TECHNICAL REPORT

SCIENCE SUPPORT FOR THE MUSGRAVE AND SOUTHERN BASINS PRESCRIBED WELLS AREAS WATER ALLOCATION PLAN

2012/15

Government of South Australia
Department for Water

SCIENCE SUPPORT FOR THE MUSGRAVE AND SOUTHERN BASINS PRESCRIBED WELLS AREAS WATER ALLOCATION PLAN

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FOREWORD

South Australia's Department for Water leads the management of our most valuable resource—water.

Water is fundamental to our health, our way of life and our environment. It underpins growth in population and our economy—and these are critical to South Australia's future prosperity.

High quality science and monitoring of our State's natural water resources is central to the work that we do. This will ensure we have a better understanding of our surface and groundwater resources so that there is sustainable allocation of water between communities, industry and the environment.

Department for Water scientific and technical staff continue to expand their knowledge of our water resources through undertaking investigations, technical reviews and resource modelling.

Allan Holmes
CHIEF EXECUTIVE
DEPARTMENT FOR WATER

ACKNOWLEDGEMENTS

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The authors would like to acknowledge staff of the Eyre Peninsula Natural Resources Management Board for their assistance with field work and collection of groundwater salinity and water level data.

The development of the Aquaveo™ Arc Hydro Groundwater model would not have been possible without holding numerous discussions regarding GIS fundamentals, technical issues and progress with Ben Plush.

CONTENTS

LIST OF FIGURES

CONTENTS

LIST OF TABLES

1. INTRODUCTION

In July 2010, the Eyre Peninsula Natural Resources Management Board (EPNRMB) commissioned the Science, Monitoring and Information (SMI) Division of the Department for Water (DFW) to undertake the Science Support for the Water Allocation Plan (SSWAP) project.

The broad scope of the SSWAP project was to review relevant existing literature and summarise key recommendations and findings, identify key knowledge gaps, undertake technical investigations to fill key knowledge gaps and provide written technical reports to assist the Board with the development of the new Water Allocation Plan (WAP) for the Musgrave and Southern Basins Prescribed Wells Areas (PWAs).

This report is one component of the broader SSWAP project. It provides an overview of the PWA's geological setting and hydrogeology, summarises the methods used to estimate the capacity of prescribed groundwater resources and demands on the resources, reviews past monitoring programs and makes recommendations regarding future monitoring.

1.1. *PURPOSE*

The purpose of this report is to provide technical hydrogeological advice, based on the best available science, that will assist the EPNRMB with the preparation and development of the new WAP for the Musgrave and Southern Basins PWAs. This includes:

- a description of the prescribed groundwater resources
- an assessment of the capacity of the prescribed water resources and demands
- estimates of the effects of taking and using prescribed water resources on other water resources (i.e. both within and outside of the PWA)
- recommendations on how to manage these effects
- monitoring recommendations.

1.2. *SCOPE*

The scope of the hydrogeological component of the SSWAP project was to:

- identify and quantify existing demands on groundwater resources and possible future demands
- undertake field investigations and data analysis to redefine the Quaternary Limestone aquifer fresh groundwater lens boundaries
- develop an Aquaveo™ Arc Hydro Groundwater model to better refine aquifer geometry to assist with the estimation of resource capacity and better understand interactions between groundwater resources
- provide, based on current technical understanding of resource condition and behaviour, suggestions in relation to:
    - consumptive pool limits and boundaries
    - groundwater management zones and allocation limits
    - a mechanism to vary allocations (if required)

- provide recommendations in relation to an effective monitoring program that:
    - enables the state and condition of the water resources to be assessed
    - enables determination of variations in allocations where relevant
    - provides sufficient information to enable assessment of whether resource condition limits are being approached or exceeded.

It should be noted that the report *Environmental Water Requirements of Groundwater-Dependent Ecosystems in the Southern Basins and Musgrave Prescribed Wells Areas on Eyre Peninsula* (Doeg *et al.* in prep.) provides for the assessment of the needs of groundwater-dependent ecosystems and recommendations in relation to an effective monitoring program that enables relevant groundwater-dependent ecosystems to be assessed. These are not addressed in this report.

2. PRESCRIBED WATER RESOURCES

2.1. BACKGROUND

In general, water resources are limited in occurrence throughout the Eyre Peninsula. The Tod Reservoir is the only major surface water storage on Eyre Peninsula (maximum capacity of 11 300 ML), however due to increasing salinity since 1930, this resource has not been used since early 2002 and is held as an emergency supply of water only (DFW 2011a). Groundwater is the principal source of water for town water supply, irrigation and stock and domestic use. The Uley South Lens in the Southern Basins PWA (Fig. 1a) contributes around 70% to Eyre Peninsula's total reticulated water demand (Zulfic, Harrington & Evans 2007).

2.2. HISTORY OF WATER MANAGEMENT IN EYRE PENINSULA

The Engineering and Water Supply Department undertook a review of Eyre Peninsula's water resources in 1984 (EWS 1984). This review identified the need to better manage and protect groundwater resources that were used for Eyre Peninsula's public reticulated water supplies and consequently, the Musgrave and Southern Basins PWAs (Fig. 1) were prescribed in 1987.

Following prescription, WAPs were developed for the Musgrave and Southern Basins PWAs to provide for sustainable use of the groundwater resource. The first WAP for the Southern Basins PWA was adopted on 31 December 2000, whilst the WAP for the Musgrave PWA was adopted on 2 January 2001. Both WAPs were subsequently reviewed in 2006. These reviews highlighted concerns regarding future sustainability of the region's groundwater resources.

In this report, DFW provides technical support to the EPNRMB in the preparation of the new WAPs in an unbundled water environment. This work draws on the outcomes of the SSWAP project investigations and where necessary, other existing literature and monitoring information relevant to the Musgrave and Southern Basins PWAs.

2.3. REGIONAL GEOLOGICAL SETTING

The Eyre Peninsula is underlain at the regional-scale by the Gawler Craton, which is a basement province that has been tectonically stable for the past 1.5 billion years (Parker 1995). Proterozoic basement rocks of the Gawler Craton outcrop as the Gawler Ranges along the EPNRM Region's northern boundary, inland of the east coast and as smaller isolated outcrops across the region. The main geological feature within basement metasediments is the Polda Trough, which has been incised as a narrow east-west trending intra-cratonic graben. The Polda Trough has been infilled by Permian, Jurassic and Tertiary sediments during periods of marine transgressions and recessions (Flint 1992). A widespread cover of Quaternary and Tertiary sediments is present across the EPNRM Region.

The Eucla Basin spans the western border of South Australia and overlies crystalline and weathered basement of the Gawler Craton. The south-eastern quadrant of the Eucla Basin covers the western-half of EPNRM Region. This interpretation of the Eucla Basin's extent is more expansive than previous estimates. The Eucla Basin comprises in part, Tertiary sediments of the onshore Polda Trough, Uley Basin and Wanilla Basin. These features were probably once contiguous (Benbow, Lindsay & Alley 1995). Smaller geological provinces within the EPNRM Region include the Marble Ranges and the Cowell Sub-basin, which are part of the larger Pirie-Torrens Basin.

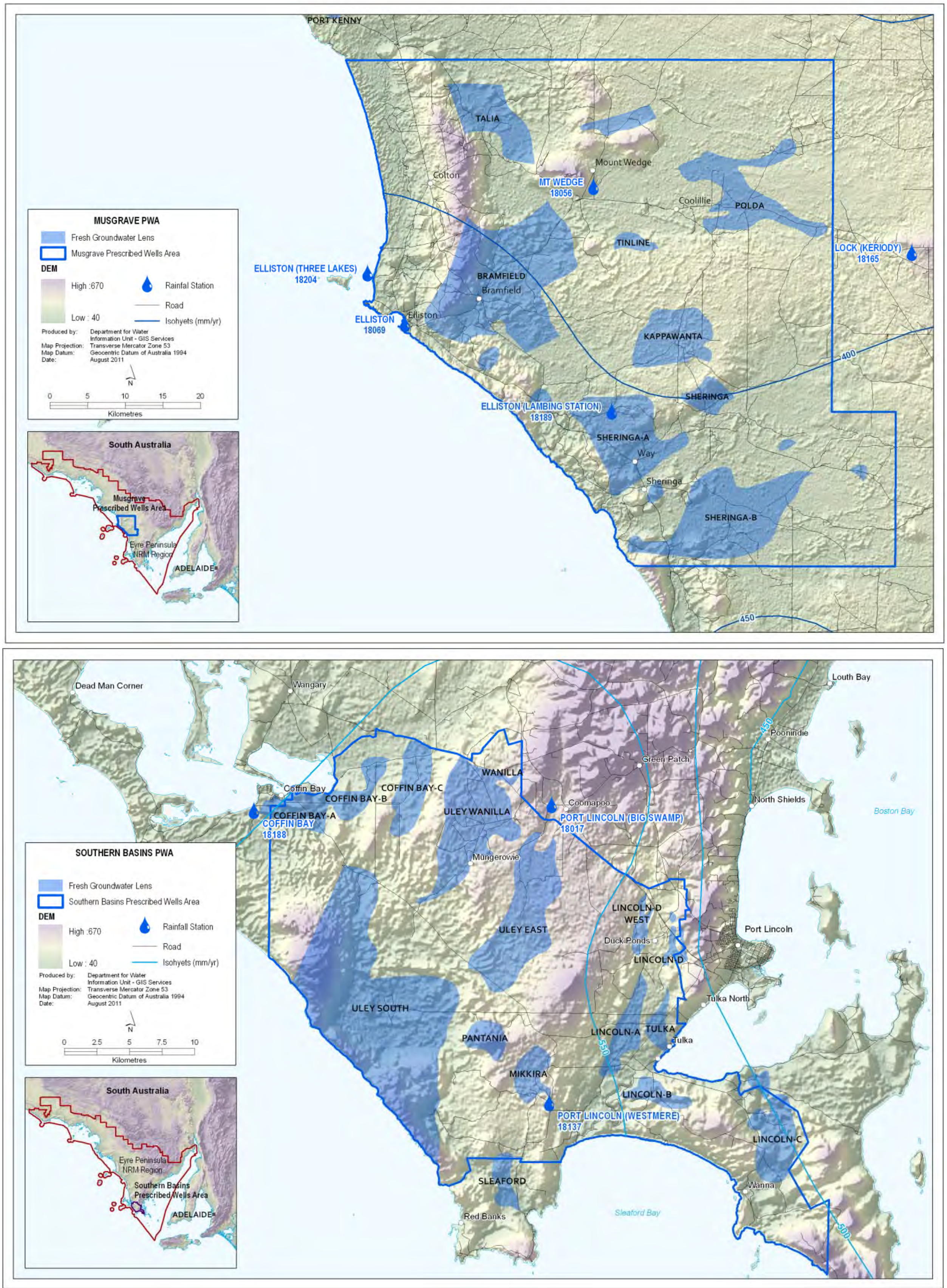

Figure 1. **Location of the (top) Musgrave Prescribed Wells Area and fresh groundwater lenses (Evans 2002a) and (bottom) Southern Basins Prescribed Wells Area and fresh groundwater lenses (Evans 2002b) including Bureau of Meteorology rainfall stations and rainfall isohyets**

2.4. DESCRIPTION OF THE PRESCRIBED WELLS AREAS

2.4.1. MUSGRAVE PWA

The Musgrave PWA spans an area of 3595 km^2 and comprises the Hundreds of Colton, Talia, Tinline, Squire, Ward, Hudd, Kappawanta, Blesing, Way, Pearce and Haig. The PWA encompasses the townships of Elliston and Bramfield. There are no major tributaries that contribute natural sources of streamflow to the Musgrave PWA.

The Musgrave PWA is characterised generally by undulating calcrete plains with skeletal soils and areas of recent sand dunes overlying an evaporative calcrete horizon. The predominant land use is stock grazing although some cropping occurs where soils are of suitable quality, depth and areal extent.

The Musgrave PWA experiences a climate with typically hot, dry summers and mild, wet winters. Rainfall is winter dominant, with long-term average annual rainfall of 430 mm (for the period 1889 to 2011) at Elliston (BoM station 18069). It should be noted that average annual rainfall has been calculated from data sourced from the SILO Climate Database, which is hosted by the Queensland Climate Change Centre of Excellence (DERM 2012). Any missing rainfall records are interpolated from nearby rainfall stations. Mean monthly rainfall exceeds mean monthly potential evapotranspiration only in June and July.

2.4.2. SOUTHERN BASINS PWA

The Southern Basins PWA covers an area of 870 km^2 and comprises all or parts of the Hundreds of Lincoln, Wanilla, Lake Wangary, Uley, Sleaford and Flinders. The main townships within or near the PWA are Port Lincoln and Coffin Bay. Surface water is scarce, with one permanent and two ephemeral saline lakes and two brackish lakes supplied by ephemeral surface watercourses.

The PWA can be described as undulating topographic relief typical of ancient dunal systems with dramatic coastal cliffs rising to around 140 m AHD (Australian Height Datum (AHD) is approximately mean sea level). Catchments are generally large, topographically enclosed basins with internal drainage. Inland depression elevations are often ~0 m AHD while basement outcrop can exceed 200 m AHD.

Rainfall in the Southern Basins PWA is greater in comparison to the Musgrave PWA. The long-term average annual rainfall at the Westmere rainfall station (BoM Station 18137) is 575 mm (for the period 1910–2011) (DERM 2012). The Southern Basins PWA has a more pronounced 'wet-winter' period between May–August during which mean monthly rainfall exceeds mean monthly potential evapotranspiration.

2.5. HYDROGEOLOGY

Groundwater resources of the PWAs are found primarily within the Quaternary Bridgewater Formation Limestone, Tertiary Sands aquifers and fractured rock basement aquifers. Eyre Peninsula's major low-salinity groundwater resources reside within the Quaternary Limestone aquifer, largely within geologically controlled structures, where the extent of the fresh groundwater lenses has been delineated by the 1000 mg/L isohaline. The geological environments within which Eyre Peninsula's groundwater resources commonly reside are outlined below and summarised in Table 1.

2.5.1. QUATERNARY AQUIFER

The Quaternary Bridgewater Formation, often referred to as the Quaternary Limestone aquifer, is generally a relatively thin veneer of aeolianite sediments and is ubiquitous across the PWAs, however these calcarenite (i.e. sand comprising of shell fragments, calcareous algae fragments and silicate grains) dune deposits are known to be over 130 m thick in parts of the Uley South Basin (Harrington, Evans & Zulfic 2006). The Bridgewater Formation is generally unconsolidated or loosely aggregated, although coastal cliff exposures suggest it to be more consolidated in parts. Secondary porosity appears to be common, evidenced by regular occurrences of surface solution features and secondary cementation is apparent via a calcrete horizon at the evaporation front.

Groundwater resources within the Musgrave and Southern Basins PWAs are extracted predominantly from the Quaternary Limestone aquifer. Quaternary aquifer salinities range between 400 and 1800 mg/L (DFW 2011b; DFW 2011c). Well yields are generally high, ranging between 5–50 L/s (Evans *et al.* 2009a).

Areas delineated by the 1000 mg/L isohaline are described as fresh groundwater lenses and their extent is partly controlled by geological structures. These lenses are the source of water for around 85% of Eyre Peninsula’s reticulated needs (EPNRMB 2011).

Watertable elevations within the Quaternary Limestone aquifer indicate that groundwater flow is predominantly (1) in a westerly to south-westerly direction toward the Southern Ocean in the Musgrave PWA (Fig. 2); and (2) in a direction toward the nearest coastline in the Southern Basins PWA (Fig. 3). Hydrochemical evidence indicates the Uley Basin Quaternary groundwaters have residence times of less than 30 years (Evans 1997).

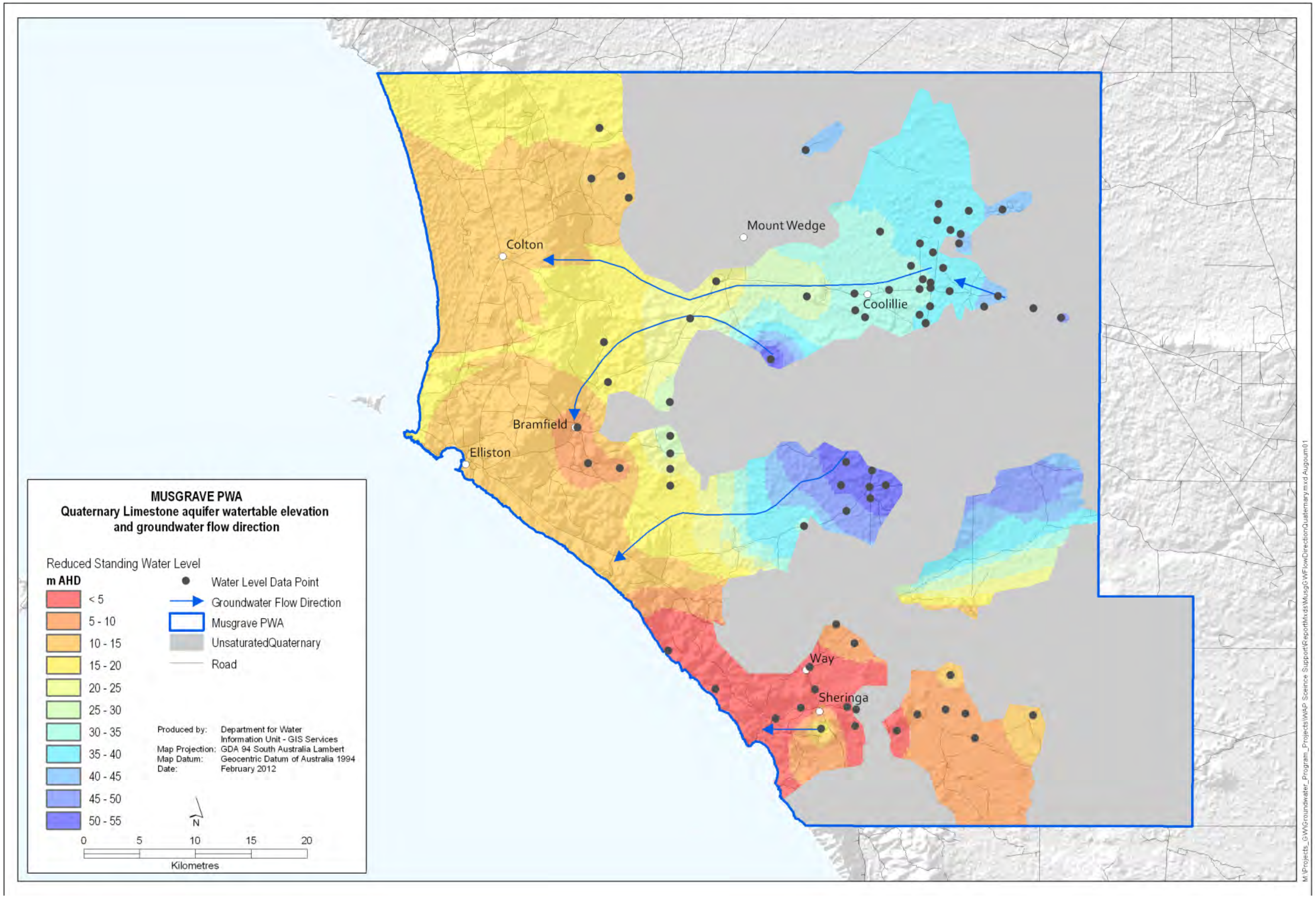

Figure 2. Groundwater flow direction for the Quaternary Limestone aquifer in the Musgrave PWA

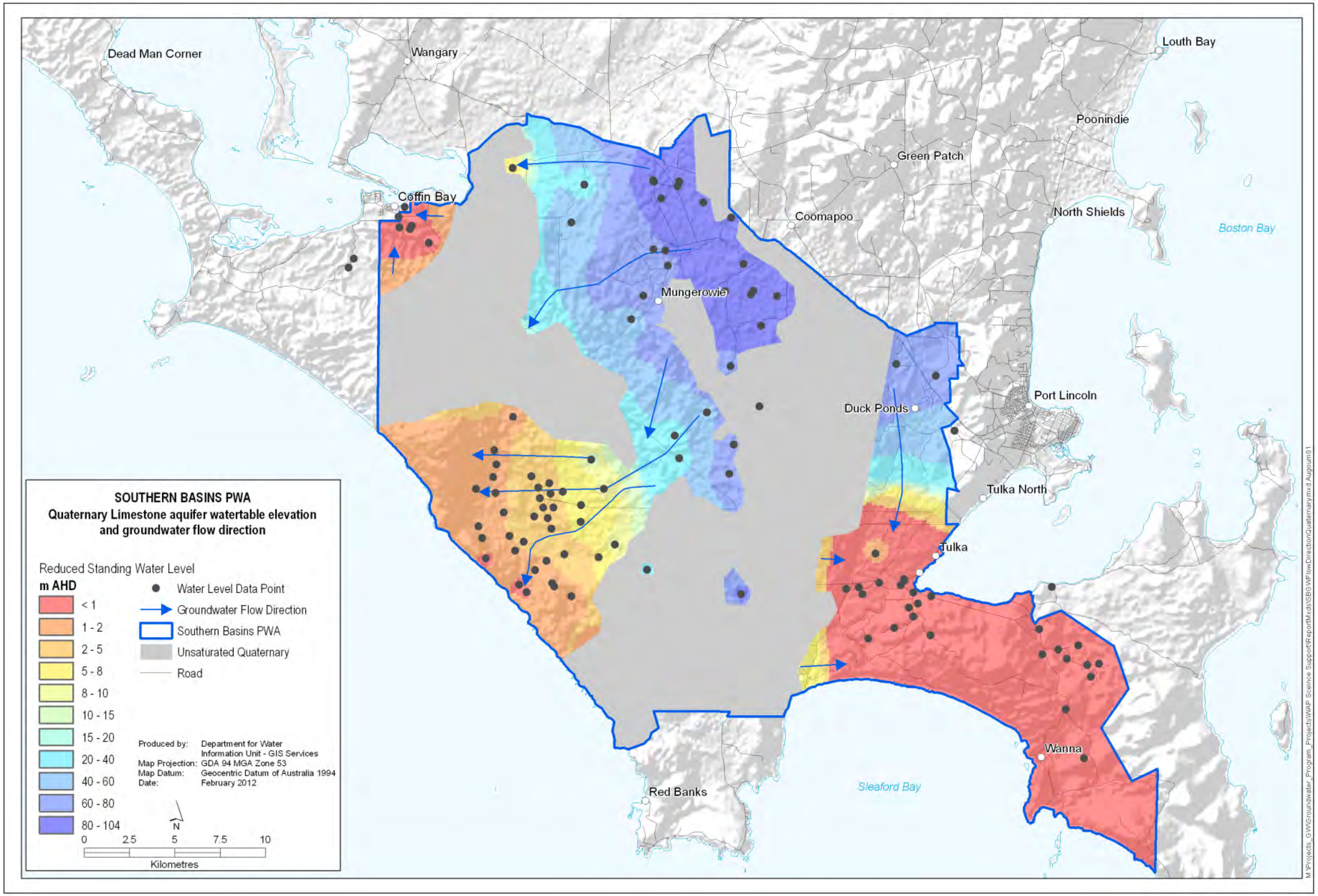

Figure 3. **Groundwater flow direction for the Quaternary Limestone aquifer in the Southern Basins PWA**

2.5.2. TERTIARY AQUIFERS

The fine, unconsolidated nature of the Tertiary Sands aquifer has resulted in well production difficulties. Consequently, these aquifers have had limited groundwater development and are used mainly for local stock and domestic supplies.

Potentiometric surfaces in the Tertiary Sands aquifer indicate that groundwater flow in this aquifer is predominantly (1) in a south-westerly direction toward the Southern Ocean in the Musgrave PWA; and (2) in a south to south-westerly direction toward the Southern Ocean in the Southern Basins PWA.

Hydrochemical evidence indicates the Tertiary groundwaters generally have residence times greater than 35 years and perhaps of the order of 3000 to 6500 years (Harrington, Evans & Zulfic 2006). The hydrogeology of Eyre Peninsula's Tertiary, Jurassic and basement sequences have been summarised by Berens, Alcoe and Watt (2011), as detailed below.

2.5.2.1. Uley Formation

The Pliocene Uley Formation aquitard was deposited between Quaternary and Tertiary units as a clayey, laterite paleosol horizon (Harrington, Evans & Zulfic 2006). It comprises a series of clayey sands and quartz sands which are generally well sorted. The top of the unit is defined by orange-brown mottled sandy clay. It has not been observed in outcrop but is known from drillholes to be restricted to the Cummins, Uley–Wanilla and Lincoln basins (Schwarz 2003). Groundwater salinities range between 500–26 000 mg/L and well yields are generally less than 0.5 L/s.

2.5.2.2. Wanilla Formation

The Middle Eocene Wanilla Formation occurs as basement trough infilling Tertiary sediments and is restricted to the Uley–Wanilla and Lincoln Basins. This sequence consists of fine-grained to gravelly fluvial sand, clays and grits interbedded with variable thicknesses of silty carbonaceous clay at its base. It rests unconformably on basement rock, attaining a maximum thickness of around 80 m and is in turn unconformably overlain by the Uley Formation (Schwarz 2003). Salinities range between 500–7500 mg/L and well yields are generally less than 0.5 L/s.

2.5.2.3. Poelpena Formation

A sequence of the Polda Trough, the Middle Eocene Poelpena Formation is a correlative of the Pidinga Formation and consists of poorly sorted, fine to coarse grained quartz sand, silt and clay which can be carbonaceous, micaceous and pyritic (Flint 1992). It acts as a confining layer between the Tertiary Sands and Quaternary Bridgewater Formation aquifers and is found extensively in central Eyre Peninsula, especially between Lock and the west coast. The formation has a highly variable thickness, but commonly exceeds 100 m thickness in the eastern part of the Polda Trough (Alley & Lindsay 1995). Most wells open to the Poelpena formation are located within the Musgrave PWA. They show salinities ranging between 240–35 000 mg/L and yields ranging between 0.01–63 L/s (median 1.3 L/s).

Table 1. Summary of major geological sequences and their hydrogeological significance

Age			Unit	Lithology	Aquifer[#]	Occurrence and Hydrogeology
Recent	Holocene		Saint Kilda Formation (coastal dunes)	Shallow marine deposits; includes shell beds, chiefly calcareous sands and clays	QLA	Widespread along Eyre Peninsula's coastal fringe; seasonal, low-yielding supplies of low salinity groundwater can occur at the base of mobile dunal systems
Quaternary	Pleistocene	Middle	Bridgewater Formation	Aeolianites; calcareous sands, broken shell fragments and limestone, often with an evaporative calcrete horizon at the surface with dissolution features (sink holes) common; karstic	QLA	Widespread across the PWAs; host to major low-salinity groundwater storages; generally unconsolidated or loosely aggregated, although coastal cliff exposures suggest it to be more consolidated in parts; high transmissivity and low gradient; and responds rapidly to seasonal and long-term changes in rainfall
Tertiary	Pliocene		Uley Formation	Clayey laterite paleosol horizon comprising a series of clayey sands and quartz sands, generally well sorted; the top of the unit is defined by orange-brown mottled sandy clay	TCA	Appears to be ubiquitous across the Musgrave PWA, but it is known to be absent in places in the Southern Basins PWA; in general occurs as a confining layer below the Bridgewater Formation; where permeable it can hold the watertable or allow downward leakage to underlying sediments
Tertiary	Miocene	Middle	Pidinga Formation	Terrigenous clastics comprising fine-grained to gravelly fluviatile sands and silt with interbeds of carbonaceous clay ; the lower formation hosts coarse to gravelly sand grading to fine while the upper section consists of medium grained sand, silt and clays	TSA	Mostly confined to palaeovalleys but occurrences have been interpreted beyond palaeovalley extents; salinities are generally high and well yields low (correlatives are the Poelpena and Wanilla Formations)
Tertiary	Eocene	Middle	Wanilla Formation	Comprises fine-grained to gravelly fluvial sand, clays and grits interbedded with variable thicknesses of silty carbonaceous clay at its base	TSA	Restricted to the Uley–Wanilla and Lincoln Basins; attains maximum thickness of around 80 m; fine-grained sediments often result in well production difficulties so development is limited to local stock and domestic supplies
Tertiary	Eocene	Middle	Poelpena Formation	Poorly sorted, fine to coarse grained quartz sand, silt and clay which can be carbonaceous, micaceous and pyritic	TSA	Found extensively in central Eyre Peninsula, especially between Lock and the west coast; commonly exceeds 100 m thickness in the eastern part of the Polda Trough; salinities range between 240–35 000 mg/L and yields range between 0.01–63 L/s
Jurassic			Polda Formation	Comprises fluvial sandstone and conglomerate; carbonaceous and lignitic claystone; sands are fine grained	JA	Occurs in the east of the Musgrave PWA; very low permeability and high salinities
Neo-Proterozoic			Pre-Cambrian basement	Metasediments, gneisses and quartzites intruded by granites and basic rocks; carbonates, banded iron formations, amphibolite and pelitic to semi-pelitic schists; basement is deeply weathered in places	BM	Groundwater occurs in the weathered horizon or within fractures and joints; the occurrence of groundwater within basement aquifers is irregular and salinities and yields are variable, which is typical of groundwater resources found within fractured rock environments

[#] QLA: Quaternary Limestone aquifer; TCA: Tertiary Clay aquitard; TSA: Tertiary Sands aquifer; JA: Jurassic aquifer; BM: Basemen

2.5.3. JURASSIC AQUIFER

The Jurassic aquifer occurs mostly toward the east of the Musgrave PWA. This aquifer has salinities that are generally greater than sea water (30 000–50 000 mg/L) (Evans *et al.* 2009a) and wells are low yielding.

> *The Neoproterozoic Polda Basin is an elongate graben extending from eastern Eyre Peninsula to the continental shelf edge offshore (Gatehouse 1995). Infilling Jurassic sedimentation is represented by the Polda Formation which occurs in the east of the Musgrave PWA. This sequence extends the full length of the graben and comprises fluvial sandstone and conglomerate; carbonaceous and lignitic claystone at up to 86 m thickness (Harris & Foster 1974). Sands are fine grained (predominantly less than 0.5 mm but may be up to 3 mm) resulting in very low permeability (Evans et al. 2009a). Groundwater salinities within this sequence are high—ranging between 30 000–50 000 mg/L (DFW 2011b)—and consequently the Jurassic aquifer has little groundwater development potential. The Jurassic aquifer is absent from the Southern Basins PWA.*

2.5.4. BASEMENT AQUIFERS

There is limited information and conceptual understanding of the basement aquifers in Eyre Peninsula. Groundwater occurring within basement aquifers is irregular and salinities and yields are variable. This is typical of groundwater resources occurring within fractured rock environments. Basement aquifers around Green Patch (immediately north-west of the Southern Basins PWA) have been developed for irrigation purposes, although the volumes extracted are likely to be small.

2.5.4.1. Hutchison Group

> *The Late Palaeoproterozoic Hutchinson Group is described as tightly folded, high-grade metamorphic rocks which were later intruded by numerous granitoids (e.g. Lincoln Complex). The Hutchison Group comprises a basal quartzite sequence (such as the Warrow Quartzite), which is overlain by carbonates, banded iron formations, amphibolite and pelitic to semi-pelitic schists (Parker & Fanning 1998). Its occurrence has been positively identified in central and northern Eyre Peninsula.*

2.5.4.2. Sleaford Complex

> *Late Archaean to Palaeoproterozoic rocks of the Sleaford Complex consist of metasediments, granites and gneisses (Flint & Rankin 1991) and are found extensively in central Eyre Peninsula and on the western half of southern Eyre Peninsula.*

2.6. RECHARGE

The main fresh groundwater lenses within the Quaternary Limestone aquifer are largely dependent on local rainfall falling on the overlying land for recharge. There are no regional-scale inflows of groundwater to the Musgrave or Southern Basins PWA's groundwater systems (DWR 2001). Analyses of watertable fluctuations within the Quaternary Limestone aquifer show that recharge occurs only after intense rainfall events (Evans 1997). This evidence suggests that short-lived runoff allows water to percolate through dissolution features (sink holes) and reach the watertable rapidly. Investigations of the Polda Basin system indicate that recharge only occurs when the lenses receive more than 60 mm of rainfall in a month between the months of May and October (Evans *et al.* 2009a). The Uley Basin system shows recharge only when the Uley Wanilla, Uley East and Uley South lenses receive more than 10 days of greater than 10 mm of rainfall between the months of May and October (Evans 1997). However, Green *et al*. (2012) found that annual rainfall amounts generally show a better correlation with annual fluctuations in the watertable in the Eyre Peninsula PWAs for the observation wells used in their climate change modelling study. It should be noted that their model conceptualisation included an assumption that all runoff contributes directly to recharge. Further, Ordens *et al.* (2011) used hydrochemistry and isotope data to infer the nature of recharge pathways and evapotranspiration processes. They concluded that sinkholes may act to by-pass the shallow soil zone and redistribute infiltrating rainfall into the deeper unsaturated zone, rather than acting as conduits between the ground surface and the water table.

2.6.1. REVIEW OF PREVIOUS GROUNDWATER RECHARGE STUDIES

There have been many studies into the sustainability of the prescribed groundwater resources in the Eyre Peninsula. These studies have estimated the recharge rate of the developed lenses using various methods (Tables 2 and 3). A considerable level of uncertainty in recharge estimates is inherent to any single recharge estimation technique and consequently, most recharge studies use a suite of techniques (e.g. Evans 1997; ERWRPC 2000; ERWRPC 2001; Ordens *et al.* 2011). Close agreement between estimates of recharge that have been calculated using a range of techniques serves to increase the confidence in those estimates.

There is general agreement that the chloride mass balance provides a good estimate of long-term average annual recharge (e.g. Love *et al.* 1994; Harrington, Evans & Zulfic 2006; Somaratne, Zulfic & Swaffer 2009; Somaratne *et al.* 2009). However, due to the dynamic responses of the Quaternary Limestone aquifer to recent rainfall (or lack thereof), long-term, flux-based approaches used in isolation may not be the most appropriate method to base ongoing allocations.

Table 2. Previous groundwater recharge studies of the Musgrave PWA

Study	Estimation technique	Bramfield	Kappawanta	Sheringa A	Polda
Coffey & Partners (1981)	Darcy's Law; groundwater modelling				45-49
Evans (1993)	Chloride mass balance; Darcy's Law				27-40
Love *et al.* (1994)	Chloride mass balance	15-78	20-49	30-59	
Water Allocation Plan (2001)	Hydrograph method; chloride mass balance; environmental isotope analysis	31	32	29	28

Table 3. Previous groundwater recharge studies of Uley Basin

Study	Estimation technique	Uley South	Uley Wanilla	Uley East
Buick (1941)	Not stated		350	350
Segnit (1942)	Not stated		145	145
Morton & Steel (1968)	Not stated	83		
Sibenaler (1976)	Not stated	40		
Barnett (1978)	Hydrograph method; limiting winter rainfall	105		
EWS (1984)		72	72	72
Evans (1997)	Chloride mass balance	64-71	33-51	
Evans (1997)	Water balance analysis	157	85	76
Evans (1997)	Water balance with salt water interface consideration	78		
Evans (1997)	Hydrograph fluctuation with specific yield calculations	46	20	11
Evans (1997)	Chlorofluorocarbon concentrations	<200	<50	<75
Water Allocation Plan (2000)	Hydrograph method; chloride mass balance; environmental isotope analysis	155	54	69
Ordens *et al.* (2011)	Chloride mass balance	52-63		
Ordens *et al.* (2011)	Watertable fluctuation	47-129		

2.6.1.1. Climate change

DFW's *Impacts of Climate Change on Water Resources* project (Green *et al.* 2012.) has undertaken detailed hydrologic modelling to evaluate the potential impact of climate change on the prescribed groundwater resources of the EPNRM Region and the surface water resource of the Tod Reservoir. The numerical models of groundwater recharge and surface water runoff were constructed to allow evaluation of the sensitivity of recharge and runoff to changes in rainfall and potential evapotranspiration. This study does not provide any guide to the most likely climate change scenario, nor does it project changes to rainfall or potential evapotranspiration, but rather it provides water resource planners and other stakeholders with tools with which one can estimate the likely reductions in runoff and recharge for a given reduction in rainfall.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology (BoM) (2007) reported on climate change projections across Australia. This work has been summarised for the South Australian regions by the Department of Environment and Natural Resources (DENR 2010). These projected reductions in rainfall can be used to estimate the likely range of reductions in groundwater recharge that may result from the impacts of climate change.

Projected (i.e. modelled) reductions in recharge have been benchmarked against historic recharge rates that have been estimated using the watertable fluctuation method. Historic recharge is based on a 1990 historic baseline climate, which comprises a 50-year period from 1961–2010, inclusive. In the Musgrave PWA, the models project that reductions in groundwater recharge resulting from median climate scenarios (as projected by CSIRO and BoM (2007)) range from 12% in a 2030 climate (median 3.5% reduction in annual rainfall with a high, medium or low emissions scenario) to 49% in a 2070 climate (median 15% reduction in annual rainfall with a medium or high emissions scenario). In the Southern Basins PWA, the corresponding projected reductions in groundwater recharge range between 11% and 47% in a 2030 climate and 2070 climate, respectively.

The models also project significant changes to the frequency of years that would in the historic record be considered to be 'low' or 'high' recharge years. Under climate scenarios generated by the least extreme of the four GCMs considered in the study, the frequency of years of relatively low recharge (arbitrarily defined by the 20th percentile recharge in the historic record) increases by 50–70% in 2030 and by 80–200% in 2070. The frequency of relatively 'high' recharge years (as defined by the 80th percentile recharge in the historic record) reduces by 10–20% in 2030 and by 50–70% in 2070.

