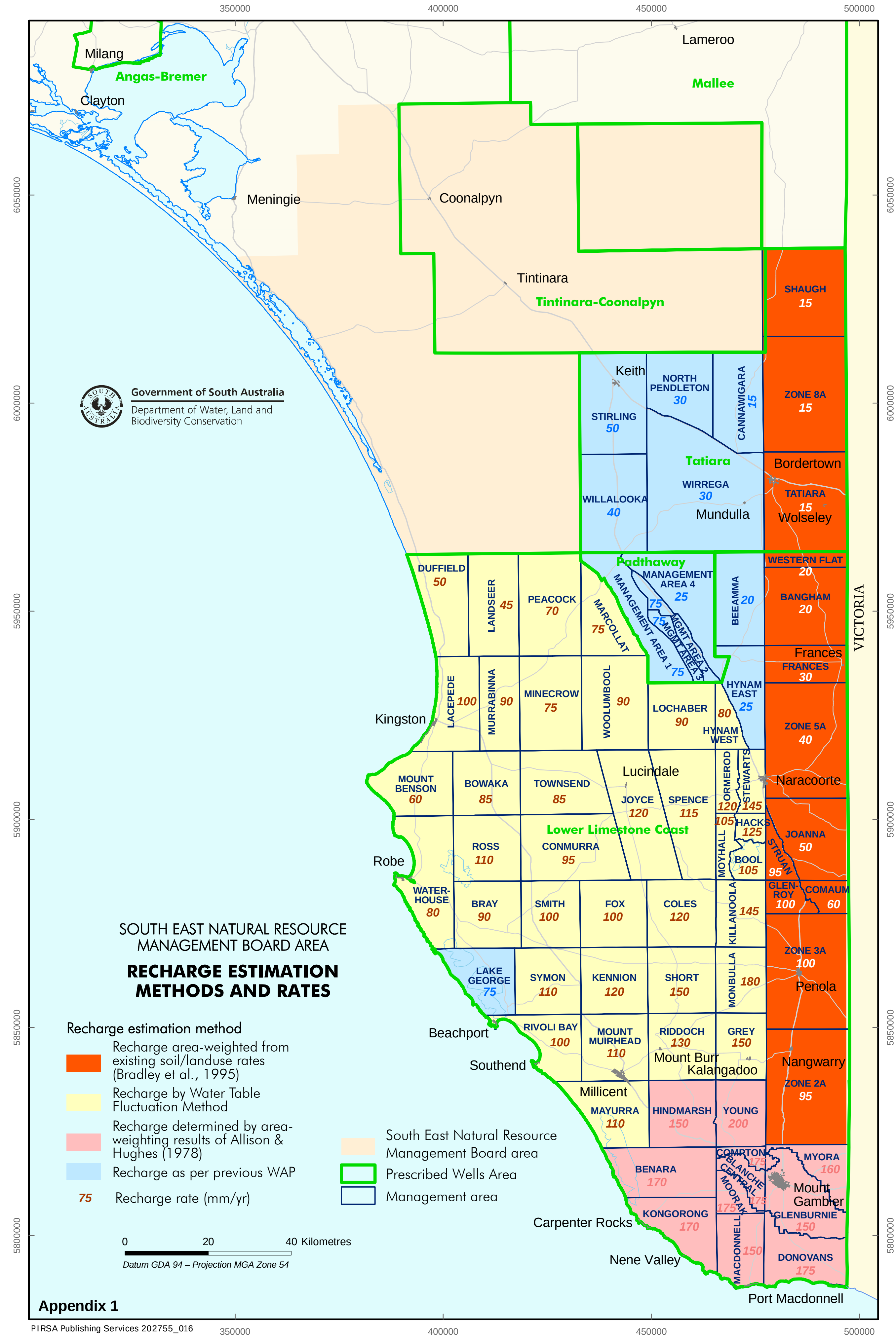
- **Hydrogeological Assessment Methods**: The adequacy of the current methods used to undertake hydrogeological assessments for the transfer of water allocation licences for both the TLA and TCSA were reviewed. For the TLA it was recommended that the 4 km x 4 km square test be changed to a 16 km^2 circle test to negate the issue of orientation of the square. A number of recommendations were made for hydrogeological assessments for transfers of TCSA licences, the most important of which is to include criteria for well interference and maximum extraction limits per well.

