

Eyre Peninsula Groundwater Dependent Ecosystem Scoping Study



EYRE PENINSULA GROUNDWATER DEPENDENT
ECOSYSTEM SCOPING STUDY

- Final
- 18 March 2010



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EXECUTIVE SUMMARY

Background

The Eyre Peninsula Natural Resource Management (EP NRM) Board engaged Sinclair Knight Merz Pty Ltd (SKM) to undertake a scoping study of groundwater dependent ecosystems (GDEs) in the Southern Basins and Musgrave Prescribed Wells Areas (PWAs), and around Robinson Basin on the Eyre Peninsula. The purpose of the GDE scoping study is to improve the understanding of GDEs in the project areas on the Eyre Peninsula in order to assist water managers to develop better strategies for incorporating GDEs into future Water Allocation Plans (WAPs).

Identifying GDEs

A key output from this study is a spatial dataset that defines the location of potentially groundwater dependent wetland and vegetation communities in the Southern Basins and Musgrave PWAs and Robinson Basin. Regional-scale wetland and vegetation mapping across these areas formed the basis for identifying the location and extent of potential GDEs and were refined based on available geological and hydrogeological information and the development of conceptual models of surface water – groundwater regimes for each potential GDE type.

The source of water to all mapped wetlands was previously classified (by the department of Environment and Heritage) as “groundwater”. However, a number of these wetlands are disconnected from the Quaternary Bridgewater Formation aquifers because water tables are either deep or confining layers occur between the wetlands and the aquifer. As a result, they are only likely to receive groundwater inflows from perched groundwater systems. As such these wetlands have been removed from the potential GDE spatial dataset.

The extent of potential groundwater dependent vegetation communities was initially classified by vegetation type. Mapped Eucalyptus forest and woodlands are considered to be the only obligate groundwater dependent vegetation community, and consistently occur over shallow water tables potentially in connection with the Quaternary Bridgewater Formation aquifer. A number of potentially facultative groundwater dependent vegetation community types are identified (Melaleuca forests and woodlands, Melaleuca shrubland > 1 m, Allocasuarina forest and woodland, sedgelands / rushlands, Tussock grassland and coastal shrubland), but in many areas they exist over deep or perched water tables indicating that these vegetation communities may be only dependent on groundwater in specific locations. Any potentially facultative GDEs that occur over deep water tables have been removed from the potential GDE spatial dataset.

A remote sensing technique (Normalised Difference Vegetation Index - NDVI) was used to interpret whether each of the potentially groundwater dependent vegetation communities has access



to groundwater based on inferred water stress signatures. NDVI is typically high where potentially groundwater dependent vegetation (obligate and facultative) communities are mapped over shallow water tables suggesting that these vegetation communities have access to groundwater. Where facultative groundwater dependent vegetation occur over deep water tables, NDVI is typically low, suggesting that these vegetation communities do not have access to groundwater and the soil water store is low. This provides some confidence in the potential for NDVI to be used as a tool for interpreting the presence or absence of groundwater dependent vegetation communities in the study areas where hydrogeological information is not available. There are, however, some inconsistencies between NDVI and facultative phreatophytes in the Southern Basins PWA. There are a number of factors (such as, vegetation health and density, perched groundwater systems) that potentially contribute to these inconsistencies, but they cannot be resolved with the currently available datasets. Some ground-truthing would be required to resolve these inconsistencies before confidently applying NDVI across the study areas to interpret the presence or absence of groundwater dependent vegetation.

There are no appropriate spatial datasets for mapping springs, soaks, hypogean, hyporheic or collapsed sinkhole ecosystems in the study areas. Hyporheic ecosystems are likely to exist wherever surface water and groundwater connection occurs, so mapped spatial extents can be assumed to be consistent with those potentially groundwater dependent wetlands, lakes, springs and swamps mapped in this study.

Environmental water requirements of GDEs

GDEs have resistance and resilience mechanisms to withstand some natural variability in groundwater condition, however they are also likely to experience natural shifts in structure and composition over time in response to naturally changing climatic conditions when their resilience mechanisms are exhausted. As such, the environmental water requirements of ecosystems are naturally dynamic and it is likely that the structure and composition of GDEs on Eyre Peninsula have changed over time in response to climatic conditions. For example, GDEs were adapted to a wetter regime during the 1980s, but over the last couple of decades, during much drier conditions, have employed physiological mechanisms for withstanding natural variability and in some cases are likely to have changed composition and structure. Therefore their environmental water requirements would be different now, than what they were during the 1980s.

Thresholds of the groundwater component of environmental water requirements of each GDE type are proposed based on maximum depths to water and groundwater salinity over the period of hydrogeological monitoring. Since groundwater levels are broadly lower now than they have been for the rest of the monitoring record, EWRs are broadly defined by current conditions. Ideally this would be compared to ecosystem condition over time to assess how GDEs respond to changes in groundwater regime. However this level of understanding about ecosystem condition is currently



limited to anecdotal evidence regarding red gum dieback in discrete areas of Musgrave PWA, indicating that whilst mature red gum (obligate phreatophyte) can withstand some water table drawdown, there are certain rates of groundwater level decline that they cannot adapt to.

Threats to GDEs

Changes in groundwater conditions that threaten GDEs have largely been driven by lower than average rainfall conditions over the last 10 to 15 years. Groundwater extraction and land uses that impact on groundwater condition in vulnerable areas are likely to exacerbate the impact on GDEs. Potential GDEs that are interpreted to occur near areas of groundwater extraction have been identified and prioritised in order of their sensitivity to changes in groundwater condition.

GDE prioritisation

GDE prioritisation is based on, in order of significance, threat of change in groundwater condition induced by groundwater extraction, the resistance and resilience of the GDE to changes in groundwater condition, and whether or not the GDE is restricted to areas where it can access groundwater (obligate or facultative). For example, those potential GDEs that are likely to occur in areas where there is a high risk of change to the groundwater regime are ranked highest. Of these, the GDEs that have the least resistance and resilience to change in groundwater regime are ranked highest, and of these, the GDEs that are restricted to areas where they have access to groundwater (obligate) are ranked highest.

This method of prioritisation identifies springs, soaks, obligate phreatophytes and hyporheic ecosystems to be the most vulnerable to changes in groundwater conditions in the study areas. However, there is very little known about springs, soaks and hyporheic ecosystems on the Eyre Peninsula.

Options for managing GDEs in PWAs

The approach adopted for the Southern Basins and Musgrave PWA is an effective approach to the management of groundwater systems that are highly sensitive to annual recharge (that is where the ratio of aquifer storage to recharge is relatively small). The use of rules that link allocations to resource conditions (e.g. saturated thickness and salinity) is also supported.

However, there are areas where further development of a management response could occur, including:

- Set clear management objectives related to the required condition of the resource, health and characteristics of GDEs and needs of consumptive users;
- Link annual allocations to discharge rates as well as recharge rates;



- Quantify the linkage between the percentage of recharge allocated annually and changes to the resource condition (water level and salinity);
- Consider a tiered management response which ensures appropriate responses are applied to the highest priority GDE assets and develop a flexible approach for consumptive users;
- Investigate and account for environmental water requirements and provisions under a variable (and drier) climate scenario; and
- Set environmental water provisions in the broader context of balancing needs of consumptive and environmental users, as well as accounting for climate variability at the inter-annual and inter-decadal time scales.

Recommendations

Some of the GDEs that are the most vulnerable to changes in groundwater condition are those that we know the least about. Further investigations need to target these vulnerable ecosystems (e.g. spring, soak and hyporheic ecosystems), and to link changes in groundwater condition to changes in ecosystem condition.

Remote sensing techniques (e.g. NDVI) show good potential for use as indicators of groundwater use by vegetation across the study area, but interpretation requires ground-truthing before it can be confidently applied.

The following actions are recommended to progress development of appropriate management responses:

- Develop agreed management objectives – balancing consumptive and environmental uses;
- Develop a framework that allows alignment of management response to risk/priority;
- Quantitatively link allocations based on rainfall recharge to changes in discharge rates, including estimation of lag times;
- Develop resource condition limits to support volumetric allocations. The resource condition limits should take into account suggested EWRs and current trends in groundwater condition;
- Develop an analysis of the influence of inter-decadal climate variability and change on the preferred management response – especially where climate is a primary driver on the management approach; and
- Develop an integrated groundwater – environmental monitoring and evaluation scheme.



1. Introduction

1.1. Background

The Eyre Peninsula Natural Resource Management (EP NRM) Board engaged Sinclair Knight Merz Pty Ltd (SKM) to undertake a scoping study of groundwater dependent ecosystems (GDEs) in the Southern Basins and Musgrave Prescribed Wells Areas (PWAs), and around Robinson Basin on the Eyre Peninsula. The purpose of the GDE scoping study is to improve the understanding of GDEs in the project areas on the Eyre Peninsula in order to assist water managers to develop better strategies for incorporating GDEs into future Water Allocation Plans (WAPs).

The South Australian *Natural Resources Management Act 2004* (the Act) provides the legislative arrangements for the integrated use and management of South Australia's natural resources. South Australia's natural resource management regions and regional boards were established under the Act. Regional Natural Resource Management Boards are accountable to the Minister and are responsible for regional natural resource planning, investment, delivery and decision-making. As part of the Boards responsibilities under the Act the Board must prepare, implement and review a WAP for each of the prescribed water resource areas. The WAP is a statutory instrument that is used for various purposes in the administration of the Act.

In particular, a WAP must provide for the allocation and use of water to achieve:

- An equitable balance between social, economic and environmental needs for the water, and sustainable rate of water use.
- Assessment of the capacity of the water resource to meet the continuing demand;
- Provision of policy for the transfer of water allocations.
- Assessment of the quantity and quality of water needed by GDEs, and any detrimental effects of using water from the resource on the quality and quantity of water available from any other water source.

The objective of WAP policy, in relation to the water needs of the environment, is to provide effective management approaches to ensure GDEs receive environmental water provisions. The environmental water provision is the water provided to the environment to sustain at least the basic function of ecosystems, whilst making allowance for economic and social interests. The environmental water requirement (EWR) is the water regime needed to sustain the ecological values of wetlands, rivers, aquatic ecosystems and terrestrial vegetation, including their processes and biological diversity, at a low level of risk. An EWR will either be the same as or more than an EWP.