2.6.2. QUATERNARY AQUIFERS

Groundwater recharge to unconfined aquifers is primarily a function of rainfall duration and intensity and is also controlled by topography, the type of vegetation and its extent, the nature of the soil profile and the underlying geology. Good quality groundwater occurs mainly within the Musgrave and Southern Basins PWAs due to slightly elevated rainfall in close proximity to the coast as opposed to further inland. In addition, the nature of the Quaternary Limestone, close to or exposed at the ground surface enables it to readily receive rainfall recharge. The combination of favourable climate and geology results in relatively high recharge rates and low salinities compared to similar semi-arid environments.

The Quaternary Limestone aquifer is generally characterised as being dynamic and responding rapidly to seasonal and long-term changes in rainfall. Water levels are observed to show a strong relationship with above and below average winter rainfall (Evans *et al.* 2009a; Evans *et al.* 2009b). Historical rainfall data indicates above or below average trends may persist for up to 25 years, highlighting the need for effective adaptive management of these resources.

Vegetation is understood to be significant in terms of canopy interception of rainfall and transpiration. Ward *et al.* (2009) report that dense, deep-rooted vegetation is likely to exclude recharge in the slightly lower-rainfall climate zones of the Musgrave PWA, but in the Southern Basins PWA there is sufficient winter rainfall to allow some recharge, even under woodland sites.

Big Swamp contributes inflows to Uley East, via downward leakage, when full approximately occurring twice every five years (Harrington, Evans & Zulfic 2006). This flux is estimated to be around 240 ML per filling event and is evidenced by the salinity impact along the length of the flow path in the Uley East lens (Evans *et al.* 2009b). Big Swamp is considered important in the overall water balance of the Uley Basin (Harrington, Evans & Zulfic 2006).

2.6.3. TERTIARY AQUIFERS

The Tertiary Sands aquifers receive little recharge in places where it is confined by impermeable Tertiary Clay.. Long groundwater residence times and muted water level response to rainfall (where confined), compared to the Quaternary Limestone aquifer, suggest that these systems are likely to receive considerably less recharge than the overlying Quaternary Limestone aquifers. In places where the Tertiary Clay is thin or absent, the Tertiary Sands aquifers generally receive recharge by downward leakage from the overlying Quaternary Limestone aquifer and responses to recharge or not dissimilar to that of the Quaternary Limestone.

2.6.4. JURASSIC AND BASEMENT AQUIFERS

Recharge to these systems is largely governed by the formation's outcrop location and extent (Evans *et al.* 2009a). In addition to vertical leakage from overlying aquifers, recharge to fractured rock aquifers occurs in areas where basement highs are exposed. The recharge rate is a function of the degree of fracturing, the composition of the rock and the presence of any impermeable weathered zone at the surface

3. CAPACITY OF THE GROUNDWATER RESOURCE

In order to assess the ability of the resource to meet demand, it is necessary to quantify the:

- capacity of the prescribed water resources; and
- demands on the prescribed water resources.

For the purpose of this report, the capacity of the resource (for groundwater management zones that are primarily recharged by rainfall) is defined as the long-term average annual recharge rate multiplied by the area of the recharge zone. This gives the volumetric capacity of the groundwater resources that are available for all uses (i.e. licensed, non-licensed, the environment and aquifer maintenance) on a continuing basis. Whilst significant work has been completed in determining the total aquifer storage volume (explained further below), it is difficult to determine what percentage of this volume would be available for use as it does not consider the volume of water entering the aquifer via recharge. It is therefore recommended that the capacity of the resource is determined by the long term average annual recharge rate, but it is proposed that changes in the total aquifer storage volume annually are used to vary allocations on an annual basis.

The demand on the resource can be described as both consumptive and non-consumptive. Consumptive demands include licensed water use, for example, irrigation and town water supply and non-licensed water use including stock and domestic use. The consumptive demands on the resource have been estimated using spatial analyses (Section 4). Non-consumptive demands include water for the environment, for example maintaining natural processes such as aquifer throughflow and groundwater discharge.

The consumptive pool is calculated as the resource capacity less the volume of water represented by non-consumptive demand. This is the volume of water available for both licensed and non-licensed use. The allocation limit is calculated as the volume of the consumptive pool, less the volume of water represented by non-licensed demand. The allocation limit is the volume of water available for licensed water use (Table 9).

The capacity of the resource in the current WAPs for the Musgrave and Southern Basins PWAs is estimated based on the long-term annual recharge volume. This is considered to be a reasonable approach, based on the dynamic nature of the aquifers, where radiocarbon dating indicates that the majority of groundwater in the Quaternary Limestone aquifer was recharged within the last 30 years (Love *et al.* 1994). Furthermore, Evans *et al.* (2009b) indicates that above or below average rainfall trends have historically lasted up to 10 years.

There is general agreement that the use of hydrogeochemical methods provides a good estimate of long-term average annual recharge (e.g. Love *et al.* 1994; Harrington, Evans & Zulfic 2006; Somaratne, Zulfic & Swaffer 2009; Somaratne *et al.* 2009). It is therefore considered suitable to use the long-term average annual recharge calculated by hydrogeochemical methods to determine the capacity of the resource.

Allocations are currently varied annually based on the recent recharge rates. Somaratne, Zulfic and Swaffer (2009) have identified some potential issues with the current method for determining the recent recharge rate, which employs a combination of information including recent rainfall and examination of rises or declines in hydrographs from selected wells (i.e. the watertable fluctuation method). Somaratne, Zulfic and Swaffer (2009) suggested that within the Uley South lens, the wells used for the watertable fluctuation method were not representative of the recharge zone as they are located in areas of lower recharge. The conclusion of this being, if the watertable fluctuation method is to be used, the wells used for the method need to be representative of the recharge zones.

It is proposed that future variations to annual allocations are undertaken by observing the change to the total aquifer storage (i.e. the saturated thickness of the aquifer) as this takes into account basin outflows, which have been identified as an ongoing process irrespective of recharge (Evans *et al.* 2009b). Declines in water levels indicate that groundwater systems are discharging at a greater rate than they are being recharged (Love *et al.* 1994). Ward *et al.* (2009) states that it is important to maintain basin outflows as they limit/reduce the risk of seawater intrusion and maintain the quality of groundwater. When considering the consumptive use limit, the consequences of reduced basin outflows need to be carefully assessed.

To inform the development of the new WAP for the Musgrave and Southern Basins PWAs, DFW used the Aquaveo™ Arc Hydro Groundwater toolbox within the ESRI ArcGIS® (geographic information system) environment to create a 3-D hydrostratigraphic model of the aquifer geometries. This 3-D modelling of aquifer geometries has enabled the redefining of freshwater lens (<1000 mg/L) extents and has allowed more accurate estimates of the total aquifer storage for the relevant fresh groundwater lenses and the areas of saturated (brackish) Quaternary Limestone aquifer within the PWAs. Also, this work has enabled estimates of the capacity of the resource based on the long-term average annual recharge.

3.1. METHOD FOR ESTIMATING RESOURCE CAPACITY

The total aquifer storage, the capacity of the resource and the consumptive pool volumes were calculated using the ArcGIS® Arc Hydro Groundwater toolbox. The toolbox contains three separate toolsets to analyse multi-dimensional groundwater data, including:

- **Groundwater Analyst**: A toolset which provides for mapping and plotting of time series data, consistent management of symbology and the creation of water quality maps and groundwater flow direction maps
- **Modflow Analyst**: A toolset which provides for the creation and visualisation of MODFLOW groundwater models within ArcGIS, including the ability to archive MODFLOW groundwater model inputs and outputs
- **Subsurface Analyst**: A toolset which provides for the creation and visualisation of both 2-D and 3-D geological models, including classification and visualisation of borehole logs, creation and editing of 2-D cross-sections and generation of 3-D GeoSections and GeoVolumes.

The geoprocessing tools of the Subsurface Analyst toolkit were used to represent the hydrostratigraphy of the PWAs, whilst the Groundwater Analyst toolkit was used to create water level maps for the area.

A summary of the method by which total aquifer storage, the capacity of the resource and the consumptive pool volumes appear below:

1. Identification of all wells for the Musgrave and Southern Basins PWAs within SA Geodata which had a hydrostratigraphic log, a stratigraphic log or a lithological log.
2. For those wells which had only a stratigraphic or a lithological log, a hydrostratigraphic log was created.
3. A number of well logs had been re-interpreted by Flinders University and SA Water and the new interpretations were compared with the existing logs and where appropriate, the existing SA Geodata logs were edited.

4. Within the Musgrave PWA, exploration company Lynch Minerals provided geological information on the depth to the basement for a number of wells. Within the Southern Basins PWA, the mineral exploration company Lincoln Minerals provided hydrostratigraphic logs for a number of wells in areas where data were lacking. Where suitable, these data sets were incorporated in the model.
5. To ensure only one data point was present in each location, multi-level piezometers were identified and after confirmation of consistent logs with depth, only the deepest well was included.
6. Microsoft Access® was used to extract the relevant hydrostratigraphic logs from the State geoserver SA Geodata and this information was used to create a Borehole Log table. The analysis employed 833 and 788 wells in the Musgrave and the Southern Basis PWAs respectively (Fig. 4).

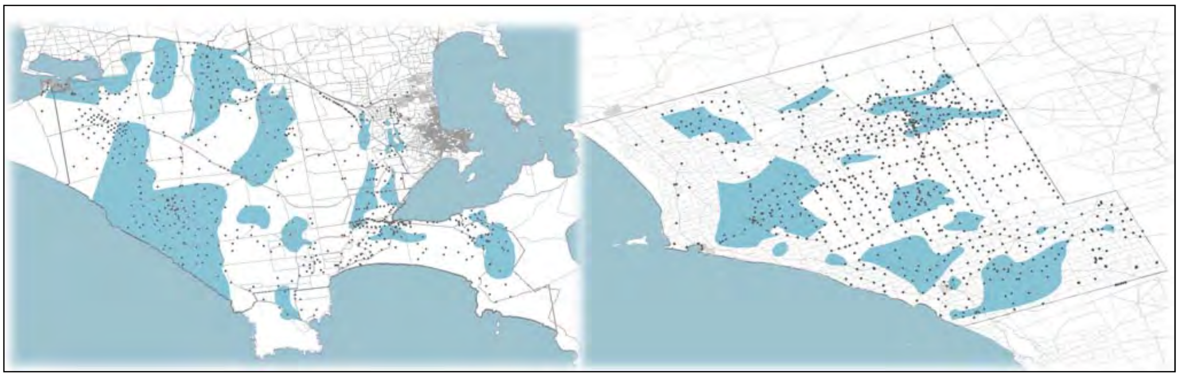

Figure 4. Location of wells with hydrostratigraphic logs within the Musgrave and Southern Basins PWAs

7. The Borehole Log table was imported into ArcGIS® and using the Arc Hydro Groundwater Subsurface Analyst toolkit, BoreLines were created to represent/visualise the hydrostratigraphy in three dimensions (Fig. 5).

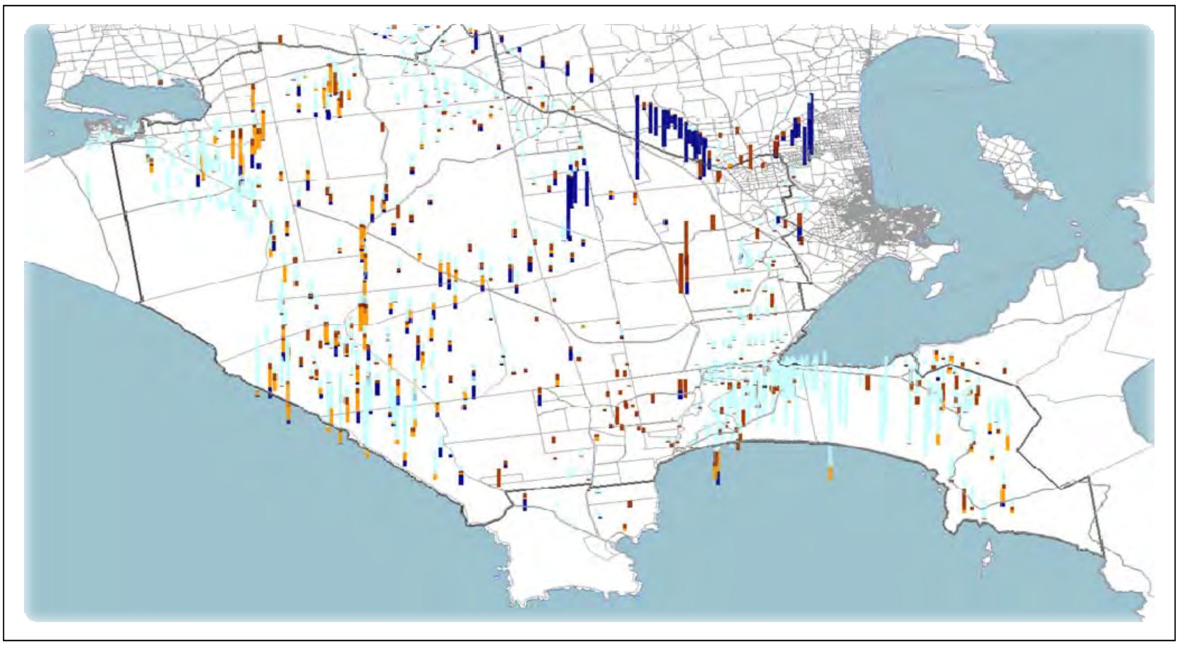

Figure 5. Example of BoreLines created by Arc Hydro Groundwater

8. Potential outliers were identified in the BoreLines and the logs were subsequently confirmed or edited within SA Geodata and the data re-imported into ArcGIS®.

9. The BoreLines were further inspected to identify any potential issues. For example, if the Tertiary Clay confining bed was absent in some areas, but all the surrounding wells indicated the presence of clay, microfiche for the relevant bores were searched to view the original lithological log. Edits were made as required and the data were then re-imported into ArcGIS®.

10. Once the hydrostratigraphic data were deemed to sufficiently represent the subsurface, the Arc Hydro Groundwater Subsurface Analyst toolkit was used to create BorePoints from the Borehole Log table, thereby creating a series of points which represented the top of each hydrostratigraphic unit. For the Musgrave PWA, the relevant hydrostratigraphic units included: Quaternary Limestone aquifer (Bridgewater Formation), Tertiary Clay aquitard (Poelpena Formation – confining bed), Tertiary Sands aquifer (Poelpena Formation - aquifer), Jurassic aquifer (Polda Formation) and basement. In the Southern Basins PWA, the hydrostratigraphic units consisted of: Quaternary Limestone aquifer (Bridgewater Formation), Tertiary Clay aquitard (Uley Formation), Tertiary Sands aquifer (Wanilla Formation) and basement.

11. Airborne electromagnetic (AEM) survey data (Fitzpatrick *et al.* 2009) are available in the Southern Basins PWA for the area between the Uley South lens and the Coffin Bay A lens. These data aimed to identify the top of the Tertiary aquitard, the top of the basement and areas of fresh groundwater. However, an analysis of how the outcomes match existing hydrostratigraphic logs in the area indicated that the AEM data does not provide a sufficiently accurate representation of the subsurface. The top of Tertiary aquitard, which has been interpreted from the AEM survey data, were compared with the existing logs at 150 intersections. The difference between the logs and AEM vary by ±50 m, with 106 of the 150 wells having a difference of less than 10 m and of these, only 49 show a difference of less than 5 m. The top of the basement, which has been interpreted from the AEM survey data, was compared with the existing logs at 117 intersections. The difference between the logs and AEM vary from -40 m to +120 m, with 27 of the 117 wells having a difference of less than 10 m and of these, 14 show a difference of less than 5 m. Consequently, the AEM data have not been used to infer the top of the Tertiary Clay aquitard or identify likely areas of groundwater presence in the Quaternary Limestone aquifer for the purpose of this report.

12. The BorePoints for each hydrostratigraphic unit were interpolated, using the Inverse Distance Weighting (IDW) interpolation method within ArcGIS®, to create a raster which represented the top of each hydrostratigraphic unit (Fig. 6).

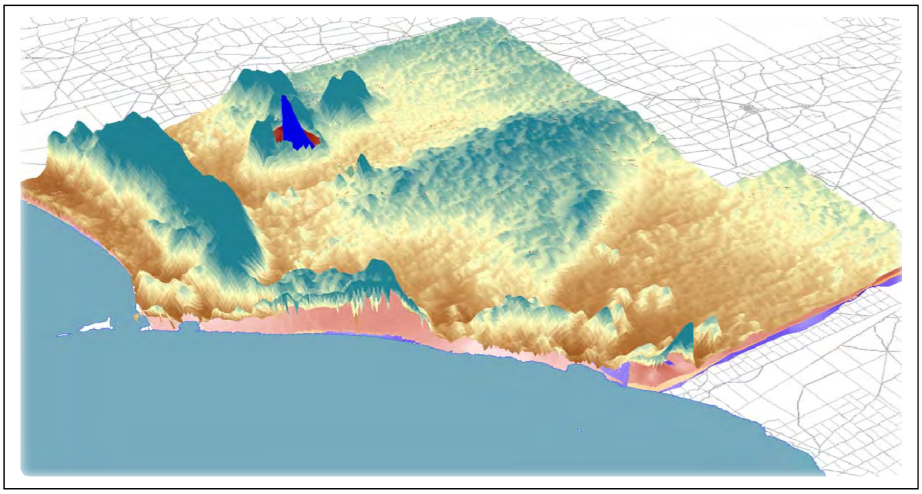

Figure 6. Example of Inverse Distance Weighting (IDW) interpolation of an aquifer surface

13. Given that some of the hydrostratigraphic units are not continuous across the PWAs, an analysis was undertaken on the BoreLines feature to identify spatial locations of hydrostratigraphic unit

absence. Areas where basement outcrops or existing literature indicates the absence of a layer were also taken into consideration, specifically the work of Flinders University (Bestland 2010) which indicates the absence of the Tertiary Clay aquitard and Tertiary Sands aquifer near the south-western coast of the Uley South lens. A polygon feature class was created which represents the absence of each unit across both PWAs. An inverse of this layer was also created to identify areas where the specific hydrostratigraphic units are thought to exist (Fig. 7). The absence of the hydrostratigraphic unit is especially significant for the Tertiary Clay aquitard (the Uley Formation or Poelpena Formation - confining bed) as it identifies areas where the Quaternary Limestone aquifer has the potential to be connected to the underlying Tertiary Sands aquifer (Wanilla Formation or Poelpena Formation - aquifer).

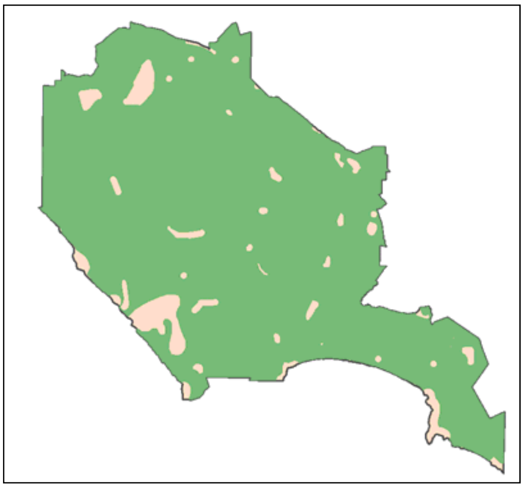

Figure 7. Example of polygon which shows the presence of a hydrostratigraphic unit (green). The beige coloured areas represent areas where the Tertiary Clay aquitard is not likely to exist

14. Each hydrostratigraphic unit raster was extracted by a mask with the relevant hydrostratigraphic unit presence polygon, to create a secondary raster which is present only in areas where the hydrostratigraphic unit is thought to exist (Fig. 8).

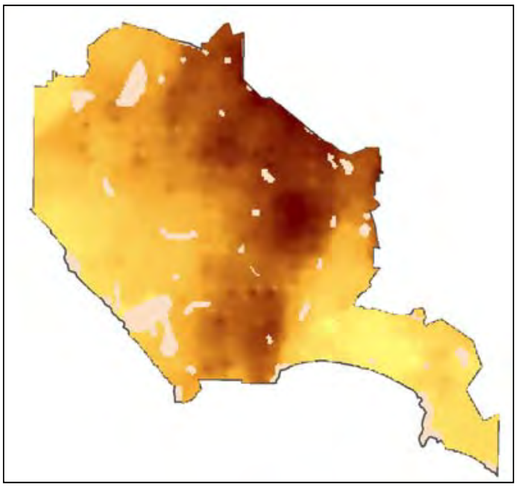

Figure 8. Example of top of aquifer raster showing areas where the hydrostratigraphic unit is likely to exist

15. In addition to creating rasters to represent the top of each aquifer, each PWA was divided into section lines (24 and 34 section lines for the Musgrave and the Southern Basins PWAs, respectively) and cross-sections of the subsurface were created from the BoreLines and the

surface geology (Fig. 9). These cross-sections allow for visualisation of the subsurface in specific locations.

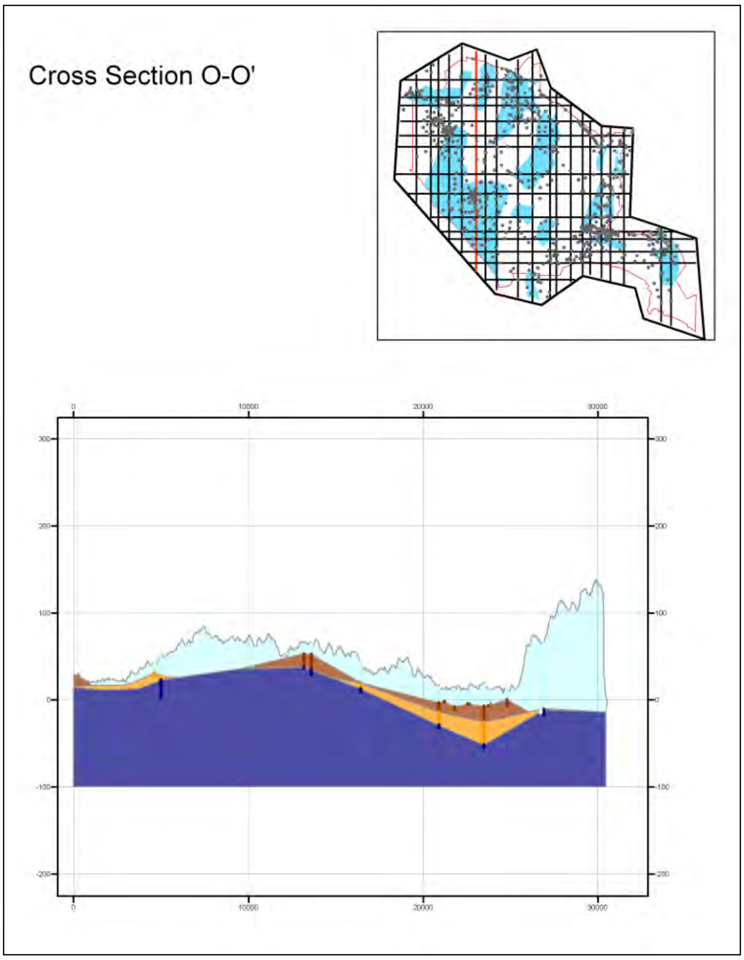

Figure 9. Example of subsurface cross-section O-O’ in the Southern Basins PWA

16. The Arc Hydro Groundwater Analyst toolkit was used to import water level time series data into ArcGIS®.

17. Water level monitoring data for the Quaternary Limestone aquifer (Obswell network data and additional data collected by EPNRMB) for the period March–May 2011 were compiled. Using the IDW tool, a raster was created which represents the Quaternary Limestone aquifer water levels for each of the fresh groundwater lenses at April 2011 (Fig. 10). The month of April was chosen because evidence from hydrochemistry and isotopic signatures suggest that recharge to the lenses occurs when rainfall exceeds more than 10 days of greater than 10 mm during the period May–October (Evans 1997; Harrington, Zulfic & Wohling 2006; Evans *et al*. 2009b). The month of April is most likely to align with the time at which the watertable is at its lowest, i.e. after the summer extraction season, but prior to any significant recharge occurring. It is acknowledged that Green *et al*. (2012) found that annual rainfall amounts generally show a better correlation with annual fluctuations in the watertable, relative to winter rainfall, in the Eyre Peninsula PWAs for the observation wells used in their climate change modelling study. However, water levels are likely to be at a minimum during April because (1) rainfall in the Musgrave and Southern Basins PWAs is clearly winter dominant (around 70-75% of mean annual rainfall falls during May-October (BoM 2012), (2) the Quaternary Limestone aquifer shows a rapid response to rainfall (if the response to rainfall was slower the water table minimum may be identified later); and (3) most observation well hydrographs support this hypothesis.

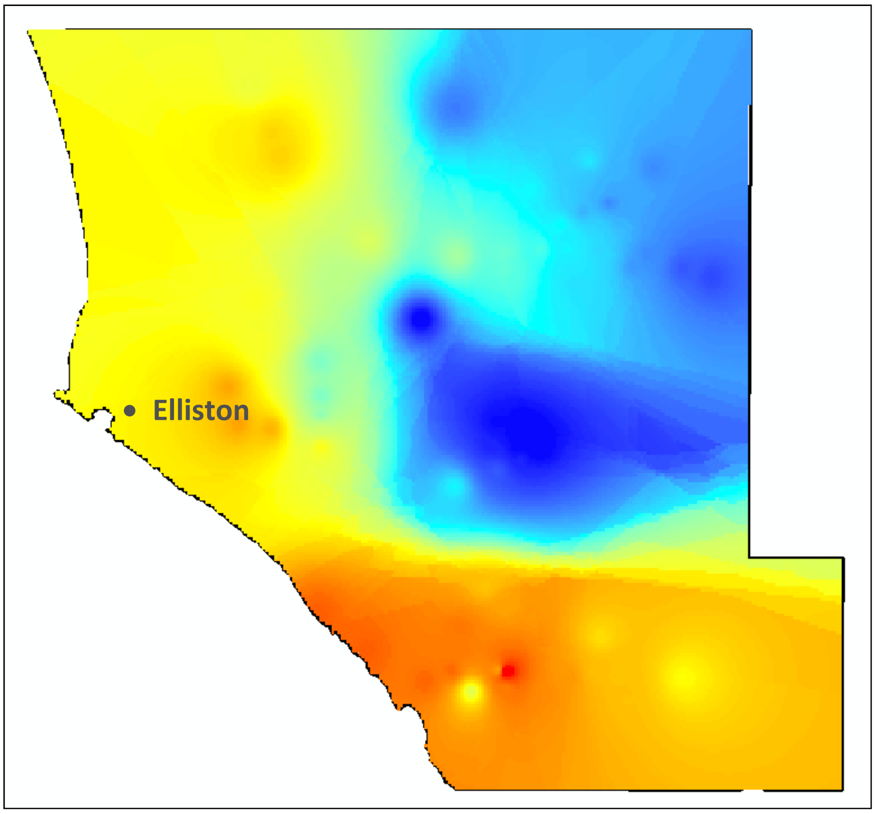

Figure 10. Example of Reduced Standing Water Level IDW interpolated surface

18. For both the Musgrave and Southern Basins PWAs, the 2011 RSWL raster was overlayed on the raster which represents the top of the Tertiary Clay aquitard (Poelpena Formation - confining bed in the Musgrave PWA and the Uley Formation in the Southern Basins PWA).
19. The Cut/Fill 3-D tool was used to determine areas where the interpolated RSWL overlies the Tertiary Clay aquitard raster and therefore outlines areas where the Quaternary Limestone aquifer is saturated with either fresh or brackish groundwater (Fig. 11a and b). It should be noted that the extent of the unsaturated Quaternary Limestone was dependent on where water level data were available at the time of modelling. There are limited data available from the unsaturated Quaternary area to inform the Aquaveo™ Arc Hydro Groundwater model and there may be small, localised areas that are saturated which the model was unable to identify or there may be areas which become ephemerally saturated in response to above average rainfall. Based on our current knowledge, there is unlikely to be any significant volumes of water available for consumptive purposes on an ongoing basis. A slight deviation from the methodology was made in the location near Coffin Bay C lens which resulted in a manual adjustment of the saturated Quaternary extent in this area, this is further described in point 25.
20. A salinity survey for a number of wells in the Quaternary Limestone aquifer was undertaken in December 2010 by the EPNRMB, which supplemented the December 2010 data for the Obswell salinity monitoring network for both the Musgrave and Southern Basins PWAs. In areas lacking data, salinity samples from May 2009 onward were considered ‘recent’ and were used to fill data gaps, provided the historically recorded salinity had a relatively stable trend. Further salinity data were provided by SA Water from production wells to fill data gaps.
21. The salinity data for the Quaternary Limestone aquifer were plotted in ArcGIS® (Fig. 12a and b) to identify areas of the saturated Quaternary Limestone where the groundwater salinity was < 1000 mg/L, indicating the current extent of the fresh groundwater lenses.

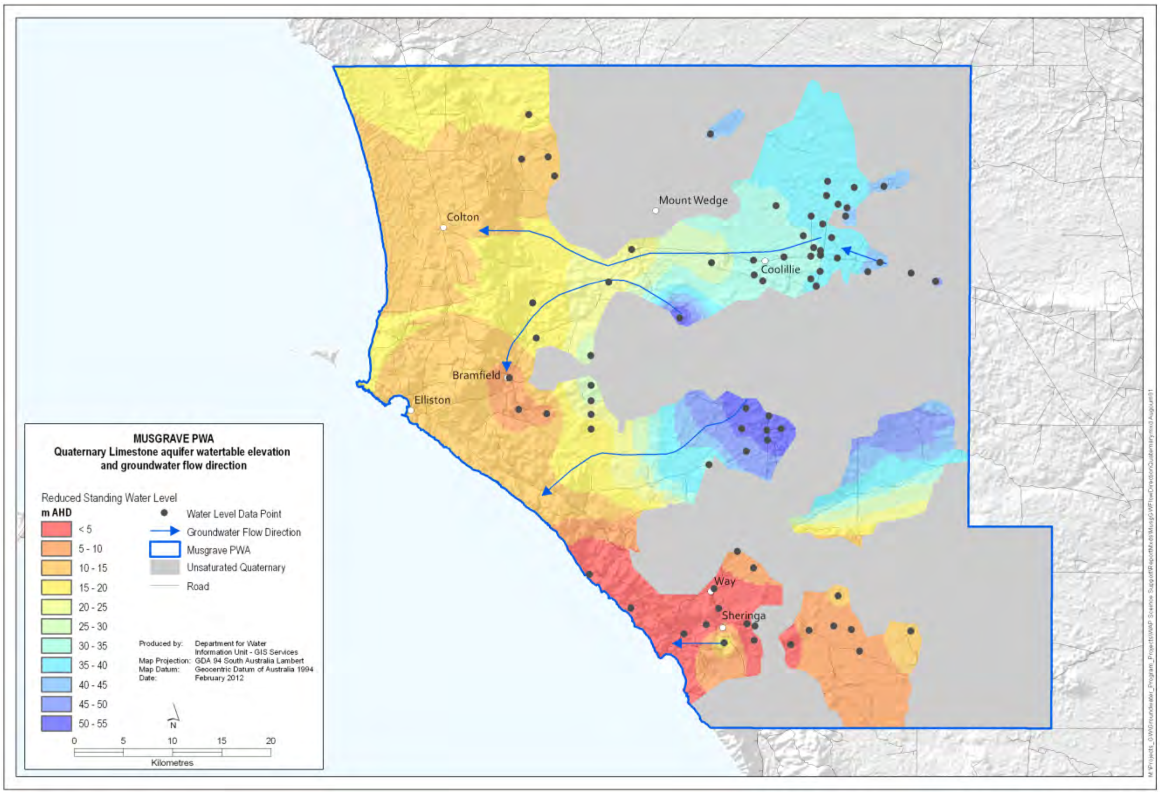

Figure 11.a. Saturated Bridgewater Formation extent for the Musgrave PWA

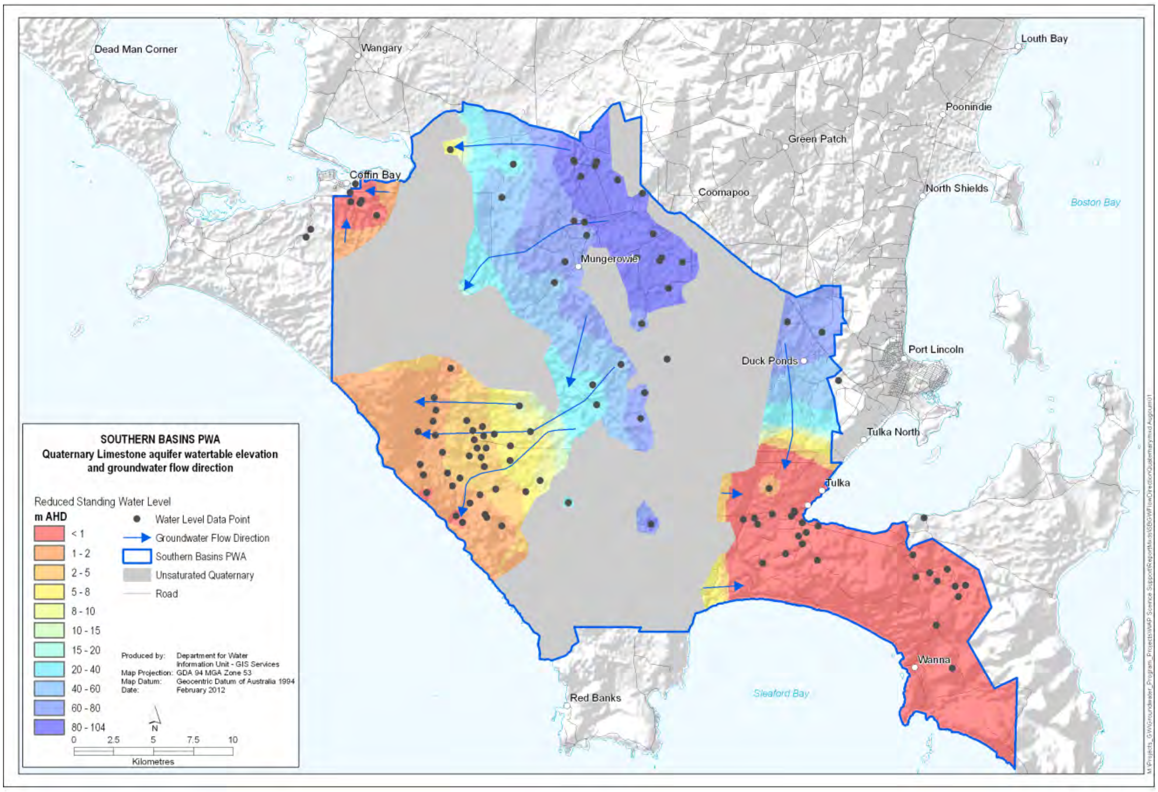

Figure 11.b. Saturated Bridgewater Formation extent for the Southern Basins PWA

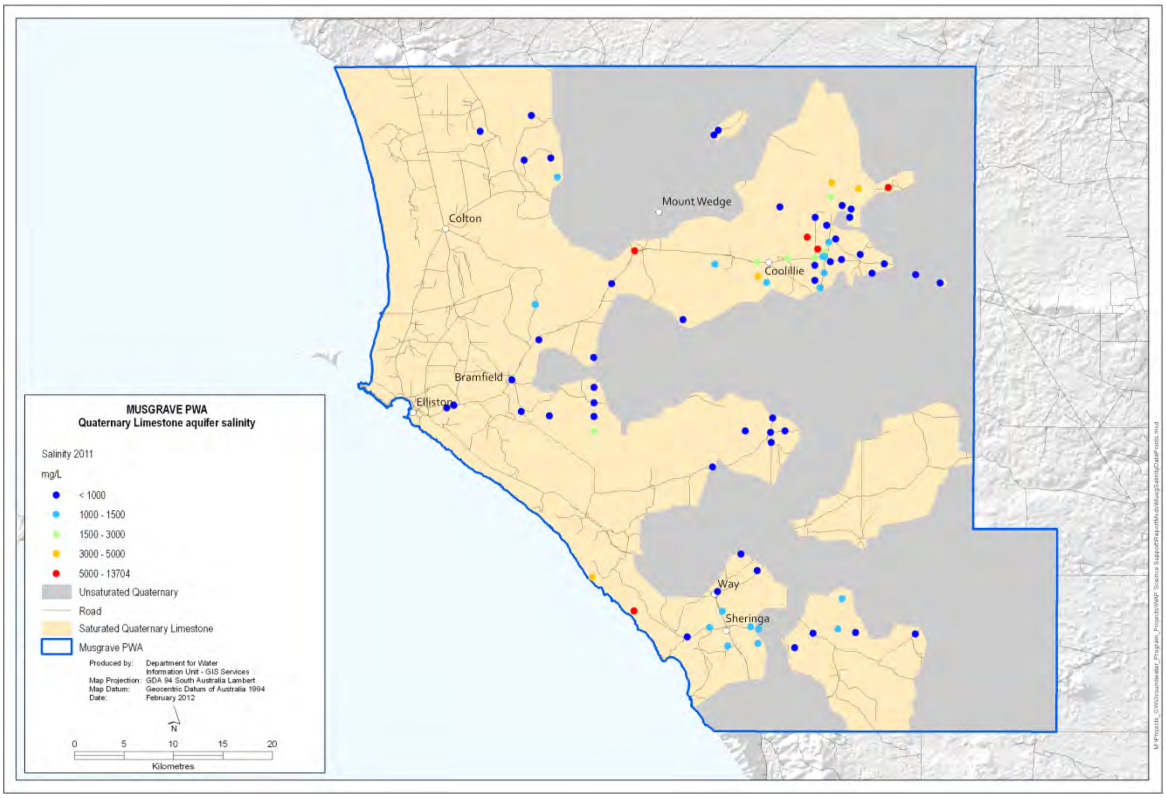

Figure 12.a. Salinity data points for the saturated Quaternary Limestone for the Musgrave PWA