- **Groundwater Resource Monitoring Systems**: While there are currently several other external reviews of the groundwater monitoring networks for the South East, this study has identified a number of areas where immediate improvements to the current monitoring networks can be made. These include:
  - Improved representation of seasonal water levels and hydrochemical trends in all management areas to aid future recharge determinations. Several representative hydrograph sites should also be instrumented with rainfall-chemistry sampling devices.
  - Automatic logging devices to be installed in many of the deeper observation wells and in areas where there is currently little pressure on the resource and numerous manual monitoring wells.
  - Incorporate some of the TLA water level monitoring sites to the salinity monitoring network for improved spatial coverage.
  - Ongoing focus on monitoring hotspot areas.
  - Increased spatial and temporal monitoring of water levels in the Camelback Member of the TLA, as this unit is the most widely used in the southern areas, rather than the surficial units that are currently being monitored.
  - All observation wells should have a hydrostratigraphic unit assigned.
  - Sampling of observation wells in near coastal environments should continue to monitor any possible migration of the seawater interface.
  - Private and DWLBC-owned confined aquifer wells should be monitored more frequently and across the whole of the SE region.

APPENDICES

1. RECHARGE ESTIMATION METHODS AND RATES

Appendix 1



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2. DIRECT EXTRACTION OF SHALLOW GROUNDWATER BY PLANTATION FOREST IN THE LOWER SOUTH EAST OF SOUTH AUSTRALIA

Introduction

The CSIRO report, *Water use by tree plantations in southeast South Australia*[1] (Benyon & Doody 2004) has established that plantations of some softwood and hardwood species in the lower South East can extract groundwater where the water table is shallow and there is no root impedance between the land surface and the water table.

The peer-reviewed report provides a summary based on a synthesis of data from CSIRO observations on research plots located in commercial forests in the lower South East. These included the most recent investigations based on six plots located in *Eucalyptus globulus* (blue gum) commercial plantation sites in the Wattle Range area.[2]

The conclusion from this aggregation of CSIRO data is that eight of the nine research plots used groundwater, whilst at the ninth site, a shallow hardpan layer is believed to have prevented *Pinus radiata* (pine) trees accessing groundwater.

Data from the CSIRO studies has been used for resource assessment purposes to develop annualised groundwater extraction estimates by forest plantations in the lower South East area of South Australia. This paper describes the rationale for developing these estimates.

Summary of direct extraction from research sites

In comparing all South East data, the CSIRO reports a mean annual extraction rate of 4.35 ML/ha for the eight water extraction sites over an investigation period of eight-years, with lower and upper 90% confidence limits of 3.22 ML/ha and 5.48 ML/ha. The annual extraction values for the observations ranged from 1.08 ML/ha to 6.70 ML/ha.

The value attributed to groundwater extraction was the difference between the annual evapotranspiration, determined by sap flow, and the rainfall at the site. Negative values indicate groundwater uptake and positive values signifies groundwater recharge. Adjustments were made for changes in soil moisture storage. The methodology is described in detail in the CSIRO report (Benyon & Doody 2004).

The shallow hardpan layer referred to above at the ninth site is a condition that has occurred at some commercial forest sites, resulting in poor forest productivity. Because of the risk of hardpan layers, the industry now uses extensive soil analysis in selecting plantation sites.

Development of direct extraction values for groundwater management purposes

Whilst the recent six CSIRO investigation sites were not selected at random, the industry was consulted on whether the chosen sites could be considered as representative of the landscape and soil on which the majority of blue gum plantations occur in the South East.

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[1] CSIRO, September 2004, Richard G. Benyon and Tanya M. Doody, CSIRO Forestry and Forest Products Technical Report No. 148

[2] Approximately 40 km west of Penola.