Existing WAPs for prescribed groundwater resources on the Eyre Peninsula include basic qualitative and environmental water provisions for various GDE types occurring in the Southern Basins and Musgrave PWAs. The current WAPs support a volume of water for maintaining the health and integrity of GDEs for the PWAs. On average 60% of the total estimated recharge to the Quaternary aquifer systems and 90% of the Tertiary aquifer systems is allocated for the maintenance of GDEs. These figures were conservatively assigned due to limitations in data regarding the EWRs of GDEs at the time of prescription. There is mounting community pressure to refine these requirements in light of new information.

Whilst a quantity of water has been allocated to the environment on the Eyre Peninsula, there appears to be no mechanism for delivery of that water to GDEs. Due to the variable climate, the timing and form of delivery of water to ecosystems is critical, however this is not described in current water allocation planning. Future analysis of GDEs needs to account for the spatial and temporal variability of the needs of high priority ecosystems. The first step toward achieving this is to identify where potential GDEs exist within the PWAs.

The EP NRM Board is undertaking an investigation into GDEs in project areas on the Eyre Peninsula as one component of a larger National Water Commission (NWC) funded project, ‘*Eyre Peninsula Groundwater Allocation, Planning and Management*’. This project was borne out of community concern expressed during a recent WAP review regarding the sustainable management of groundwater basins. The purpose of the scoping study is to improve the knowledge of GDEs in the region and assist managers to incorporate adequate and informed provisions for GDE management into future WAPs to ensure the long-term sustainability of the region’s water resources.

It is expected that the outcomes of this project will feed into a future review of the WAPs and be part of a decision making process to develop an equitable allocation regime.

The delivery of water to priority ecosystems via a water allocation planning process should be undertaken as part of a process that identifies *acceptable levels* of impact to the groundwater resource given the range of threats and a sound understanding of the hydrogeology. This analysis should take into account the needs of consumptive and environmental users – such as critical water and salinity thresholds.



1.2. Project objectives and scope

1.2.1. Objectives

The key project objectives are to:

- Use existing information to identify and represent GDEs in a GIS coverage;
- Demonstrate a qualitative understanding of the EWRs for each GDE, including identification of drivers and threats;
- Review and suggest amendments to the current WAPs with regard to GDEs; and
- Suggest further technical work in order to close knowledge gaps.

1.2.2. Scope of work

There are three key components to this project:

- Identify and develop an understanding of the spatial distribution of potential GDEs;
- Assess the EWRs of potential GDEs; and
- Develop policy options for managing GDEs through water allocation planning in the Eyre Peninsula PWAs.

1.3. What are GDEs?

1.3.1. GDE Categories

GDEs can be both terrestrial and water-based ecosystems (both saline and fresh) and are unique from other ecosystems in that they rely on groundwater for some or all of their water requirements. There are typically five categories of GDEs:

Wetland GDEs are ephemeral or permanent wetland systems that receive seasonal or continuous groundwater contribution to water ponding or shallow water tables. The ecosystems include fringing (riparian) vegetation, aquatic flora and fauna (e.g. water birds and terrestrial fauna) (SKM, 2007).

River Baseflow GDEs occupy or fringe ephemeral or permanent streams to which there is a continuous or seasonal groundwater contribution to flow. In many senses these GDEs interact with groundwater similarly to wetland GDEs, except that water turnover is usually quicker (SKM, 2007).



Terrestrial vegetation GDEs include deep and/ or shallow rooted vegetation communities that use groundwater to meet some or all of their water requirements. Also includes fauna that utilises the habitat formed by the vegetation community (e.g. birds, mammals and reptiles) (SKM, 2007).

Estuarine/marine GDEs include coastal springs which can create unique hydrological conditions where they occur; influencing the local temperature and quality of coastal waters and potentially providing unique habitat for specialised flora and fauna.

Subsurface GDEs are those below the surface of the ground which depend on groundwater to an extent that they would be significantly altered if the quantity and quality of groundwater were to change. Such ecosystems include stygofaunal communities which exist within aquifer systems, including caves and subsurface voids that can also harbour terrestrial fauna as well as those endemic to aquifers. Of all GDEs, less is generally known about these ecosystems, although research in this area is increasing.

1.3.2. Types of groundwater dependence

There are four key groundwater attributes that GDEs may rely on (either individually or in combination) in different environments, these are:

- Level – e.g. water table elevation to sustain subsurface ecosystems.
- Quality – e.g. groundwater discharge providing essential nutrients to aquatic ecosystems.
- Flux – e.g. maintenance of baseflow to rivers during dry periods.
- Pressure – e.g. groundwater discharge from confined aquifers, such as the Great Artesian Basin, to springs that support unique flora and fauna.

GDEs are described as having either “obligate” or “facultative” dependence on groundwater. The term “obligate” GDE does not refer to the need for continuous access to groundwater, it means the ecosystems will only exist where groundwater is available at critical times. Some obligate GDEs may require continuous access to groundwater, whilst others will only require access to groundwater seasonally or episodically.

Facultative GDEs rely on groundwater, where available, but can also exist where groundwater is not available if surface water and soil water resources are sufficient to sustain them. That is, the presence of groundwater is not critical to the presence of facultative GDEs. Other factors, such as landscape position, dictate the sources of water used.

1.3.3. GDE resistance and resilience

The ability of an ecosystem to withstand reduced water availability depends on the **resistance** and **resilience** of the various components of the ecosystem to change, and the condition of the



ecosystem at the time of water shortage. Resistance relates to the capacity of the ecosystem to resist change (e.g. by increasing leaf water potential to overcome the effect of water table drawdown, by extending roots to keep in contact with the capillary fringe, by maintaining a reduced population of aquatic fauna in surface or subsurface refuges). Resilience relates to the capacity of an ecosystem that has been adversely affected by water shortage to recover to its prior condition (e.g. for leaves to commence normal rates of photosynthesis, for aquatic ecosystems to recover population, structure and biodiversity).

The resistance of GDEs to changed groundwater conditions (level, quality, pressure, flux) will be impacted by the timing and the duration of the altered groundwater regimes, which may then affect the degree of resilience. Forms of groundwater dependency are defined in Table 1.1.

■ **Table 1.1 Forms of groundwater dependence (from Howe *et al.*, 2006)**

Form of dependence	Definition
Total	Non-resilient ecosystems, where only small changes in groundwater condition (level, quality, pressure, flow) have a drastic affect.
High	Ecosystems having low resistance, or low resilience, to altered groundwater condition, where “moderate” change affects species distribution, composition and/or health.
Proportional	Ecosystems exhibiting a degree of resistance, or resilience, to altered groundwater condition, resulting in subdued (or proportional) response.
Limited	Ecosystems having limiting reliance on groundwater, typically at the end of dry seasons or during drought.
None apparent	Ecosystems not dependent on groundwater.

It is important to note that a part of GDE resilience to altered groundwater regime hinges on successful recruitment which is severely hampered if areas are heavily grazed. That is, groundwater management can enable favourable groundwater regimes for GDEs, but if grazing and other land use pressures prevent juvenile trees from reaching maturity to replace older trees, then the structure and composition of forests, shrublands and woodlands and the habitats they provide will change.



2. Physical Environment

2.1. Location

The Eyre Peninsula, located in South Australia, is bordered by the Spencer Gulf to the east, the Great Australian Bight to the west and to the north by the Gawler Ranges.

This project focuses on three groundwater resource areas of the Eyre Peninsula (Figure 2.1):

- Southern Basins PWA, located to the south and west of Port Lincoln on the southern coast;
- Musgrave PWA, which surrounds the town of Elliston on the east coast; and
- Robinson Basin, located close to Streaky Bay, north of Musgrave.

2.2. Climate

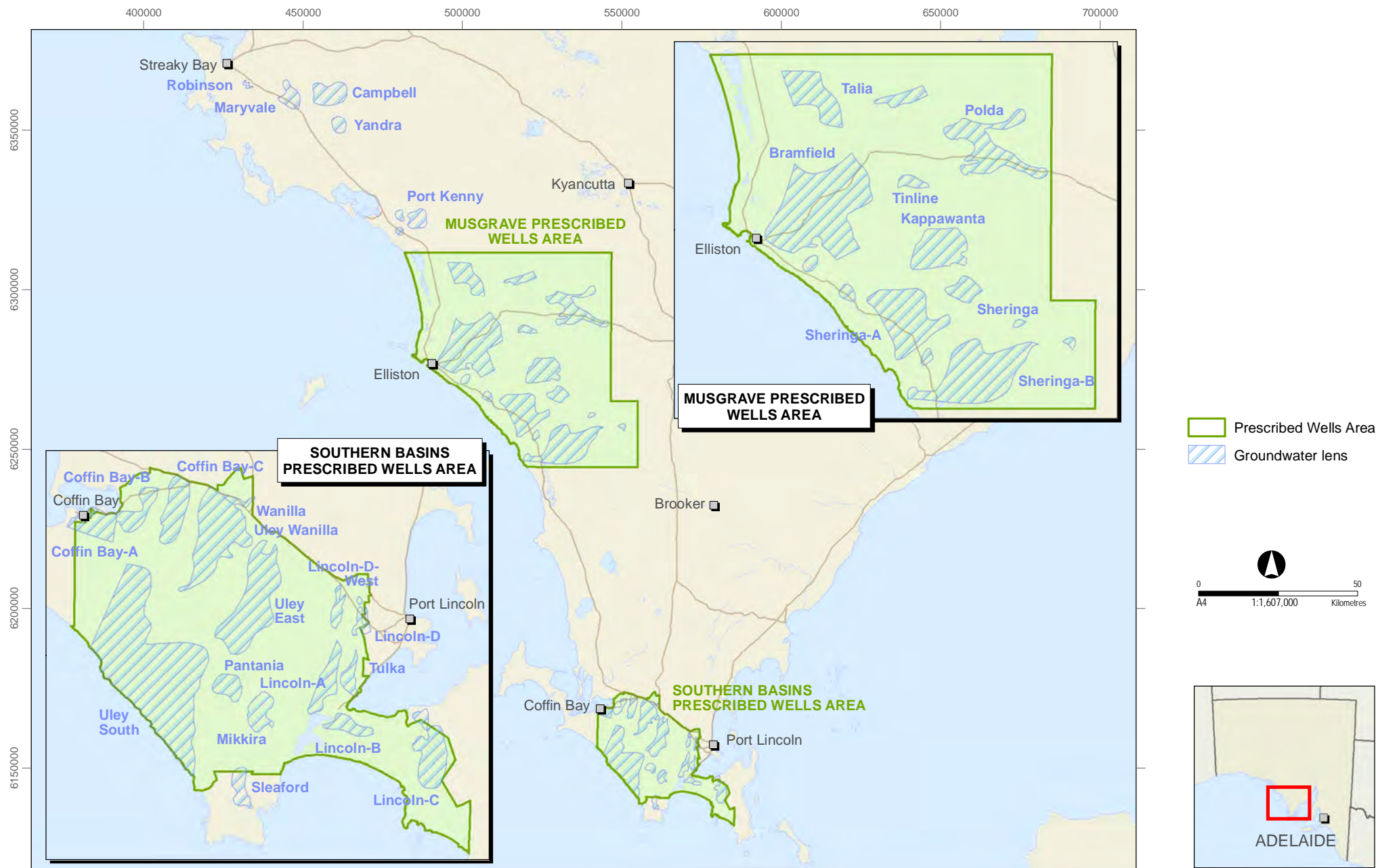
Eyre Peninsula has a characteristic Mediterranean climate, with warm to dry summers and cool, wet winters. It enjoys a mild, moist, coastal climate in the south and southwest, with warmer, drier climates inland to the north and northeast. Mean annual rainfall ranges from 250 mm in the north and northwest to more than 500 mm in the south. Annual rainfall is variable with 50% typically occurring between May and August.