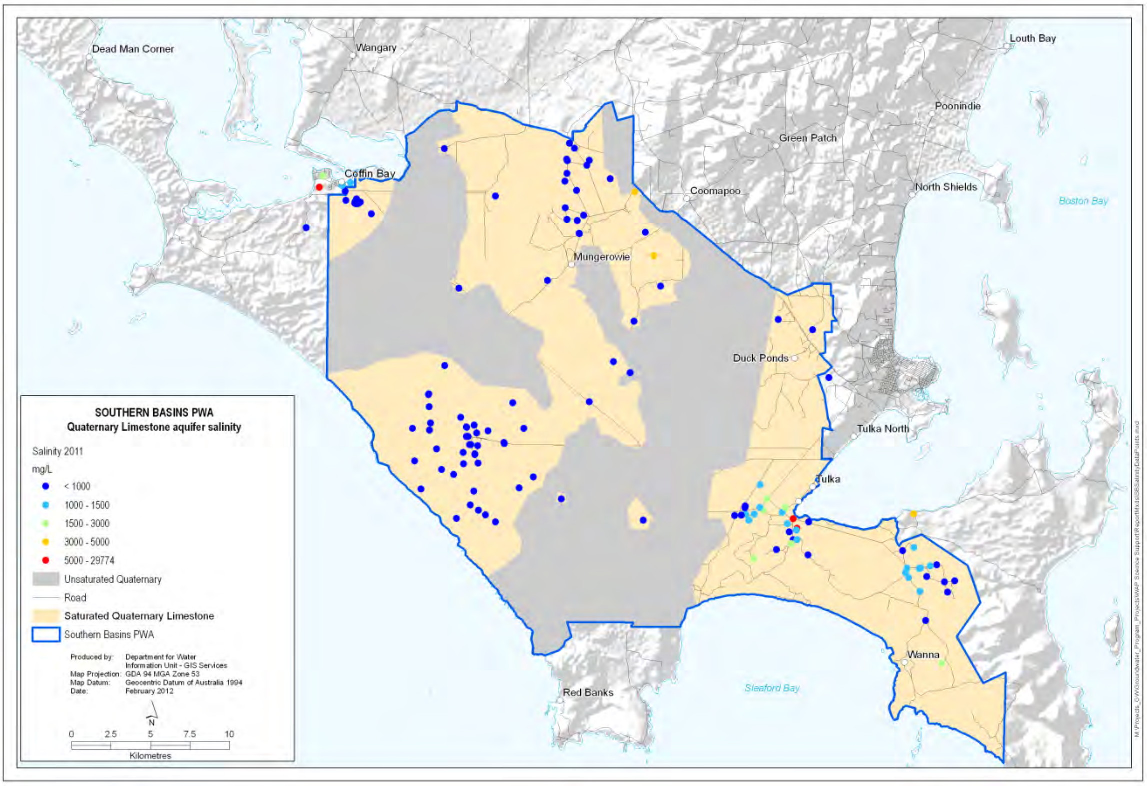

Figure 12.b. Salinity data points for the saturated Quaternary Limestone for the Southern Basins PWA

22. The extent of the fresh groundwater lenses were manually interpreted based on the available salinity data points. Where the location of wells recorded salinity of less than 1000 mg/L the location was incorporated into the lens. Where data exceeded the 1000 mg/L these areas where excluded from the lens. The boundary of the lens was drawn close to the wells with the salinity less than 1000 mg/L rather than some location between 1000 mg/L and higher values. Resulting in a conservative approach in relation to estimates of the extent of the lenses. This approach may result in under-estimates of the extent of the lenses, but is consistent with the precautionary principle and is based on best available science. The extent of the freshwater lenses is based only on the extent of the saturated Quaternary Limestone derived in Step 19 and the salinity data points collected in Step 20. The following lenses are defined for Musgrave: Talia, Talia East, Tinline, Bramfield, Sheringa A, Sheringa B, Polda, Polda East A, Polda East B and Kappawanta. The Southern Basins PWA has the following lenses: Coffin Bay A, Coffin Bay B, Coffin Bay C, Lincoln A, Lincoln B, Lincoln C, Lincoln D, Uley South, Uley Wanilla, Uley East A, Uley East B, Mikkira, Pantania (Fig. 13a and b). The extent of the Lincoln D lens was unable to be estimated by the Arc Hydro Groundwater model due to a lack of sufficient data, consequently the lens boundary is derived from the location of wells which have recent salinities of <1000 mg/L.
23. The remaining extent of the saturated, brackish Quaternary Limestone aquifer was divided into areas of (1) high confidence – i.e. data available but salinity greater than 1000 mg/L and (2) low confidence – i.e. The model suggests that the water level sits above the Tertiary Clay aquitard but there are few water level data points in this area and few salinity data available to confirm the location of freshwater. The Musgrave PWA has the following saturated, brackish Quaternary Limestone aquifer areas: Saturated Quaternary A, Saturated Quaternary B, Saturated Quaternary C, Saturated Quaternary D, Saturated Quaternary E and Saturated Quaternary F. The Southern Basins PWA has the following saturated Quaternary Limestone areas: Saturated Quaternary Uley, Saturated Quaternary Lincoln South and Saturated Quaternary Lincoln North. The extent of the Saturated Quaternary Lincoln North region was unable to be estimated by the Arc Hydro Groundwater model due to a lack of data, consequently the boundary is derived from the location of wells known to be intercepting Quaternary Limestone aquifer and the nature of the topography (Fig. 14a and b).
24. After estimating the extent of the fresh groundwater lenses and the total saturated Quaternary Limestone areas, an assessment of the volume of the void area (area between the top of the Tertiary Clay aquitard to the top of the April 2011 water level) for each freshwater lens and saturated Quaternary Limestone area was undertaken. To constrain the estimates, the calculations were undertaken via three different techniques: (1) Cut/Fill tool from the 3-D Analyst Toolset, (2) Raster Calculator from the Spatial Analyst Toolset and (3) Arc Hydro Groundwater GeoVolumes tool from the Subsurface Analyst Toolset (Table 4). The error associated with the three techniques is generally less than 7.76% in the Musgrave PWA and generally less than 3.20% in the Southern Basins PWA. The error associated with the three different techniques allows for likely ranges of error to be estimated for each lens. However, the smaller lenses (Pantania and Coffin Bay B in the Southern Basins PWA and Tinline and Polda East A and B in the Musgrave PWA) had anomalously large errors using the GeoVolumes technique due to the coarse discretisation of the Triangulated Irregular Network (TIN) used in the calculation, therefore these lenses have only been assigned an error margin from the difference between the raster calculator and cut/fill techniques. Volumes for the Lincoln D lens and Saturated Quaternary Lincoln North have not been estimated as data limitations prevented accurate modelling of the groundwater system in this area.

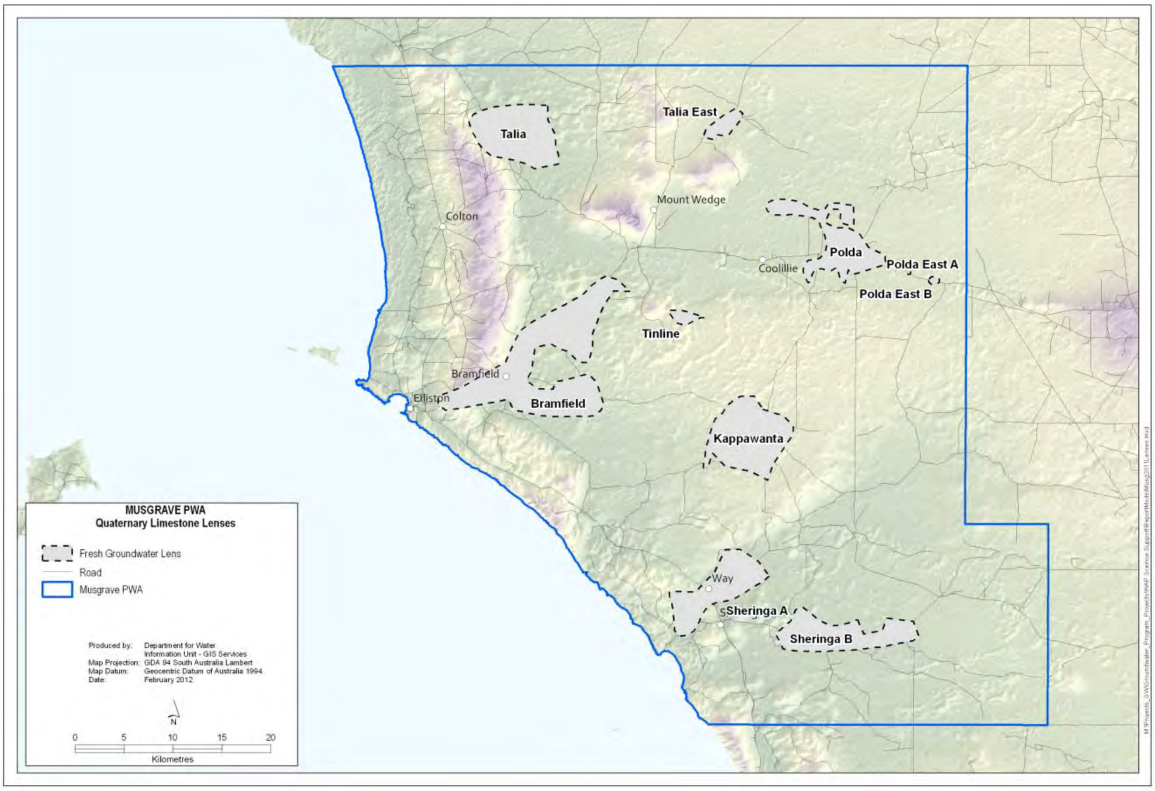

Figure 13.a. **Location and extent of fresh groundwater lenses as defined by 2011 water level and 2009–11 salinity data for the Musgrave PWA**

Figure 13.b. **Location and extent of fresh groundwater lenses as defined by 2011 water level and 2009–11 salinity data for the Southern Basins PWA**

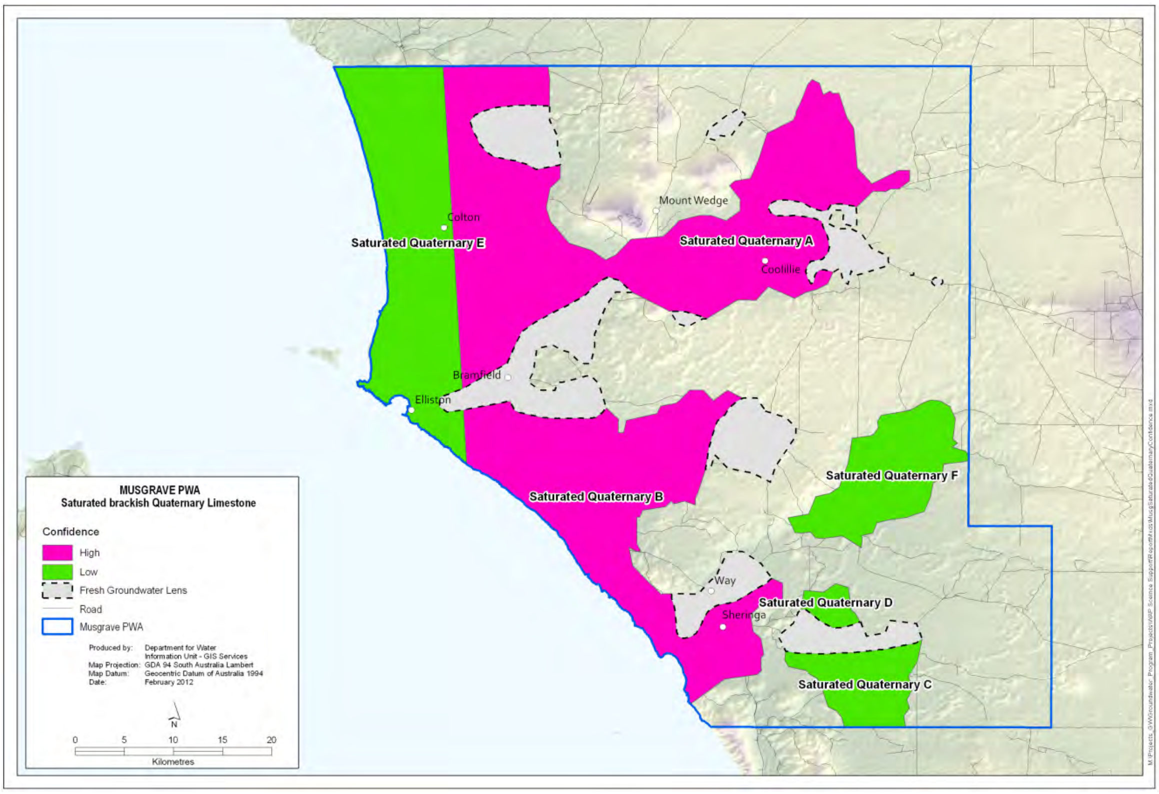

Figure 14.a. **Areas of saturated Quaternary limestone and confidence rating for the Musgrave PWA**

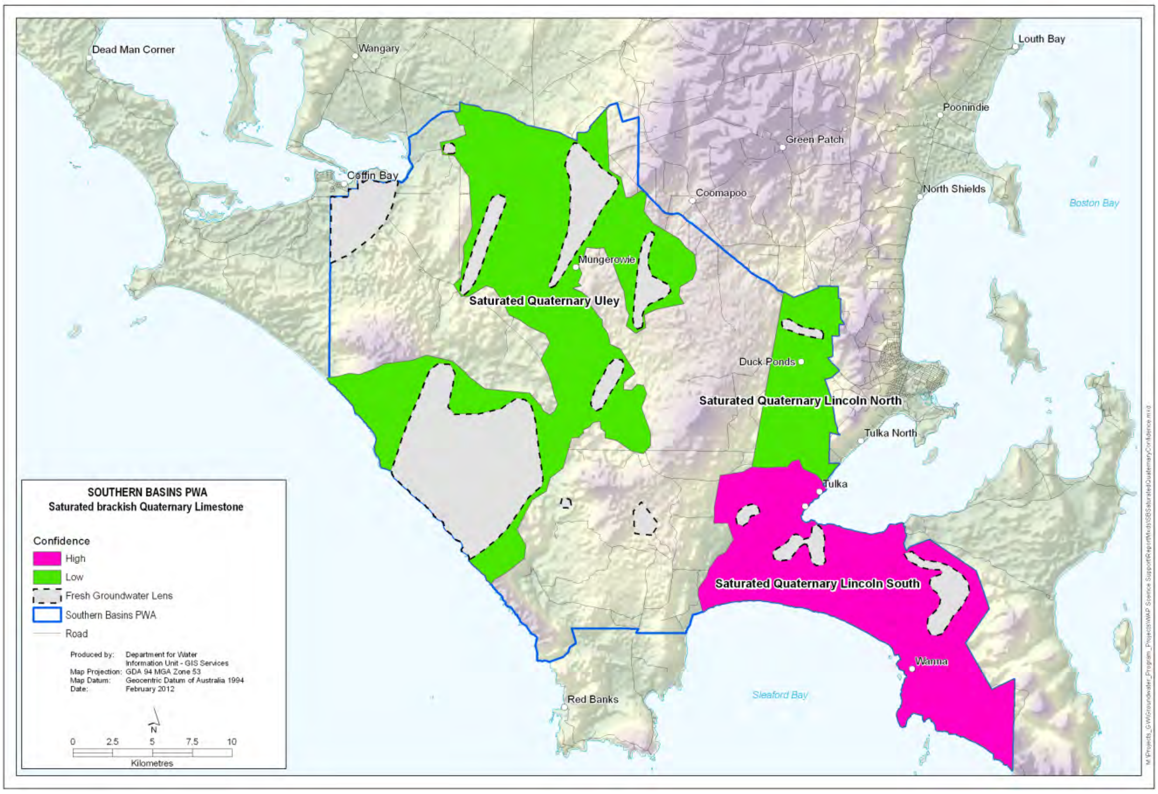

Figure 14.b. **Areas of saturated Quaternary limestone and confidence rating for the Southern Basins PWA**

Table 4. Estimates of total aquifer storage for the Musgrave and Southern Basins PWAs using three different spatial analysis techniques. The absolute percentage differences between estimates using the cut-fill method and raster calculator/GeoVolume methods are shown.

Consumptive pool	Cut/Fill (GL)	Raster Calculator (GL)	GeoVolume (GL)	Cut-Fill Vs Raster Calculator (%)	Cut-Fill vs. GeoVolume (%)	Maximum error of 3 methods (%)	Void Volume (GL)		
Musgrave PWA									
Bramfield	434.89	434.84	427.78	0.01	1.64	6.41	434.89	±	27.89
Kappawanta	197.23	197.21	190.90	0.01	3.21	3.21	197.23	±	6.33
Polda	92.26	92.25	88.47	0.01	4.11	4.11	92.26	±	3.79
Polda East A & B	0.31	0.31	0.15	0.01	52.26	0	0.31	±	0
Sheringa A	112.63	112.62	114.72	0.01	1.86	1.86	112.63	±	2.09
Sheringa B	105.27	105.25	101.54	0.01	3.54	3.54	105.27	±	3.72
Talia	296.80	296.76	306.62	0.01	3.31	3.31	296.80	±	9.82
Talia East	11.37	11.37	10.85	0.01	4.56	4.56	11.37	±	0.52
Tinline	12.52	12.51	9.98	0.01	20.28	0.01	12.52	±	0.001
Saturated Quaternary A	3820.20	3819.76	3793.94	0.01	0.69	0.69	3820.20	±	26.36
Saturated Quaternary B	2742.25	2741.94	2725.44	0.01	0.61	0.61	2742.25	±	16.73
Saturated Quaternary C	127.70	127.69	117.79	0.01	7.76	7.76	127.70	±	9.91
Saturated Quaternary D	38.74	38.73	39.71	0.01	2.50	2.50	38.74	±	0.97
Saturated Quaternary E	3145.36	3145.00	3144.29	0.01	0.03	0.08	3145.36	±	2.44
Saturated Quaternary F	882.72	882.62	881.68	0.01	0.12	0.12	882.72	±	1.04
Southern Basins PWA									
Coffin Bay A	233.21	233.07	225.75	0.06	3.20	3.2	233.21	±	7.46
Coffin Bay B	0.58	0.58	0.51	0.06	10.67	0	0.58	±	0
Coffin Bay C	27.46	27.44	27.12	0.06	1.22	1.2	27.46	±	0.33
Lincoln A	12.32	12.31	12.46	0.06	1.15	1.1	12.32	±	0.14
Lincoln B	110.77	110.71	111.70	0.06	0.84	0.8	110.77	±	0.93
Lincoln C	87.09	86.99	86.57	0.12	0.60	0.6	87.09	±	0.52
Mikkira	9.58	9.57	9.33	0.06	2.63	2.6	9.58	±	0.25
Pantania	0.79	0.79	0.68	0.06	13.32	0	0.79	±	0
Uley East A	53.13	53.10	52.79	0.06	0.65	0.7	53.13	±	0.35
Uley East B	18.14	18.13	18.65	0.06	2.80	2.8	18.14	±	0.51
Uley South	728.18	727.76	714.25	0.06	1.91	1.9	728.18	±	13.93
Uley Wanilla	151.09	151.01	149.68	0.06	0.94	0.9	151.09	±	1.41
Saturated Quaternary Lincoln South	2280.44	2279.13	2210.67	0.06	3.06	3.1	2280.44	±	69.77
Saturated Quaternary Uley	1397.52	1396.72	1375.35	0.06	1.59	1.6	1397.52	±	22.17

25. A raster of saturation thickness (Fig. 15a and b) was created for each of the PWAs from the Raster Calculator output, which estimates the extent of saturated thickness of the fresh groundwater lenses and saturated Quaternary Limestone. From the IDW interpolation the Coffin Bay C lens appears to be only half saturated (Fig. 15b), however a well located at the base of the lens sampled in April 2011 indicated that water was present and was fresh and this area has been incorporated into the Coffin Bay C lens despite being displayed in Figure 15b as being unsaturated. In supporting this decision, the elevation contours in the vicinity of the Coffin Bay C lens indicate that the lens occurs in a depression in the landscape and it is therefore likely that water would pool in this area and recharge the lens. Furthermore, the maximum historical saturated extent (Fig. 23b) for this area indicates that groundwater has been present historically. Whilst the same can be said for the area between Uley East A and Uley East B, there were no data available to indicate the current presence of water in the historical saturated extent as there is with the Coffin Bay C lens. As such the extents of the saturated Quaternary Limestone and the Coffin Bay C lens have been adjusted in this region to address these findings. Note that calculations of the total aquifer storage are based only on the saturated extent of the Coffin Bay C lens, whilst the recharge area is based on the spatial lens extent outlined.
26. The volumes calculated in Step 24 represent the void area between the top of the Tertiary Clay aquitard (Uley Formation or Poelpena Formation - confining beds) and the top of the 2011 April water level. To estimate aquifer storage volumes, the void volume results from the ArcGIS® processing need to be multiplied by the specific yield of the Quaternary Limestone aquifer. Where specific yield is defined as the volume of water released from a unit volume of saturated aquifer material drained by a falling watertable (Freeze & Cherry 1979). Drilling and aquifer testing across the Musgrave and Southern Basins PWAs suggest that the specific yield varies significantly within the Quaternary Limestone aquifer, ranging from 2×10^{-5} to 0.72 (Table 5; Appendix A).

Table 5. Specific yield estimates from previous studies

Lens/area	Minimum Sy	Maximum Sy	Adopted Sy*
Musgrave PWA			
Bramfield	0.005	0.032	0.0135
Kappawanta	0.022	0.11	0.045
Musgrave (regional)	0.00003	0.06	0.030015
Sheringa A	0.0051	0.0052	0.0061
Sheringa B	0.012	0.036	0.01
Polda	0.00002	0.069	0.0265
Southern Basins PWA			
Coffin Bay A			0.172
Uley South	0.02	0.72	0.146
Uley Wanilla	0.02	0.28	0.188

*Adopted Sy is the average of all the recorded adopted Sy values in the literature for each lens – see Appendix A

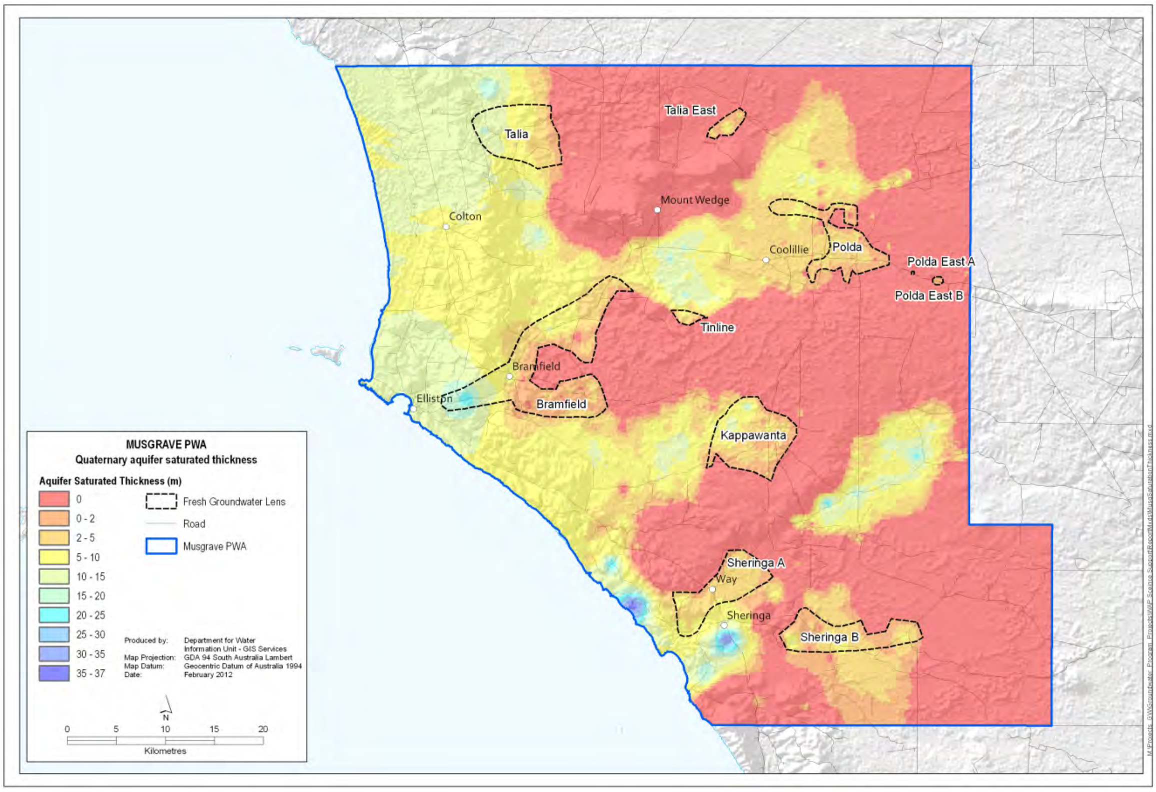

Figure 15.a. **Saturated Quaternary Limestone aquifer thickness for the Musgrave PWA**

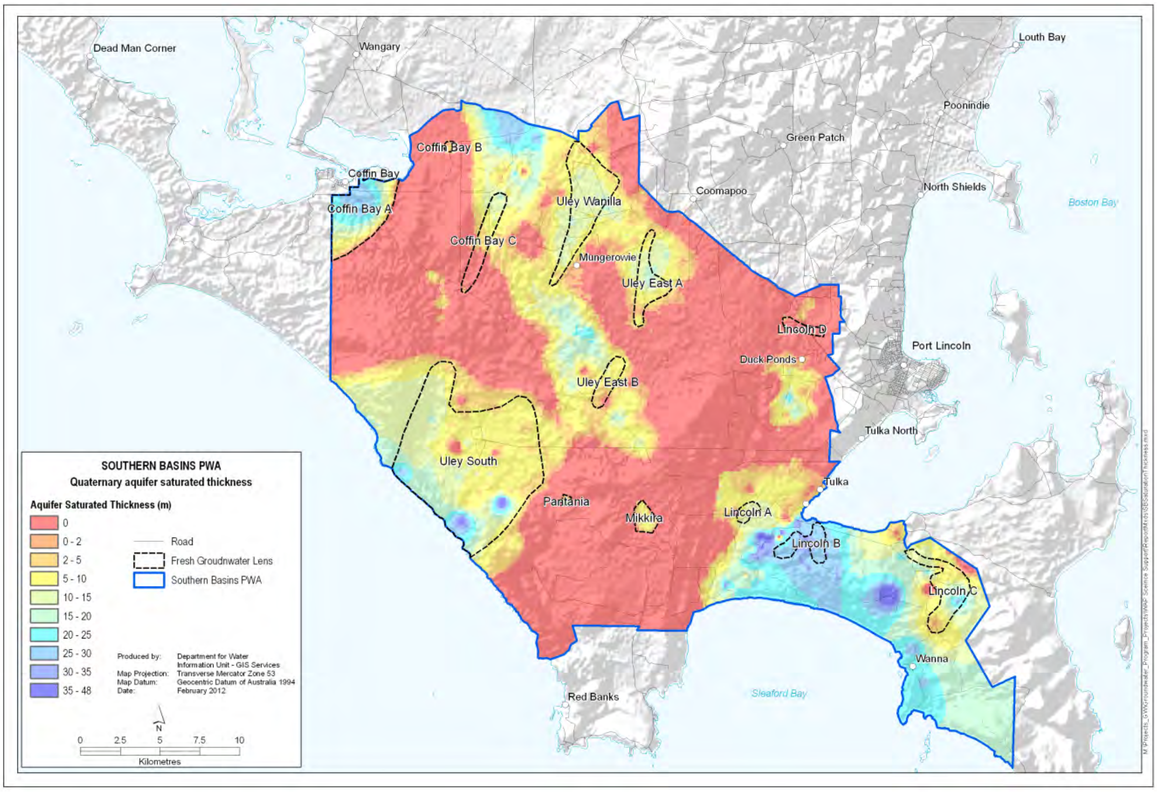

Figure 15.b. **Saturated Quaternary Limestone aquifer thickness for the Southern Basins PWA**

27. Given the range of values of specific yield for the various lenses, the 'adopted' specific yield value (i.e. the value adopted as the likely representative specific yield from a given pump test(s)) was

used to calculate the total aquifer storage volume of the lenses and saturated Quaternary Limestone areas (Table 6). In lenses where pump tests have not been conducted, values of specific yield have been estimated from adjacent lenses that are thought to have similar aquifer properties. The estimated total aquifer storage volumes (Table 6) do not represent the volume of water available for allocation, but indicate the volume of water in storage for the relevant lenses and saturated Quaternary Limestone areas. These values can be re-calculated annually at the same time of year to estimate the changes in aquifer saturation thickness and thereby estimate changes in aquifer storage. The estimated changes in aquifer storage can be linked to variation in annual allocations. Given that Lincoln D lens and the Saturated Quaternary Lincoln North area have not had aquifer storages estimated, these resources have been omitted from further analyses.

Table 6. Total aquifer storage of the consumptive pools

Consumptive pool	Void volume (GL)	Specific yield (adopted values)	Total aquifer storage (GL)
Musgrave PWA			
Bramfield	434.89	0.0135	5.9
Kappawanta	197.23	0.045	8.9
Polda	92.26	0.0265	2.4
Polda East A & B	0.31	0.0265	0.01
Sheringa A	112.63	0.0031	0.3
Sheringa B	105.27	0.01	1.1
Talia	296.8	0.03	8.9
Talia East	11.37	0.03	0.3
Tinline	12.52	0.03	0.4
Saturated Quaternary A	3820.2	0.03	114.6
Saturated Quaternary B	2742.25	0.03	82.3
Saturated Quaternary C	127.7	0.03	3.8
Saturated Quaternary D	38.74	0.03	1.2
Saturated Quaternary E	3145.36	0.03	94.4
Saturated Quaternary F	882.72	0.03	26.5
Southern Basins PWA			
Coffin Bay A	233.21	0.172	40.1
Coffin Bay B	0.58	0.172	0.1
Coffin Bay C	27.46	0.172	4.7
Lincoln A	12.32	0.146	1.8
Lincoln B	110.77	0.146	16.2
Lincoln C	87.09	0.146	12.7
Mikkira	9.58	0.146	1.4
Pantania	0.79	0.146	0.1
Uley East A	53.13	0.188	10.0
Uley East B	18.14	0.188	3.4
Uley South	728.18	0.146	106.3
Uley Wanilla	151.09	0.188	28.4
Saturated Quaternary Lincoln South	2280.44	0.146	332.9
Saturated Quaternary Uley	1397.52	0.146	204.0

28. To give an indication of the likely annual change in aquifer storage, the 2011 maximum and minimum water level data were extracted from SA Geodata for each water level observation well across both the Musgrave and Southern Basins PWAs. Interpolated surfaces were created using the IDW technique. By comparing the maximum and minimum RSWL surfaces, changes in storage volume (absolute and percentage changes) were estimated. This was not able to be undertaken for the Polda East A & B lenses as the lenses are small and derived by one data point each (Table 7). Allocations for each management zone can be varied annually, based on the change in total aquifer storage. This approach will not be possible for the Lincoln D lens and Saturated Quaternary Lincoln North area and (see Steps 22 and 23) therefore, allocations for these areas could be varied annually (if required) using the existing watertable fluctuation method.

Table 7. Potential change in storage annually

Consumptive pool	Total aquifer storage (GL)	Change in void volume (GL)	Specific yield (adopted value)	Change in storage (GL)	Change in storage (%)
Musgrave PWA					
Bramfield	5.9	21.50	0.0135	0.29	4.94
Kappawanta	8.9	8.98	0.045	0.40	4.55
Polda	2.4	11.41	0.0265	0.30	12.37
Sheringa A	0.3	3.40	0.0031	0.01	3.02
Sheringa B	1.1	1.92	0.01	0.02	1.82
Talia	8.9	13.55	0.03	0.41	4.57
Talia East	0.3	1.73	0.03	0.05	15.22
Tinline	0.4	0.64	0.03	0.02	5.11
Saturated Quaternary A	114.6	139.50	0.03	4.19	3.65
Saturated Quaternary B	82.3	106.44	0.03	3.19	3.88
Saturated Quaternary C	3.8	4.39	0.03	0.13	3.44
Saturated Quaternary D	1.2	0.88	0.03	0.03	2.26
Saturated Quaternary E	94.4	65.86	0.03	1.98	2.09
Saturated Quaternary F	26.5	25.97	0.03	0.78	2.94
Southern Basins PWA					
Coffin Bay A	40.1	3.15	0.172	0.54	1.35
Coffin Bay B	0.1	0.07	0.172	0.01	12.92
Coffin Bay C	4.7	1.42	0.172	0.25	5.19
Lincoln A	1.8	0.47	0.146	0.07	3.78
Lincoln B	16.2	2.27	0.146	0.33	2.05
Lincoln C	12.7	1.44	0.146	0.21	1.65
Mikkira	1.4	0.74	0.146	0.11	7.74
Pantania	0.1	0.08	0.146	0.01	9.69
Uley East A	10.0	1.40	0.188	0.26	2.63
Uley East B	3.4	0.34	0.188	0.06	1.90
Uley South	106.3	14.11	0.146	2.06	1.94
Uley Wanilla	28.4	6.77	0.188	1.27	4.48
Saturated Quaternary Lincoln South	332.9	48.05	0.146	7.02	2.11
Saturated Quaternary Uley	204.0	50.11	0.146	7.32	3.59

Note: This analysis could not be completed for Polda East as there were limited monitoring data in the vicinity of the lens

29. The capacity of the resource has been estimated for each groundwater management zone using the long-term average annual recharge rate outlined in the existing WAPs (Table 8) (ERWRPC 2000; ERWRPC 2001) with the exception the Uley South lens. A recent study (Ordens *et al.* 2011) which aimed to refine the existing long-term average annual recharge estimates for the Uley South lens

reports that recharge, as estimated by the chloride mass balance and watertable fluctuation methods, ranges between 47 and 129 mm/y. The upper limit of 129 mm/y has been selected for the Uley South lens. This is because water levels are currently displaying stable trends, indicating that the current level of extraction (around 6500 ML/y) is sustainable. Selecting the lower range of the new recharge estimates would not accurately reflect the current status of the resource. Further to this, the Uley South lens is a geologically bound basin with all rainfall occurring over the basin contributing to recharge in the area. Consequently, a separate recharge area has been delineated (Fig. 16).It should also be noted that Harrington, Evans and Zulfic (2006) estimated the likely upward leakage to the Uley South lens from the underlying Tertiary Sands aquifer (for further information refer to Table 9). The location of the recharge area is based on the current extent of saturation to the north and east as is consistent with the methodology applied to all other lenses. To the north-east, where the saturation extent continues to the north towards Uley East B, the topographical divide has been used to infer the boundary of the recharge area for the Uley South lens (Fig. 16). The boundary does not continue to follow the topographical high to the west because the maximum historic saturated extent indicates that this area remains unsaturated. In all other cases the area of the fresh groundwater lenses that are not geologically bound, but exist as a localised area of water with salinity of <1000 mg/L in brackish water have been used as the recharge area.