Data was collected from these typical lower South East sites during the same two year time period using the same methodology, thus providing observations with a high level of integrity. At five of the sites, the water table was less than 7 metres from ground level[3], whilst at the sixth, the water table was 11 metres, with no observed extraction at the site.

Statistically, the mean annual groundwater extraction value for the five sites that extracted groundwater is 3.64 ML/ha. The standard deviation from the mean value is 1.83 ML/ha, indicating that if the data lay within a normal distribution, there would be an expectation that 68 percent of plantations overlaying shallow water tables would extract groundwater at annual rates between 1.81 ML/ha and 5.48 ML/ha, but with a mean value of 3.64 ML/ha.

Water resource management

CSIRO has no evidence to suggest that either pine or blue gum have any greater propensity to extract groundwater than the other. Consequently the assumption has been made by CSIRO that the mean annual impact of the two species are identical.

For management purposes, it is suggested that groundwater extraction impacts are based on the principle that all hydrogeological impacts are averaged, on an annual basis, over the forest life cycle. This is the same approach adopted in estimating plantation impacts on groundwater recharge. The recharge model assumptions are expanded below to provide the base assumptions for a groundwater extraction model, with the additional assumptions shown in italics:

Tasmanian blue gum

- One year of land preparation pre planting.
- Three years from planting to canopy closure.
- Eleven years from planting to clear felling.
- *No groundwater extraction until canopy closure.*
- *Groundwater extraction reaches peak rate six years after planting.*
- *Groundwater extraction is constant until clear felling.*
- *Groundwater extraction is zero at clear felling.*
- *Coppice growth is destroyed and extraction of groundwater reverts to zero.*

Second rotation and subsequent forest is by replanting.

Pine

- One year of land preparation pre planting.
- Six years from planting to canopy closure.
- Thirty years from planting to clear felling.
- *No groundwater extraction until canopy closure.*

[3] CSIRO investigation refers to a median depth to the watertable of less than 6 m. Because SE water tables have significant seasonal fluctuation (about 2 metres), to avoid confusion with respect to interpretation, it is recommended that a ‘shallow’ water table, for assessing forest impacts in direct extraction, be considered as one where the highest observed seasonal water table is less than 7 metres.

- *Groundwater extraction reaches peak extraction rate at ten years after planting.*
- *Groundwater extraction is constant until clear felling*[4]*.*
- *Groundwater extraction is zero at clear felling.*

Other technical considerations

In adapting results from the CSIRO technical investigation to a management system, it is assumed that the annual extraction will remain relatively constant after canopy closure[5]. The recent Wattle Range CSIRO investigation was for a two-year period, and the plantations were generally between four and six years old. No evidence has emerged during or since this investigation that there is any significant reduction in groundwater extraction during the later years of the blue gum plantation life.

In the above blue gum model there is an assumption that second rotation forest will be established by replanting. However, it is reported that some industry operators are considering adopting the practice of coppice regeneration for a second rotation. Coppicing requires a modified calculation to reflect the changes to the characteristics presented above.

Mean annual extraction impact for water resource management

In applying the assumptions set out above and using the mean annual extraction rate of 3.64 ML/ha, the mean annual extraction rate of all likely forest types, for the life of those forests, is presented in Table 2. The calculations developing these values against the above described models are appended.

Table 2. Mean annualised extraction for different forest types and second rotation establishment

Forest type	Comment on likely occurrence	Forest rotation length in years, including pre plant period	Total extraction for rotation per ha in ML	Mean annual extraction per ha in ML
CSIRO investigation at 5 sites		same 2 year observation period		3.64
blue gum single rotation only	Current common condition	12	23.69	1.97
blue gum, second rotation by replant	Most likely for second rotation	12	23.69	1.97
blue gum, second rotation by coppice	Option to reduce time to 2nd harvest	21	49.2	2.34
pine, all by replant	Only method available	31	80.2	2.59

[4] There may be minor and temporary trend changes in extraction after thinning operations.
[5] It is generally assumed that the life span of blue gum plantation is of the order of 10 –12 years after planting, meaning that the canopy is closed for about 7-9 years. Monitoring has been continued at some sites with trees aged 9 years.