Rainfall records over the last 100+ years show varying deviation from the annual average rainfall, i.e. wet and dry cycles (Figure 2.2). Since the early 1990s, annual rainfall has shown a declining trend, remaining below average, and credible climate models predict increasing drier conditions in the future (Howe & Clark, 2009).

2.3. Hydrology

Eyre Peninsula does not have abundant surface water resources. The low rainfall, high evaporation rate, permeable soils and relatively flat landscape, typical of much of the region, allows little surface run-off and few surface water resources. Surface water flow is limited to the eastern and southern ranges of the catchment, which covers approximately 400 square kilometres. The Tod River is the only permanent flowing river system in the catchment.

There are over 2800 designated land-based wetlands in the region (Wainwright, 2008), some of which are considered significant on a regional and national scale. Saline lakes are by far the most common, such as Lake Hamilton and Lake Newland in the Musgrave PWA, followed by saline marshes, shrub swamps and freshwater sedge marshes (Wainwright, 2008), which are generally intermittent wetlands, which are present in winter when rainfall and groundwater levels are highest, and typically dry in summer when water inputs are lowest and evapotranspiration is high.

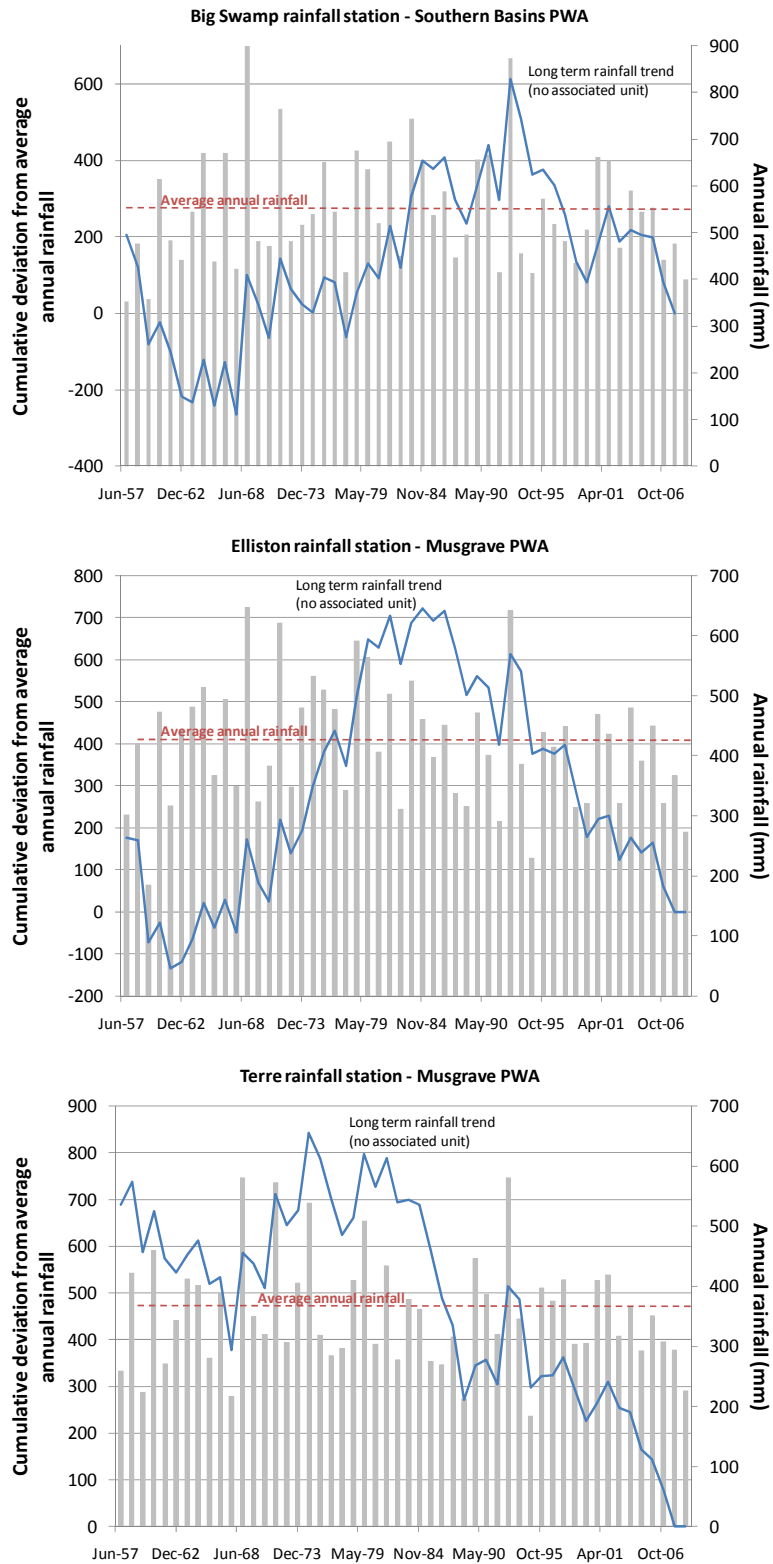


Locality map

GDA 1994 MGA Zone 53

Figure 2.1: Location of study areas and PWA boundaries

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■ **Figure 2.2 Eyre Peninsula annual rainfall data**



The total wetland area for Eyre Peninsula is approximately 64,000 hectares with a mean of 21 hectares and a maximum size of 3,170 hectares (Seaman, 2002). About 20% of wetlands are relatively well understood with long-term baseline information.

2.4. Hydrogeology

2.4.1. Overview

Eyre Peninsula lies on some of the oldest basement rocks known in South Australia. In recent times this ancient surface, has been overlain by Tertiary Sand and Quaternary limestone sediments. The overlying sediments are thin over the basement highs, and thick within the basement troughs forming basins which contain the accessible groundwater resources. The two main aquifers are the Quaternary Bridgewater Formation and the Tertiary Sands Aquifers. In some areas of the basins, a clay sequence occurs on top of the Tertiary Sands and behaves as an aquitard between these two layers, however the clay sequence does not extend across all of the basins and there are several areas of the Southern Basins and Musgrave PWA where the formation is not present. Such areas include the southern extents of Uley East and Uley Wanilla lenses. Beyond this the interaction between these two aquifers is not well understood (Howe and Clark, 2009).

The potable groundwater resources in the basins occur as isolated shallow water table lenses within the Bridgewater Formation. These resources are delineated by geological structure and the 1.5 mS/cm isohaline (Clarke 2003). In areas where the clay sequence is not present there is a high potential for local hydraulic connection between the aquifers.