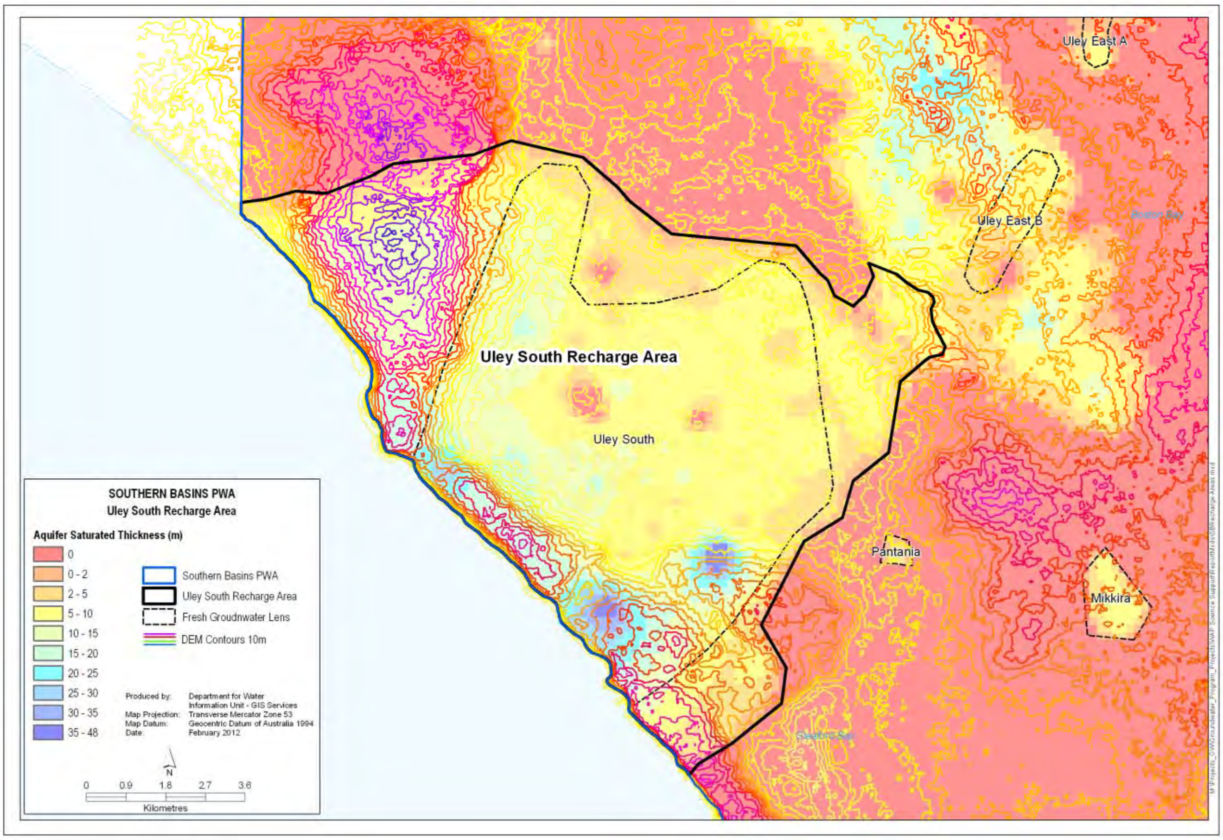

Figure 16. Uley South recharge area (in the Southern Basins PWA)

Table 8. Long-term average annual recharge calculations for the consumptive pools within the Musgrave and Southern Basins PWAs

Consumptive pool	Long-term average annual recharge (mm/y)	Reference
Musgrave PWA		
Bramfield	31	Bramfield existing WAP
Kappawanta	32	Kappawanta existing WAP
Polda	28	Polda existing WAP
Polda East A & B	11	Polda East existing WAP
Sheringa A	29	Sheringa A existing WAP
Sheringa B	28	Sheringa B existing WAP
Talia	28	Talia existing WAP
Talia East	28	Talia existing WAP
Tinline	31	Tinline existing WAP
Saturated Quaternary A	25	Minor Lenses existing WAP
Saturated Quaternary B	25	Minor Lenses existing WAP
Saturated Quaternary C	25	Minor Lenses existing WAP
Saturated Quaternary D	25	Minor Lenses existing WAP
Saturated Quaternary E	25	Minor Lenses existing WAP
Saturated Quaternary F	25	Minor Lenses existing WAP
Southern Basins PWA		
Coffin Bay A	34	Coffin Bay A existing WAP
Coffin Bay B	16	Coffin Bay B existing WAP
Coffin Bay C	18	Coffin Bay C existing WAP
Lincoln A	56	Lincoln A existing WAP
Lincoln B	56	Lincoln B existing WAP
Lincoln C	56	Lincoln C existing WAP
Lincoln D	56	Lincoln D existing WAP
Mikkira	40	Minor Lenses existing WAP
Pantania	40	Minor Lenses existing WAP
Uley East A	69	Uley East existing WAP
Uley East B	69	Uley East existing WAP
Uley South	129	Ordens et al (2011)
Uley South from upward Tertiary leakage	14	Harrington, Evans and Zulfic (2006)
Uley Wanilla	54	Uley Wanilla existing WAP
Saturated Quaternary Lincoln North	40	Minor Lenses existing WAP
Saturated Quaternary Lincoln South	40	Minor Lenses existing WAP
Saturated Quaternary Uley	40	Minor Lenses existing WAP

30. For the purposes of calculating the capacity of the resource, both PWAs were divided into the following areas: (1) the Musgrave PWA – Saturated Quaternary Limestone, Unsaturated Quaternary Limestone (Bridgewater Formation), Tertiary Sands (Poelpena Formation), Jurassic aquifer (Polda Formation) and basement and (2) the Southern Basins PWA - Saturated Quaternary Limestone, Unsaturated Quaternary Limestone (Bridgewater Formation), Tertiary Sands (Uley Formation and Wanilla Formation) and basement. The Tertiary Clay aquitard has not been assigned a consumptive pool. Figure 17 shows the consumptive pools for the Musgrave PWA (Note that the cross-sections have a vertical exaggeration of 300). Figure 18 shows the consumptive pools for the Southern Basins PWA (Note that the cross-sections have a vertical exaggeration of 50).

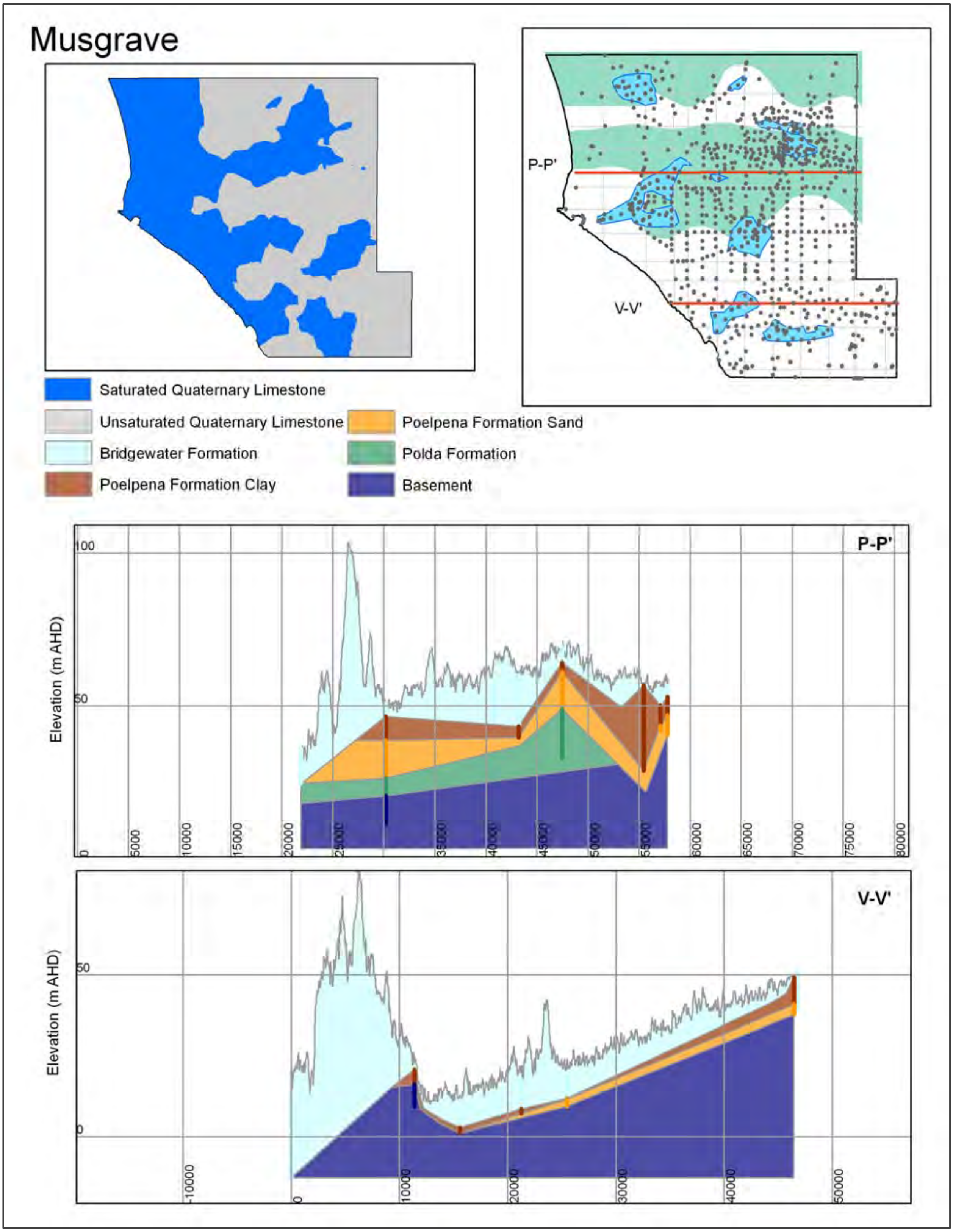

Figure 17. **Consumptive pool areas for the Musgrave PWA**

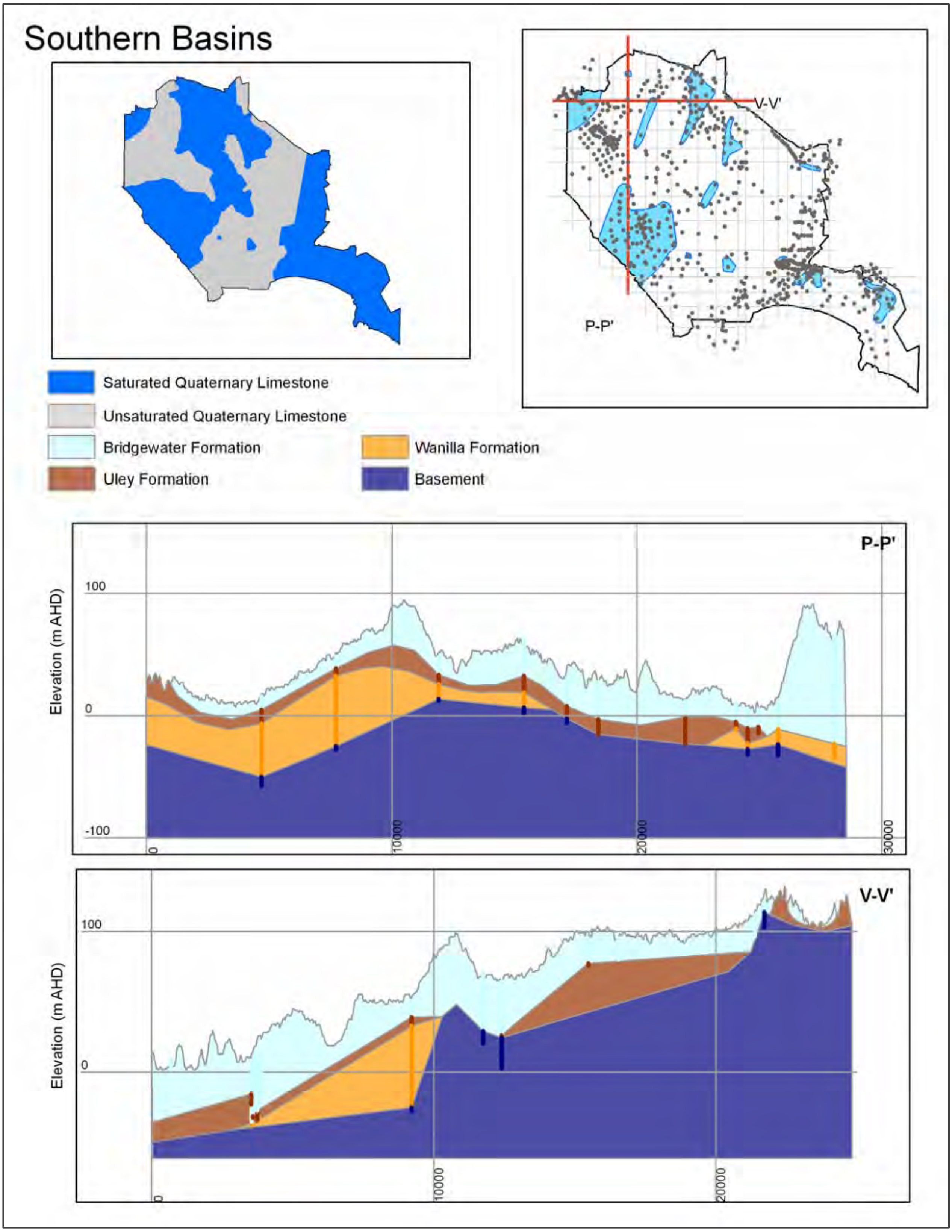

Figure 18. Consumptive pool areas for the Southern Basins PWA

31. The capacity of the resource of the Saturated Quaternary Limestone aquifer, which represents the volume of water available for aquifer maintenance, licensed and non-licensed uses, was estimated by multiplying the long-term average annual recharge by the recharge area of the various groundwater management zones in the Saturated Quaternary Limestone. The groundwater management zones include the lenses (Talia, Talia East, Tinline, Bramfield, Sheringa A, Sheringa B, Polda, Polda East A & B, Kappawanta, Coffin Bay A, Coffin Bay B, Coffin Bay C, Lincoln A, Lincoln B, Lincoln C, Lincoln D, Uley South, Uley Wanilla, Uley East A, Uley East B, Mikkira and Pantania) and the Saturated Quaternary Limestone areas (Saturated Quaternary A, Saturated Quaternary B, Saturated Quaternary C, Saturated Quaternary D, Saturated Quaternary E, Saturated Quaternary F, Saturated Quaternary Uley, Saturated Quaternary Lincoln South and Saturated Quaternary Lincoln North). The volumetric capacities of each groundwater management zone within each of both PWAs were summed to estimate the capacity of the Saturated Quaternary Limestone (Table 9).

32. Consideration could be given to assigning a nominal volume of water available from the consumptive pool in the Unsaturated Quaternary Limestone. It should be noted there are limited data available from the area to inform the Aquaveo™ Arc Hydro Groundwater model and there may be small, localised areas that are temporarily saturated. Based on our current knowledge, there is unlikely to be any significant volumes of water available for consumptive purposes on an ongoing basis. In the event there were, the supply is likely to be highly unreliable. Consequently and for the purpose of this report, it is suggested the Unsaturated Quaternary Limestone be assigned a small nominal volume of water from the consumptive pool for potential stock and domestic purposes only and a zero allocation limit (Table 9).

33. Refinement of the estimates of the capacity of the Tertiary Sands aquifers (Poelpena Formation in the Musgrave PWA and Wanilla Formation in the Southern Basins PWA) and the basement aquifers is not possible due to a lack of new data and therefore, it is suggested that the existing estimates of resource capacities as outlined in the existing WAP should be retained (Table 9).

34. In the current WAP, the Jurassic aquifer (Polda Formation) and basement aquifer in the Musgrave PWA were not assigned capacities in the existing WAP as it was considered that the water was too saline for use. Given the advancement in desalinisation technologies and the potential for increased mining activity, these aquifers have an increasing potential to be developed. The resource capacity for these pools has been estimated by assuming a 1 mm/y recharge across their areal extent. For the basement aquifer the calculation was applied over the whole PWA area, but for the Jurassic aquifer the calculation was applied over the areas of the Polda Trough and Yaninee Channel (where it is known to exist) (Fig. 19).

35. The capacity of the resource outlines the volume of water available for licensed and non-licensed use and aquifer maintenance. The consumptive pool outlines the volume of water available for consumption – i.e. licensed and non-licensed purposes. It is suggested that 50% of the capacity of the resource of the Saturated Quaternary Limestone be set aside for aquifer maintenance, which would result in a volume of 50% of the capacity of the resource being available for the consumptive pool (Table 9). The suggestion of setting aside 50% of the consumptive pool for aquifer maintenance is based on the assumption that there is a need to maintain natural flows through the aquifer, this includes natural discharges also. If too much water is made available for the consumptive pool this may impact on the water balance in other areas, such as reducing natural discharges and altering flow direction. These natural discharges do not only include discharges to bays, such as Coffin Bay, but also discharges to water-dependent ecosystems.

Table 9. Assessment of the Capacity and Demands for the Prescribed Water Resources

PWA		Fresh groundwater lens/Saturated Bridgewater Formation	Long-term average annual recharge (mm/y)	Area (km^2)	Capacity of the resource (ML)	Aquifer maintenance %	Consumptive Pool (ML)	Domestic demands (ML)*	Stock Demands (ML)	Conservative 2011 lenses Allocation Limit (ML)	2010–11 Existing Licences Extraction Limit (ML)	2011 Licensed usage (ML)	Available for Allocation Conservative 2011 (ML)	Average Use (ML) 2004/05–2010/11
Southern Basins	Saturated Quaternary Limestone	Coffin Bay A	34	13.82	469.8	50	234.9	0.28	0	235	111.934	102.604	123	126
		Coffin Bay B	16	0.42	6.7	50	3.3	0	0	3	0	0	3	0
		Coffin Bay C	18	5.47	98.5	50	49.2	0	2.21	47	0	0	47	0
		Lincoln A	56	1.20	67.1	50	33.6	0	0.11	33				
		Lincoln B	56	3.95	221.2	50	110.6	0	0	111	625	440.6	-259	737
		Lincoln C	56	7.92	443.8	50	221.9	0	0	222				
		Lincoln D	56	1.407	78.8	50	39.4	0.28	0.40	39	26.797	0.265	12	0.57
		Mikkira	40	2.13	85.0	50	42.5	0	0.77	42	0	0	42	0
		Pantania	40	0.38	15.0	50	7.5	0	0.11	7	0	0	7	0
		Uley East A	69	5.67	391.4	50	195.7	0	0.42	195	6.374	0	189	0
		Uley East B	69	3.10	214.0	50	107.0	0	0	107	144.116	0	-37	0
		Uley South	129	112.90	14 561.5	50	7345.8	0	2.59	7343	6887.398	4939.9	456	6429
		Uley South from upward Tertiary leakage	14	9.29	130.1	50								
		Uley Wanilla	54	14.33	774.0	50	387.0	1.12	0.36	386	155.379	119.2	230	194
		Saturated Quaternary Lincoln North	40	44.65	1786.0	50	893.0	3.36	2.04	888	9.964	0.479	878	0.59
		Saturated Quaternary Lincoln South	40	136.81	5472.4	50	2736.2	1.40	0.35	2734	0	0	2734	0
		Saturated Quaternary Uley	40	184.74	7389.6	50	3694.8	0.56	7.08	3687	32.064	1.898	3655	1.97
	Unsaturated Quaternary Limestone				0.0	n/a	0.0	1.68	22.57	n/a	n/a	n/a	n/a	n/a
	Tertiary Sand				3240.0	90	324.0	0.28	38.00	286	7.535	0.018	278	0.162
	Basement				1000.0	50	500.0	0.28	38.00	462	101.177	25.934	361	24.485
Musgrave	Saturated Quaternary Limestone	Bramfield	31	99.46	3083.1	50	1541.6	7.56	17.10	1517	816.97	93.85	700	86.34
		Kappawanta	32	48.86	1563.4	50	781.7	0	0	782	384	0	398	0
		Polda	28	37.21	1041.8	50	520.9	1.12	2.85	517	479.57	1.63	37	101.62
		Polda East A & B	11	0.80	8.8	50	4.4	0	0	4	0	0	4	0
		Sheringa A	29	36.23	1050.6	50	525.3	0.84	8.96	516	25.87	0	490	0
		Sheringa B	28	37.53	1050.9	50	525.4	0.28	2.21	523	0	0	523	0
		Talia	28	44.17	1236.8	50	618.4	0.28	3.00	615	0	0	615	0
		Talia East	28	6.15	172.2	50	86.1	0	3.00	83	0	0	83	0
		Tinline	31	3.13	96.9	50	48.4	0	0.32	48	0	0	48	0
		Saturated Quaternary A	25	566.12	14 152.9	50	7076.4	3.92	62.50	7010	60.65	0	6949	6.02
		Saturated Quaternary B	25	382.42	9560.5	50	4780.3	3.64	38.10	4739	0	0	4739	0
		Saturated Quaternary C	25	74.02	1850.6	50	925.3	0.28	6.80	918	0	0	918	0
		Saturated Quaternary D	25	17.06	426.5	50	213.3	0	2.10	211	0	0	211	0
		Saturated Quaternary E	25	305.20	7629.9	50	3815.0	10.92	20.60	3783	0	0	3783	0
		Saturated Quaternary F	25	128.52	3212.9	50	1606.5	0	2.50	1604	0	0	1604	0
	Unsaturated Quaternary Limestone				0.0	n/a	0.0	3.36	145.92	n/a	n/a	n/a	n/a	n/a
	Tertiary Sand				33 900.0	90	3390.0	1.12	59.00	3330	0	0	3330	0
	Polda Formation		1	1474	1474.0	50	737.0	0	0	737	0	0	737	0
	Basement		1	3595.5	3595.5	50	1797.8	0	59	1739	0	0	1739	0

- Stock, domestic and licensed use values vary from those viewed in Tables 13 to 19 as their data summarises 2010–11 data and has been applied to the newly defined lenses. Stock demands were applied by apportioning the change in lens extent to the stock water usage. These numbers could be further refined with more work if required.
- The numbers outlined in this table represent the volumes appropriate for consumptive pools solely from a scientific perspective. They do not take into account social and economic tradeoffs. A triple bottom line approach should be undertaken in the process of writing the WAP.

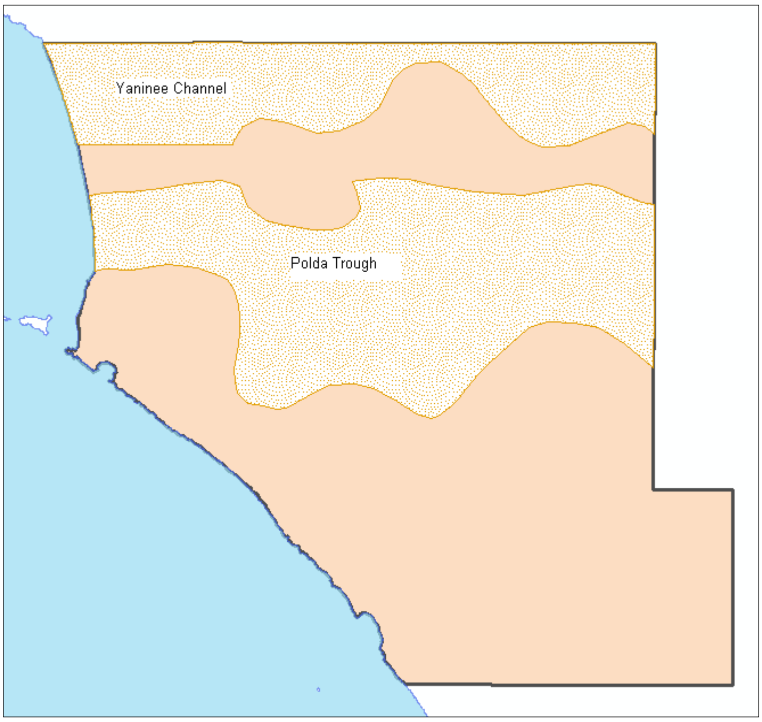

Figure 19. Areal extent of the Jurassic aquifer within the Musgrave PWA

35. (Cntd.) Aquifer maintenance includes maintaining groundwater flow gradients, which is particularly important in costal lenses such as Uley South. The maintenance of groundwater flow gradients helps manage the risk of sea water intrusion. The actual percentage assigned for aquifer maintenance can be varied depending on community and stakeholder consultation, however a similar approach of setting aside 50% of the capacity of the resource for aquifer maintenance has also been undertaken in the Manitoba province in Canada (S Topping [Department of Water Stewardship, Manitoba] 2011, pers. comm.). It is suggested that for the basement in the Southern Basins PWA and all Tertiary Sands management zones, the volume assigned to provide for aquifer maintenance be retained from the previous WAP – i.e. 50% and 90% of the resource capacity be set aside for aquifer maintenance for the basement and the Tertiary aquifers, respectively (Table 9). This is largely following the precautionary principle as we have limited knowledge of these aquifers. The Jurassic aquifer and the Musgrave PWA basement aquifers were not assigned consumptive pools in the previous WAP. It is suggested that 50% of the resource capacity of each of these management areas (Table 9) be set aside for aquifer maintenance to align with the approach undertaken for the Quaternary Limestone aquifer.

36. Within the Uley South groundwater management zone, there is postulated to be upward leakage of groundwater from the Tertiary Sands into the Quaternary Limestone aquifer. Harrington, Evans and Zulfic (2006) estimate this leakage to be 14 mm/y and whilst it is a small component of the overall water balance, it is an additional recharge component for Uley South. In areas where the Tertiary Clay aquitard is thought to be absent (Fig. 20), an estimated recharge of 14 mm/y has been applied to the area of absent aquitard (9.29 km^2) resulting in an additional recharge of 130 ML/y to the Uley South groundwater management zone. Fifty per cent of this recharge is set aside for aquifer maintenance and the remaining volume (65.03 ML/y) forms part of the allocation limit for the Uley South Groundwater Management Zone (Table 9). Whilst there are areas in the remainder of the Musgrave and Southern Basins PWAs which have an absence of clay, there is no evidence that indicates that there is an upward leakage potential where water from the Tertiary aquifer feeds into the Quaternary aquifer.

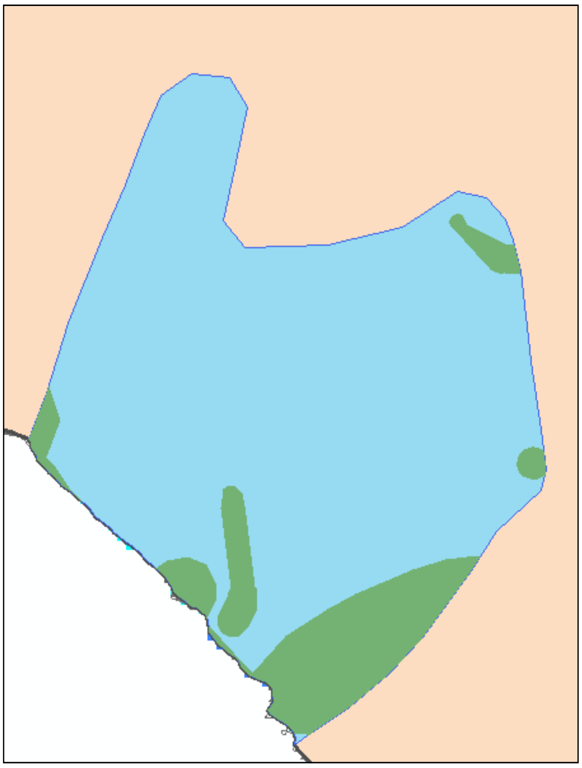

Figure 20. Areal extent of likely Tertiary Clay absence (green) in the Uley South Groundwater Management Zone within the Southern Basins PWA

37. Volumetric estimates of stock and domestic demand (Section 4) were subtracted from the consumptive pool volumes – for each of the different management zones – and an allocation limit was suggested for each zone (Table 9).

38. Buffers of 500 m around the fresh groundwater lens Groundwater Management Zones are suggested to minimise the risk that any new extraction adjacent the lens may have on the lens itself (Fig. 21a and b). The buffer zone approach is suggested in line with the precautionary principle as the lenses are likely to vary seasonally and annually. The distance of 500 m is suggested as Table D3 outlines that for a pumping rate of 667 kL/d (annual allocation of 50 ML) and a specific yield of 0.15 (refer to Appendix A), when transmissivity ranges from 10–14000 m^2/d the potential radius of impact ranges from 0–468 m. A buffer of 500 m has been suggested to manage any impacts of small extractions. Management options may be applied to the buffered lens extents e.g. an application for a licence to extract water from within the buffered lens extent will be subject to the same conditions as the lens itself, rather than the Saturated Quaternary Limestone Groundwater Management Zone.

39. Buffers were also applied around the areas of likely aquitard absence as there is the potential for drawdown effects due to extraction from the Tertiary Sands. The buffer distance suggested for each area is based on the calculations undertaken in Section 6.1.4 and has been applied for extraction volumes of 5 ML/y and 10 ML/y (assuming the allocation is used in its entirety and extracted continuously over an irrigation season of 75 days). The buffers indicate the likely distance around areas of probable aquitard absence, where extraction from the Tertiary Sands or basement aquifers may have a deleterious impact on the Quaternary Limestone aquifer. These buffers may be used for management purposes (Fig. 22a and b).

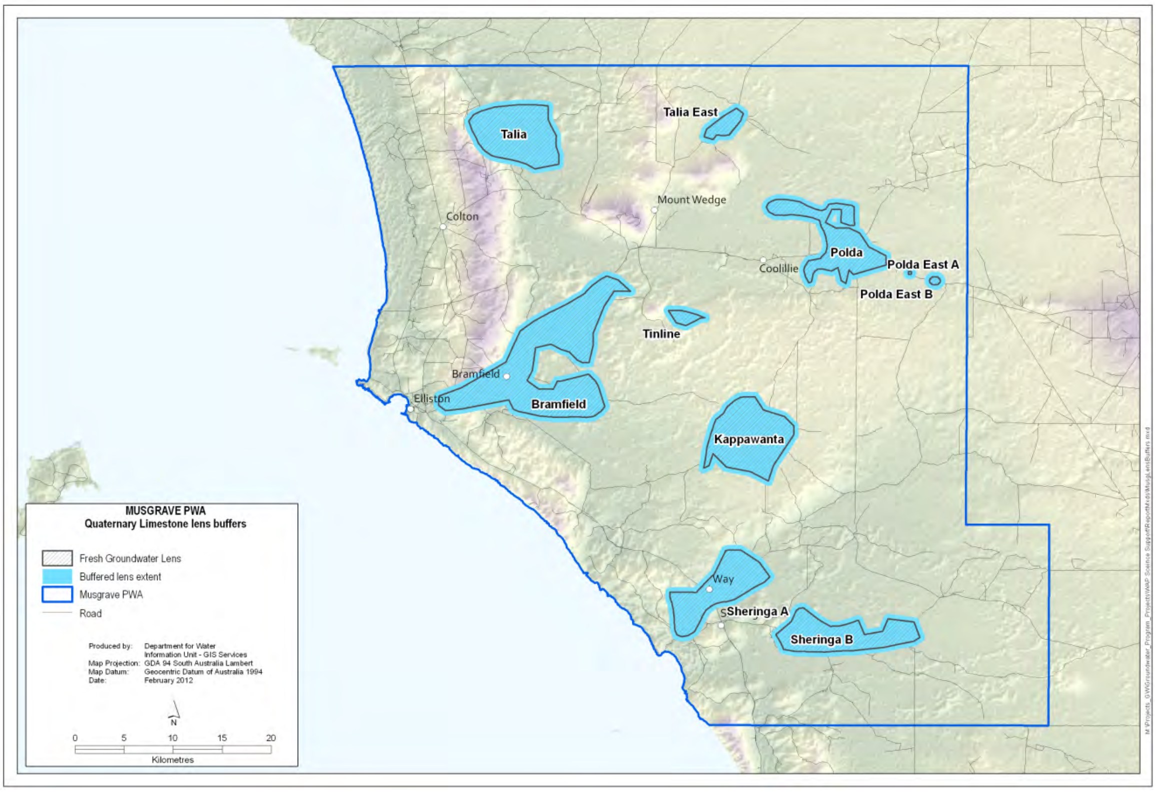

Figure 21.a. Buffer zones for management of the fresh groundwater lenses in the Musgrave PWA

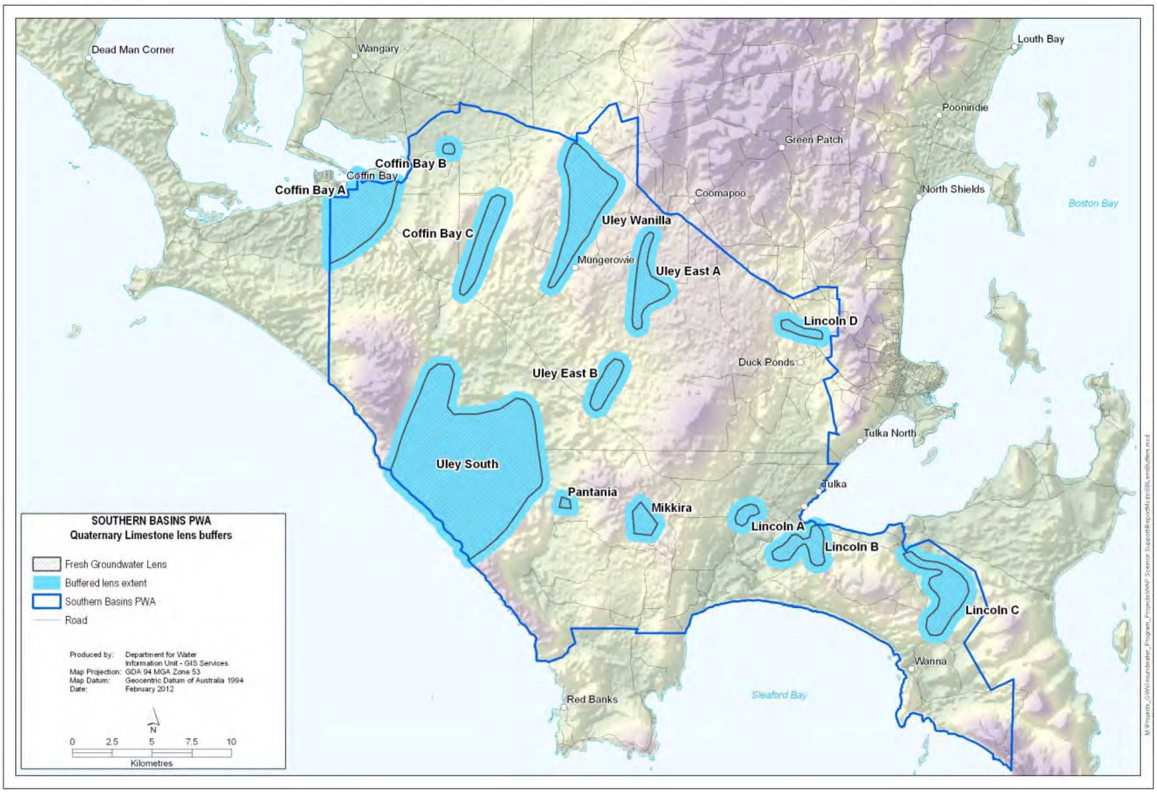

Figure 21.b. Buffer zones for management of the fresh groundwater lenses in the Southern Basins PWA

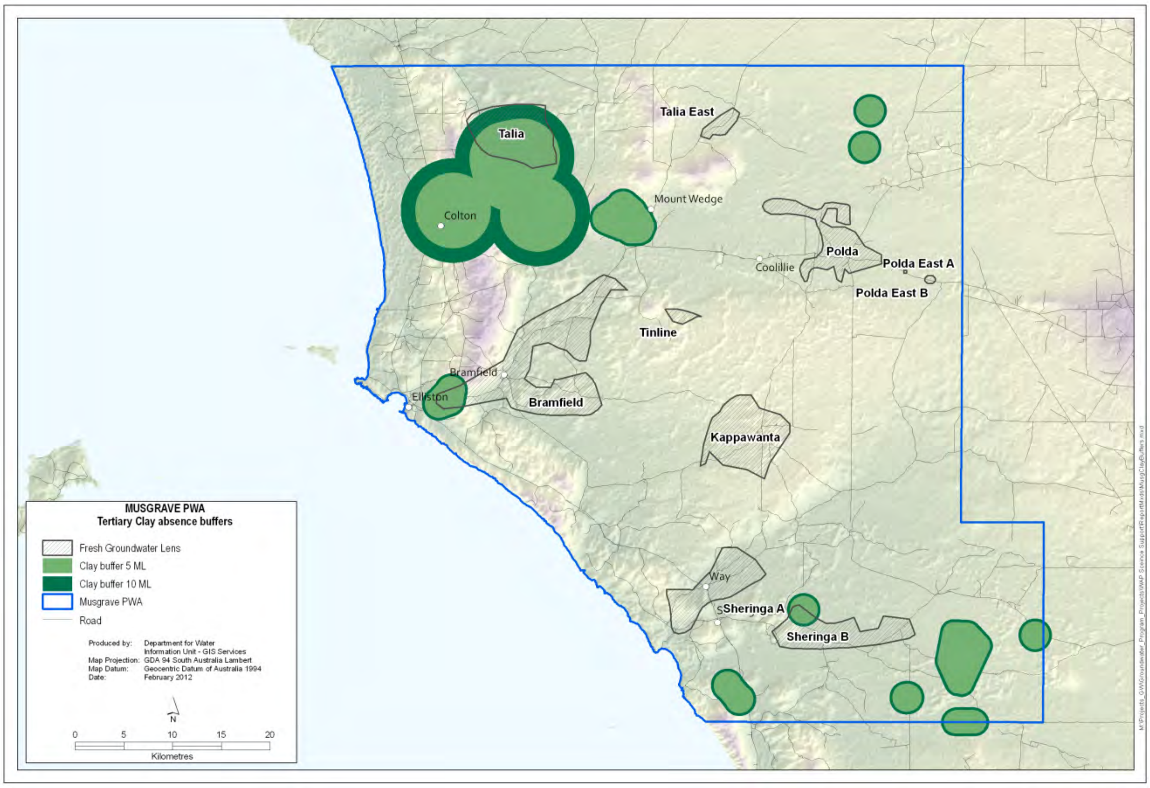

Figure 22.a. Buffer zones around likely clay absence for the Musgrave PWA

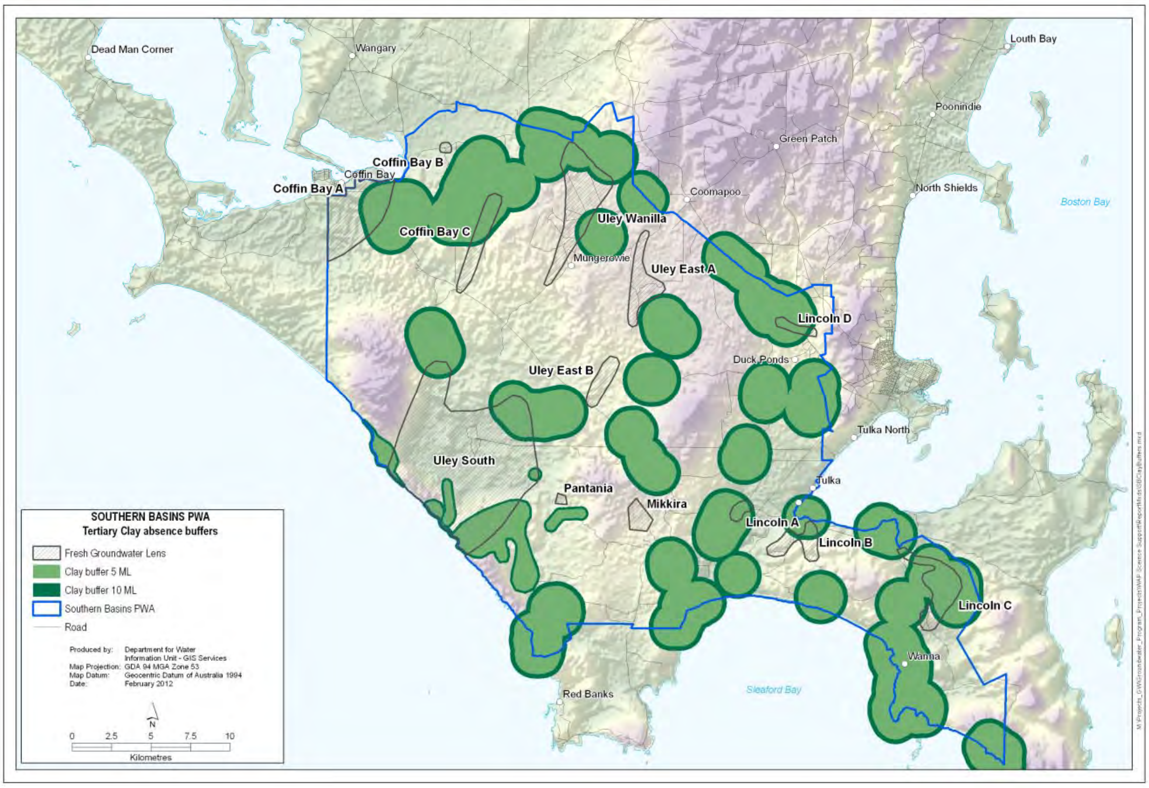

Figure 22.b. Buffer zones around likely clay absence for the Southern Basins PWA

40. The maximum recorded saturated extent of the Quaternary Limestone aquifer was determined by searching Obswell data for the highest watertable elevation on record for each observation well. A point shapefile was created for these points and a water level surface was interpolated using the IDW tool in ArcGIS® to create a Reduced Standing Water Level raster. The raster was overlayed over the Tertiary Clay aquitard raster and the Cut/Fill tool was used to identify a theoretical maximum possible saturated extent of the Quaternary Limestone aquifer (Fig. 23a and b). Whilst all the estimates of the capacity of the resources have been made based on the 2011 saturated extent and saturated thickness of the aquifers, management options may be applied to the theoretical maximum saturated extent.