Conclusions

It is considered that based on the best available data that is applicable to forestry conditions in the lower South East, the values in Table 2 provide a useful guide to annualised extraction rates of shallow groundwater by plantation species. Given the range of plantation planting dates and the robustness of the local unconfined aquifers, the annualised values provides a range of values that can be applied in assessing water resource budgets for water resource modelling and management purposes.

The following values have been adopted for assessment purposes:

- 2.59 ML/year for all existing and future pine plantations; and
- 2.34 ML/year for all existing blue gum plantations, assuming that coppicing will be used for the initial second rotation plantation.

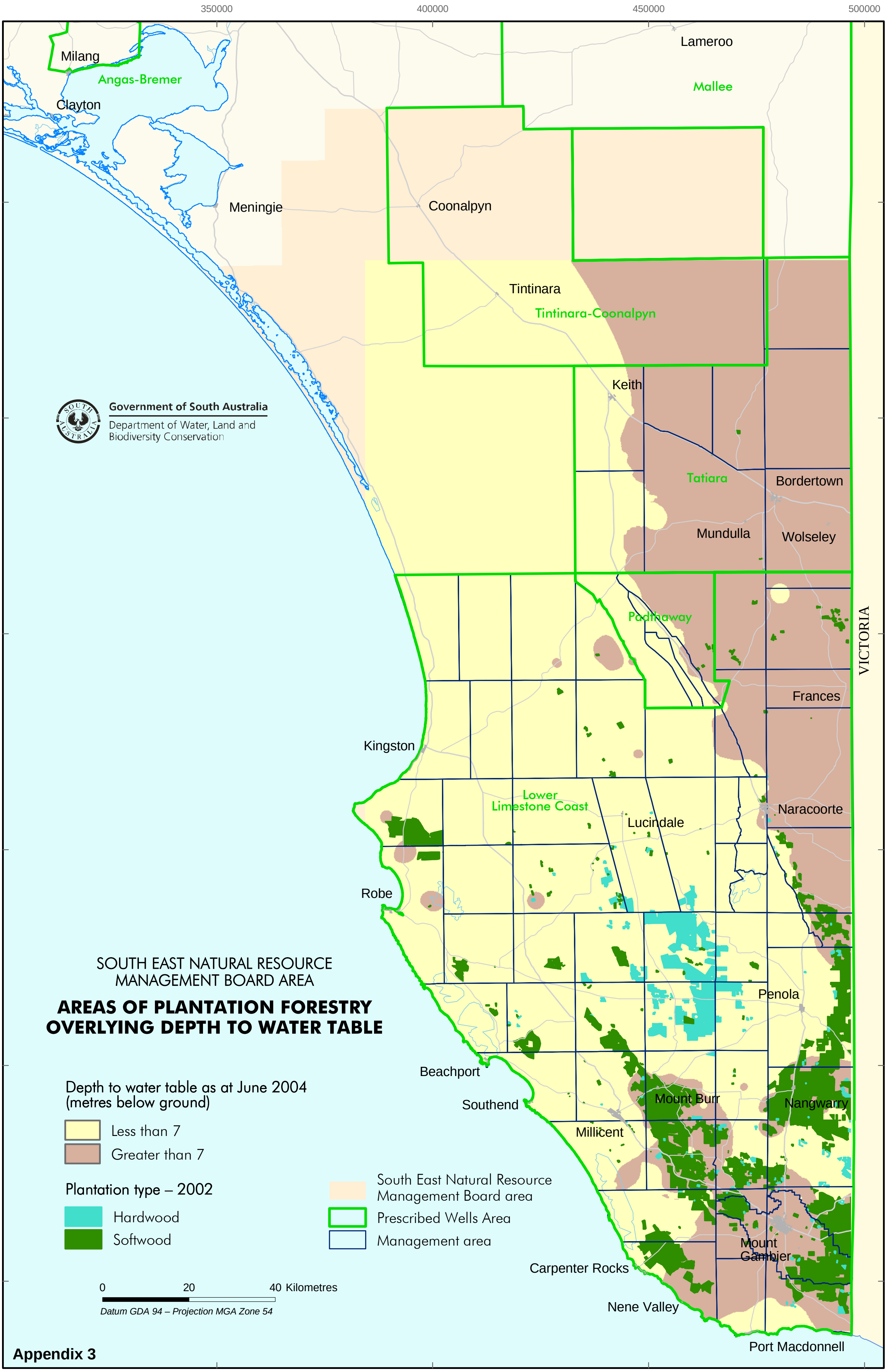
Calculations to annualise impacts of direct extraction from shallow water tables