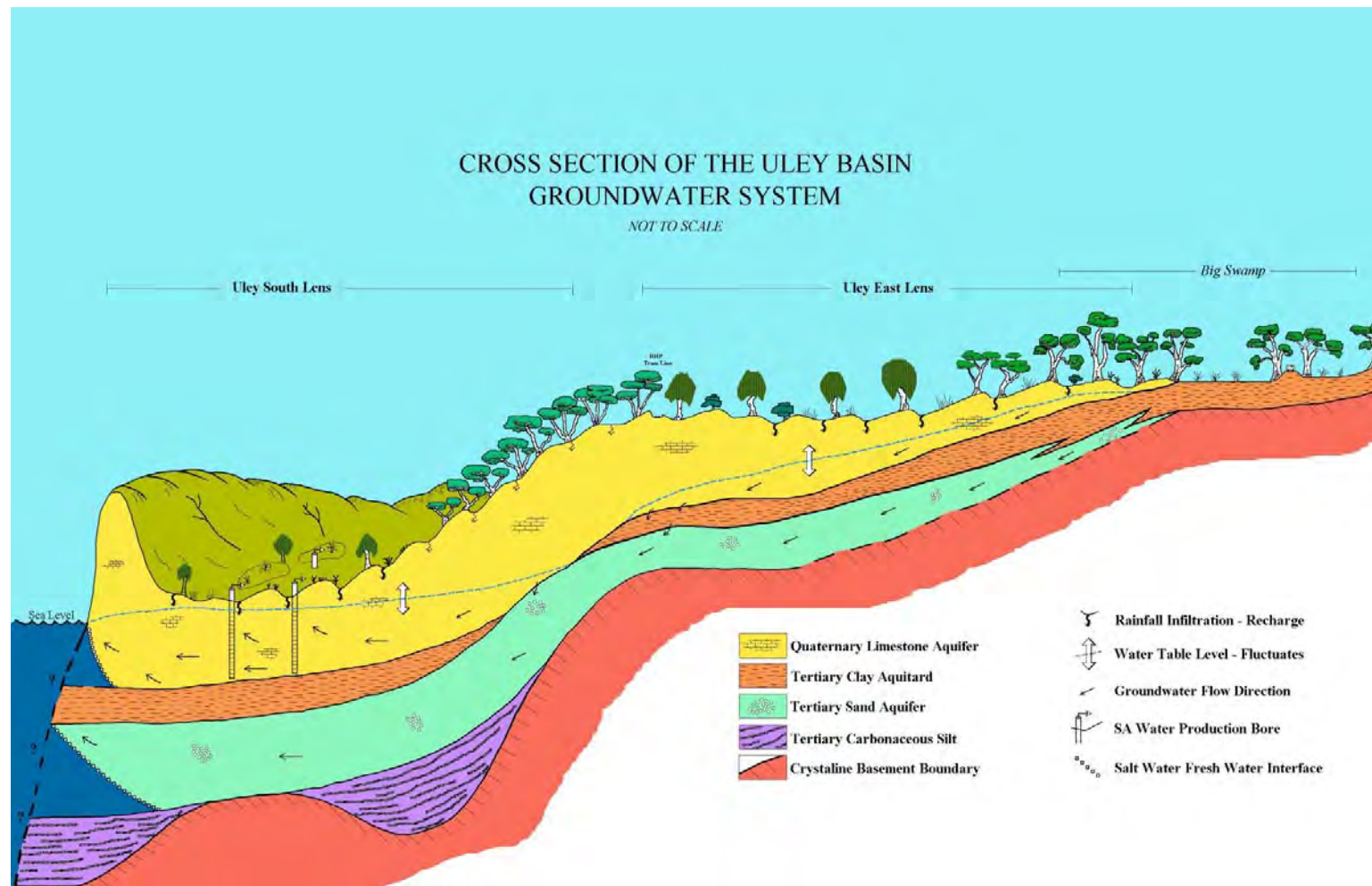
Groundwater level monitoring data collected across the Eyre Peninsula show a distinct correlation with rainfall, often irrespective of groundwater extraction trends. The recharge reductions associated with predicted drier conditions may therefore result in a continued declining trend in groundwater levels across the majority of the Eyre Peninsula despite groundwater management implementation.

Water level behaviour within the Quaternary Bridgewater Formation reveals that recharge occurs after intense rainfall events, where short lived overland flow is directed to solution features (sinkholes) and infiltrate to the water table rapidly. The sinkholes are often characterised by washouts with no soil. Research of the Uley Basin system in the Southern Basin PWA (Evans, 1997) indicates that these resources show an annual water level rise when they receive more than 10 days of >10 mm of rainfall between the months of May and October. It is estimated that up to 30% of the annual rainfall will infiltrate as recharge to these Quaternary lenses.

The underlying geology and hydrogeology of the Eyre Peninsula is summarised in Table 2.1 and a conceptual model of the hydrogeology is illustrated in Figure 2.3.

■ **Table 2.1 Geology and hydrogeology of the Eyre Peninsula (after Evans, 2002)**

Age			Stratigraphy	Hydrostratigraphy	Southern Basins	Musgrave Basin	Streaky bay (Robinson lens)
Cainozoic	Recent	Holocene	<i>Coastal dunes</i> : Fine-grained aeolianites, unconsolidated, actively mobile. Grains comprise calcite and shell fragments.	<i>Unconfined aquifer</i> : seasonal, small yielding, thin, low salinity supplies located at the base of the mobile sand dune systems	Semaphore Sand and Gantheaume Sand Members (St Kilda Formation)		
	Quaternary	Pleistocene	<i>Bridgewater Formation</i> : Aeolianites, fine to medium-grained, cross-bedded, weakly to moderately cemented, Grains are calcite and shell fragments, mainly 0.1–1.5 mm. Generally calcrete at surface.	<i>Unconfined aquifer</i> : generally low salinity. Permeability ranges from low to very high. Transmissivity ranges from 2.0 x 10 ³ to 8.0 x 10 ³ m ³ /d/m. The usual target aquifer for large water supplies on Eyre Peninsula.	Bridgewater Formation		
	Tertiary	Eocene	<i>Uley Formation</i> : Sandstone, clayey to orange– brown quartz, well sorted and rounded, minor lateritic and non-lateritic gravel.	<i>Aquitard</i> : generally a confining layer beneath the Quaternary Aquifer. Where it is permeable can hold the water table or allow infiltration to the underlying sediments	Uley Formation	Undifferentiated	
			<i>Wanilla, Poelpena and Pidinga Formations</i> : Clays, sands (quartz) and gravels with thin lignite layers. Sand is generally fine-grained, less than 0.5 mm, uncemented or weakly cemented.	<i>Semi-confined to confined aquifer</i> : low to moderate permeability but with marked variations vertically and laterally. Salinity variable and generally higher than the overlying unconfined aquifer.	Wanilla Formation	Poelpena Formation	Pidinga Formation
Mesozoic	Jurassic		<i>Polda Formation</i> : Sands (quartz), silts and clays. Sand grains usually less than 0.5 mm; occasionally up to 3 mm. Sediments generally carbonaceous and contain lignite beds.	<i>Confined aquifer</i> : very low permeability, high groundwater salinity generally exceeding 14 000 mg/L.	-	Polda Formation	-
Proterozoic	Neo-Proterozoic		<i>Pre-Cambrian Basement</i> : Schists, gneisses and quartzites intruded by granites and basic rocks. Deeply weathered in places.	<i>Semi-confined to confined aquifers</i> : groundwater occurs in the weathered profile or within the fracture spaces of these rocks. Salinity generally exceeds 7000 mg/L, occasionally lower.			



■ **Figure 2.3 Conceptual model of hydrogeology across the Southern Basins PWA, Eyre Peninsula (after Evans, 2002)**



2.4.2. Southern Basins Prescribed Wells Area

The major lenses in the Southern Basins PWA are grouped into three distinct zones (Figure 2.1):

- Coffin Basin, comprised of three freshwater lenses: Coffin Bay A, B and C;
- Uley Basin, comprised of three major freshwater lenses: Uley Wanilla, Uley East and Uley South, and some minor freshwater lenses; and
- Lincoln Basin, comprised of four freshwater lenses: Lincoln A, B, C and D.

Together these provide 85% of the regions reticulated water. Uley South is the largest lens, supplying 70% of reticulated demand. Groundwater elevation in this lens has seen sharp declines attributed to increased groundwater usage from the mid 1970s and decreased annual rainfall during the 1990s but currently remains relatively stable. Groundwater is also extracted from the Uley Wanilla lens, which is currently at the allocated limit (Howe & Clark, 2009).

Groundwater elevations vary widely between basins as shown in the hydrographs in Figure 2.4 and typically range between ~3 mAHD to ~78 mAHD, with lower groundwater elevations generally occurring in areas closer to the coast; increasing with distance inland (Figure 2.4). Previous work in the Southern Basins (Harrington *et al.*, 2006) identified the presence of steep groundwater gradients and low transmissivities in the Uley East and Uley Wanilla lenses, whereas the Uley South lens was characterised by flat gradients and higher transmissivities. Groundwater flow in the area is generally away from topographically high areas, in a westerly direction in Uley Wanilla lens and southerly direction in Uley East lens (Evans, 2002). These steep gradients may be contributed to by significant downward leakage from the Quaternary Bridgewater Formation to the Tertiary Sands Aquifers at the southern extents of the Uley East and Uley Wanilla aquifers. The Uley Wanilla lens has also had a northern discharge point through Fountain Springs in the past. This discharge has subsequently been controlled via a low permeability barrier and sump pumps, however, current water levels now prevent the possibility of natural discharge to the surface (Evans, 2002). In the Uley South Basin, dominant groundwater flow is southwest towards the Southern Ocean and west toward Coffin Bay.

Within the Lincoln Basin, consisting of Lincoln A to D lenses, groundwater is primarily recharged via direct rainfall, although Lincoln D receives some surface water inflow from Little Swamp. Groundwater flows are thought to be northeasterly within Lincoln A and C lenses, northerly in Lincoln B lens and southerly in Lincoln D lens (Evans, 2002).

Coffin Bay Basin consists of three discrete freshwater lenses: A, B and C. Water is extracted from the Coffin Bay A lens, which naturally discharges to the sea. Groundwater levels in bores constructed within these lenses are characteristically low, reaching ~1 mAHD close to production wells.