41. To estimate the change in total aquifer storage consistently from one year to the next, water levels in specific wells (Fig. 24a and 24b; Appendix B) need to be monitored in April of each year. Data can be imported into ArcGIS® and a Reduced Standing Water Level raster can be created (Step 17). An estimate of the total aquifer storage volume can be calculated and compared with estimates of the previous year's storage. Changes in storage could be used to evaluate whether reductions or increases in allocations are appropriate.

42. A paucity of data in the Lincoln D and Saturated Lincoln North groundwater management zones limits the ability to estimate annual variations in total aquifer storage. If required, any annual changes in allocations in this area will need to be calculated via the watertable fluctuation method, unless the monitoring network is expanded in this area.

43. In groundwater management zones, where an aquifer's saturated thickness is of significance (<5 m) and the lens is used for licensed use, trigger levels may be implemented to monitor the aquifer thickness to alert water managers of when falling water levels are likely to become a risk to the resource. Water level declines due to climatic processes can not be managed by any form of groundwater management, however restrictions on take, when the saturation thickness is low, may be implemented. Within the central Polda lens area it would be advised to use well SQR002 (2011 thickness 4.1 m) and well SQR008 (2011 thickness 2.8 m) to monitor the saturation thickness (where possible) with the objective of maintaining water levels at least at the April 2011 level, noting the inability of the WAP to manage overriding climate impacts. These wells are located in the thicker portion of the lens and are best positioned to alert water resource managers of any change in aquifer saturated thickness. Whilst selecting trigger level wells in a thinner portion of the lens may alert changes in the saturation thickness earlier, it should be noted that these areas are likely to vary significantly seasonally and would therefore not provide water managers with an accurate response of the resource to the previous year's recharge and extraction on which to base sound decisions.

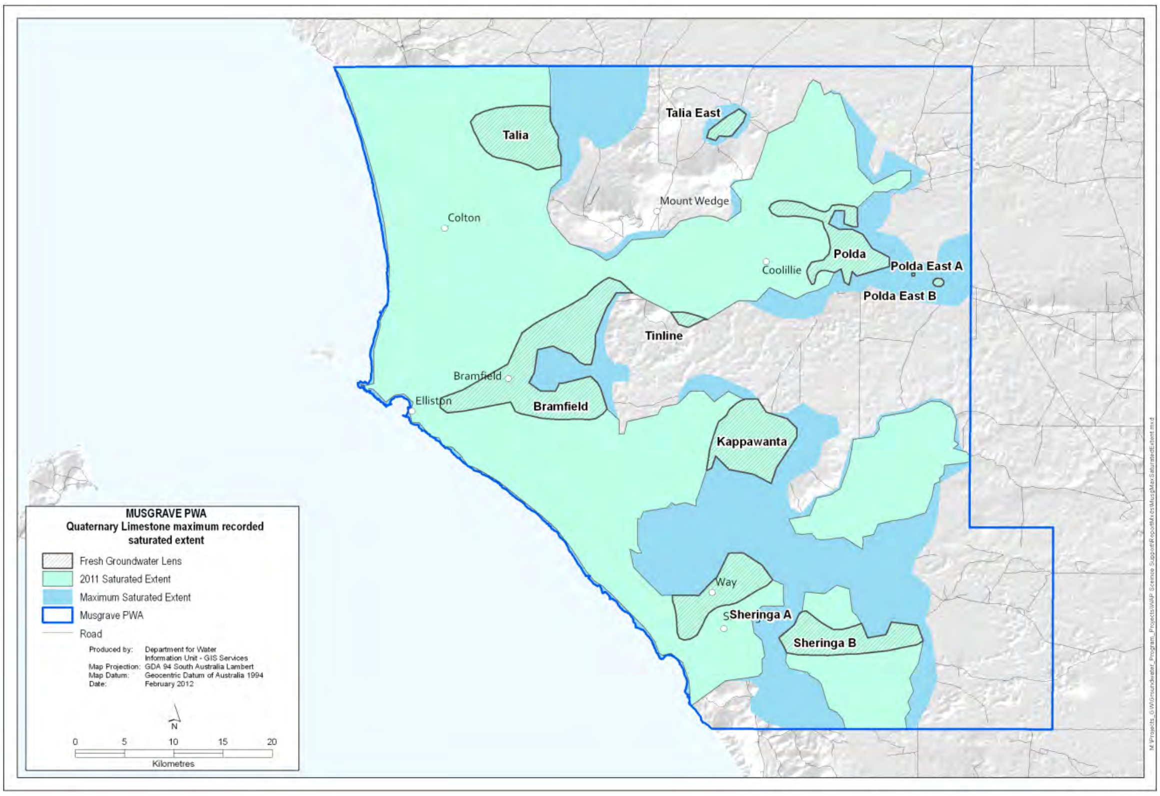

Figure 23.a. **Theoretical maximum 2011 saturated Quaternary Limestone extent for the Musgrave PWA**

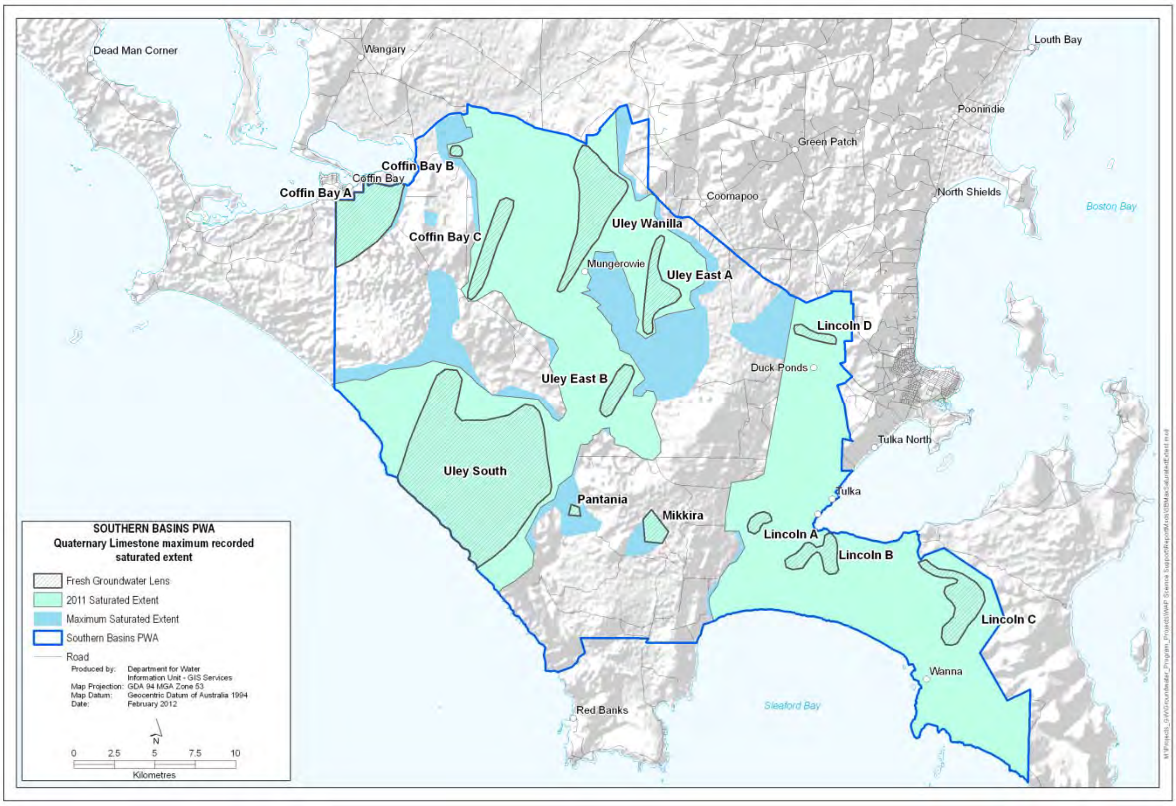

Figure 23.b. **Theoretical maximum 2011 saturated Quaternary Limestone extent for the Southern Basins PWA**

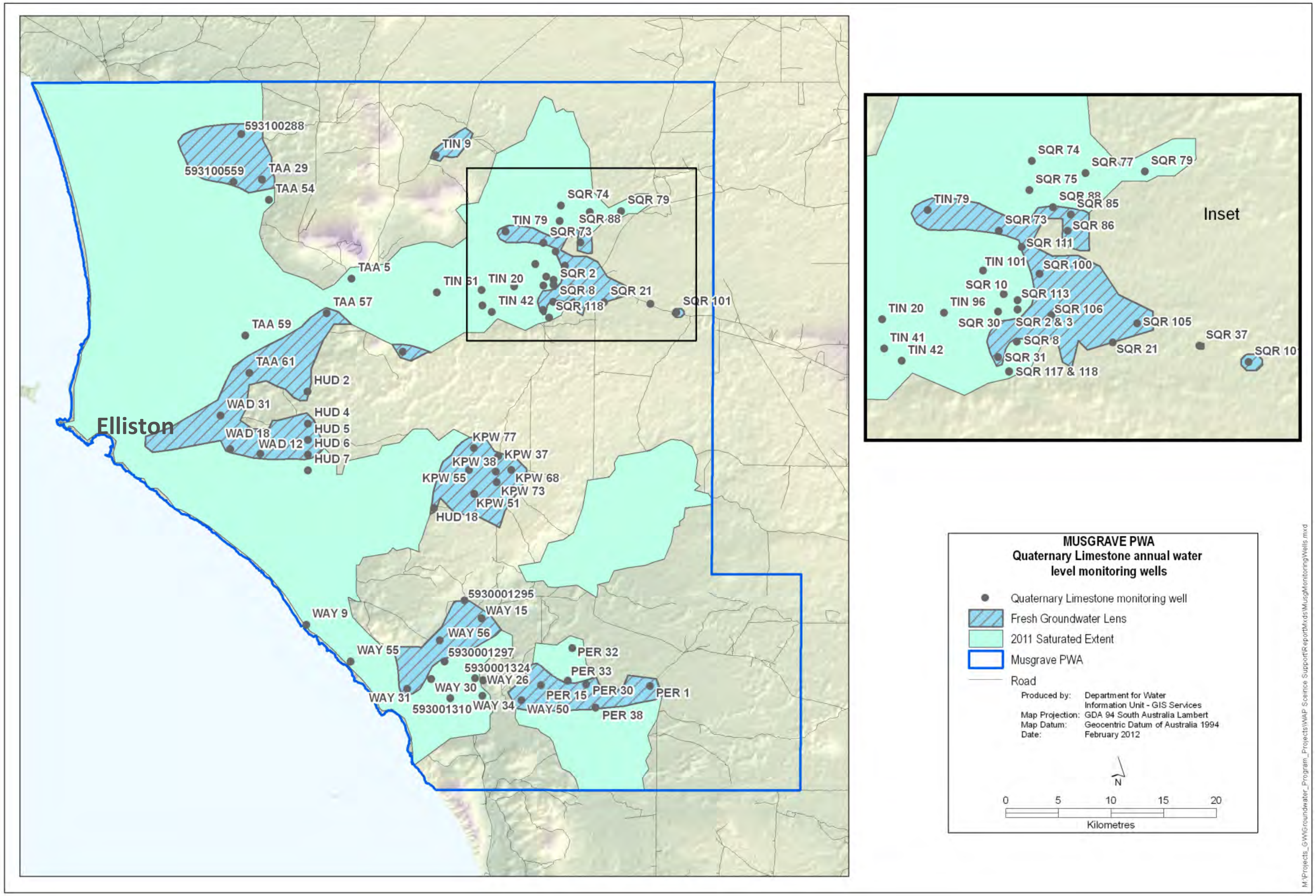

Figure 24.a. **Water level monitoring wells for the Musgrave PWA to be monitored annually in April**

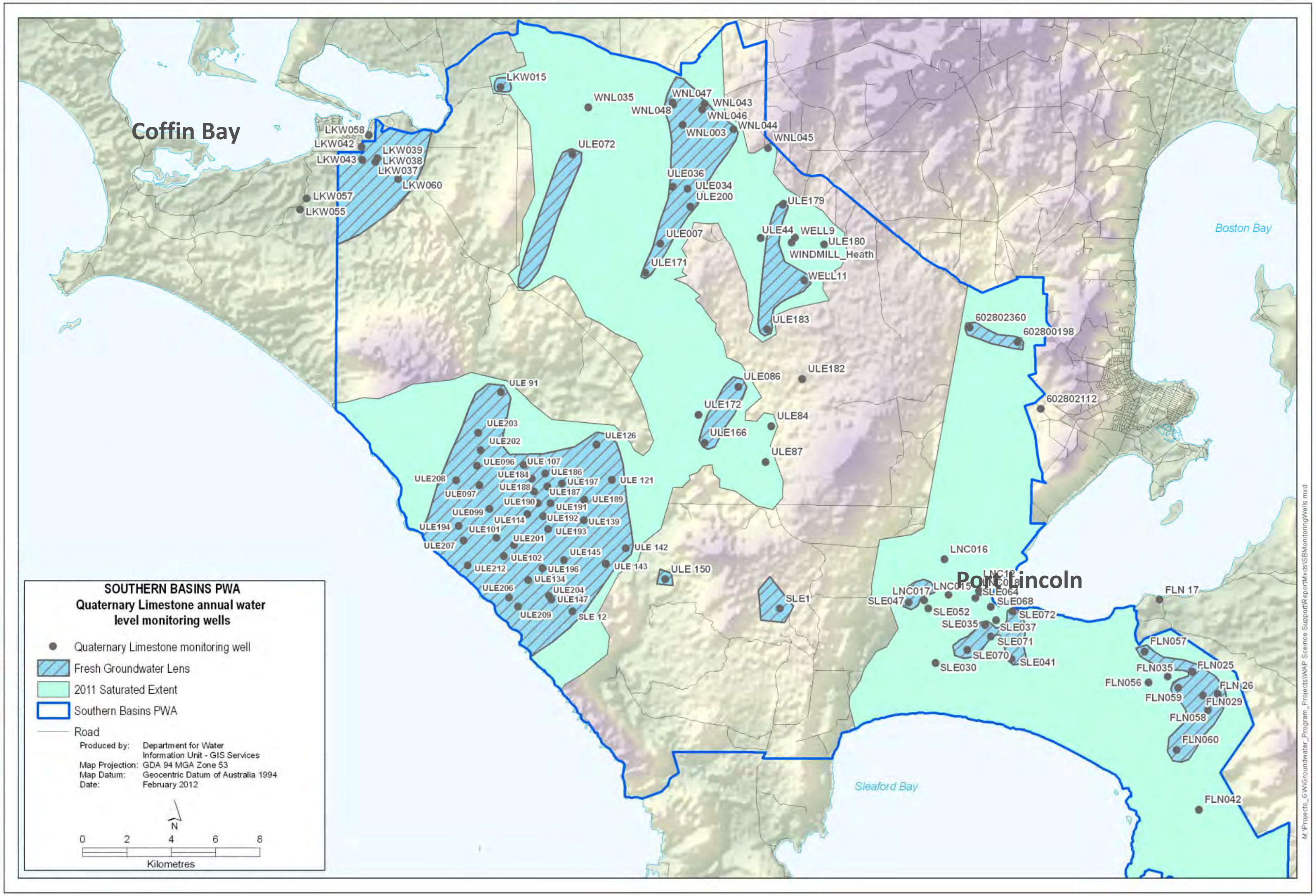

Figure 24.b. Water level monitoring wells for the Southern Basins PWA to be monitored annually in April

3.2. LIMITATIONS, UNCERTAINTIES AND ASSUMPTIONS

It is important to recognise that there is no such thing as a perfect model, and all models should be regarded as works in progress of continuous improvement as hydrogeological understanding and data availability improves. By definition, model limitations comprise relatively negative statements, and they should not necessarily be viewed as serious flaws that affect the fitness for purpose of the model, but rather as a guide to where improvements should be made during work (Middlemis 2000).

Models of natural systems necessarily include a number of assumptions and simplifications. These manifest as limitations of the model that potentially limit how and where the model might be used and also lead to a degree of uncertainty in the model's outputs. The following factors are considered to be the most significant in terms of model limitations and uncertainty.

3.2.1. INTERPOLATION TECHNIQUE

There are a number of approaches available by which a continuous surface can be interpolated from point data. Most interpolation techniques use a moving average formula of the form:

$$Z(X_j) = \frac{\sum_{i=1}^{n} w_i z(x_i)}{\sum_{i=1}^{n} w_i} \qquad \textbf{(Eq. 1)}$$

where $Z(X_j)$ is the cell value of a regular grid which spans the continuous surface to be interpolated, $z(x_i)$ is the value of each point x_i (i.e. the data from which the surface is interpolated) and w_i is the weighting given to each of the point data. The mathematically simplest technique is termed Inverse Distance Weighting (IDW) and it uses a w_i of 1/distance$_i$ to weight each point value.

In this study, IDW is the technique that has been used to interpolate the top of formation (i.e. aquifers) and the watertable in the Arc Hydro model. This is because the robustness and simplicity of the technique means that the same interpolations can be repeated by different spatial analysts and the interpolated surfaces will be identical, provided that the analysts are using identical point data. This consistency in results is not assured when interpolating using kriging because the analyst chooses a mathematical model to be used in a subjective manner. In addition, resource constraints were an important factor when considering various interpolation techniques.

Although some studies have shown that kriging offers little advantage over simplified methods such as IDW (e.g. Boman, Molz & Giiven 1995), evidence from published literature strongly suggests that stochastic interpolation methods are superior to those that are deterministic (e.g. Tabios & Salas 1985; Rouhani 1986; Zimmerman *et al.* 1999; Sun *et al.* 2009). Burrough & McDonnell (1998) report that using kriging and 'soft data' together (termed universal kriging) greatly improves the predictive power of GIS. This point is illustrated where unconfined aquifers flow under topographic gradients, in which case the water table is a subdued replica of the overlying ground surface. A digital elevation model can act as 'soft data', which provides the underlying trend of the water table and can supplement the point data from which the continuous surface is interpolated (e.g. Desberats 2002).

It is recommended that any future refinement of the Arc Hydro model should include an evaluation of the benefits that might be derived from using universal kriging when interpolating water table elevations. Similarly, future iterations of the Arc Hydro model may be improved if the top of formation layers are also interpolated using a stochastic approach.

3.2.2. GEOVOLUMES UNCERTAINTY

The GeoVolumes method is reliant upon a raster catalog (including the Tertiary Clay aquitard and water level rasters), as well as a Triangulated Irregular Network (TIN) (derived from the polygon of each lens's extent) as inputs. The output is a three-dimensional multipatch feature class. In ArcGIS® 10, a volume can be calculated for a multipatch using the 3-D Analyst tools. However, the multipatch does have to be closed and this can only happen if the length of the sides of the TIN is appropriate. The cell size of these rasters was originally determined based upon the ArcGIS® default values, which assigns a cell size based on the quantity and distribution of the points from which it is derived. It is not reliable to generate multipatch feature classes for areas smaller than the individual cell size of the input rasters. They do not reliably represent areal extent of the input raster, instead they result in a smaller areal extent and therefore a significantly smaller multipatch volume. The cell size of the rasters could be reduced but the accuracy of the multipatch feature data would not be improved.

In the smaller lenses, Pantania and Coffin Bay B in the Southern Basins PWA and Tinline and Polda East in the Musgrave PWA, the GeoVolumes tool was unable to calculate an accurate volume due to the raster cell size resulting in a high degree of uncertainty in the GeoVolume technique when used at such a fine scale. However, the confidence in both the Cut/Fill technique and Raster Calculator technique remains high and generally has a volume correlation of only 0.1% error between the two methods.

3.2.3. POROSITY/STORATIVITY VALUES

Specific yield of the Quaternary Limestone aquifer throughout the Musgrave and Southern Basins PWAs is highly variable, due to the karstic nature of the Quaternary Limestone geology. However, a principal assumption in the construction of the Arc Hydro groundwater model is that the aquifer is homogeneous. There have been few aquifer tests undertaken to determine the spatial distribution of the Specific Yield of the Quaternary Limestone aquifer. However, where data are available, values for the different lenses and areas of brackish saturated Quaternary Limestone have been summarised (Appendix A). These data acts to constrain estimates of the likely values of specific yield in a given area.

For the purpose of this Arc Hydro Groundwater model, the 'equivalent porous medium' approach (Cook 2003) is considered to be adequate to estimate specific yield. Within this approach, individual karstic features are not treated explicitly in the model. The true spatial distribution of specific yield is assumed to be equivalent to a continuous porous medium having equivalent hydraulic properties (Cook 2003).This is a reliable modelling approach if the representative elementary volume – the smallest volume over which a measurement can be made that will yield a value representative of the whole – is defined. It has been assumed that each modelled Groundwater Management Zone is homogeneous and isotropic and hence each Groundwater Management Zone has a constant specific yield at any point within that zone (Table 4).

Scanlon *et al.* (2003) found that the equivalent porous media technique could be used to adequately simulate regional groundwater flow in a highly karstified aquifer, which suggests that this is a reasonable approach for Eyre Peninsula's Quaternary Limestone aquifer.

3.2.4. RECHARGE ESTIMATES

Due to the limitations and uncertainties inherent in any single recharge rate estimation technique, the Average Annual Recharge in the existing WAPs has been determined by comparing the results of hydrological investigations into the rainfall/recharge relationship, the rainfall and groundwater chloride balance, environmental isotope analysis and the response of groundwater levels to varying groundwater extraction schemes. The use of multiple recharge estimation methodologies acts to constrain the estimates of recharge and reduce the level of uncertainty.

3.2.5. WATER REQUIREMENTS FOR AQUIFER MAINTENANCE

In calculations of the capacities of the consumptive pools (within this report) it has been assumed that within the fresh and brackish saturated Quaternary Limestone for both PWAs, 50% of the capacity of the resource is required to be set aside for aquifer maintenance. Aquifer maintenance includes maintaining natural flow through the aquifer and discharge processes. This differs from the current WAPs that set aside 60% of the 10-year rolling average recharge for groundwater dependent ecosystems such as springs (ERWRPC 2000; ERWRPC 2001). The resulting volumes of water available for allocation are not dissimilar to previous estimates, despite the slightly different approach taken and the revised lens area boundaries.

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4. WATER DEMAND

A key commitment in *Water for Good* is the development of Regional Demand and Supply Statements to ensure that long-term water security solutions for each of the State's eight NRM regions are based on a thorough understanding of the state of all local water resources, the demand for these resources and likely future pressures. The Eyre Peninsula Demand and Supply Statement (DFW 2011a) was the first in the State to be released. Consideration of Eyre Peninsula's demand for water at the regional scale is important because SA Water provides town water supply across the majority of Eyre Peninsula (Fig. 26), as far as the west-coast township of Ceduna.

The Eyre Peninsula Demand and Supply Statement (DFW 2011a) details demand and supply projections for high and low population growth scenarios and for scenarios of high and low greenhouse gas emissions. Projections for all four combinations of scenarios address the demand and supply for (1) drinking quality water only; and (2) for all water sources and human demands. Demand for water (both potable and non-potable) is currently attributable to stock use, residential use and non-residential purposes (e.g. industrial, commercial and institutional) (Fig. 25). The irrigation and mining sectors are currently only minor consumers of water.

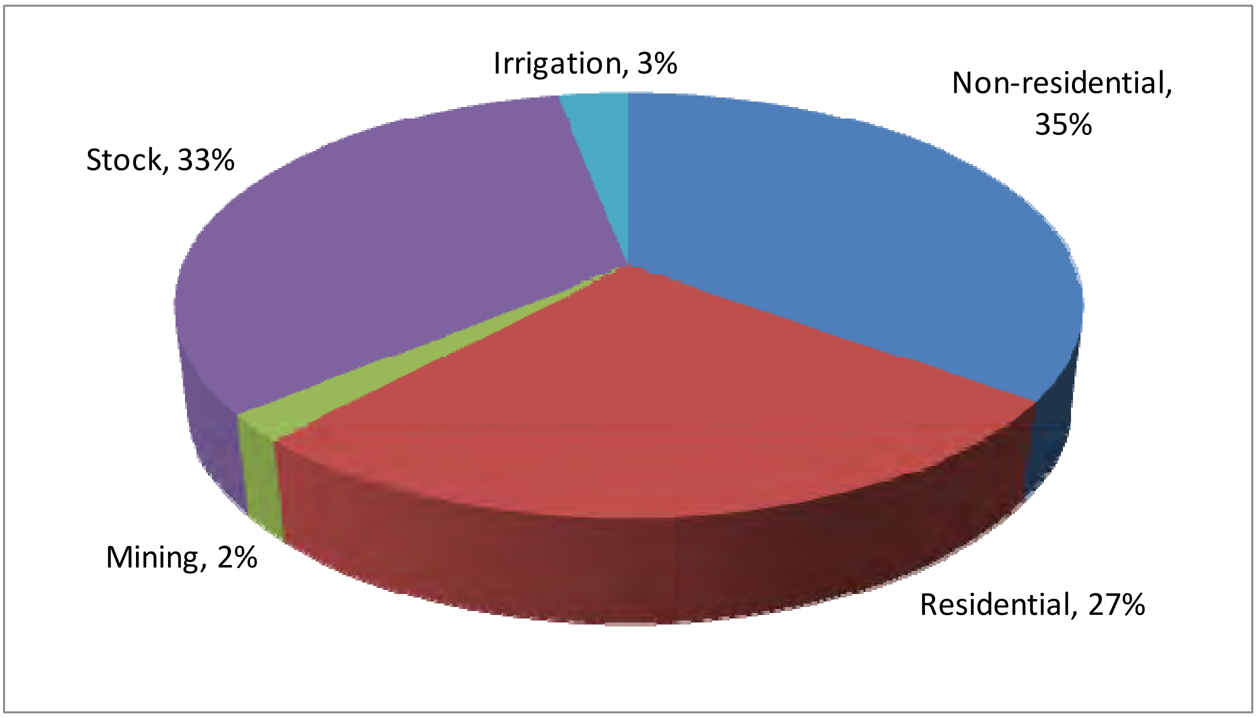

Figure 25. Eyre Peninsula's current water use sectors from drinking and non-drinking quality supplies (DFW 2011a)

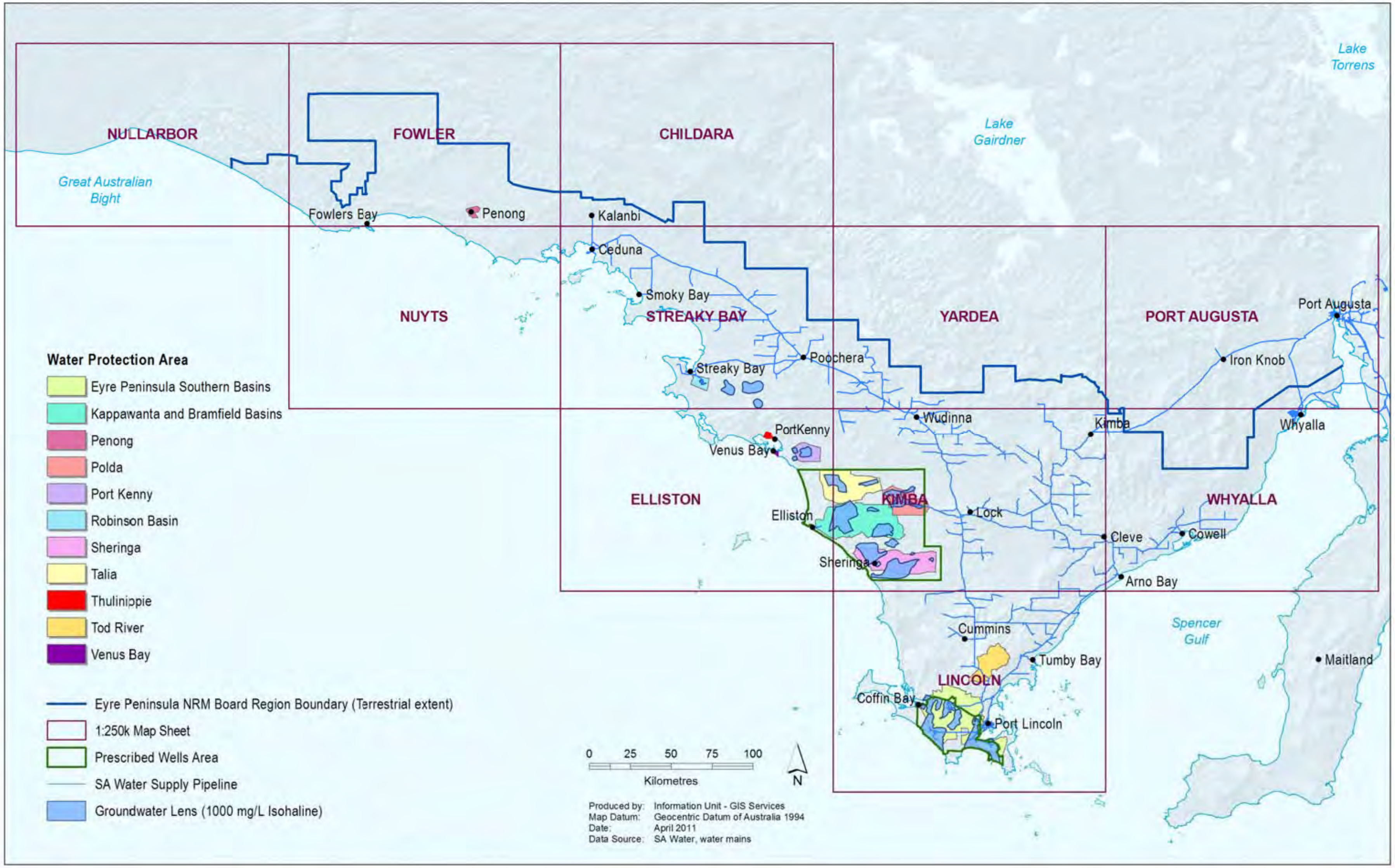

Figure 26. **Eyre Peninsula's reticulated water supply infrastructure**

Volumetric estimates of potable water demand and supply have been projected to 2050 using the SimulAlt Demand-Supply Water Simulation Model (DFW 2011a). Demand comprises residential, non-residential, visitors, stock, demand management and unaccounted water. Supply sources comprise River Murray water, groundwater from the Musgrave and Southern Basins PWAs and roof runoff. Model assumptions include (1) up to 0.4% p.a. decrease in groundwater supply from the Musgrave and Southern Basins PWAs (from a baseline supply of around 10 000 ML/y); and (2) a ceiling of 9800 ML/y[1] supply from the River Murray. Model results suggest that under the high population growth scenario, demand is expected to exceed supply around 2023–24, while demand is projected to exceed supply around 2025–26 under the low population growth scenario (DFW 2012).

4.1. NON-LICENSED DEMAND – STOCK AND DOMESTIC

As part of the WAP process, the *Act* requires that demand for stock and domestic water must be estimated for each consumptive pool. While stock and domestic water use is not licensed in the PWAs, it is important to account for stock and domestic water use because both licensed and non-licensed demands are met from the consumptive pools. The methods used to estimate stock and domestic water demand in the Musgrave and Southern Basins PWAs are presented below.

Data acquired from the Department for Primary Industries and Regions South Australia's (PIRSA's) Primary Industries Information Management System (PIIMS) assigns stock numbers to land parcels and can therefore be used to identify which areas carry more or less stock (Figs. 27 and 28). This can in turn be used to estimate water use from each consumptive pool. For example, stock assigned to land parcels that intersect a freshwater lens are assumed to access that lens for their water requirements. If stock are assigned to a land parcel that does not intersect a freshwater lens, water requirements are assumed to be met from the brackish Quaternary Limestone, Tertiary or fractured rock (basement) aquifers. In a similar way, domestic water use can be assigned to each individual lens or aquifer using GIS software. SA Water advise that the mains supply is used for stock water in some areas (SA Water 2008), however this is accounted for in volumes extracted for licensed water use.

4.1.1. METHOD FOR ESTIMATING STOCK WATER USE

A summary of the method by which stock water use has been estimated appears in Box 1 below. To estimate stock water use, the number of stock held on any given parcel of land are normalised to a standard unit—the Dry Sheep Equivalent (DSE) (Table 10). The DSE is a standard unit used to estimate feed requirements of different classes of stock or to assess the carrying capacity and potential productivity of a given area of land (McLaren 1997). Normalising absolute stock numbers to DSEs enables water demand estimates to be calculated based on estimated water consumption per unit DSE (Luke 2003).