Tasmanian blue gum				
Plantation stage	**Time interval :yrs**	**Extract rate ML/year**	**Denominator for calc. taper = / 2 constant = 1**	**Total extract for interval: ML**
Extraction ML/yr		**3.64**		
Pre plant	1	0		0
Plant/ canopy closure	3	0	2	0
Canopy close/ peak	3	3.64	2	5.46
Peak extract/ fell	5	3.64	1	18.2
Sub period first rotation	12			23.6
Single rotation mean				**1.97**

Pine				
Plantation stage	**Time interval :yrs**	**Extract rate ML/year**	**Denominator for calc. taper = / 2 constant = 1**	**Total extract for interval: ML**
Extraction ML/yr		**3.64**		
Pre plant	1	0		0
Plant/canopy closure	6	0	2	0
Canopy close/peak	4	3.64	2	7.28
Peak extract/fell	20	3.64	1	72.8
Sub period first rotation	31			80.0
Mean for rotation				**2.59**

Coppice regeneration 2nd rotation				
Fell/coppice	1	3.64	2	1.82
Cop/peak extract	3	3.64	2	5.46
Peak extract/fell	5	3.64	1	18.2
Sub period second rotation	9			25.4
Mean for rotation				2.83
Total for two rotations	21			4.91
Two rotation mean				**2.34**

3. AREAS OF PLANTATION FORESTRY OVERLYING DEPTH TO WATER TABLE



Appendix 3

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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

GLOSSARY

ΔV. The difference between TAR and total groundwater "use", where the latter is defined herein as the sum of (i) licensed allocations for irrigation (haIE system) and public water supply, (ii) potential forestry impacts (recharge interception and direct groundwater extraction) and (iii) estimated stock & domestic use.

AAV. Allowable Annual Volume, defined in the South Australian – Victorian Border Groundwaters Agreement Review Committee 20th Annual Report as "the allowable volume of extraction, which is specified, for each aquifer within a zone of the (Border) Designated Area, which is a component of the Permissible Annual Volume for the zone."

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.

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, 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.

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.

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.

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

EWR. Environmental Water Requirements, nominally assigned as 10% of the TAR for this study the water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk..

Groundwater. *See underground water.*

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

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

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

MDBC. Murray-Darling Basin Commission.

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

ML. *See megalitre.*

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.

PAV. Permissible Annual Volume, defined by the —

> 2001 Water Allocation Plans for the TLA as *"the volume of water that can be sustainably used or assigned from the unconfined aquifer on an annual basis, in a particular management area."*
>
> South Australian – Victorian Border Groundwaters Agreement Review Committee 20th Annual Report as *"the permissible annual volume of extraction that is prescribed for each zone of the (Border) Designated Area. It is the maximum volume that may be authorised for extraction."* NB. PAV in this context comprises the sum of the AAV for the unconfined aquifer (TLA) and the AAV for the confined aquifer (TCSA).

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

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.)*

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

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.

TAR. Total Available Recharge for allocation in each management area, calculated as the area not covered by native vegetation multiplied by the adopted recharge rate for that area, less 10% for EWR.

TCSA. Tertiary Confined Sand Aquifer, existing as either the Dilwyn or Mepunga Formations in the Otway Basin, or the Renmark Group Aquifer in the Murray Basin.

TLA. Tertiary Limestone Aquifer, existing as either the Gambier Limestone in the Otway Basin or the Murray Group Aquifer in the Murray Basin, or a younger geological unit in either province.

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).

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-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.

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.

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