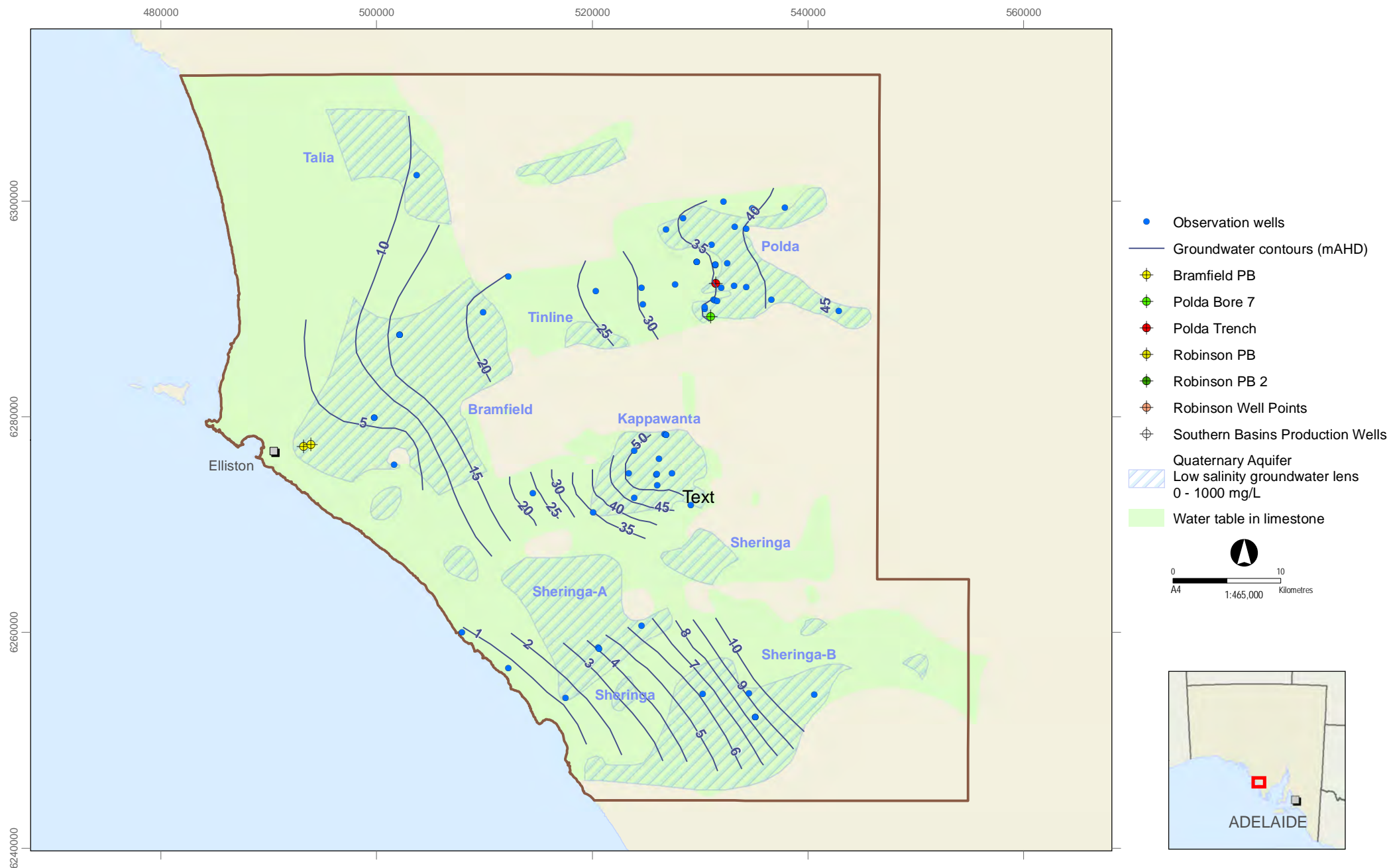
Groundwater salinity of the Southern Basins is thought to be influenced primarily by evaporation of rainfall recharge; leaving salt in surface soils in summer which is later leached into the aquifer during winter recharge events (Harrington *et al.*, 2006). Timeseries data in some areas show groundwater salinities have varied over a relatively small range despite increased extraction, which in other areas has lead to increased salinity levels.

Previous reports suggest that there has been a general groundwater level decline in the majority of lenses irrespective of wellfield development (Evans, 2002). This highlights the dominance of effective recharge on storage and is evident in the Uley Wanilla lens where groundwater elevation is currently at an all time low despite extraction levels also being at their lowest since commencement of pumping. Groundwater elevation is often more reflective of annual rainfall but they have continued to decline despite a recent return to average rainfall patterns. The reported downward leakage from the Quaternary aquifer to the underlying Tertiary aquifer at the southern extents of Uley Wanilla (Howe & Clark, 2009) may account for the continued decline in water table elevation. In the Uley South lens groundwater levels show distinct correlation with cumulative deviation from the mean annual rainfall observed at Big Swamp Rainfall Station, irrespective of increases and decreases in extraction levels, showing relatively stable patterns in recent years.

2.4.3. Musgrave Prescribed Wells Area

The water resources of the Musgrave PWA are mainly contained within isolated freshwater lenses that are separated by geologically-controlled structures. These include: Bramfield, Kappawanta, Polda, Polda North, Polda East, Talia, Tinline and Sheringa A and B lenses. Tinline lens (Figure 2.1) is characterised by high variation in groundwater elevations as shown in Figure 2.5. Similar to lenses in the Southern Basins (Figure 2.4), groundwater elevations in the Musgrave lenses show considerable spatial variability owing to the disconnected nature of the aquifers. Groundwater elevations have historically ranged between ~5 mAHD and ~64 mAHD and are generally shallow close to the coast; increasing towards the higher topographies in the west of the area (Figure 2.5).

Groundwater levels in the Polda lens are currently at their lowest since records began, with characteristic signs of stress seen in some Red Gum communities and groundwater levels dropping below the base of pumping infrastructure prohibiting extraction (Howe and Clark, 2009). Similarly, groundwater levels are at an all time low in the Bramfield lens, of which 90% of associated allocations are currently unused. In Kappawanta Lens groundwater extraction is limited to stock and domestic use and very little is known about levels of extraction.



Musgrave PWA

Figure 2.5: Quaternary limestone aquifer and water table elevations

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The continued decline in groundwater levels despite a reduction or plateau in annual groundwater extraction can be attributed to climatic factors. A continued period of increasingly below average rainfall observed at Terre Rainfall Station since the late 1970s corresponds with groundwater level data observed in monitoring bores up-gradient, adjacent, and down-gradient from the extraction zone in Poldia Lens (Howe and Clark, 2009).

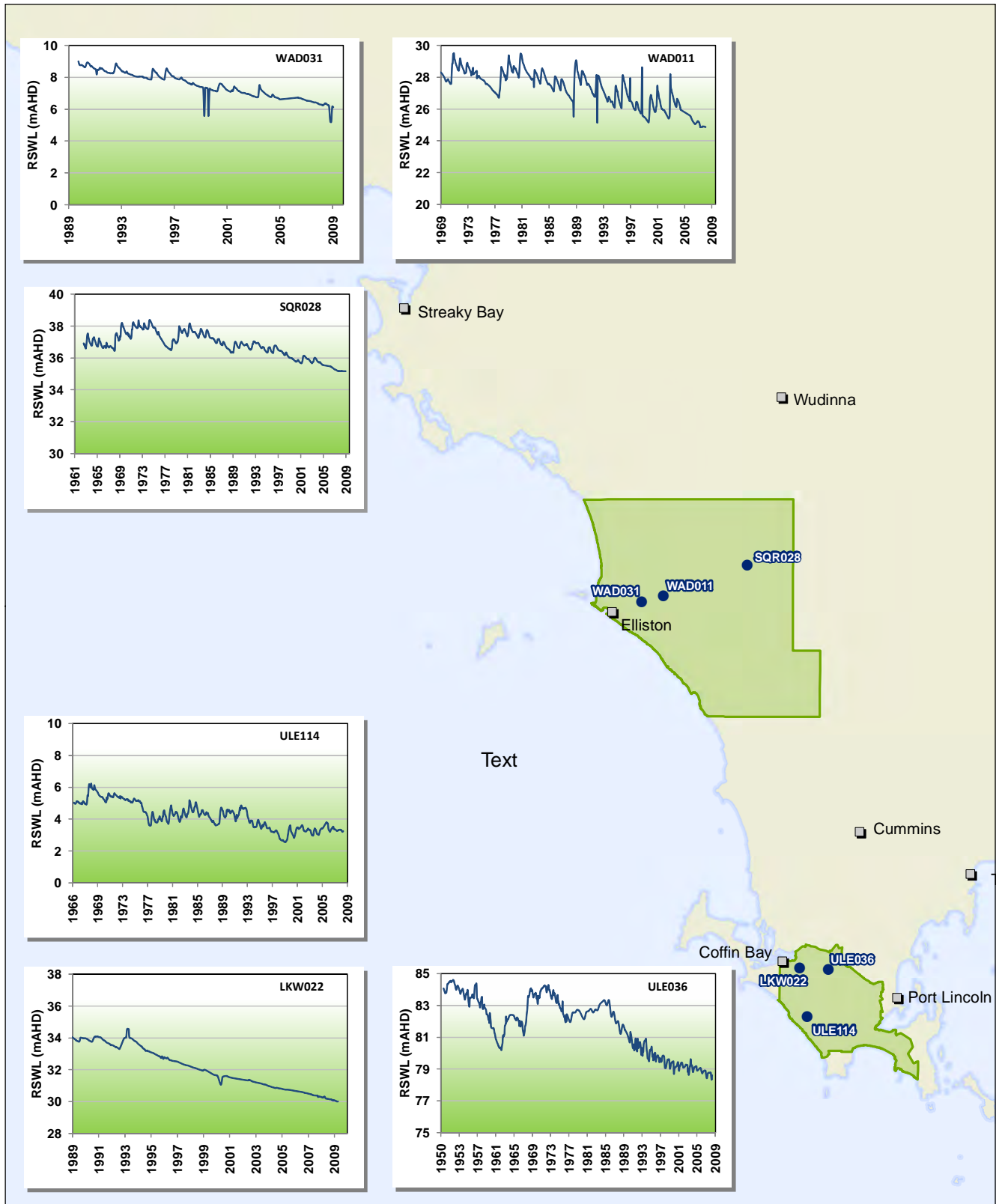
Similarly, in the Bramfield lens, groundwater elevations show declining trends over the last three decades, correlating with a declining trend in cumulative deviation from the mean annual rainfall (observed at Elliston Rainfall Station). Groundwater extraction has remained relatively stable over the same period and hence appears to have limited impact on groundwater levels, although there was a relatively sharp decline in water table elevation following commencement of extraction in 1974.

In the Kappawanta lens where annual extraction is limited to stock and domestic use, groundwater levels are also at their lowest since records began (with reductions of ~2 m), and trends generally correspond with annual average rainfall at Elliston.

The high recharge rate facilitated by the Quaternary limestone across the region has resulted in relatively low salinity groundwater (<1.5 mS/cm), which is unusual for similar semi-arid climates.

2.4.4. Robinson Lens

Robinson lens is located within Robinson Basin and has historically supplied the reticulated water demands for Streaky Bay. However, in recent years extraction has ceased due to the unsuitably high groundwater salinity yielded from production wells (Howe & Clark, 2009). Groundwater elevation contours from February 2002 show levels across the lens to be below sea level, with a constant cone of drawdown in the southwestern portion of the water protection reserve, owned by SA Water. This is the region within the reserve where all trenches and production wells are situated (Brown & Harrington, 2002). Hydrographs from representative bores show a distinct decline in levels since the mid 1990s (Figure 2.6), with groundwater levels remaining up to 1 m below sea level since 1998. This correlates with higher extraction since 1995 and typically below average rainfall (Brown & Harrington, 2001). Since 2003 extraction has reduced significantly and although groundwater levels show a small recovery in the mid 2000s, they have continued to decline. This suggests climate to be the greatest factor influencing water table elevation. Depths to water across the site range from ~9.5 m below ground level (bgl) in the northeast to ~2.5 m bgl in the southwest, generally mirroring topography. These depths to water mean that the water table is unlikely to be directly influenced by evaporation.