[1] The majority of Eyre Peninsula's take on River Murray water is supplied to Whyalla. This supply is considered adequate for the projected future growth in Whyalla (SA Water 2008)

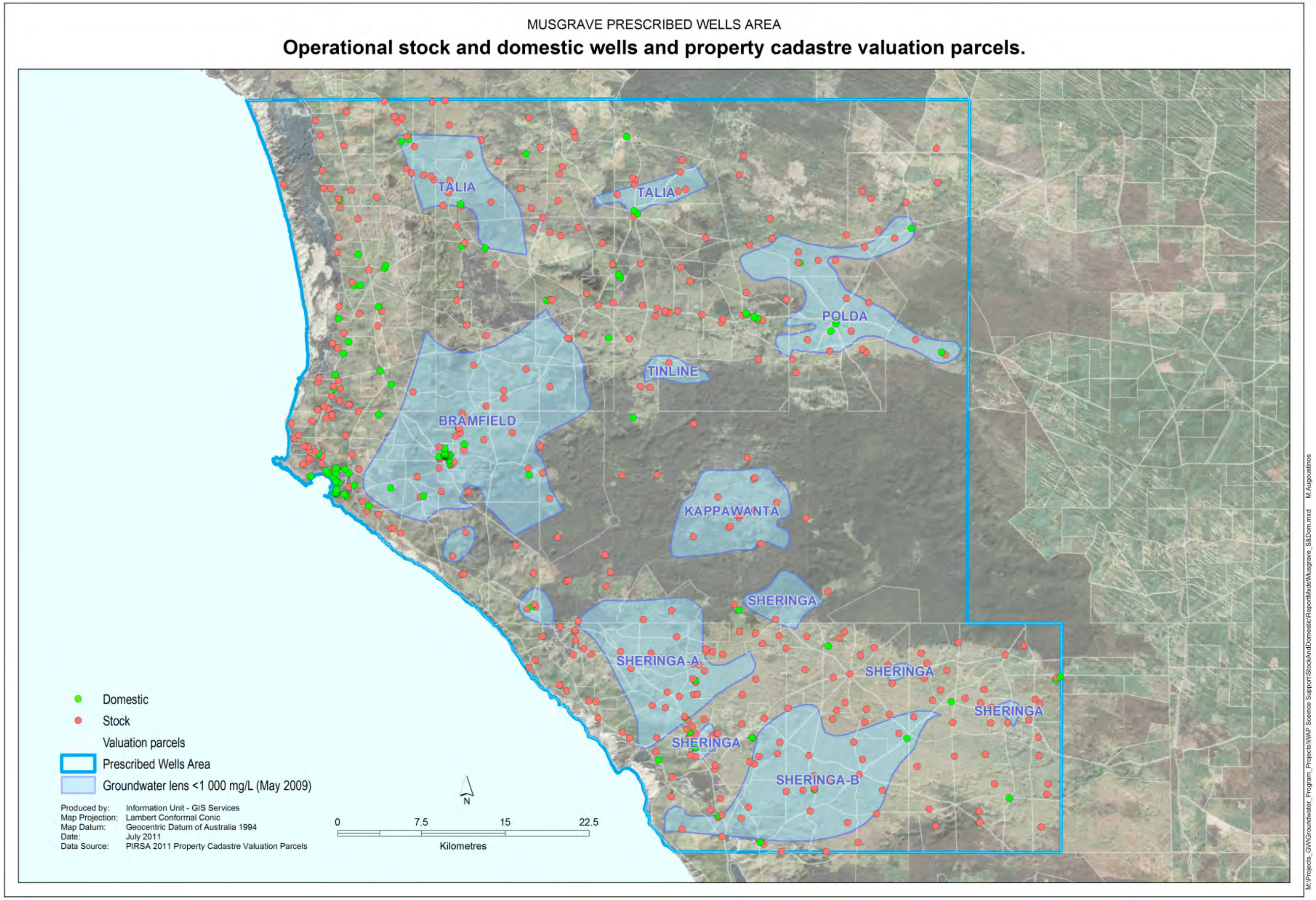

Figure 27. **Spatial analysis of the Musgrave PWA showing PIIMS valuation parcels, stock and domestic well locations and fresh groundwater lenses (<1000 mg/L)**

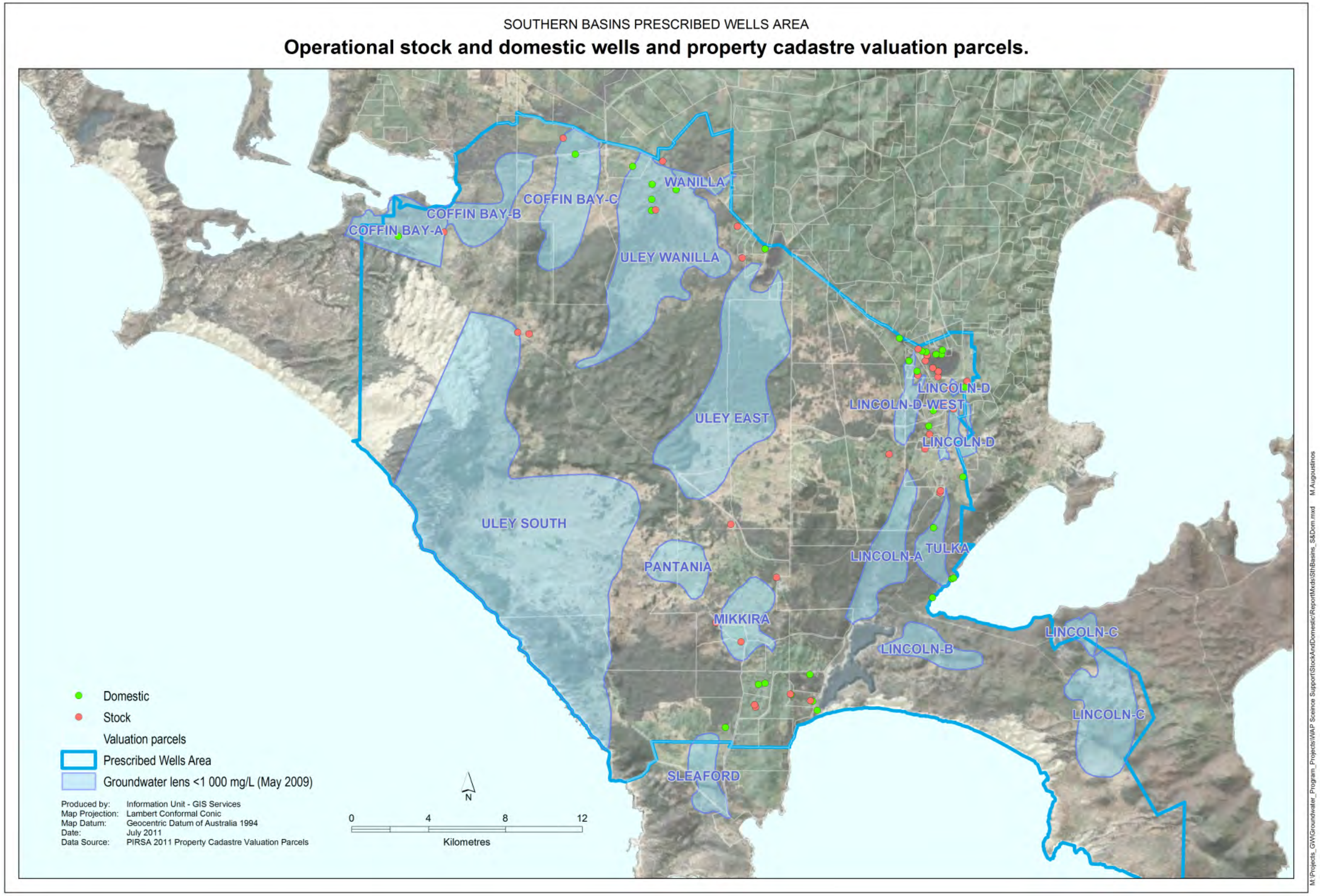

Figure 28. Spatial analysis of the Southern Basins PWA showing PIIMS valuation parcels, stock and domestic well locations and fresh groundwater lenses (<1000 mg/L)

A number of estimates of Eyre Peninsula's stock numbers have been made. The existing WAP estimates average stock capacity as 1 and 2 DSE/ha for the Musgrave (3595 km^2) and Southern Basins (870 km^2) PWAs, respectively. Assuming all land can be effectively grazed, this stock capacity can be converted to stock numbers in DSEs (Table 12). Stock numbers have also been estimated from local, anecdotal evidence (P Das [EPNRMB] 2011, pers. comm.) and using the PIIMS methodology outlined below.

Table 10. Dry Sheep Equivalents (DSEs) for different classes of stock

Stock type	Conversion factor (DSE per head of stock)	Reference
Cattle, buffalo	13	Dry sheep equivalents for comparing different classes of livestock (McLaren 1997) Mary Chirgwin [PIRSA Biosecurity] 2010, pers. comm., September)
Sheep	1.4	Mary Chirgwin [PIRSA Biosecurity] 2010, pers. comm., September)
Deer, goats alpaca	1	Grazing livestock – a sustainable and productive approach (AMLRNRMB 2010)
Pigs, horses	10	Luke (2003)

Estimates of water consumption per unit DSE are variable and range between 3 and 28.5 L/DSE/d (Table 11). These estimates depend on a number of factors, including but not limited to climate, season, salinity of the water, quantity and quality of feed, physiological state of the animal and type of stock. The estimated water use of sheep located on Eyre Peninsula, as cited in the Eyre Peninsula Demand and Supply Statement, is 10 L/sheep/d (or 7.14 L/DSE/d) (DFW 2011a). This estimate of water use is based on advice from PIRSA and includes an allowance for on-farm losses.

Table 11. Comparison of estimated stock water use per Dry Sheep Equivalent

Region	Stock water use (L/DSE/d)	References
Eyre Peninsula	3 7.14	Water Allocation Plan Southern Basins PWA (ERWRPC 2000) Water Allocation Plan Musgrave PWA (ERWRPC 2001) Eyre Peninsula supply and demand statement (DFW 2011a)
Eastern Mount Lofty Ranges	6.85	Estimates of stock and domestic water demand for the Eastern Mount Lofty Ranges (SAMDBNRMB 2008)
South-west Western Australia	7.85-28.50	Consumption of water by livestock (Luke 2003)

Table 12. Estimates of stock numbers reported in Dry Sheep Equivalents

Prescribed Wells Area	Current Water Allocation Plan	Anecdotal local advice	PIIMS analysis
Musgrave	360 000	153 400	166 030
Southern Basins	174 000	10 000	44 179

BOX 1. METHODOLOGY FOR ESTIMATING STOCK WATER USE FROM PIIMS DATA

Stock water use for EP's PWAs has been estimated in the following way:

- For Musgrave and Southern Basins PWAs, extract Primary Industries Information System (PIIMS) data for each National Property Identification Code (PIC), including stock class and number of stock
  - The valuation parcel polygon(s) geometry is based on valuation parcels extracted from the 'property cadastre' layer of the SA Geodata
  - Multiple valuation parcels may exist for any given PIC
- Filter out redundant data (e.g. double accounting of stock due to multiple entries in the PIIMS data 'production system' field) to give total number of each type of stock ($STOCK_{Total}$)
- Using Geographic Information System (ArcGIS®) software and PIIMS spatial data, calculate the area of each PIC's valuation parcel that intersect fresh groundwater lenses (<1000 mg/L) within each of the PWAs
- For each PIC, calculate the Proportion of Valuation Parcel Area (PVPA):
  - $PVPA = VPA_{FreshGW}/VPA_{Total,}$ where
    VPA_{Total} = Total valuation parcel area for a given PIC
    $VPA_{FreshGW}$ = Valuation parcel area that intersects a fresh groundwater lens
- For each PIC, estimate the number of stock sourcing water from fresh groundwater lenses using PVPA:
  - $STOCK_{FreshGW} = STOCK_{Total} \times PVPA$, where
    $STOCK_{Total}$ = The total number of a stock type for a given PIC
    $STOCK_{FreshGW}$ = The estimated number of stock sourcing water from a fresh groundwater lens
- For each PIC, and for each class of stock, calculate the total $DSE_{FreshGW}$ using the conversion factors in Table 1:
  - $DSE_{FreshGW} = STOCK_{FreshGW} \times$ Conversion factor
- For each fresh groundwater lens, estimate total stock water use ($TSWU_{FreshGW}$) using $DSE_{FreshGW}$ and estimated water use per unit DSE:
  - $TSWU_{FreshGW} = DSE_{FreshGW} \times$ water use per unit DSE (ML/y)
- Estimates for TSWU are repeated for groundwater residing within (1) brackish Quaternary Limestone and (2) Tertiary Sands and fractured rock (basement) aquifers.

4.1.2. METHOD FOR ESTIMATING DOMESTIC WATER USE

One possible method for estimating domestic water allowance is by multiplying the number of domestic wells by the average water consumption per household. The SA Geodatabase maintains a record of the intended purpose of all wells via the Department for Water's permitting system. Wells that have been ascribed the purpose 'domestic use' have been used in this assessment. An analysis of these data shows that the number of 'domestic use' wells in Eyre Peninsula's PWAs is 121 wells for Musgrave and 75 wells for Southern Basins.

The current WAPs estimate domestic consumption to be 500 kL per household per year. The State's water plan *Water for Good* reports that average household mains water consumption in the greater Adelaide region, prior to water restrictions, was 280 kL/y.

On Eyre Peninsula, particularly in rural areas, anecdotal evidence suggests that most households use rainwater tanks for drinking water and some household tasks. Houses in urban areas also have access to mains water. For these reasons, it has been assumed that groundwater represents half of the domestic household water budget. To calculate estimates of domestic groundwater consumption, a conservative rate of 280 kL/y has been used.

4.1.3. ESTIMATES OF STOCK AND DOMESTIC WATER USE

Estimates of stock and domestic water use for each groundwater lens or aquifer are detailed in Tables 13 and 14. The estimated annual recharge rate for each groundwater lens is also shown. These long-term recharge rates are based on the current WAPs (ERWRPC 2000; ERWRPC 2001) and are provided as an indication of the size of the consumptive pool.

The results show that stock and domestic demand for water within the PWAs is a small proportion of the estimated long-term average annual recharge rates. Stock and domestic demand varies between 0 and 2.3% of recharge in the Musgrave PWA (Table 13) and between 0 and 2.8% of recharge in the Southern Basins PWA (Table 14).

A comparison of current and historical estimates of stock and domestic water requirements shows that:

- the number of stock (reported in DSEs) estimated by the PIIMS methodology is markedly lower than the estimates calculated from the current WAPs (Table 12), but
    - the number of stock estimated by the PIIMS methodology is in closer agreement with anecdotal evidence (i.e. local knowledge from long-term land holders) than the stock numbers estimates calculated from the current WAPs
- the rate of stock water use used in the PIIMS analysis (estimated in the Eyre Peninsula Supply and Demand Statement to be 7.14 L/DSE/d) (DFW 2011a) is markedly higher than the estimated rate calculated from the current WAPs (3 L/DSE/d) (ERWRPC 2000; ERWRPC 2001)
- the total stock water use (from all groundwater sources) estimated in the current WAP is of a similar order of magnitude to stock water use estimated by the PIIMS analysis (Tables 15 and 16).

Table 13. PIIMS analysis results showing estimates of stock and domestic water use (ML/y) in the Musgrave PWA. The rate of stock water use is estimated to be 7.14 L/DSE/d (DFW 2011a)

Aquifer or groundwater lens	Recharge# (ML/y)	Stock use (ML/y)	Domestic use (ML/y)	Stock and domestic	
				TOTAL (ML/y)	Proportion of recharge (%)
Bramfield	4 500	42	8	50	1.1
Polda	1 350	7	2	9	0.7
Sheringa A	1 230	27	1	28	2.3
Sheringa B	1 730	9	1	10	0.6
Sheringa	-	6	0	6	-
Talia	1 520	12	1	13	0.9
Tinline	400	1	0	1	0.3
Kappawanta	1 980	0	0	0	0
Brackish limestone	-	212	16	228	-
Tertiary Sands/FRA (basement)	-	118	4	122	-
TOTAL	**-**	**434**	**33**	**467**	-

Long-term recharge rates as reported in the current Musgrave WAP (ERWRPC 2001)

Table 14. PIIMS analysis results showing estimates of stock and domestic water use (ML/y) in the Southern Basins PWA. The rate of stock water use is estimated to be 7.14 L/DSE/d (DFW 2011a)

Aquifer or groundwater lens	Recharge## (ML/y)	Stock use (ML/y)	Domestic use (ML/y)	Stock and domestic	
				TOTAL (ML/y)	Proportion of recharge (%)
Uley South	20 000	5	0	5	0.0
Coffin Bay A, B & C	610	6	11	17	2.8
Lincoln A	-	1	0	1	-
Lincoln B & C	-	0	0	0	-
Lincoln D & Lincoln D West	1 250	2	1	3	0.2
Wanilla & Uley Wanilla	2 020	1	1	2	0.1
Uley East	1 310	3	0	3	0.2
Pantania	-	2	0	2	-
Mikkira	-	3	0	3	-
Brackish limestone	-	16	0	16	-
Tertiary Sands/FRA (basement)	-	76	5	81	-
TOTAL	**-**	**115**	**18**	**133**	**-**

Long-term recharge rates as reported in the current Southern Basins WAP (ERWRPC 2000)

Table 15. Stock water use for all groundwater (GW) resources as estimated in the current Eyre Peninsula WAPs

	Musgrave PWA All GW	Southern Basins PWA All GW
Number of stock (DSEs)	360 000	174 000
Rate of water use (ML/DSE/d)	3×10^{-6}	3×10^{-6}
Total (ML/y)	**394**	**191**

Table 16. Eyre Peninsula PWA stock water use estimated by the PIIMS analysis categorised by: (1) all groundwater (GW) and (2) fresh groundwater lenses (<1000 mg/L) only

	Musgrave PWA		Southern Basins PWA	
	All GW	<1000 mg/L	All GW	<1000 mg/L
Number of stock (DSEs)	166 030	39 453	44 179	8 918
Rate of water use (ML/DSE/d)	7.14×10^{-6}	7.14×10^{-6}	7.14×10^{-6}	7.14×10^{-6}
Total (ML/y)	**433**	**103**	**115**	**23**

4.2. LICENSED WATER DEMAND ESTIMATES

Of the available allocation in 2010–11 from Eyre Peninsula's prescribed wells areas, South Australia's public water utility, SA Water, has a licence for 92% of the total water available in the Musgrave PWA and 97% of the total water available in the Southern Basins PWA (Table 17). SA Water's licences are for the purpose of public water supply.

Licensed groundwater extractions for the Musgrave and Southern Basins PWAs have been reported in *Groundwater Status Reports* prepared for each of these areas (available online: http://www.waterconnect.sa.gov.au/GSR). The *Groundwater Status Reports* detail historic licensed groundwater use and extraction limits (as prescribed by the current WAP) on an annual basis for the past 10 years. Licensed use is also reported on a per-basin basis. Extractions for 2009–10 are shown in Table 18. The majority of extractions are from the Uley South Basin which accounts for around 90% of the total extractions from the Southern Basins PWA. Annual groundwater extractions solely for the purpose of public water supply for the past 10 years are shown in Table 19.

Table 17. Eyre Peninsula's public water supply demands

	Extraction limit (2010–11) (ML)	SA Water allocation (ML) (% of limit)	SA Water actual usage (2010–11) (ML)
Musgrave PWA[#]	1786	1649 (92.3)	86
Southern Basins PWA	8136	7924 (97.4)	5583
TOTAL	**9922**	**9573**	**5678**

[#] Due to the continued low effective recharge, increasing groundwater salinity and the characteristics of the extraction infrastructure, groundwater extractions by SA Water (the main user of groundwater in the basin) from the Polda lens ceased in June 2008 and is currently restricted by a Notice of Prohibition. This notice also significantly restricts extractions by other license holders (DFW 2011b).

Table 18. Licensed groundwater use and extraction limit (as prescribed by the current WAP) per basin for the Musgrave and Southern Basins PWAs for 2009–10

PWA	Basins	Licensed use (ML/y)		TOTAL USE	Extraction limit
		Irrigation	Public supply	(ML/y)	(ML/y)
Musgrave PWA					
	Polda	1	0	**1**	506
	Bramfield	11	70	**81**	817
	Kappawanta	N/A	0	**0**	384
	Sheringa A	0	N/A	**0**	26
	Minor Quaternary	0	N/A	**0**	53
TOTAL		***12***	***70***	***82***	***1786***
Southern Basins PWA					
	Coffin Bay A	25	91	**116**	141
	Coffin Bay C	0	N/A	**0**	30
	Lincoln A, B & C	N/A	581	**581**	732
	Lincoln D	1	N/A	**1**	20
	Lincoln D West	0.1	N/A	**0.1**	98
	Uley East	0	0	**0**	0
	Uley South	N/A	5789	**5789**	6887
	Uley Wanilla	2	131	**133**	155
	Minor Quaternary	N/A	N/A		
	Tertiary	0.2	N/A	**0.2**	18
	Basement*	12	N/A	**12**	81
TOTAL		***40.3***	***6592***	***6632.3***	***8162***

Irrigation in the Southern Basins PWA is limited to mainly golf courses and not ascribed to individual basins

*Data have been estimated where source data are not able to be defined

4.3. FUTURE DEMAND FOR WATER

The *Act* requires that future demands on groundwater resources are considered in the development of a WAP. Ultimately, future demand will be driven by a range of factors that include but are not limited to, land carrying capacity, commodity prices and local climatic conditions. Contingencies can be incorporated into the estimates of the volume of water used for stock and domestic purposes to accommodate uncertainties in future demand for EP's prescribed groundwater resources.

Peri-urban development is increasing within some of the PWAs and it is understood that reticulated public water supply is not available to these newly developed areas (J. Clark [EPNRMB] 2011, pers. comm.). Consequently it is likely that demand for groundwater for domestic purposes will increase.

Table 19. SA Water licensed groundwater extractions (ML/y) for the purpose of public water supply

PWA	Basins	2001–02	2002–03	2003–04	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11
Musgrave PWA											
	Polda	127	200	153	266	239	212	137	117	0	0
	Bramfield	69	67	74	75	78	72	66	70	70	86
TOTAL		**269**	**220**	**340**	**314**	**289**	**210**	**183**	**70**	**70**	**86**
Southern Basins PWA											
	Uley South	7413	7570	7575	7567	6559	7297	6408	6440	5789	4940
	Lincoln	1011	909	928	928	900	922	877	509	581	441
	Uley Wanilla	251	266	231	262	215	230	227	176	131	119
	Coffin Bay	130	112	113	109	99	96	104	103	91	83
TOTAL (ML/y)		**8805**	**8857**	**8847**	**8866**	**7772**	**8545**	**7616**	**7228**	**6591**	**5583**

PIRSA has reported that future water requirements for increasing stock numbers are extremely difficult to predict. PIRSA forecast an increase in demand for water in rural areas of 1.5% per annum for the period 2008–18 (SA Water 2008). It should be noted that this predicted increase in demand for water is not limited to stock water use but all sectors that comprise rural demand.

A map of land carrying capacity (i.e. grazing potential) has been produced using ArcGIS® software (Fig. 29). The aim was to identify three grazing potential classes (GPC) based on a number of soil/landscape attributes (see below), which have been used to estimate the carrying capacity for each of several rainfall zones covering the Eyre Peninsula. High potential implies that land has high productive potential and requires no more than standard management practices to sustain productivity or the land has moderately high productive potential and/or requires specific, but widely used and accepted management practices to sustain productivity. Moderate potential implies that land has moderate productive potential and/or requires specialised management practices to sustain productivity. The method by which the three GPCs were determined is detailed in Appendix C.

The three grazing potential classes are:

- GPC 1 – No reduction of carrying capacity
- GPC 2 – 25% reduction of carrying capacity
- GPC 3 – 50% reduction of carrying capacity.

The criteria for producing the map are:

- Rockiness or moisture holding capacity (whichever is more limiting)
- Water erosion potential
- Slope (estimated)
- Soil salinity.

Most of the Musgrave and Southern Basins PWAs have low grazing potential (Fig. 29). The results of this analysis suggest that it is unlikely that stock numbers will increase markedly in the near future. This conclusion is in agreement with anecdotal local advice. Long-term landholders have observed that stock numbers in both the Musgrave and Southern Basins PWAs have been largely static and they believe a significant increase is stock numbers in the future is highly unlikely (J. Clark [EPNRMB] 2011, pers. comm.). Discussions about potential changes in stock numbers across the region during a council community engagement meeting held in June–July 2007 highlighted that community opinions on whether stock numbers were likely to increase or decrease were varied (SA Water 2008). It should be noted that diversifying farm income has been identified as an adaptation measure to address future climate variability – e.g. adaptation options for cropping systems may include integration with other farming activities such as intensive livestock raising (Crimp *et al*. 2008).

4.4. MINING

There is considerable evidence that there will be significant growth in the South Australian mining industry over the next forty years (e.g. Government of South Australia 2007; RESIC 2010). As mentioned in Section 4, demand for water from the mining sector in Eyre Peninsula is expected to increase in the future (Berens, Alcoe & Watt 2011; DFW 2011a). Mining operations require significant volumes of water, which can typically be of a lower quality than is required for stock or irrigation (e.g. mineral processing or dust suppression). It is important that associated water resource demands are considered, planned for and managed, while balancing this against environmental and social requirements. Potential impacts from mining can include issues associated with aquifer dewatering and aquifer interference.

The State's water plan, *Water for Good* covers issues related to mining and water resources. In particular, Action 48 outlines that mining ventures must provide their own water supplies within the sustainable framework of natural resources management planning and regional demand and supply plans for water. Within PWAs, the take of water for mining is subject to the same licensing requirements as any other water use.

DMITRE is the principal State Government regulatory agency for mining related activities, irrespective of whether mining activity takes place within or outside of a PWA. The *Mining Act 1971* requires that (1) the mining proponent must obtain a mining lease from DMITRE; and (2) a Program for Environmental Protection and Rehabilitation (PEPR) must be approved by the Minister (or delegate) before mining can commence. The PEPR must include a water management plan for the proposed mine.

DMITRE liaises with other regulatory agencies during the assessment phase of the PEPR. DFW provides scientific and technical advice regarding potential impacts on rivers and aquifers resulting from mining activity. Cross contamination of aquifers is a principal concern and DMITRE works closely with DFW to ensure that the PEPR addresses any risk of this occurring.

4.4.1. INTEGRATING THE MINING SECTOR INTO WATER PLANNING

The National Water Commission has commissioned a project to investigate emerging issues and options for incorporating the water used by the mining sector into water planning and allocation processes (Hamstead & Fermio 2012).

The main recommendations reported by Hamstead and Fermio (2012) are:

- As a general principle, mining companies should be required to hold a water entitlement to take water in any circumstance where other water users would be required to hold a water entitlement
- Where incidental water take during mine operation or post closure could cause significant impacts on developed water systems that cannot be mitigated either during mining or in the long term, mining should be excluded from proximity to those systems. (This applies only to proposed new mining).

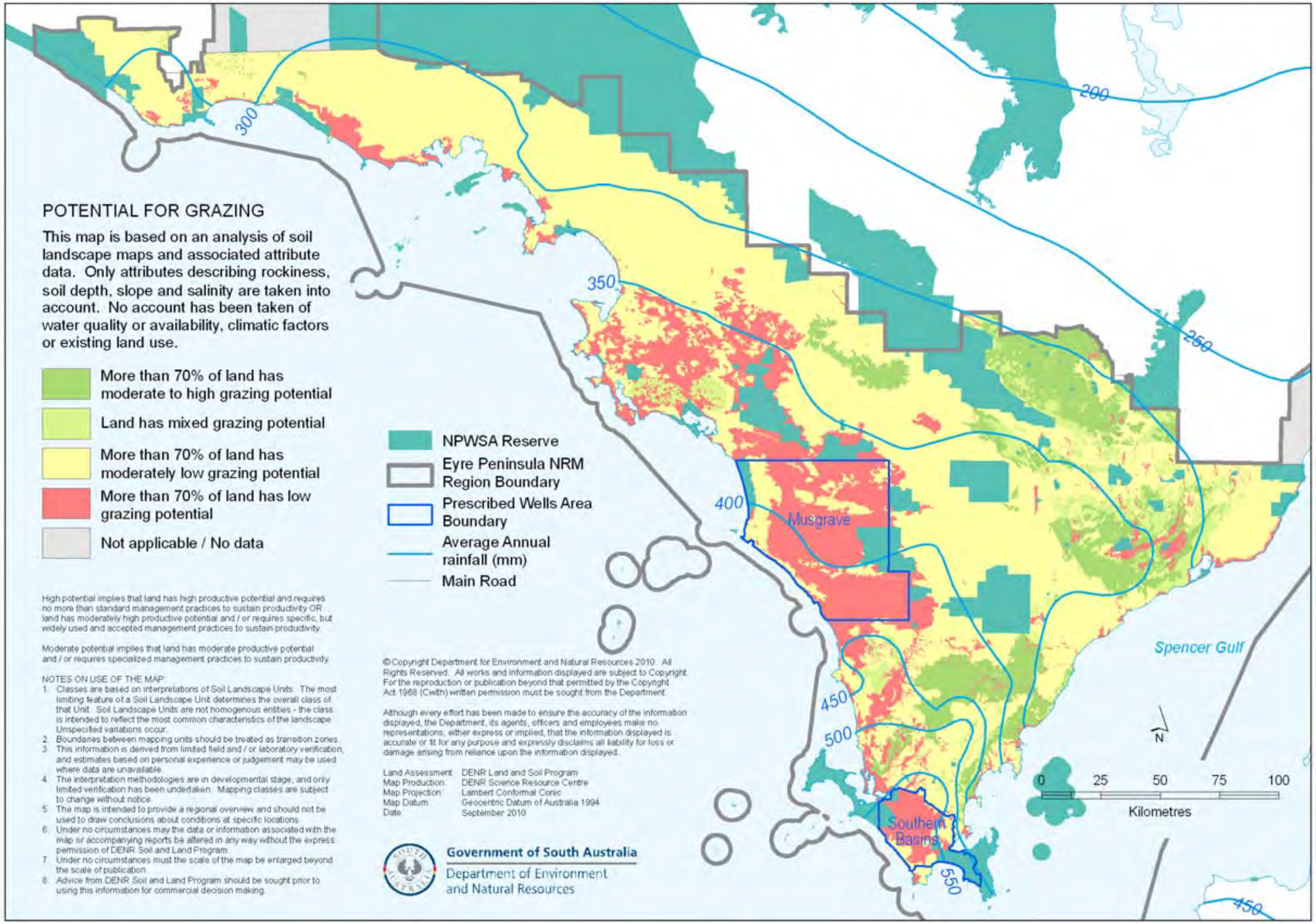

Figure 29. Land carrying capacity for the Eyre Peninsula Natural Resources Management region (Source: DENR 2010)

- Mining development approval processes should respect and not be able to over-ride, provisions of water allocation plans regarding availability of water entitlements.

4.4.2. CURRENT MINING VENTURES

There is only one potential future mine currently in advanced stages of exploration within Eyre Peninsula's PWAs. The Lincoln Minerals Gum Flat iron ore project is located within the Southern Basins PWA, around 20 km west of Port Lincoln. Phase 1 of the project is estimated to be completed within around three years. If phase 2 of the project is determined to be viable, the mine has an expected life in the order of 10 years. The projected demand for water ranges from 1000 ML/y for the period 2010–14 and up to 2500 ML/y beyond 2020 (DFW 2011a). It is proposed that groundwater will be extracted from the basement aquifer for the purpose of aquifer dewatering.

5. ASSESSMENT OF EFFECT ON OTHER WATER RESOURCES

Section 76(6) and Section 76(7) of the *Act* requires that a Water Allocation Plan includes an assessment of whether the taking or use of water from the prescribed resource will have a detrimental impact on the quantity or quality of water that is available from any other water resource. This includes water resources in neighbouring prescribed and non-prescribed areas.

5.1. *HYDROGEOLOGICAL PRINCIPLES: IMPACTS FROM WELL EXTRACTIONS*

Aquifers that are hydraulically connected to one another may not behave independently, so taking water from one aquifer may impact on other aquifers. Barriers to hydraulic connection between aquifers, such as aquitards or geological controls, may act to isolate an aquifer and consequently it would behave independently of nearby aquifers. In instances where there are large differences in the permeability (i.e. hydraulic conductivity) of connected, contiguous aquifers, extractions from the higher-yielding aquifer are unlikely to have marked impacts on the lower-yielding aquifer.

In the past, the vast majority of licensed groundwater extractions in the two PWAs have been from low-salinity lenses within the Quaternary Limestone aquifer. However in the future, there could be additional demands on poorer quality groundwater within the Quaternary Limestone aquifer, or from other aquifers adjacent to, or below the Quaternary Limestone aquifer such as the Tertiary Sands, the Jurassic aquifer or fractured rock aquifers in basement rocks. It should be remembered that climatic influences may also affect other water resources and it may be difficult to differentiate the impacts of groundwater extraction and extended periods of below-average rainfall, either of which may manifest as decreasing water levels.

5.1.1. INDUCED GROUNDWATER FLOWS

High rates of groundwater extraction from the Quaternary Limestone aquifer freshwater lenses, or from the Quaternary Limestone aquifer near the boundary of these lenses, can result in declining freshwater lens water levels. A fall in water level may alter the hydraulic gradient and cause inflows of higher-salinity groundwater to the freshwater lenses. However, due to the high transmissivity of the Quaternary Limestone aquifer, large drawdowns have not been observed. Furthermore, it is unlikely that taking water from the Quaternary Limestone aquifer will adversely impact on the quality of the freshwater lenses, provided extractions are appropriately managed (e.g. trigger-level management; buffer zones; set back distances), thereby minimising the risk of any deleterious impacts.

Taking water from the Tertiary Sands aquifer is unlikely to have any adverse impacts on the Quaternary Limestone aquifer where the Tertiary aquitard exists. Where the Tertiary aquitard is very thin and/or leaky, extractions from the Tertiary Sands aquifer may induce groundwater flow from the Quaternary Limestone aquifer to the Tertiary Sands aquifer. Due to the general low yields of the Tertiary Sands aquifer, impacts of taking from this resource on the Quaternary Limestone aquifer are likely to be negligible. As a precaution, buffers could be applied to restrict extractions from the Tertiary Sands aquifer in areas where the Quaternary and Tertiary aquifers are thought to be connected, in order to minimise the risk of any deleterious impacts to the Quaternary Limestone aquifer.

5.1.2. SEAWATER–FRESHWATER INTERFACE AND SALTWATER UP-CONING

Under natural conditions, coastal aquifers which are hydraulically connected to the sea exhibit a hydraulic gradient toward the sea, such that freshwater discharges from the aquifer to the sea. This freshwater discharge results in a hydrostatic balance which protects the freshwater in the aquifer from seawater incursion. The location of the saltwater–freshwater interface is generally static, only varying with tidal action and seasonal or annual changes in freshwater discharge. A change to this hydrostatic balance may cause lateral landward migration of the seawater–freshwater interface, in a process termed *seawater intrusion* (Freeze & Cherry 1979). The remediation of seawater intrusion is difficult and resource intensive and in many instances, impacted groundwater systems cannot be restored to freshwater conditions (Custodio 1987; Maimone *et al.* 2003).

Seawater intrusion can occur as a result of natural perturbations such as changes in long-term climate or from anthropogenic influences, most notably groundwater pumping. *Active seawater intrusion* (Fetter 1994) is a term given to the situation where the hydraulic gradient (i.e. slope of the water table) has reversed so instead of the gradient sloping toward the sea it slopes landward. Importantly, and counter-intuitively, *passive seawater intrusion* can occur when groundwater pumping results in landward ingress of freshwater–saltwater interface despite the hydraulic gradient of the freshwater aquifer still sloping toward the sea. Estimation of the rate at which seawater intrusion may occur is complex but it may occur abruptly.

A different occurrence of saline intrusion is possible in aquifers where groundwater salinity stratification is present. Saline groundwater exists naturally in the lower part of some aquifers and the lower-density freshwater stratifies over the higher-density saline groundwater to form a freshwater lens. In a process termed *saltwater up-coning* (Brown 1925), pumping from the thin freshwater lens can cause a reduction in pressure on the underlying saline groundwater resulting in lateral and upward entrainment of the saline water causing the salinity of a well to increase sharply and abruptly (Fig. 30). The Coffin Bay A and Lincoln B lenses for example, are thin freshwater lenses occurring above saline groundwater and have been identified as being vulnerable to saltwater up-coning (Ward, Werner & Howe 2009). Strategies such as basing allocations on trigger-level management principles may act to minimise the risk to these groundwater resources.

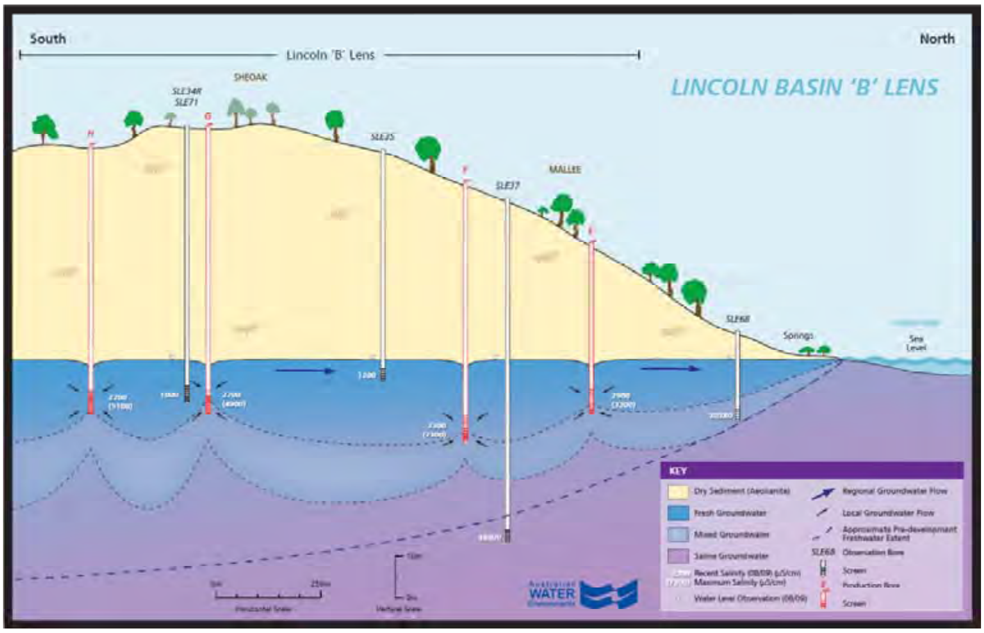

Figure 30. Example of saltwater up-coning for Lincoln B lens in the Southern Basins PWA (Werner, Ward & Howe 2009)

5.2. IMPACT OF TAKING FROM ONE RESOURCE ON ANOTHER

Taking from the Quaternary Limestone aquifer may result in a small decrease in leakage to the underlying Tertiary Sands aquifer, but this decrease is likely to be negligible. Where the Tertiary Sands aquifer underlies the Tertiary aquitard, the aquifer is confined. In these areas taking from the Quaternary Limestone aquifer is unlikely to have any impact on the Tertiary Sands aquifer. Confined groundwater can vary in age from less than 30 years to in excess of 18 000 years (Love *et al.* 1994).

There is limited knowledge of the basement fractured rock aquifer in the Musgrave and Southern Basins PWAs due to the separation of the basement aquifer by the Tertiary Sands aquifer and Tertiary aquitard. Also, the target aquifer for fresh groundwater extractions is the Quaternary Limestone aquifer. Consequently, few investigation wells extend beyond the Quaternary Limestone aquifer. However, the available evidence suggests that the basement aquifer is irregular in occurrence, yield and salinity (Evans *et al.* 2009a; Evans *et al.* 2009b). The small number of extraction wells which are completed within the basement aquifer are for the purpose of stock or domestic supplies. It is not anticipated that current extractions from this resource will impact on the Quaternary Limestone aquifer. Setback or buffer distances could be applied as a conservative approach in areas where there is a lack of data and knowledge (Section 6.1.4).

5.3. MUSGRAVE PWA

The Musgrave PWA Quaternary Limestone groundwater system comprises numerous fresh groundwater lenses that include Bramfield, Kappawanta, Polda, Sheringa A, Sheringa B, Talia and Tinline. Love *et al.* (1994) reported that the majority of potable groundwater residing in the Quaternary Limestone has been recharged within the past 30 years. Furthermore, it was concluded that local recharge dominates the water budget and lateral throughflow is minimal. The Tertiary Sands aquifer is understood to receive inflows via downward leakage from the Quaternary Limestone aquifer and lateral inflow (Evans *et al.* 2009b).

Each of the Quaternary Limestone fresh groundwater lenses in the Musgrave PWA have experienced declining water levels between 1–5 m since around 1980, irrespective of the rate of groundwater extraction (Evans et. al. 2009b). Love *et al.* (1994) reported a net decrease of 10% in the areal extent of the saturated limestone between 1973 and 1994 which was attributed to a decline in regional recharge. The Quaternary Limestone aquifer becomes partly unsaturated up-gradient from the Bramfield Lens (Evans *et al.* 2009b). This highlights the independencies of the Polda and Bramfield Lenses and the local flow paths that operate. Given the groundwater gradient, extractions from the Bramfield lens are unlikely to have an impact on the Polda lens.

There are no surface water resources in the Musgrave PWA and licensed extractions are currently limited to the Bramfield lens for the purpose of town water supply for the township of Elliston (population 377 (ABS 2011)). Extractions from the Polda Basin do not affect basins to the west (i.e. Bramfield, Tinline and Talia) because they occur at a lower elevation and groundwater cannot move uphill against gravity. The Kappawanta Basin is also not affected by extractions from the Bramfield lens because the Quaternary Limestone is dry between the two basins.