- Project Area
- Prescribed Wells Area
- Observation wells



Prescribed Wells Areas

Figure 2.6: Groundwater hydrographs for selected bores



Under pre-pumping conditions groundwater flow is thought to have been radially outwards from the recharge zone, but following pumping, the permanent drawdown cone has meant groundwater flow in the opposite direction, inwards towards the centre of pumping, with the result of reduced extent of the lens.

The freshwater lens sits above, and is separated from, the underlying saline groundwater by the Tertiary aquitard. The surrounding subsurface geology means that lateral inflow is very limited. Groundwater salinities have been increasing steadily ranging between ~1.9 and 2.8 mS/cm over the last decade.

2.5. Vegetation

Since European settlement, 55% of the original vegetation on Eyre Peninsula has been cleared, with an estimated 2,188,000 ha of native vegetation remaining (Matthews *et al.*, 2001); the majority occurring in areas of conservation and natural environments. Many of the largest blocks are in soils less suited to agriculture, such as deep sands or calcrete, with steeper country in the Cleve and Koppio Hills also retaining reasonably intact patches (EPCMB, 2005). Although remaining vegetation is generally highly fragmented, Eyre Peninsula provides an important habitat for numerous species of flora and fauna. The biogeographical isolation of the region has resulted in at least 40 endemic plant species (Matthews *et al.*, 2001).

In study areas, Mallee forest dominated by *Eucalyptus* spp, particularly *E. diversiflora* is the most widespread community with other important vegetation including *Melaleuca* spp. and *Allocasuarina verticillata*. Such communities make up the major component of vegetation coverage in the study areas; dominating the Southern Basins PWA, where the majority of land is managed for conservation and natural environments, these *Eucalyptus* dominated stands are present throughout the varying topographies of the area. In Musgrave, clearance for agriculture and plantations has resulted in lower percentage vegetation cover, especially in the lower coastal regions and lower topographies. *Eucalyptus* Mallee forest and tussock grassland predominate in this area with small patches of *Melaleuca* spp. shrubland. Similarly, the Streaky Bay area, including overlying Robinson lens contains patches of Mallee forest and tall *Melaleuca* spp. shrubland.



3. Groundwater dependent ecosystems

3.1. Eyre Peninsula GDEs and their value

Eyre Peninsula contains a range of ecosystems that are potentially dependent on groundwater. These are likely to include some wetland, river, spring, swamp, forest, shrubland, grassland as well as subsurface and marine ecosystems.

Eyre Peninsula contains over 1200 wetlands made up of several different types. Groundwater has been recognised as a significant contributor to many of the regions wetlands, and in many cases is considered to provide a significant proportion of wetland water requirements, particularly during dry periods, due to low surface water runoff and high pan evaporation. During wetter periods they are likely to receive the majority of their water requirements from surface water runoff. These include both saline wetlands, including Lakes and Lagoons such as Lake Newland and Sleaford Mere, and freshwater - brackish systems such as Peolpena and Myrtle Swamps, and Lake Hamilton.

Relatively little is known about coastal springs in Eyre Peninsula. Kelledie Bay hosts one such spring, where groundwater discharge is visible in the shallow coastal waters. It is likely that there are more coastal springs across the region in light of the hydrogeological nature of the region.

Springs and subsurface water soaks on Eyre Peninsula are associated with the limestone aquifers, sink holes and caves of the Bridgewater Formation. Examples of freshwater springs on Eyre Peninsula include the washpool at Baird Bay and Weepa Spring at Lake Newland. Marine springs and seepages also occur on Eyre Peninsula, such as in Gull Lake. Spring sand soak environments generally support sedges and rushes such as Knobby Club-rush (*Isolepis nodosa*).

A variety of vegetation communities and species exist across Eyre Peninsula that are potentially groundwater dependent. These include red gum woodlands (such as Tula West) containing potentially phreatophytic species such as Eucalyptus spp. (e.g. *Eucalyptus diversiflora*), Melaleuca spp. (e.g. *M. helmutorum* or Swamp Paperbark) and Allocasuarina spp. (e.g. *Allocasuarina verticillata*). Tussock grasslands, where Austrostipa spp. and Gramineae spp. dominate, may also exist over shallow water tables, acquiring some of their water requirement from the water table aquifer with roots that have been found to extend up to 4 m (Canadell *et al.* 1996). Rushland / sedgeland (predominantly Gahnia spp. and *Lomandra effusa*), typically associated with wetter soil conditions, may also rely on groundwater to some degree, especially where they occur in association with wetlands.

Table 3.1 provides a description of potential groundwater dependent ecosystems occurring within the study areas, their water requirements and value.



■ **Table 3.1 Description of potential groundwater dependent ecosystems occurring within the study areas, their groundwater requirements and value (information taken from Seaman (2002), WAPs, Boggons and Evans (2006), Matthews *et al.* (2001))**

Potential GDE type	Description	Water requirements in addition to surface water and soil moisture store	Value
Saline Swamps	<p>Swamps are generally level or closed depressions with seasonal or permanent water at or above the surface (may be due to shallow water table or locally perched system); sometimes biological (peat) accumulation occurs. Stands of Swamp Tea-tree (or Paper-bark) (<i>Melaleuca halmaturorum</i>), Mallee Honey Myrtle (<i>Melaleuca neglecta</i>), and Cutting Grass (<i>Gahnia trifida</i>). Saltmarsh (typically samphire flats) occurs within estuaries and sheltered bays along the west coast of Eyre Peninsula and coastal saline swamps may occur in similar locations but are dominated by sedges (mostly <i>Cyperaceae</i>).</p> <p>Examples in the study area include Hamp Lake and Myrtle Swamp.</p>	Seasonal small amounts of water, EC<5 mS/cm.	Saline swamps are important ecologically for providing vital habitat for wading birds. Eyre Peninsula saltmarshes also support plant species of high conservation value including the threatened species: bead samphire (<i>Halosarcia flabelliformis</i>) and cushion centrolepis (<i>Centrolepis cephaloformis</i>). Saltmarshes are also important hydrological buffers at the land/sea interface, regulating salinity and limiting erosion, and decreasing the suspended sediment load entering the marine environment. Coffin Bay Coastal Wetland is recognised as a nationally important wetland.
Saline Lakes	<p>Saline lakes are the predominant type of wetlands on Eyre Peninsula. They can be either permanent or ephemeral bodies of saline water that may be supplied by groundwater, surface water runoff or seepage of seawater. Salinity is controlled by water sources, geomorphology and local climatic conditions. On Eyre Peninsula, salt lakes occur primarily in the western region, with some lakes scattered inland. Most of these lakes are fed by discharge from groundwater and surface drainage from local rain. Many of the salt lakes on Eyre Peninsula are ephemeral with those along the coastline having more permanent waters than those further inland. Aquatic flora is generally scarce and mainly terrestrial-aquatic species dominate these wetlands. Genera of the family Chenopodiaceae are common including Halosarcia and Sarcocornia (glassworts or samphires). Several species of submerged aquatic genera (<i>Ruppia</i> and <i>Lepilaena</i>) also occur and are important food sources for wading birds.</p> <p>The most common canopy vegetation type is <i>Melaleuca halmaturorum</i> ssp. <i>halmaturorum</i>, however stands of Mallee Honey Myrtle (<i>Melaleuca neglecta</i>), Cutting Grass (<i>Gahnia trifida</i>) and occasional river Red Gum (<i>Eucalyptus camaldulensis</i>) may also occur.</p> <p>Examples in the study area include Lake Tungketta, Middle Lake, Lake Newland and Sleaford Mere.</p>	Seasonal large amounts of water, EC<5 mS/cm.	<p>Saline lakes provide important habitat for a wide range of waders, shorebirds and other waterbirds. Some saline lakes such as Sleaford Mere, Lake Newland and Pillie Lake are recognised as being nationally important. These lakes support vulnerable waterfowl and provide drought refuge. Some are internationally important for Banded Stilt and nationally important as a summer feeding habitat for the Vulnerable Hooded Plover. The <i>Melaleuca halmaturorum</i> ssp. <i>halmaturorum</i> tall shrubland vegetation community is also considered rare on Eyre Peninsula.</p> <p>The bottoms of many salt lakes are covered with benthic microbial mats dominated by producers. Thus flora provides the basis of the food chain in many salt lakes. The macro-invertebrate populations of many salt lakes are important in supporting water birds.</p>
Grasslands/Sedgeland	<p>These ecosystems consist of perennial species and help maintain high invertebrate fauna diversity. Tussock grasslands cover a significant area of the landscape in the Southern Basins and Musgrave PWAs. Dominant species include Austrostipa spp. and Gramineae spp. Sedgeland communities on the Eyre Peninsula are dominated by Cutting Grass (<i>Gahnia trifida</i>), Thatching Grass (<i>Gahnia filum</i>) and also Swamp Tea-tree (<i>Melaleuca halmaturorum</i>) and Mallee Honey Myrtle (<i>Melaleuca neglecta</i>).</p> <p>Examples in the study area include old plough swamp.</p>	Seasonal moderate amounts of water, EC<1 mS/cm.	Several species of butterfly are totally dependent on Gahnia sedgeland for part of their life cycle. Sedgeland also provide important habitat for the Nationally Vulnerable and State and Regionally Endangered Eyre Peninsula Southern Emu-wren, which is endemic to southern Eyre Peninsula (Matthews <i>et al.</i> , 2001). Typically they support the following threatened ecological communities: freshwater aquatic herbland/sedgeland; and gahnia sedgeland.



Potential GDE type	Description	Water requirements in addition to surface water and soil moisture store	Value
Springs and Underground Water Soaks	<p>The location of springs is controlled by local geology, such as faults or erosion of confining beds of rock that control the upward flow of groundwater. Outflow from a spring can result in the formation of an open body of water, swamp and/or a small creek. The area of wetland vegetation supported by a spring is directly proportional to the flow rate of the spring and topography. On Eyre Peninsula freshwater springs are associated with the limestone aquifers, sink holes and caves of the Bridgewater Formation. Spring sand soak environments generally support sedges and rushes such as Knobby Club-rush (<i>Isolepis nodosa</i>).</p> <p>Examples of freshwater springs on Eyre Peninsula include the Weepdra Spring at Lake Newland.</p>	Seasonal large amounts of water, EC <1 mS/cm.	Springs are important because they can provide a source of permanent water, maintain the water level of lakes and provide a unique habitat. The springs on Eyre Peninsula probably support a unique flora and fauna. Springs are also important as drought refuges for wildlife and as habitat for migratory birds. In semi-arid landscapes, such as Eyre Peninsula, spring communities are often more biologically diverse than other wetland systems because there is a constant supply of water. For this reason they support significant populations of macro-invertebrates, which in turn support abundant water bird populations.
	<p>Although not relying on groundwater, marine springs and seepages which also occur in the Lake Newland wetland complex. These springs rely on sea water (EC>30,000 mS/cm) that seeps through the rock (e.g. limestone) profile and are not connected to the sea over the land surface. Marine springs are species-rich because they support fauna that is normally absent from inland wetlands, such as marine fauna, and provide a permanent water source for wetlands that would otherwise be dry. The marine springs on Eyre Peninsula are dominated by molluscs. Such springs are also likely to acquire part of their water requirements from rainfall seepage.</p>	EC >30 mS/cm	
Hypogean and Hyporheic Ecosystems	<p>These ecosystems occur underground or move between underground and surface environments and usually consist of macro-invertebrates and micro-organisms.</p> <p>Hyporheic zones are areas of intensive biological activity driven by the mixing of oxygenated surface water and anaerobic groundwater in the subsurface surrounding wetland, river and potentially collapsed sinkhole systems. The mixing of the different water types facilitates redox reactions that transform and transfer critical chemicals to surface water and subsurface habitats.</p>	Seasonal large amounts of water, EC<1, mS/cm.	The ecosystems within these subsurface environments are likely to provide habitat for rare macro- and micro-fauna, with a high likelihood of undescribed and poorly understood species. Hyporheic ecosystems are likely to be represented as a component of other groundwater dependent ecosystems. These environments provide an important refuge for macro-invertebrates and micro-organisms when surface water environments dry-out. Macro-invertebrates and micro-organisms within hypogean and hyporheic environments are important drivers of biotic and biochemical processes within the broader system.
Collapsed Sink Holes	<p>These ecosystems consist of shady and moist environment plant forms, including Rock Fern (<i>Cheilanthes austrotenuifolia</i>).</p>	Seasonal moderate amounts of water (from groundwater and surface water runoff), EC<1 mS/cm.	Provide important habitat for unique and diverse flora and fauna, including species that rely on damp conditions that may not be available outside of the sinkholes. Sinkholes may be fed by groundwater or surface water or both and may support similar macro-invertebrates and micro-organisms as freshwater lakes. Sink holes are also likely to be regionally significant in a landscape context, potentially providing watering points for grainivorous birds following localised run-off or if groundwater fed. Collapsed sink-holes are likely to support a differing community of plant species from surrounding areas, including species tolerant of prolonged water-logging which are potentially rare or uncommon from a regional context.



Potential GDE type	Description	Water requirements in addition to surface water and soil moisture store	Value
Phreatophytes (e.g. Red Gums)	These ecosystems consist of deep rooted plants that tap into underground water including the River Red Gum (<i>Eucalyptus camaldulensis</i>) and Tiny Bog-rush (<i>Schoenus nanus</i>).	Intermittent large amounts of water, EC<1 mS/cm ¹ .	<p>Provide habitat for waterbirds and other bird species. Phreatophytes provide vital habitat for a large range of local fauna species, as well as migratory bird species commonly found in association with aquatic environments. Large trees, such as <i>Eucalyptus</i> and <i>Allocasuarina</i> species, provide significant roosting, nesting and foraging opportunities. Large trees offer vantage points for birds of prey, including both terrestrial and aquatic dependent species (e.g. white bellied sea eagles, kingfishers). Large trees and shrubs also support nectivorous species (via production of flowers and nectar), granivorous species, and insectivores.</p> <p>Phreatophytes such as red gums may be regionally significant, in that, they may be surrounded by cleared land that is used for other purposes which may not be suitable for use as habitat and food resources by local and migratory fauna.</p>
Freshwater Lakes	<p>They can be either permanent or ephemeral bodies of fresh water that may be supplied by groundwater or surface runoff.</p> <p>Examples in the study area include Big Swamp.</p>	Seasonal large amounts of water, EC<1 mS/cm.	<p>Freshwater lakes provide important habitat for a wide range of waterbird guilds, through the provision of feeding sites, as well as roosting and nesting sites in surrounding water dependent and tolerant vegetation. A number of water birds are migratory species protected Nationally under the EPBC Act by international agreements (JAMBA, CAMBA and ROKAMBA). Freshwater lakes support high levels of faunal and floral diversity compared with surrounding landscapes, particularly in arid landscapes, due to the ecotonal transition between aquatic, riparian and terrestrial vegetation within a confined geographic region. As such, these ecosystems can represent refuge areas, or biodiversity 'hotspots' in periods of prolonged drought.</p> <p>Freshwater lakes may contribute to "gaining" and "losing" conditions with underlying aquifers. Lakes may lose their surface water during aquifer recharge but gain surface water from bank storage as the pool level declines. Vegetation surrounding freshwater lakes may be dependent on the lake for water. During dry conditions where lakes may lose their surface water to aquifer recharge, surrounding phreatophytic vegetation may utilise shallow water tables until surface water is re-established in the freshwater lakes.</p> <p>Freshwater lakes that are not directly connected to the underlying aquifer as a result of confining layers do not access groundwater but may still provide valuable habitat for a wide variety of waterbirds, macro-invertebrate fauna and micro-organisms.</p>
Damp Coastal and Sub-Coastal Heath	These generally infertile, waterlogged coastal wetland communities occur in bays and estuaries that are sheltered from wave action. They are influenced by oceanic water and in some cases freshwater runoff and groundwater. Often characterised by Cutting grass (<i>Gahnia trifida</i>) with Swamp Tea-tree (<i>Melaleuca halmaturorum</i>).	Winter flooding, large amounts of water EC 5 - 40 mS/cm.	Coastal heath vegetation supports a wide variety of local fauna, including a range of reptiles and many small bird species reliant on dense vegetation communities for refuge and nesting. Coastal heath communities are known to comprise of high diversities of flora, resulting in disparate flowering and fruiting times, thereby providing food resources for fauna all-year round. These systems therefore provide good refuges for fauna during periods of prolonged drought. This wetland type is known to provide vital habitat for the Eyre Peninsula Southern Emu-wren (<i>Stipiturus malachurus parimeda</i>) which is Nationally Vulnerable including in coastal areas around Coffin Bay and Sleaford Bay.

¹On the Murray floodplain river red gum have been found to survive at groundwater salinities up to 25 mS/cm.



3.2. Threats to Eyre Peninsula GDEs

It is recognised that GDEs are not only threatened by changes in groundwater conditions. They are also vulnerable to grazing, disease, weed infestation, climate change, land use change, natural disasters, surface water diversion, pollution, for example. As such GDE condition cannot be protected by groundwater management strategies alone. Broader ecosystem management also needs to be considered, such as land management and pest control.

Eyre Peninsula GDEs are adapted (resistant/resilient) to some natural variability in groundwater conditions (amplitude of change in groundwater levels and pressures, fluxes and ranges of groundwater salinity) due to the highly variable climate. However, land use change and groundwater extraction, might modify groundwater conditions beyond critical limits of change that GDEs can withstand, resulting in changes to ecosystem structure and loss of biodiversity.

The key threats to groundwater condition within the Sothern Basins PWA, Musgrave PWA and Robinson Basin are groundwater extraction, land use change and the drier than average climatic conditions that have persisted over the last decade or so. These have resulted in reduced availability of low salinity groundwater to support GDEs. In some cases this may be due to increased depth to groundwater, but in other cases might be through depletion of low salinity groundwater lenses and induced inflows of higher salinity groundwater.



4. Conceptualisation of GDEs and their Interactions with Groundwater Systems

GDEs are often high value ecosystems, serving several functions in the landscape. These values are outlined in Table 3.1.

4.1. Saline swamps

There are two types of potentially groundwater dependent saline swamps existing in the study areas (Figure 4.1). These are:

- 1) Seasonal saline swamps, which contain waterlogged soils for a portion of most years, occur where water tables rise to the ground surface. Swamps that occur at topographical low points are also likely to collect surface water runoff. As surface water recedes, water tables fall and the soils dry seasonally, ecosystem species are still likely to require access to groundwater from shallow water tables since shallow soil reservoirs may not be sufficient to sustain vegetation for long periods; and
- 2) Inter-tidal saline swamps, which are inundated by seawater during high tides, occur where water tables are close to the ground surface and require access to lower salinity groundwater (via the capillary fringe) to offset seawater to sustain them.

Seasonal saline swamps are likely to be more resistant to changes in groundwater condition than intertidal salt swamps, because they are naturally adapted to a variable groundwater regime. Whereas groundwater conditions near the coast, where intertidal salt swamps occur, are buffered by seawater levels and are likely to be less variable than seasonal saline swamps.

Water table drawdown by groundwater extraction is also likely to be buffered by seawater near the coast. Whilst groundwater extraction near the coast can lead to seawater intrusion, the shape of the salt wedge (due to density effects) is likely to maintain a lower salinity water zone at the top of the water table (if the water table is not drawn down below sea level). Therefore seasonal saline swamps are likely to be more vulnerable to groundwater extraction than intertidal saline swamps.

4.2. Saline lakes

There are three types of saline lakes recognised in the study areas, two of which are potentially dependent on groundwater (Figure 4.2). These are:

- 1) Permanent saline lakes that are connected to the Quaternary aquifer, which maintain a surface water expression of water all year round due to groundwater discharge, particularly during summer and prolonged dry periods.