5.4. SOUTHERN BASINS PWA

There is limited development of defined surface watercourses within the Southern Basins PWA. Overflow from both Little and Big Swamp catchments drains to the northern portions of the Lincoln and Uley basins, respectively. Big Swamp has three sections, the first two have an underlying layer of Tertiary clay and therefore the primary mechanism of discharge from these is evaporation over summer. Salinity during the latter stages of drying in these sections has been observed to be 10 300 mg/L, compared with 1000–5500 mg/L during the wet season. The most-southerly third section fills in wetter years (around two in five years) and the primary mechanism of discharge from this section is infiltration into the underlying Quaternary Limestone unconfined aquifer. The overflow drains south into the Uley East lens area, then west into the Uley Wanilla area approximately one year in twenty (Harrington, Evans & Zulfic (2006).

The only surface water resources in this PWA intermittently fill in wet years. When full, the surface water enters the Quaternary Limestone aquifer (which lies at a lower elevation) by vertical drainage.

Future extractions from adjacent or underlying aquifers may affect water levels in the Quaternary Limestone aquifer lenses if they are located in close proximity. The confining layers between the Quaternary Limestone aquifer and deeper aquifers, where they exist, will reduce such impacts.

5.4.1. ULEY BASIN LENSES

The majority of inflow from each of these lenses is understood to be predominately from infiltration of local rainfall (both rapid and diffuse). Therefore, the water balance of each lens can largely be considered independently of any other lens. Where information is available, some evidence of connection is apparent. The Uley South Flow model (Werner 2009) provides estimates of the water balance, including interactions between adjacent lenses and the ocean boundary. These estimates could be used to inform average annual basin outflow and assist in refining the water balance. Inter-lens fluxes of the Uley Basin are generally considered to be of secondary importance to local recharge and discharge processes. Significant discharge from the Quaternary Limestone aquifer occurs toward the southern boundaries of Uley East and Uley Wanilla lenses to the underlying Tertiary Sands aquifer (Evans *et al.* 2009b).

Harrington, Evans and Zulfic (2006) identified an area in Uley South where there is potential for upward leakage from the Tertiary Sands aquifer to the Quaternary Limestone aquifer at a rate of approximately 14 mm/y. Numerical modelling results (Zulfic, Harrington & Evans 2007) confirmed this process and the authors reported that the Quaternary Limestone and Tertiary Sands aquifers are hydraulically connected due to the absence and/or leaky nature of the Tertiary aquitard. The Uley East and Uley Wanilla lenses are understood to be connected to the Uley South lens via the Tertiary Sands aquifer.

Lateral inflows to the Uley Wanilla lens are considered to be negligible. Some inflows are believed to be derived from Big Swamp but this occurs only once every 10–15 years (Harrington, Evans & Zulfic 2006). Groundwater outflows from the Uley Wanilla lens to Fountain Springs have been estimated to be around 310 ML/y (Harrington, Evans & Zulfic 2006). This discharge has been controlled historically through the construction of low permeability barriers and sump pumps, however water levels in the Uley Wanilla lens are currently too low for discharge to occur (Evans *et al.* 2009b).

Lower recharge under climate change scenarios is a risk to future seawater intrusion and water quality. It is important to maintain basin outflows as they limit/reduce the risk of seawater intrusion and maintain the quality of water in the aquifers (Ward, Werner & Howe 2009). When considering the consumptive use limit, the consequence of reduced basin outflows needs to be carefully assessed. Scenario modelling undertaken by Werner (2009) indicates that extraction primarily influences groundwater discharge to the ocean, but also impacts on groundwater levels and aquifer storage.

5.4.2. COFFIN BAY LENSES

Results of an AEM survey conducted in 2006 (Fitzpatrick *et al.* 2009) suggested the presence of high-salinity groundwater (presumed to be seawater) at depth in the Coffin Bay National Park (CBNP) area. This high-salinity groundwater extends from the CBNP southern boundary to Coffin Bay. Limited drilling at two locations in CBNP confirmed the presence of a significant thickness (~40 m) of freshwater overlying the saline water (Smith *et al.* 2008), suggesting that the areal extent of the Coffin Bay A lens may be greater than displayed in the current WAP. A significant basement ridge separates the Coffin Bay and Uley South lenses with the exception of a low point near the north-western extent of the Uley South lens. Inter-lens connection may occur at this low point (Fitzpatrick *et al.* 2009), however the AEM data are inferred and further investigation is required to test this hypothesis.

Somaratne *et al.* (2009) estimate the total lens area of Coffin Bay A lens to be 7600 ha. The authors estimated the location of a groundwater divide from a map of Quaternary Limestone aquifer watertable elevations which was interpolated from around nine observation wells. The lens was divided into two parts based on the assumption that groundwater discharge occurs in generally north-west and south-west directions (Fig. 31). They estimated that an area of around 3500 ha discharges toward the north (southern coastline of Kellidie Bay) and around 4100 ha discharges to the Southern Ocean.

Groundwater flow from the Coffin Bay C lens is generally toward the north. Groundwater from Coffin Bay B lens flows toward the west before discharging to Kellidie Bay. Groundwater discharge is evident as surface springs along the southern coast of Kellidie Bay (Evans *et al.* 2009a) and submarine groundwater discharge can be observed near the eastern shoreline of Kellidie Bay.

5.4.3. LINCOLN BASIN LENSES

Groundwater recharge to Lincoln D lens is via direct rainfall infiltration and inflows from Little Swamp. Little Swamp inflows are evident from a north–south trending salinity gradient (Evans *et al.* 2009a). Alcorn (2009) identified a total of 136 farm dams in the Little Swamp catchment from aerial photography. He estimated their capacity to be around 214 ML.

Alcorn (2009) assessed the impacts of farm dams on streamflow in the Big and Little Swamp catchments using an annual time step rainfall-runoff model. Reductions to stream flow from farm dams at both Big and Little Swamp in median-to-wet rainfall years were estimated to be low at around 5%. Modelled reductions were reportedly greater in drier years with around 12% of streamflow extracted upstream of both swamps. An estimated 13% of stream reaches (by length) had more than 20% of flow extracted and 35% of reaches had between 10-20% of streamflow extracted in these drier years. It was concluded that these levels of extraction are cause for concern given the ecological significance of Big and Little Swamp. However, Alcorn (2009) did not consider impacts to groundwater recharge to Uley or Lincoln Basin from reduced streamflow in the Big or Little Swamp catchments because his study focused only on streamflow entering the two swamps.

Groundwater discharge for the Lincoln A and B lenses is evident at springs that occur near Tulka West (Evans *et al.* 2009a). Discharge from Lincoln A lens is also evident toward the northern shoreline of Sleaford Mere. Extractions from the Lincoln A lens may result in decreasing water levels, leading to decreased fresh groundwater spring discharge to Sleaford Mere. Trigger-level management is one option which is likely to minimise the potential impact to this GDE. Potential impacts to GDEs from falling groundwater levels are discussed in the report *Environmental Water Requirements of Groundwater-Dependent Ecosystems in the Southern Basins and Musgrave Prescribed Wells Areas on Eyre Peninsula* (Doeg *et al.* in prep.).

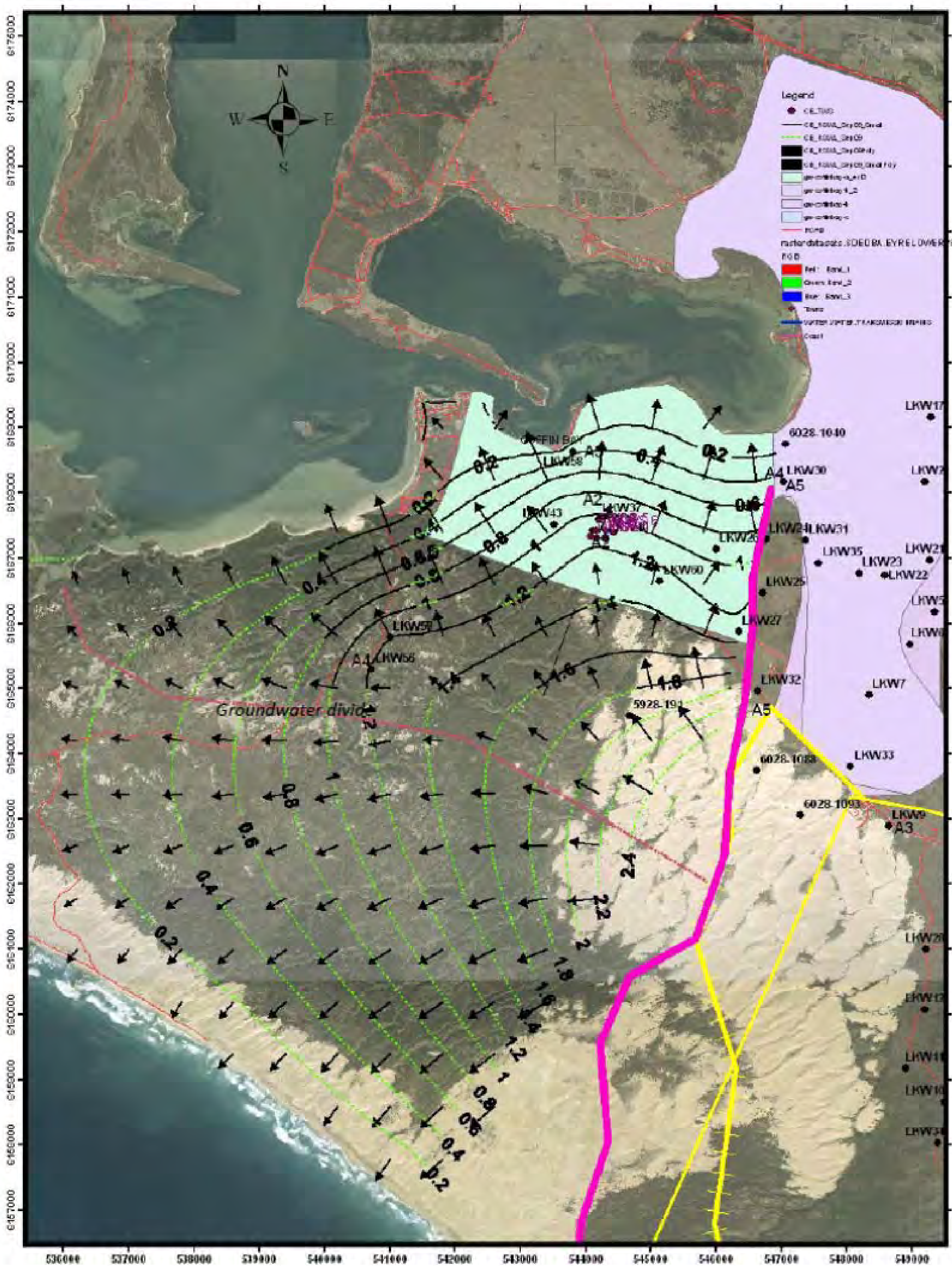

Figure 31. Coffin Bay A groundwater divide as outlined from watertable elevation data by SA Water (Source: Somaratne *et al.* 2009)

6. WATER MANAGEMENT FRAMEWORK PROPOSED FOR THIS PLAN

Eyre Peninsula's management approach to groundwater allocation is presently based on estimates of annual recharge volumes. Trigger-level management presents as an alternative strategy to flux-based approaches (i.e. based on recharge volumes) that allows for adaptive controls on groundwater abstraction, based on the condition of the aquifer at any given time (e.g. Liu *et al.* 2006; Lee, Moon & Lee 2008; Bekesi, McGuire & Moiler 2008). Trigger-level management relies on measured groundwater levels, groundwater salinities and/or ecosystem health indicators, which are compared to objective values (trigger levels), thereby invoking management responses (e.g. alterations to pumping regimes). Suggested management options have been provided to the EPNRMB or can be viewed in Doeg *et al.* (in prep.).

6.1. WATER RESOURCE MANAGEMENT APPROACHES

6.1.1. FLUX-BASED MANAGEMENT

Flux-based methods of groundwater allocation apportion groundwater extraction volumes based on estimates of groundwater recharge and discharge. Despite their shortcomings, flux-based groundwater management approaches still accord several operational advantages. Forward planning of groundwater use by both water resource managers and end-users is facilitated by the allocation process – i.e. groundwater users are able to strategise based on forecasts of available water. Importantly, an increasingly robust understanding of system dynamics often results from long-term, periodic analyses of water balance fluxes (Bredehoeft 2002). However, the principal shortcoming of a flux-based approach is the uncertainty regarding the estimation of recharge volumes (Evans, Merrick & Gates 2004). Furthermore, flux-based management strategies fail to address issues of scale (DEWR 2003) – i.e. recharge estimation made at a regional or catchment scale can often neglect localised effects, such as drawdown at the single-well scale (e.g. GDE degradation caused by pumping).

There are a number of cases indicating that systems failure has been linked to traditional flux-based groundwater allocation, illustrating the shortcomings of a non-adaptive management approach. (e.g. the Choushui River alluvial, Taiwan (Liu 2004), north-eastern Korinthia aquifers, Greece (Voudouris 2006) and various national groundwater-monitoring stations in South Korea (Lee, Moon & Lee 2008)). There are very few analyses of the performance of groundwater management approaches in Australia (Werner *et al.* 2011).

Groundwater allocations for Eyre Peninsula's licensed users are currently determined through consideration of Recent Recharge Rates. Recent Recharge Rates are set out in a Notice published in the South Australian Government Gazette each year, which set the allocation for the following water-use year. The Recent Recharge Rate of each lens takes into account the actual recharge that has occurred to the underground water resource over the previous ten year period.

The current WAPs consider long-term recharge (i.e. Average Annual Recharge) to calculate the resource capacity as it relates to each discrete groundwater lens then sets aside 60% of the derived volume for the environment as well as a percentage for stock and domestic demand. The remaining percentage is the volume of water available for allocation. The estimated Average Annual Recharge has been derived using a number of techniques for particular (but not all) lenses. These techniques included the examination of rainfall/recharge relationships, chloride mass balance, environmental isotope analysis and the response of underground water levels to various extraction regimes. These derived values for particular lenses have then been used as a basis to estimate recharge to minor fresh groundwater lenses. Ward *et al.* (2009) suggested that the proportions of recharge distributed between groundwater lenses as described in the current WAPs agree with the outputs of their LEACHM model and are therefore reasonable.

6.1.2. TRIGGER-LEVEL MANAGEMENT

Adaptive trigger-level management (sometimes referred to as groundwater level response management (Bekesi, McGuire & Moiler 2008)) acts to modify the rate of pumping with the aim of achieving sustainable levels of abstraction. Bekesi, McGuire and Moiler (2008) contend that a shift toward sustainable abstraction can be achieved by making corrections to existing allocations, based on change in groundwater storage (i.e. water levels). Typically, trigger levels are based explicitly on water level; however other measures of the state of the system such as water quality (e.g. salinity) or environmental indicators (e.g. vegetation health or biological indicators) are also used (Nation, Werner & Habermehl 2008).

There are many advantages and disadvantages to adopting a trigger-level management approach to groundwater resources management (Table 20). Being adaptive in nature, trigger-level management does not require *a priori* recharge estimation. Further, trigger-level management accommodates temporal and spatial variability in both groundwater pumping and rainfall recharge. However, effective management is contingent on selecting parameters which are appropriate to monitoring the full spectrum of risks faced. Any successful application of trigger-level management will be flexible, such that triggers can be fine-tuned based on historical performance of the trigger-level management regime (Nation, Werner & Habermehl 2008).

Table 20. Advantages and disadvantages of adopting a trigger-level approach to groundwater resources management (Evans, Merrick & Gates 2004)

Advantages	Disadvantages
Better reflection of the true (short-term) availability of groundwater	A higher-risk strategy, but able to be mitigated
Concept is readily understood (community acceptance)	Extreme adjustments in allocations are possible (i.e. difficulty in specifying risks on future water availability)
Scientific underpinning through appropriate software	Higher management costs
Depending upon rainfall (i.e. recharge) announced allocations can be expected to be more generous in wet years	Difficulty in determining appropriate target levels (e.g. allowing for unexpected factors)
Specifically addresses too high concentrations of uses	Needs to comply with other water management objectives (e.g. Murray-Darling Basin Water Cap)
Can be made to work with Council of Australian Governments (COAG) and the National Water Initiative framework of water reforms	Potential for perception of social inequities
	Less flexible water accounting rules (e.g. less water available in a drought)
	Changes the security of access to *license*d volumes of water

6.1.3. HYBRID APPROACH TO GROUNDWATER ALLOCATION

Werner *et al.* (2011) conducted a study of flux-based and trigger-level approaches to groundwater management. They used a simple water-balance modelling approach to evaluate different management regimes, using the Uley South coastal aquifer located in the Southern Basins PWA as a case study. Their study used a proxy for the risk of seawater intrusion (based on the location of the 'toe' of the freshwater–seawater interface) as an indicator of the efficacy of different groundwater management approaches. The authors concluded that a 'hybrid' approach, which integrates pumping protocols common to both trigger-level *and* flux-based management, showed optimal risk reduction. Werner *et al.* (2011) modelling results show that the addition of trigger-level management to a flux-based management regime leads to: (1) increased water availability manifested as higher allowable pumping volumes, (2) reduced risk of seawater intrusion and protection against recharge estimate inaccuracies, (3) a better understanding of groundwater system dynamics; and (4) adaptive management practices.

6.1.4. ENVIRONMENTAL BUFFERS

A range of policy options are available which are aimed at protecting GDEs. Environmental buffers – now termed Environmental Protection Zones (EPZs) (Howe & Howieson 2006) – is one option that has been adopted by the South East Natural Resources Management Board (SENRMB) in their draft WAP for the Tintinara Coonalpyn Prescribed Wells Area (SENRMB 2011). Howe and Howieson (2006) define an EPZ as "…the desirable set-back distance that any water affecting activity must be from a GDE so as to mitigate the effect of groundwater use on maintenance of GDE access to groundwater". The EPZ approach to GDE protection proposed by the SENRMB is considered transferable to Eyre Peninsula's PWAs due to the similarities in geology and hydrogeology – i.e. both regions rely on groundwater resources which reside primarily within Quaternary Limestone aquifers.

The formula that is used to calculate environmental buffer distances is based on the (non-equilibrium) Theis Solution (Fetter 1994). The Theis Solution is subject to the following assumptions:

- The aquifer is bounded on the bottom by a confining layer
- All geologic formations are horizontal and of infinite horizontal extent
- The potentiometric surface of the aquifer is horizontal prior to the start of pumping
- The potentiometric surface is not changing with time prior to pumping
- All changes in the position of the potentiometric surface are due to the effects of pumping alone
- The aquifer is homogeneous and isotropic
- All flow is radial toward the well
- Groundwater flow is horizontal
- Darcy's Law is valid
- Groundwater has a constant density and viscosity
- The pumping well and the observation wells are fully penetrating – i.e. they are screened over the entire thickness of the aquifer
- The pumping well has an infinitesimal diameter and is 100% efficient.

Although Theis' analytical solution describes flow of water to wells which are fully screened within confined aquifers, his method is commonly applied to unconfined aquifers by substituting the confined aquifer storage parameter 'specific storage' (Ss) for the unconfined aquifer storage parameter 'specific yield' (Sy) (Freeze & Cherry 1979). The Theis Solution is reliable in predicting water level drawdowns in unconfined aquifers contingent on the drawdown being small relative to the saturated thickness of the aquifer (Jacob 1950). Drawdowns in the unconfined Quaternary Limestone aquifer are likely to be relatively small relative to saturated thickness due to the aquifer's high transmissivities, as indicated by aquifer tests (Table 21). The Theis Solution, after modification such that it can be applied to unconfined aquifers, is given by:

$$s_{max} = \frac{Q}{4\pi T} W(u) \qquad \textbf{(Eq. 2)}$$

where s_{max} [L] is the maximum allowable watertable drawdown, Q [L^3T^{-1}] is the pumping rate, T [$L^3T^{-1}L^{-1}$] is aquifer transmissivity and $W(u)$ [] is the Theis Well Function, which is given by:

$$W(u) = -0.5772 - \ln(u) \qquad \textbf{(Eq. 3)}$$

where

$$u = \frac{r^2 Sy}{4Tt} \qquad \textbf{(Eq. 4)}$$

where r [L] is the environmental buffer distance (EPZ) from the pumping well at the point of maximum allowable watertable drawdown s_{max}, Sy [] is the specific yield and t [T] is the number of days of continuous pumping.

Solving for r gives:

$$r = \sqrt{\frac{e^{\left(-0.5772 - \frac{4 s_{max} \pi T}{Q}\right)} 4Tt}{Sy}} \qquad \textbf{(Eq. 5)}$$

Aquifer parameters for Eyre Peninsula's groundwater basins have been estimated based on a review of the published literature (Table 21). Ranges and adopted values of transmissivity and specific yield have been listed where they are available. Buffer distances (Appendix D) have been calculated from (1) the adopted (or the mean of the range) values of transmissivity and specific yield and (2) pumping rates of 67, 133 and 667 kL/d (i.e. annual allocations of 5, 10 and 50 ML, used in their entirety and extracted continuously over an irrigation season of 75 days).

Table 21. Transmissivity and Specific Yield values from previous studies

Basin/lens	T_{range} ($m^3 d^{-1} m^{-1}$)	$T_{adopted}$^ ($m^3 d^{-1} m^{-1}$)	Sy_{range}	$Sy_{adopted}$^	r# (m) (Allcn=5 ML)	r# (m) (Allcn=10 ML)	r# (m) (Allcn=50 ML)	Author(s)
Musgrave PWA								
	1280–2030	1290	0.029–0.11	0.041	0	5	683	Painter (1970)
		800		0.05	1	38	772	Painter (1970)
	750-2150	800	0.012–0.036	0.01	2	85	1727	Painter (1970)
		3450		6.1×10^{-3}	0	0	378	Painter (1970)
	2010–2940	2550	0.013–0.032	0.022	0	0	400	Painter (1970)
		1600		5.0×10^{-3}	0	4	1625	Painter (1970)
Polda (Quaternary)		2600		3.0×10^{-5}	0	1	10 422	Coffey & Partners (1981) in Evans (1993)
	2070–2890	*2480*	3.6×10^{-4}–0.052	0.02	0	0	441	Evans (1993)
	1370–2290	*1830*	2.0×10^{-3}–0.069	0.032	0	1	553	Evans (1993)
	1820–4150	*2985*	2.0×10^{-5}–0.04	0.024	0	0	275	Evans (1993)
	1800–2080	2080	0.10–0.28	*0.19*	0	0	191	Evans, Naravna & Power (1994)
Polda (Tertiary)	80–270	80	2.0×10^{-4}–0.011	1.0×10^{-3}	1727	2518	3404	Painter (1972)
	50–300	80	2.0×10^{-4}–0.11	1.0×10^{-3}	1727	2518	3404	Painter (1972)
		8.2		7.0×10^{-3}	411	427	441	Coffey & Partners (1981) in Evans (1993)
		10.0		9.0×10^{-4}	1245	1305	1355	Coffey & Partners (1981) in Evans (1993)
Talia (Tertiary)		115		1.7×10^{-4}	3611	6209	9578	Dowie & Love (1996)
		21		1.9×10^{-4}	3540	3908	4230	Dowie & Love (1996)

Basin/lens	T_{range} ($m^3d^{-1}m^{-1}$)	$T_{adopted}$^ ($m^3d^{-1}m^{-1}$)	Sy_{range}	$Sy_{adopted}$^	r# (m) (Allcn=5 ML)	r# (m) (Allcn=10 ML)	r# (m) (Allcn=50 ML)	Author(s)
Southern Basins PWA								
Uley South (Quaternary)		682		0.007	7	163	2130	Morton & Steel (1966) in Evans (1997)
		3973		0.69	0	0	23	Morton & Steel (1966) in Evans (1997)
		1894		0.14	0	0	253	Morton & Steel (1966) in Evans (1997)
		10 440		0.02	0	0	0	Painter (1969) in Evans (1997)
		11 079		0.03	0	0	0	Painter (1969) in Evans (1997)
		3980		0.692	0	0	23	Morton & Steel (1970)
		1890		0.138	0	0	256	Morton & Steel (1970)
		10 420		0.017	0	0	1	Painter (1971)
		11 150		0.028	0	0	0	Painter (1971)
		10 000		0.02	0	0	1	Sibenaler (1976) in Evans (1997)
	4000–6500	*5250*	0.05–0.18	*0.12*	0	0	19	Sibenaler (1976) in Evans (1997)
		10 000	0.15–0.72	*0.435*	0	0	0	Sibenaler (1976) in Evans (1997)
	10 000–12 000	*11 000*	0.08–0.12	*0.1*	0	0	0	Sibenaler (1976) in Evans (1997)
	4000–5000	*4500*		0.03	0	0	72	Sibenaler (1976) in Evans (1997)
	10 000–12 000	*11 000*		0.08	0	0	0	Sibenaler (1976) in Evans (1997)
	12 000–13 000	*12 500*		0.35	0	0	0	Sibenaler (1976) in Evans (1997)
	1000–5000	2000		0.2	0	0	197	Barnett (1978)
	680–13 000	*6840*	0.2-0.3	*0.25*	0	0	3	Zulfic, Harrington & Evans (2007)
Uley South (Tertiary)		682		7.0×10^{-3}	7	163	2130	Harrington, Evans & Zulfic (2006)

Basin/lens	T_{range} ($m^3d^{-1}m^{-1}$)	$T_{adopted}$^ ($m^3d^{-1}m^{-1}$)	Sy_{range}	$Sy_{adopted}$^	r# (m) (Allcn=5 ML)	r# (m) (Allcn=10 ML)	r# (m) (Allcn=50 ML)	Author(s)
Southern Basins PWA (cntd.)								
Uley Wanilla		455		0.135	10	88	491	EWS (1943) in Evans (1997)
	252–866	*559*	0.02–0.12	*0.07*	6	83	685	EWS (1990) in Evans (1997)
	255–1099	*677*	0.05–0.28	*0.17*	1	34	433	EWS (1990) in Evans (1997)
	550–598	*574*		0.35	2	35	306	EWS (1953) in Evans (1997)
	298–1087	*693*	0.03–0.13	*0.08*	2	46	629	EWS (1989) in Evans (1997)
	263–1612	*938*	0.02–0.13	*0.08*	0	17	581	EWS (1989) in Evans (1997)

The buffer distance is based on a maximum acceptable watertable drawdown of 0.1 m, values of $T_{adopted}$, $Sy_{adopted}$ and pumping rates of 67; 133 and 667 kL/d (i.e. an allocation of 5; 10 and 50 ML, used in its entirety and extracted continuously over an irrigation season of 75 days)

^ Where values of $T_{adopted}$ and/or $Sy_{adopted}$ have not been reported, the mean of T_{range} and/or Sy_{range} values have been substituted and these are denoted by italics

7. MONITORING

7.1. MONITORING NETWORK REVIEWS

The groundwater resources on Eyre Peninsula have been subject to regular reviews since the region's groundwater resources were developed for public water supply in the 1940s. Previous groundwater monitoring and sustainability reviews have resulted in some rationalisations of Eyre Peninsula's PWAs monitoring networks (Table 22). The most recent reviews of the Musgrave and Southern Basins PWAs groundwater monitoring networks have been conducted by Howe and Clark (2008) as part of the Groundwater Allocation, Planning and Management project and by Evans *et al.* (2009a; 2009b) as part of regular hydrogeological conceptualisation and monitoring reviews.

7.1.1. RECOMMENDATIONS FROM RECENT GROUNDWATER MONITORING NETWORK REVIEWS

A number of recommendations have been made following the recent reviews of Eyre Peninsula's PWA monitoring networks. In summary, recommendations made by Howe and Clark (2008) include:

- establishing a formal agreement between EPNRMB, SA Water and DFW which outlines which groundwater parameters are to be monitored, the agency responsible for data collection and the frequency of monitoring; it was suggested this agreement could be incorporated into WAPs
- augmentation of the Lincoln and Coffin Bay observation well networks to address significant gaps in water level and salinity data
- consultation between SA Water and relevant key stakeholders to ensure SA Water's upgraded telemetered monitoring systems achieve optimal resource management and operational outcomes
- sampling of salinity on a network-wide basis and a subsequent increase in frequency of salinity data collection
- review of groundwater level data logger status and staff training in download and maintenance procedures

Recommendations made by Evans *et al.* (2009a; 2009b), in addition to those above, include:

- consideration of automated logging of monitoring data to allow the timing and magnitude of actual water level peaks and troughs
- sampling groundwater levels at least monthly between April–October to monitor effective recharge
- augmentation of groundwater level monitoring with regular reporting of production wells pumped and recovered static groundwater level observations from licensed extraction wells
- monitoring of rainfall intensity in conjunction with water levels to enable rainfall-recharge relationships to be established across the PWAs
- evaluation of the extent of saturation near the perimeter of groundwater resources, at points where licensed extractions are occurring, to confirm aquifer storage and thereby ensure that the capacity of the resource to meet demand is met
- sampling of groundwater across the fresh–saline groundwater interface pre- and post-extraction season where licensed extraction points are near the interface to monitor the behaviour of the resource in response to seasonal stresses
- undertake a five-yearly complete network groundwater level monitoring survey to provide baseline data for long-term analysis (e.g. climate change)

- monitor any increased extractions from Coffin Bay A lens to ensure adequate management of the resource.

7.2. *CURRENT MONITORING*

A number of observation networks which monitor current groundwater levels and salinities are established across the EPNRM Region (Figs. 32a and 32b). The location of current groundwater observation wells and the status of water levels and salinities for the most recent water-use year can be viewed online in Groundwater Level and Salinity Status Reports for each of the PWAs (DFW 2011b; DFW 2011c). The existing networks are focussed on monitoring high value water resources such as those that provide town water supplies. Effective monitoring is important due to the relatively small aquifer storage to annual recharge ratios – termed “system robustness” (IAH 2004) – of most of the potable lenses within the two PWAs.

Network augmentation has been based historically on a risk management approach – e.g. near-coastal wells with fully penetrating screens have recently been installed in the Uley South lens to enable monitoring of the location of the freshwater–sea water interface. Migration of this interface is an indicator of the risk of sea water intrusion. Many observation wells have been rehabilitated since the 1980s. Original steel casings have been replaced with inert PVC casings and wells originally left open between the Quaternary and Tertiary aquifers are now screened within a single formation (Evans *et al.* 2009b).

7.2.1. STANDARDISED MONITORING METHODS AND PROCEDURES

The Monitoring Standards and Procedures Project, a component of the State Water Monitoring Network Optimisation Project within DFW’s Groundwater Program, aims to describe standard methods for surface water and groundwater monitoring in a combined, uniform context. The priority, under the Groundwater Program, is to develop a set of procedures describing groundwater monitoring from installation of a monitoring site, the management and use of telemetered data and archiving of all monitoring data. It is anticipated that this initiative will result in improved quality of hydrological data and greater efficiencies in data access.

7.2.2. CURRENT MONITORING RECOMMENDATIONS

Subject to the policy approach selected by the EPNRMB, the following monitoring recommendations should be considered. It should be noted that a number of the recommendations would have resourcing implications for the Board if adopted.

- Annual monitoring of all wells identified in Table B1 and B2 (Appendix B) for Reduced Standing Water Level is required to be undertaken in April each year. These data are required to recreate the Arc Hydro model annually and changes in saturation thickness may be used to alter annual allocations. The wells outlined in Table B1 and B2 are largely already monitored in the current monthly bore run, this assessment would require an additional 40 privately owned or historic obswells to be monitored in April annually.
- It is recommended that all wells outlined in Table B3 (Appendix B) be added to the Obswell monitoring network to be monitored for both salinity and water level. There is a significant knowledge gap within the Lincoln D lens area. Adding these wells to the current network will provide for a better understanding of the resource in this region and will allow the Arc Hydro model to be improved in this area. A number of these wells could be used as trigger-level monitoring sites. Consideration could also be given to extending the network in the vicinity of Coffin Bay B where monitoring is currently limited. These wells would require surveying to gain accurate ground elevations.

- It would be ideal to have a sampling of all observation wells across both PWAs for water level and salinity to provide a snapshot of the region. These data would assist with numerical model calibration, Arc Hydro work and would provide a better understanding of the condition of the resource. It would be advantageous to include one monitoring round at the hydrograph maximum and one at the hydrograph minimum. Observation wells currently used for recharge assessment and annual allocation variation are recommended to be maintained as these are useful for resource condition monitoring and changes in the resource overtime.
- It is suggested that irrigators are given the opportunity to be involved in resource management, whereby they may have the option to monitor groundwater salinity potentially on an annual or biannual basis (thereby capturing salinities at the beginning of both wet and dry seasons, as suggested by Howe and Clark (2008)) from equipped bores. This will minimise data gaps in the current monitoring network in addition to providing landholders with valuable scientific information such as salinity trends and estimates of salt loads resulting from irrigation.
- It is recommended that salinity monitoring of the saltwater-freshwater interface be undertaken quarterly in wells ULE209 and ULE156.
- In addition there are two long-screened wells (ULE205 & SLE069) which allow the direct measurement of the saltwater-freshwater interface by salinity profiling (sonding). Ward, Werner and Howe (2009) indicate that previous sonding results could be considered to provide baseline information on the position of the interface. They suggest as a preliminary measure, to sonde the wells monthly for 1 year. This will allow the observation of a seasonal water level maximum and minimum, accompanied by transient interface behaviour on the seasonal timescale. The tidal impacts on the interface position can be assessed by comparing monitoring data against the known tidal movement. When the ambient fluctuations in the saltwater-freshwater interface have been identified, ongoing monitoring (biannually) will provide an early warning measure for any impending sea water intrusion. Ward, Werner and Howe (2009) indicated that “frequent monitoring will be more useful than sporadic monitoring and will improve the understanding of relative changes in the interface depth over time”.
- Similar sonding could be undertaken in the Lincoln Basin to observe any change in the salinity stratification and up-coning.
- For monitoring recommendations specific to groundwater-dependent ecosystems and the environment, refer to Doeg *et al.* (in prep.).

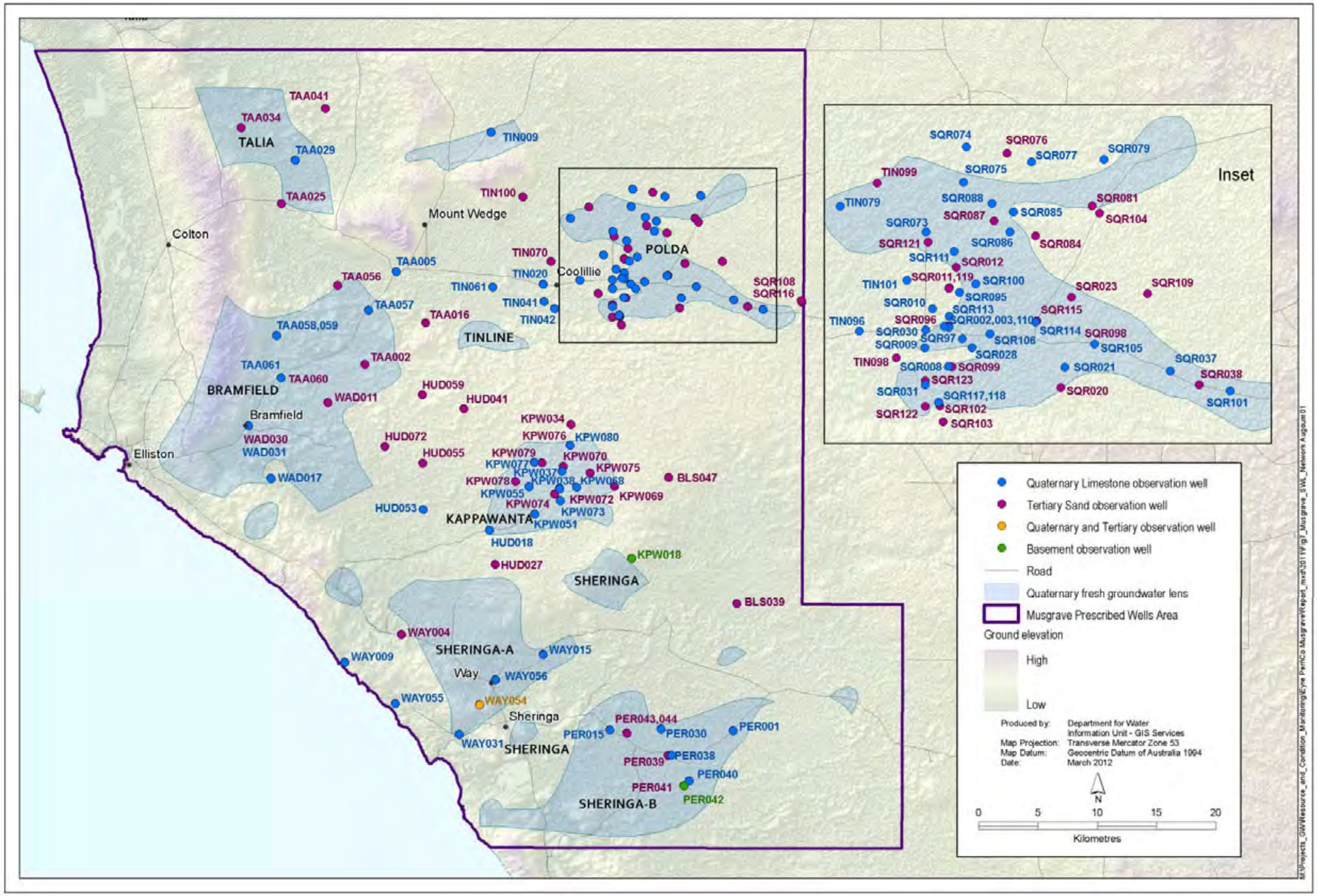

Figure 32.a. **Indicative locations of Musgrave PWA water-level observation wells. Well locations are current at December 2011; see Groundwater Status Reports (online at www.waterconnect.sa.gov.au\GSR) for up-to-date observation well location maps.**

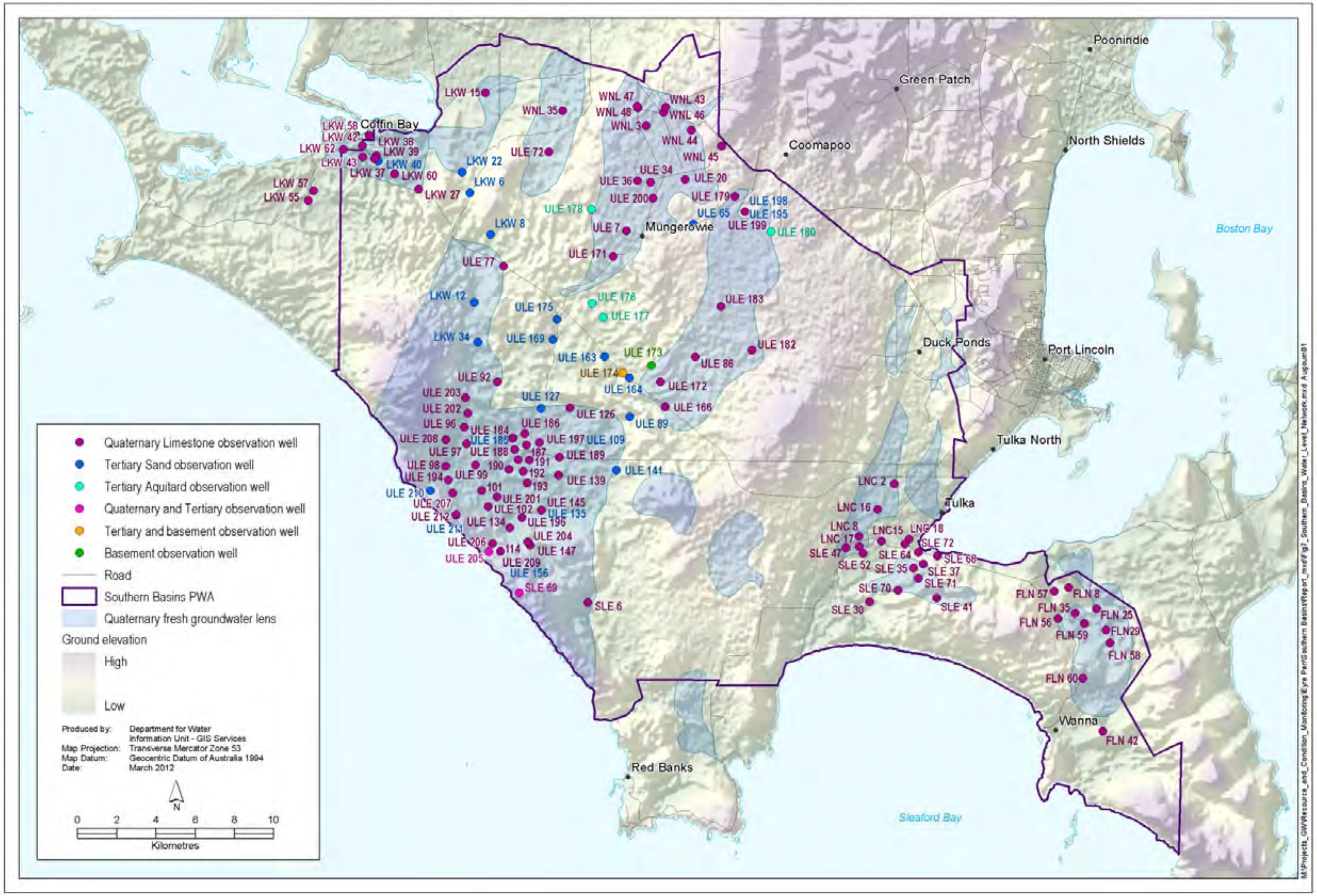

Figure 32.b. Indicative locations of Southern Basins PWA water-level observation wells. Well locations are current at December 2011; see Groundwater Status Reports (online at www.waterconnect.sa.gov.au\GSR) for up-to-date observation well location maps.

Table 22. Summary of Eyre Peninsula's Prescribed Wells Areas' groundwater monitoring networks (see Section 2.5 for aquifer descriptions)

Aquifer	Water Level Monitoring Wells	Water Level Monitoring Frequency	Salinity Monitoring Wells	Salinity Monitoring Frequency
Musgrave PWA				
Quaternary (Bridgewater Formation)	66	43 x monthly & 23 x 6 monthly	62	39 x yearly & 23 every three years
Tertiary (Poelpena Formation)	58	33 x monthly & 25 x 6 monthly	55	31 x yearly & 24 every three years
Quaternary & Tertiary	1	6 monthly	1	Every three years
Basement	2	6 monthly	2	Every three years
Total	**127**		**120**	
Southern Basins PWA				
Quaternary (Bridgewater Formation)	97	86 x monthly & 11 x 6 monthly	97	22 x yearly & 75 every 3 years
Tertiary aquitard (Uley Formation)	4	1 x monthly & 3 x 6 monthly	4	every three years
Tertiary Sands (Wanilla Formation)	23	12 x monthly &11 x 6 monthly	23	2 x yearly & 21 every three years
Quaternary & Tertiary (sea water interface)	2	2 x monthly	2	every three years
Tertiary & Basement	1	1 x 6 monthly	1	every three years
Basement	1	1 x 6 monthly	1	every three years
Total	**128**		**128**	

APPENDICES

A. *Specific yield variability within the quaternary limestone aquifer*

Table A1. Specific yield (Sy) variability as outlined in previous studies for the Quaternary Limestone aquifer in the Musgrave and Southern Basins PWAs

Groundwater Lens	Unit Number	Well Name	Depth of well (m)	Screen Type	Production Zone		Location within the aquifer	Aquifer thickness (m)	Sy Range		Adopted Sy	Reference
Uley South									0.03	0.7	0.2	Somaratne *et al.* 2009a
	6028-703	PT 2 (Prod Bore 1)	13.11	OH + SC	3.05	13.11	Whole	9.75			0.69	Morton & Steel (1966) in Evans 1997
	6028-703	PT 2 (Prod Bore 1)	13.11	OH + SC	3.05	13.11	Whole	9.76	0.05	0.18		Sibenaler (1976) in Evans 1997
	6028-782	PT3	12.80					6.74			0.14	Morton & Steel (1966) in Evans 1997
	6028-699	PT U4 (Prod Bore 8)	15.24	S	10.30	13.72	Bottom	7.62			0.02	Painter (1969) in Evans 1997
	6028-699	PT U4 (Prod Bore 8)	15.24	S	10.30	13.72	Bottom	7.70			0.02	Sibenaler (1976) in Evans 1997
	6028-777	PT U5	21.34					13.72			0.03	Painter (1969) in Evans 1997
	6028-702	HDO 6 (Prod Bore 2)	14.25	OH	7.86	14.25	Bottom	9.74	0.15	0.72		Sibenaler (1976) in Evans 1997
	6028-701	HDO 7 (Prod Bore 3)	14.60	OH	9.01	14.60	Bottom	11.20	0.08	0.12		Sibenaler (1976) in Evans 1997
	6028-700	HDO 8 (Prod Bore 4)	15.80	OH	9.92	15.50	Bottom	10.68			0.03	Sibenaler (1976) in Evans 1997
	6028-698	HDO 11 (Prod Bore 5)	14.50	OH	8.00	14.50	Bottom	9.77			0.08	Sibenaler (1976) in Evans 1997
	6028-697	HDO 12 (Prod Bore 6)	16.00	OH	8.02	16.00	Bottom half	10.10			0.35	Sibenaler (1976) in Evans 1997
	6028-905	HDO 22	26.00		15.20	26.00	Bottom	11.70			0.007	Barnett (1978) in Evans 1997
											0.15	Evans (1997)
	Well details unavailable, Sy value calculated from hydrograph method										0.2	Barnett(1978)
	Well details unavailable, Sy value calculated as a fixed value over whole basin area.										0.3	Shepherd (1980)
	Well details unavailable, uniform Sy value selected for entire model area										0.1	James-Smith & Brown (2002)
	Well details unavailable, Sy value calculated by Evans (1997) using watertable recovery curves										0.15	Harrington, Evans & Zulfic (2006)
	6028-703	PT 2	13.11	OH + SC	3.05	13.11	Whole	9.4	0.05	0.18	0.07	Werner (2009)
	6028-782	PT3	12.80					6.8			0.10	Werner (2009)
	6028-699	PT U4	15.24	S	10.30	13.72	Bottom	7.6			0.017	Werner (2009)
	6028-777	PT U5	21.34					13.7			0.29	Werner (2009)
	6028-702	HDO 6	14.25	OH	7.86	14.25	Bottom	10.8	0.03	0.15	0.14	Werner (2009)
	6028-701	HDO 7	14.60	OH	9.01	14.60	Bottom	11.4	0.07	0.13	0.12	Werner (2009)
	6028-700	HDO 8	15.80	OH	9.92	15.50	Bottom	10.7	0.02	0.10	0.026	Werner (2009)
	6028-698	HDO 11	14.50	OH	8.00	14.50	Bottom	10.3	0.07	0.10	0.079	Werner (2009)
	6028-697	HDO 12	16.00	OH	8.02	16.00	Bottom half	10.6	0.13	0.41	0.35	Werner (2009)
	6028-905	HDO 22	26.00		15.20	26.00	Bottom	11.7			0.007	Werner (2009)
Uley Wanilla	6028-1528	Prod Bore 1	30.48	S				11.45			0.135	EWS unpub. 1943 In Evans (1997)
	6028-2286	Prod Bore 5A	25.80	S	21.35	25.50	Bottom	13.80	0.02	0.12		EWS unpub. 1990 In Evans (1997)
	6028-1694	Prod Bore 7A						13.65	0.05	0.28		EWS unpub. 1990 In Evans (1997)
	6028-1530	Prod Bore 8	19.66		14.94	19.66	Bottom	13.87			0.35	EWS unpub. 1953 In Evans (1997)
	6028-1656	Prod Bore 8A	21.5	S	13.5	18.5	Whole	8.50	0.03	0.13		EWS unpub. 1989 In Evans (1997)
	6028-1655	Prod Bore 9A	21.5	S	14.3	18.5		10.20	0.02	0.13		EWS unpub. 1989 In Evans (1997)
											0.08	Evans (1997)
Coffin Bay A	5928-307	TWS 2	36	OH	24	36	Bottom				0.172	Somaratne *et al.* (2009b)
Musgrave									3×10^{-5}	0.06		Love *et al.* (1994)
Kappawanta	Unknown	PT9							0.029	0.11	0.041	Evans (1993)

Groundwater Lens	Unit Number	Well Name	Depth of well (m)	Screen Type	Production Zone	Location within the aquifer	Aquifer thickness (m)	Sy Range		Adopted Sy	Reference
	Unknown	PT11						0.022	0.026	0.05	Evans (1993)
Sheringa B	Unknown	PT13						0.012	0.036	0.01	Evans (1993)
Sheringa A	Unknown	PT14						0.0051	0.0052	0.0061	Evans (1993)
Bramfield	Unknown	PT15						0.013	0.032	0.022	Evans (1993)
	Unknown	PT17								0.005	Evans (1993)
Polda	Unknown									0.03	Evans (1993)
	Unknown	PT4						3.6×10^{-4}	0.052	0.020	Evans (1993)
	Unknown	PT5						0.002	0.069	0.032	Evans (1993)
	Unknown	PT7						2×10^{-5}	0.04	0.024	Evans (1993)

B. MONITORING WELLS

Table B1. Wells required to be monitored annually in April for water level in the Musgrave PWA

Consumptive pool	Water Level				
	Unit Number	Obs number	Easting	Northing	In current network
Bramfield	5930-188	HUD002	508053	6282274	N
	5930-190	HUD004	508083	6279241	N
	5930-191	HUD005	508088	6277660	N
	5930-192	HUD006	508090	6276280	N
	5930-1063	TAA057	509879	6289721	Y
	5930-5	TAA061	502517	6284040	Y
	5930-137	WAD012	503551	6276348	N
	5930-132	WAD018	500709	6276791	N
	5830-235	WAD031	499759	6279981	Y
Kappawanta	*5930-253*	*HUD018*	*520082*	*6271194*	*Y*
	5930-754	KPW037	526165	6276147	Y
	5930-753	KPW038	525954	6274664	Y
	5930-751	KPW051	523883	6272534	Y
	5930-755	KPW055	523401	6274832	Y
	5930-757	KPW068	527407	6274828	Y
	5930-1060	KPW073	526029	6273671	Y
	5930-1088	KPW077	523838	6276898	Y
Polda	5930-912	SQR021	536242	6290783	Y
	5930-1005	SQR031	530439	6290049	Y
	5931-128	SQR085	534116	6297263	Y
	5931-123	SQR086	533965	6296442	Y
	5931-129	SQR088	533218	6297627	Y
	5931-397	SQR100	532531	6294267	Y
	5930-1046	SQR105	537483	6291748	Y
	5930-1059	SQR106	533129	6292171	Y
	5931-402	SQR111	531629	6295621	Y
	5931-200	TIN079	526887	6297504	Y
Polda East	5930-885	SQR037	540633	6290623	Y
	5930-1045	SQR101	543117	6289799	Y
Sheringa A	5930-453	WAY015	524584	6260669	Y
	5930-361	WAY031	517531	6253966	Y
	5930-315	WAY056	520597	6258567	Y
	5930-1295	-	522964	6262362	N
Sheringa B	5930-546	PER001	540599	6254256	Y
	5930-535	PER015	530228	6254336	Y
	5930-550	PER030	534532	6254404	Y
	5930-1081	PER038	535401	6252221	Y
	5930-489	WAY050	528383	6252896	N
Talia	5931-297	TAA029	503727	6302439	Y
	5931-288	-	501753	6306768	N
	5931-559	-	501001	6302232	N
Talia East	5931-262	TIN009	520221	6304787	Y
Tinline	5930-1245	-	517089	6286081	N
Saturated Quaternary A	5930-977	SQR002	531418	6292447	Y
	5930-983	SQR003	531418	6292447	Y

Consumptive pool	Water Level				
	Unit Number	Obs number	Easting	Northing	In current network
	5930-958	SQR010	530735	6293225	Y
	5930-962	SQR030	530445	6292345	Y
	5931-131	SQR074	532145	6299987	Y
	5931-130	SQR075	532022	6298503	Y
	5931-133	SQR077	534854	6299356	Y
	5931-51	SQR079	537867	6299454	Y
	5930-1072	SQR113	531429	6292921	Y
	5930-969	SQR117	530995	6289309	Y
	5930-971	SQR118	530993	6289326	Y
	5930-57	TAA005	512222	6293038	Y
	5930-28	TAA059	502140	6287618	Y
	5930-660	TIN020	524583	6291957	Y
	5930-653	TIN041	524666	6290475	Y
	5930-625	TIN042	525552	6289857	Y
	5930-86	TIN061	520333	6291713	Y
	5930-639	TIN096	527695	6292289	Y
	5931-408	TIN101	529675	6294419	Y
Saturated Quaternary B	5930-205	HUD007	508094	6274787	N
	5930-320	WAY009	507909	6260040	Y
	5930-474	WAY026	524725	6254787	N
	5930-364	WAY030	519795	6254917	N
	5930-485	WAY034	524657	6253319	N
	5930-1067	WAY055	512136	6256582	Y
	5930-1297	-	521064	6256574	N
	5930-1310	-	521597	6253076	N
	5930-1324	-	523949	6254979	N
Saturated Quaternary C		N/A			Y
Saturated Quaternary D	5930-568	PER032	533209	6257843	N
	5930-551	PER033	532768	6254771	N
Saturated Quaternary E		N/A			
Saturated Quaternary F		N/A			

Table B2. Wells required to be monitored annually in April for water level in the Southern Basins PWA

Consumptive pool	Water Level				
	Unit Number	Obs number	Easting	Northing	In current network
Coffin Bay A	5928-301	LKW037	544192	6167594	Y
	5928-303	LKW038	544106	6167428	Y
	5928-304	LKW039	544098	6167422	Y
	5928-203	LKW042	543474	6168098	Y
	5928-308	LKW043	543514	6167515	Y
	5928-435	LKW058	543808	6168636	Y
	5928-436	LKW060	545131	6166655	Y
Coffin Bay B	6028-1038	LKW015	549747	6170794	Y
Coffin Bay C	6028-815	ULE072	552978	6167777	Y
Lincoln A	6028-641	SLE047	568128	6147582	Y
Lincoln B	6028-440	SLE035	571566	6146550	Y
	6028-397	SLE041	572756	6145021	Y

Consumptive pool	Water Level				
	Unit Number	Obs number	Easting	Northing	In current network
	6028-2703	SLE070	570774	6145423	Y
	6028-2704	SLE071	571827	6146043	Y
	6028-2705	SLE072	572798	6147174	Y
Lincoln C	6028-524	FLN025	580909	6144450	Y
	6028-539	FLN026	582072	6143351	Y
	6028-536	FLN029	581387	6143377	Y
	6028-2706	FLN057	578746	6145364	Y
	6028-2707	FLN058	581600	6142722	Y
	6028-2708	FLN059	580276	6143721	Y
	6028-2709	FLN060	580199	6140928	Y
Mikkira	6028-581	SLE001	562030	6147294	N
Pantania	6028-726	ULE150	557153	6148636	N
Uley East A	6028-1607	ULE179	562457	6165503	Y
	6028-1610	ULE183	561750	6159877	Y
	6028-2744	-	563422	6162092	N
Uley East B	6028-854	ULE086	560448	6157305	Y
	6028-906	ULE166	558927	6154779	Y
Uley South	6028-877	ULE091	549788	6157034	N
	6028-657	ULE096	548678	6153739	Y
	6028-755	ULE097	548797	6152875	Y
	6028-752	ULE099	549245	6151804	Y
	6028-773	ULE101	549563	6150502	Y
	6028-743	ULE102	549893	6149686	Y
	6028-658	ULE107	550802	6153912	N
	6028-775	ULE114	550945	6151573	Y
	6028-709	ULE121	554628	6153171	N
	6028-894	ULE126	554070	6154700	Y
	6028-744	ULE134	550992	6148604	Y
	6028-711	ULE139	553492	6151286	Y
	6028-717	ULE142	555286	6149955	N
	6028-724	ULE143	554371	6149264	N
	6028-746	ULE145	552601	6149494	Y
	6028-759	ULE147	552034	6147706	Y
	6028-767	ULE184	551157	6153167	Y
	6028-735	ULE186	551763	6153404	Y
	6028-734	ULE187	551844	6152819	Y
	6028-792	ULE188	551244	6152586	Y
	6028-721	ULE189	553516	6152207	Y
	6028-793	ULE190	551426	6152066	Y
	6028-733	ULE191	551985	6152055	Y
	6028-794	ULE192	551672	6151480	Y
	6028-795	ULE193	551891	6150894	Y
	6028-1747	ULE194	547857	6151029	Y
	6028-1750	ULE196	551618	6149131	Y
	6028-1751	ULE197	552506	6152937	Y
	6028-2295	ULE201	550348	6150179	Y
	6028-660	ULE202	548851	6154439	Y
	6028-2157	ULE203	548741	6155231	Y
	6028-2165	ULE204	551915	6147884	Y

Consumptive pool	Water Level				
	Unit Number	Obs number	Easting	Northing	In current network
	6028-2318	ULE206	550117	6147799	Y
	6028-2316	ULE207	548078	6150373	Y
	6028-2317	ULE208	547736	6153092	Y
	6028-2711	ULE209	550522	6157398	Y
	6028-2727	ULE212	548261	6149265	Y
	6028-567	SLE012	553029	6147158	N
Uley Wanilla	6028-981	ULE007	556943	6163746	Y
	6028-968	ULE034	558163	6166227	Y
	6028-950	ULE036	557507	6166304	Y
	6028-999	ULE171	556267	6162441	Y
	6028-938	ULE200	558291	6165413	Y
	6028-1517	WNL003	557940	6169102	Y
	6028-1605	WNL043	558930	6170054	Y
	6028-1603	WNL044	560235	6168887	Y
	6028-4	WNL046	558831	6169788	Y
	6028-214	WNL047	557485	6170106	Y
	6028-1654	WNL048	557524	6170020	Y
Saturated Quaternary Lincoln South	6028-554	FLN035	579800	6144236	Y
	6028-514	FLN042	581210	6138238	Y
	6028-1748	FLN056	578929	6143971	Y
	6028-357	LNC012	571299	6148108	N
	6028-2700	LNC016	569742	6149534	Y
	6028-2701	LNC017	568822	6147660	Y
	6028-2702	LNC018	571334	6148031	Y
	6028-457	SLE030	569335	6144843	Y
	6028-389	SLE037	572071	6146761	Y
	6028-428	SLE052	569009	6147296	Y
	6028-417	SLE064	571131	6147776	Y
	6028-1745	SLE068	571829	6147371	Y
Saturated Quaternary Uley	6028-860	ULE044	561448	6164029	N
	6028-850	ULE084	561982	6155584	N
	6028-668	ULE087	561665	6153915	N
	6028-872	ULE172	558668	6156043	Y
	6028-2741	ULE180	564312	6163715	Y
	6028-1159	WNL035	553700	6169880	Y
	6028-1606	WNL045	561795	6168058	Y
	6028-2742	-	563003	6164014	N
		well adjacent ULE44 LM			N
		Windmill_Heath (LM)			N
Other	6028-503	FLN017	579449	6147569	N
	5928-418	LKW055	540715	6165292	Y
	5928-419	LKW057	540998	6165781	Y
	6028-1612	ULE182	563331	6157650	Y
	6028-198	-	572904	6159454	N
	6028-2112	-	574299	6156701	N
	6028-2360	-	570880	6159966	N

Table B3. Wells required to be added to the current monitoring network for both water level and salinity in the Lincoln D lens vicinity in the Southern Basins PWA

Unit Number	Easting	Northing	Zone	Depth (m)	Aquifer Monitored
6028-00132	571095	6161053	53	6	Bridgewater Formation
6028-00143	573108	6156575	53	23	Bridgewater Formation
6028-00198	572903	6159453	53	12.58	Bridgewater Formation
6028-02112	574298	6156700	53	24	Bridgewater Formation
6028-02202	570899	6160767	53	15.8	Bridgewater Formation

C. METHODOLOGY FOR ANALYSING GRAZING POTENTIAL

Aim: To identify three 'grazing potential classes' (GPC) based on a limited number of soil/landscape attributes, which will be used to discount carrying capacity for each of five rainfall zones covering the eastern Mt Lofty Ranges.

GPC 1 No reduction of carrying capacity
GPC 2 25% reduction of carrying capacity
GPC 3 50% reduction of carrying capacity

The attributes to be used are:

- 'rockiness' (r) / moisture holding capacity (m) (whichever is more limiting)
- 'water erosion potential' (e) (an estimate of slope)
- 'salinity' (s)

Data statistics:

1. Area of GPC 3 land

1.1 Calculate area of shallow rocky soil (SRS) as follows:
For each lan_slu, determine areas of: [r = 6 + 8]
[m = 5]
Whichever value is larger is the 'SRS' value for the lan_slu.

1.2 Calculate area of [s = 5 + 7 + 8]
This is the area of saline land 'SL' for the lan_slu

1.3 Add 'SRS' values for all lan-slu's in catchment – Total area [GPC 3 (SRS)] for catchment

1.4 Add 'SL' values for all lan_slu's in catchment – Total area [GPC 3 (SL)] for catchment.

1.5 Add {GPC 3 (SRS) + GPC 3 (SL)} – Total area [GPC 3] for catchment.

2. Area of GPC 2 land

2.1 Calculate area of steep, shallow or rocky soil (SSRS) as follows:
For each lan_slu, determine areas of: [r = 5]
[m = 4]
[e = 6]
Whichever value is larger is the 'SSRS' value for the lan_slu.

2.2 Calculate area of [s = 4]
This is the area of saline land 'SL' for the lan_slu

2.3 Add 'SSRS' values for all lan-slu's in catchment – Total area [GPC 2 (SSRS)] for catchment

2.4 Add ‘SL’ values for all lan_slu’s in catchment – Total area [GPC 2 (SL)] for catchment.

2.5 Add {GPC 2 (SSRS) + GPC 2 (SL)} – Total area [GPC 2] for catchment.

3. Area of GPC 1 land is the remainder less any ‘not applicable’ area.

Map legend:

The map is to delineate lan_slu’s which are predominantly either GPC 1, GPC 2 or GPC 3 and an additional class for lan-slu’s in which none of these three classes dominates. Rules are (reading from the top, once a class has been allocated, it cannot be over-written):

1. If $\geq$ 70% of lan_slu in ‘not applicable, Class X
2. If $\geq$ 70% of lan_slu is GPC 3, Class D
3. If $\geq$ 70% of lan_slu is [GPC 2 + GPC 3], Class C
4. If $\geq$ 70% of lan_slu is GPC 1, Class A
5. Remainder, Class B

Legend
This map is based on an analysis of soil landscape maps and associated attribute data. Only attributes describing rockiness, soil depth, slope and salinity are taken into account.

Class A	More than 70% of land has moderate to high grazing potential
Class B	Land has mixed grazing potential
Class C	More than 70% of land has moderately low grazing potential
Class D	More than 70% of land has low grazing potential

Notes on use of the map and disclaimers:

Potential based on soil and landscape attributes only - no account has been taken of water quality or availability, climatic factors or existing land use.

High potential implies that land has high productive potential and requires no more than standard management practices to sustain productivity
OR
land has moderately high productive potential and / or requires specific, but widely used and accepted management practices to sustain productivity.

Moderate potential implies that land has moderate productive potential and / or requires specialized management practices to sustain productivity.

NOTES ON USE OF THE MAP:

1. Classes are based on interpretations of Soil Landscape Units. The most limiting feature of a Soil Landscape Unit determines the overall class of that Unit. Soil Landscape Units are not homogenous entities - the class is intended to reflect the most common characteristics of the landscape.

Unspecified variations occur.
2. Boundaries between mapping units should be treated as transition zones.
3. This information is derived from limited field and / or laboratory verification, and estimates based on personal experience or judgement may be used where data are unavailable.
4. The interpretation methodologies are in developmental stage and only limited verification has been undertaken. Mapping classes are subject to change without notice.
5. The map is intended to provide a regional overview and should not be used to draw conclusions about conditions at specific locations.
6. Under no circumstances may the data or information associated with the map or accompanying reports be altered in any way without the express permission of DENR Soil and Land Program.
7. Under no circumstances must the scale of the map be enlarged beyond the scale of publication.
8. Advice from DENR Soil and Land Program should be sought prior to using this information for commercial decision making.

D. ENVIRONMENTAL BUFFER DISTANCE LOOK-UP TABLE

The following look-up tables give environmental buffer distances (r) for a range of transmissivity and specific yield values. The buffer distances are calculated assuming:

- the assumptions underpinning the Theis Solution (Section 4.1.4) are satisfied
- a maximum drawdown of 0.1 m at a distance of r metres from the well
- pumping rates (in three individual tables) of:
    1. 67 kL/d (annual allocation of 5 ML)
    2. 133 kL/d (annual allocation of 10 ML)
    3. 667 kL/d (annual allocation of 50 ML)
- the allocation is used in its entirety
- the well is pumped continuously for 75 days.

Table D1. Environmental buffer distances look-up table for a pumping rate of 67 kL/d (i.e. annual allocation of 5 ML)

T ($m^3d^{-1}m^{-1}$)/Sy	0.00001	0.0001	0.001	0.01	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60
10	11811	3735	1181	374	118	96	84	75	68	59	53	48
50	18116	5729	1812	573	181	148	128	115	105	91	81	74
100	15992	5057	1599	506	160	131	113	101	92	80	72	65
150	12226	3866	1223	387	122	100	86	77	71	61	55	50
250	6151	1945	615	194	62	50	43	39	36	31	28	25
500	824	261	82	26	8	7	6	5	5	4	4	3
750	96	30	10	3	1	1	1	1	1	0	0	0
1000	10	3	1	0	0	0	0	0	0	0	0	0
1500	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0
3000	0	0	0	0	0	0	0	0	0	0	0	0
4000	0	0	0	0	0	0	0	0	0	0	0	0
5000	0	0	0	0	0	0	0	0	0	0	0	0
6000	0	0	0	0	0	0	0	0	0	0	0	0
7000	0	0	0	0	0	0	0	0	0	0	0	0
8000	0	0	0	0	0	0	0	0	0	0	0	0
9000	0	0	0	0	0	0	0	0	0	0	0	0
10000	0	0	0	0	0	0	0	0	0	0	0	0
12000	0	0	0	0	0	0	0	0	0	0	0	0
14000	0	0	0	0	0	0	0	0	0	0	0	0

Table D2. Environmental buffer distances look-up table for a pumping rate of 133 kL/d (i.e. annual allocation of 10 ML)

T ($m^3d^{-1}m^{-1}$)/Sy	0.00001	0.0001	0.001	0.01	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60
10	12381	3915	1238	392	124	101	88	78	71	62	55	51
50	22929	7251	2293	725	229	187	162	145	132	115	103	94
100	25619	8102	2562	810	256	209	181	162	148	128	115	105
150	24790	7839	2479	784	248	202	175	157	143	124	111	101
250	19978	6318	1998	632	200	163	141	126	115	100	89	82
500	8698	2751	870	275	87	71	62	55	50	43	39	36
750	3280	1037	328	104	33	27	23	21	19	16	15	13
1000	1166	369	117	37	12	10	8	7	7	6	5	5
1500	135	43	14	4	1	1	1	1	1	1	1	1
2000	15	5	1	0	0	0	0	0	0	0	0	0
2500	2	0	0	0	0	0	0	0	0	0	0	0
3000	0	0	0	0	0	0	0	0	0	0	0	0
4000	0	0	0	0	0	0	0	0	0	0	0	0
5000	0	0	0	0	0	0	0	0	0	0	0	0
6000	0	0	0	0	0	0	0	0	0	0	0	0
7000	0	0	0	0	0	0	0	0	0	0	0	0
8000	0	0	0	0	0	0	0	0	0	0	0	0
9000	0	0	0	0	0	0	0	0	0	0	0	0
10000	0	0	0	0	0	0	0	0	0	0	0	0
12000	0	0	0	0	0	0	0	0	0	0	0	0
14000	0	0	0	0	0	0	0	0	0	0	0	0

Table D3. Environmental buffer distances look-up table for a pumping rate of 667 kL/d (i.e. annual allocation of 50 ML)

T ($m^3d^{-1}m^{-1}$)/Sy	0.00001	0.0001	0.001	0.01	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60
10	12857	4066	1286	407	129	105	91	81	74	64	57	52
50	27685	8755	2768	875	277	226	196	175	160	138	124	113
100	37350	11811	3735	1181	374	305	264	236	216	187	167	152
150	43639	13800	4364	1380	436	356	309	276	252	218	195	178
250	51270	16213	5127	1621	513	419	363	324	296	256	229	209
500	57286	18116	5729	1812	573	468	405	362	331	286	256	234
750	55433	17529	5543	1753	554	453	392	351	320	277	248	226
1000	50572	15992	5057	1599	506	413	358	320	292	253	226	206
1500	38663	12226	3866	1223	387	316	273	245	223	193	173	158
2000	27868	8813	2787	881	279	228	197	176	161	139	125	114
2500	19450	6151	1945	615	194	159	138	123	112	97	87	79
3000	13300	4206	1330	421	133	109	94	84	77	66	59	54
4000	5984	1892	598	189	60	49	42	38	35	30	27	24
5000	2607	824	261	82	26	21	18	16	15	13	12	11
6000	1113	352	111	35	11	9	8	7	6	6	5	5
7000	468	148	47	15	5	4	3	3	3	2	2	2
8000	195	62	20	6	2	2	1	1	1	1	1	1
9000	81	25	8	3	1	1	1	1	0	0	0	0
10000	33	10	3	1	0	0	0	0	0	0	0	0
12000	6	2	1	0	0	0	0	0	0	0	0	0
14000	1	0	0	0	0	0	0	0	0	0	0	0

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	365 or 366 days	time interval

Shortened forms

~	approximately equal to
[]	Dimensionless
bgs	below ground surface
EC	electrical conductivity (µS/cm)
[L]	Dimension of length
K	hydraulic conductivity (m/d)
pH	acidity
pMC	percent of modern carbon
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
[T]	Dimension of time
w/v	weight in volume
w/w	weight in weight

GLOSSARY

ABS – see Australian Bureau of Statistics

Act (the) — In this document, refers to the *Natural Resources Management (SA) Act 2004,* which supersedes the *Water Resources (SA) Act 1997*

AMLRNRMB – see Adelaide and Mount Lofty Ranges Natural Management Resources Board

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through

Aquifer, confined — Aquifer in which the upper surface is impervious (see 'confining layer') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer

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

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

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

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

BoM — Bureau of Meteorology, Australia

Bore — See 'well'

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

^{14}C — Carbon-14 isotope (percent modern Carbon; pmC)

Catchment — That area of land determined by topographic features within which rainfall will contribute to run-off at a particular point

CFC — Chlorofluorocarbon; measured in parts per trillion (ppt)

CMB — Chloride mass balance

Confining layer — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

DENR – see Department of Environment and Natural Resources

DES — Drillhole Enquiry System; a database of groundwater wells in South Australia, compiled by the South Australian Department of Water, Land and Biodiversity Conservation (DWLBC)

DEWR – see Department of Environment and Water Resources

DFW — Department for Water (Government of South Australia)

DMITRE — Department for Manufacturing, Innovation, Trade, Resources and Energy

Domestic purpose — The taking of water for ordinary household purposes; 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)

DWR – see Department for Water Resources

EC — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS

Environmental water provisions — That part of environmental water requirements that can be met; what can be provided at a particular time after consideration of existing users' rights, and social and economic impacts

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

EP — Eyre Peninsula

EPNRMB — Eyre Peninsula Natural Resources Management Board

ERWRPC – see Eyre Region Water Resources Planning Committee

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

EWS – see Engineering and Water Supply Department

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or high flow conditions; measured in metres per day

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers; see also 'hydrology'

Hydrostratigraphic Log — a log of a well which outlines sections of a geological formation that exhibit similar hydraulic properties regardless of their composition

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

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

Isohaline —Of equal or constant salinity; typically drawn as a contour line on a map

Licence — A licence to take water in accordance with the *Act*; see also 'water licence'

Licensee — A person who holds a water licence

Lithological Log — a log of a well which outlines sections of a geological formation that exhibit similar macroscopic features, consistent physical characteristics (e.g. texture or petrology)

m AHD — Defines elevation in metres (m) according to the Australian Height Datum (AHD); 0 m AHD is approximately mean sea level

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

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things

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

NRM — Natural Resources Management; 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

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

Obswell — Observation Well Network

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

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

Permeability — A measure of the ease with which water flows through an aquifer or aquitard, measured in m^2/d

Piezometer — A narrow tube, pipe or well; used for measuring moisture in soil, water levels in an aquifer, or pressure head in a tank, pipeline, etc

PIRSA — Primary Industries and Regions South Australia (Government of South Australia)

Potable water — Water suitable for human consumption such as drinking or cooking water

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface

Prescribed well — A well declared to be a prescribed well under the *Act*

Production well — The pumped well in an aquifer test, as opposed to observation wells; a wide-hole well, fully developed and screened for water supply, drilled on the basis of previous exploration wells

PWA — Prescribed Wells Area

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

Reduced Standing Water Level (RSWL) — Reduced Standing Water Level - the elevation of the water level, typically measured in m AHD. It is calculated by subtracting the Depth to Water (DTW) from the reference elevation. A negative value indicates that the water level is below mean sea level

RESIC - see Resources and Energy Infrastructure Council

SA Geodata — A collection of linked databases storing geological and hydrogeological data, which the public can access through the offices of DMITRE. Custodianship of data related to minerals and petroleum, and groundwater, is vested in DMITRE and DWLBC, respectively. DWLBC should be contacted for database extracts related to groundwater

SAMDBNRMB – see South Australian Murray-Darling Basin Natural Resources Management Board

SA Water — South Australian Water Corporation (Government of South Australia)

Secondary porosity — Secondary porosity refers to voids within rocks which are formed after sedimentary deposition, e.g. solution features (i.e. sink holes or caves) occurring within limestone formations

SENRMB – see South East Natural Resources Management Board

Specific storage (S_s) — Specific storativity; the amount of stored water realised from a unit volume of aquifer per unit decline in head; it is dimensionless

Specific yield (S_y) — The volume ratio of water that drains by gravity, to that of total volume of the porous medium. It is dimensionless

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

Stratigraphic Log — a log of a well which outlines sections of a geological formation that are discrete and definable. Such units are defined based on their lithology, fossil content or their time span

(S) — Storativity; storage coefficient; the volume of groundwater released or taken into storage per unit plan area of aquifer per unit change of head; it is dimensionless

Sustainability — The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time

T — Transmissivity; a parameter indicating the ease of groundwater flow through a metre width of aquifer section (taken perpendicular to the direction of flow), measured in m^2/d

TDS — Total dissolved solids, measured in milligrams per litre (mg/L); a measure of water salinity

Tertiary aquifer — A term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago)

The *Act 2004* – see Government of South Australia 2012b

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

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

Transmissivity (T) — A parameter indicating the ease of groundwater flow through a metre width of aquifer section

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 (eg. 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 — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) 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

WAP — Water Allocation Plan; a plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with the *Act*

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

Water 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 resource monitoring — An integrated activity for evaluating the physical, chemical, and biological character of water resources, including (1) surface waters, groundwaters, estuaries, and near-coastal waters; and (2) associated aquatic communities and physical habitats, which include wetlands

Well — (1) An opening in the ground excavated for the purpose of obtaining access to underground water. (2) An opening in the ground excavated for some other purpose but that gives access to underground water. (3) A natural opening in the ground that gives access to underground water

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