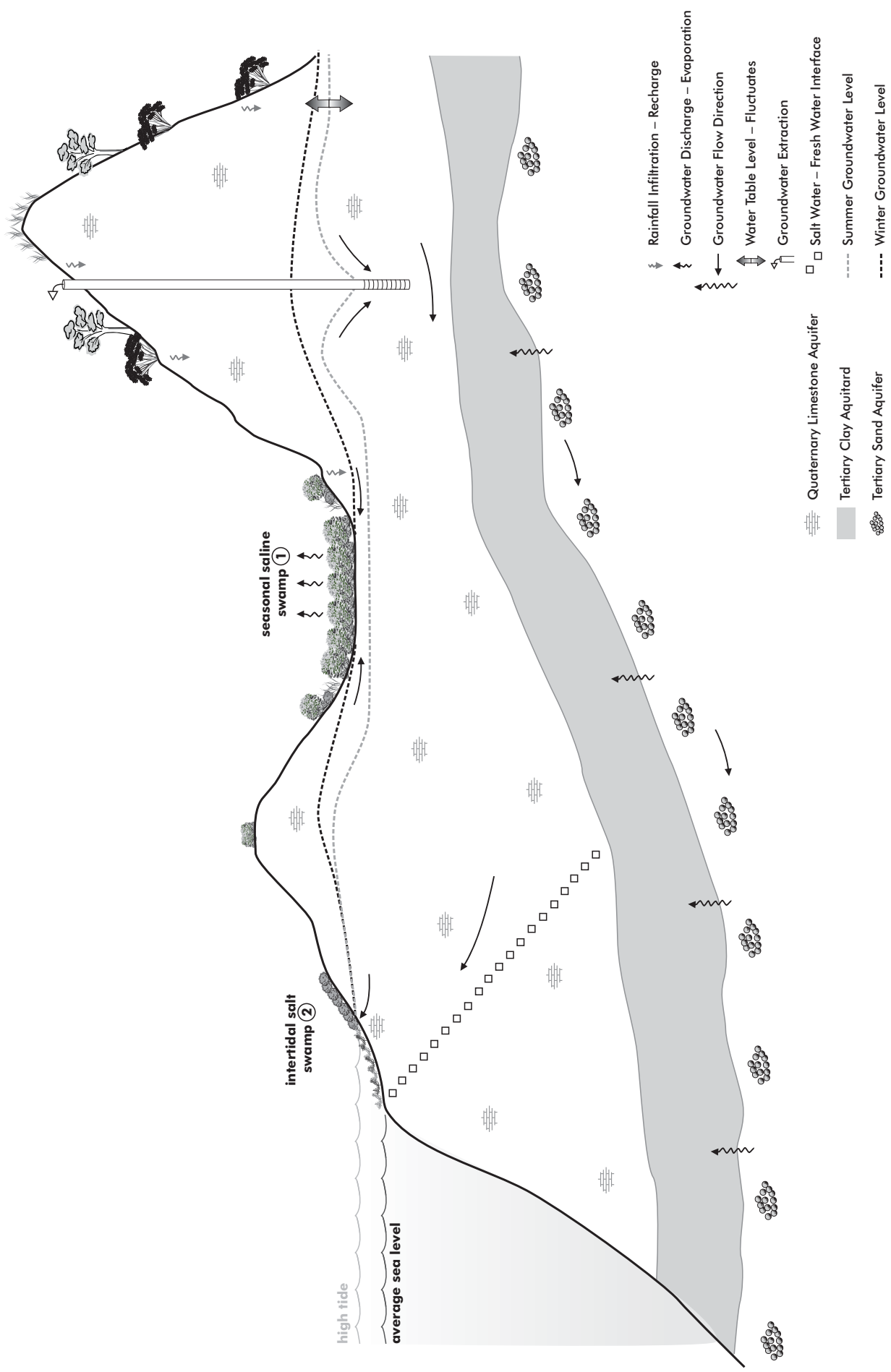


Figure 4.1 Saline Swamps

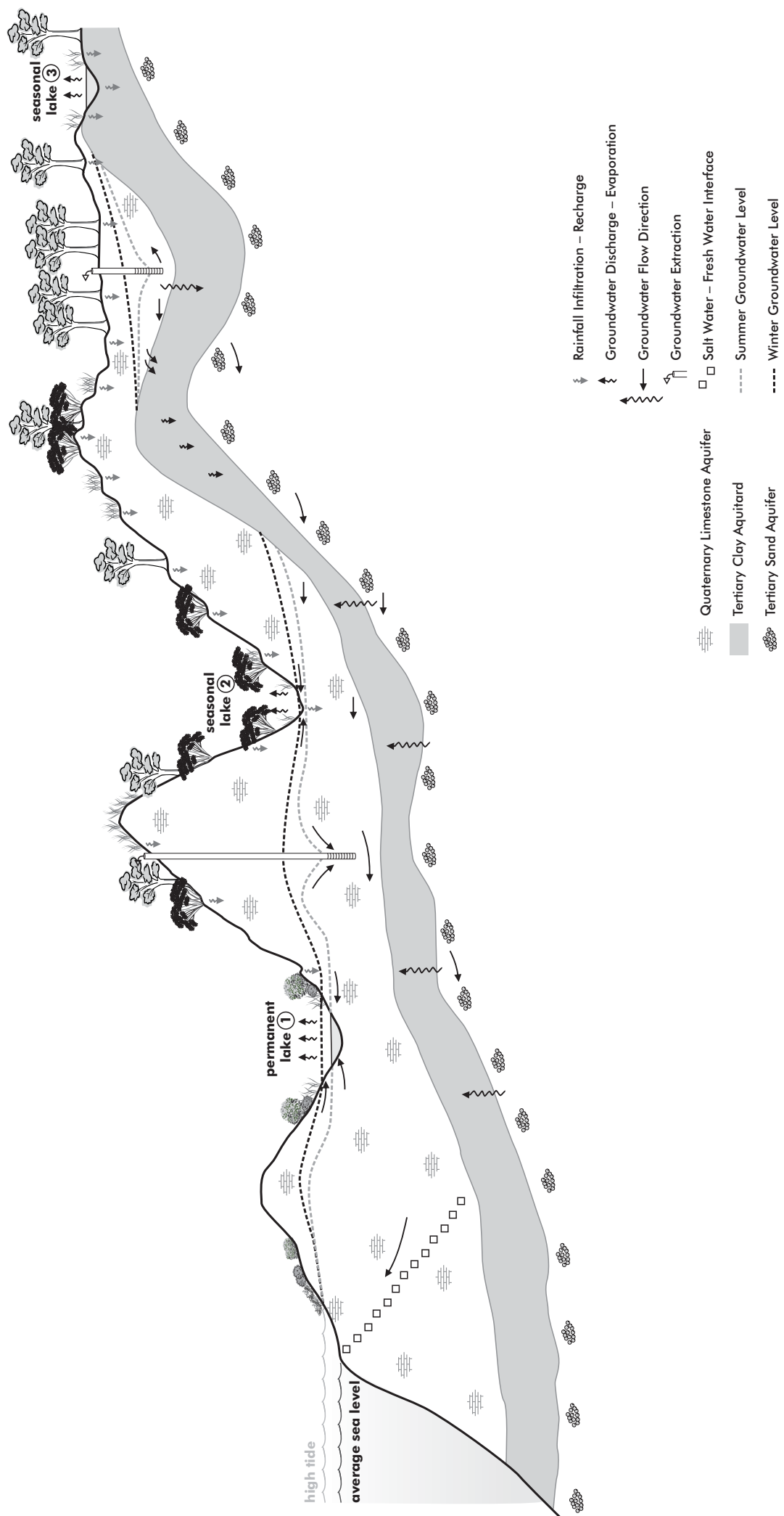


Figure 4.2 Saline Lakes



- 2) Seasonal / intermittent saline lakes that are connected to the Quaternary aquifer, which receive groundwater discharge as surface water levels recede, extending the period of time that these lakes maintain a surface expression of water seasonally or episodically. Once surface water has dried, some species that exist within the seasonal / intermittent saline lake ecosystem are likely to be maintained by shallow water tables to sustain them during the dry periods since shallow soils are unlikely to hold sufficient moisture to sustain them for long periods.
- 3) Seasonal / intermittent saline lakes that are disconnected from, and therefore do not access, groundwater from the Quaternary aquifer.

Seasonal / intermittent saline lakes that are disconnected from the Quaternary aquifer may receive groundwater inflow from perched aquifer systems, but will not be impacted by (are resistant to) groundwater extraction from the Quaternary aquifer. Permanent saline lakes and seasonal / intermittent saline lakes that are connected to the Quaternary aquifer are less resilient to changes in groundwater condition due to groundwater extraction in the Quaternary aquifer.

Seasonal / intermittent saline lakes are likely to be more resistant to changes in groundwater condition than permanent saline lakes, because they are naturally adapted to a more variable surface water and groundwater regime. Therefore permanent saline lake ecosystems are likely to be more vulnerable to groundwater extraction than seasonal / intermittent saline lake ecosystems.

4.3. Springs and underground water soaks

Springs are surface expressions of groundwater and will often persist longer than surface water fed systems during summer and prolonged dry periods, providing habitat and refuges for wildlife and habitats for migratory birds.

Springs also feed into other surface water systems such as to rivers, wetlands, estuaries or the marine environment (Figure 4.3 and Figure 4.4) where groundwater discharge is likely to maintain critical surface water levels or quality (e.g. salinity or temperature) for particular elements of ecosystem function (e.g. fish spawning). Spring-fed ecosystems are likely to have a low resistance to changes in groundwater regime because they are adapted to receiving groundwater inflows at critical times to maintain water levels or quality. Their resilience to recover from changes in the groundwater regime once more favourable groundwater conditions return is unknown.

Seawater fed springs are also reported to occur in the study areas. These occur where seawater flows through the aquifer system and discharges to inland surface depressions (Figure 4.4). In these environments, it is seawater inflow, rather than groundwater inflow that maintains surface water levels and quality that are critical for ecosystem function.

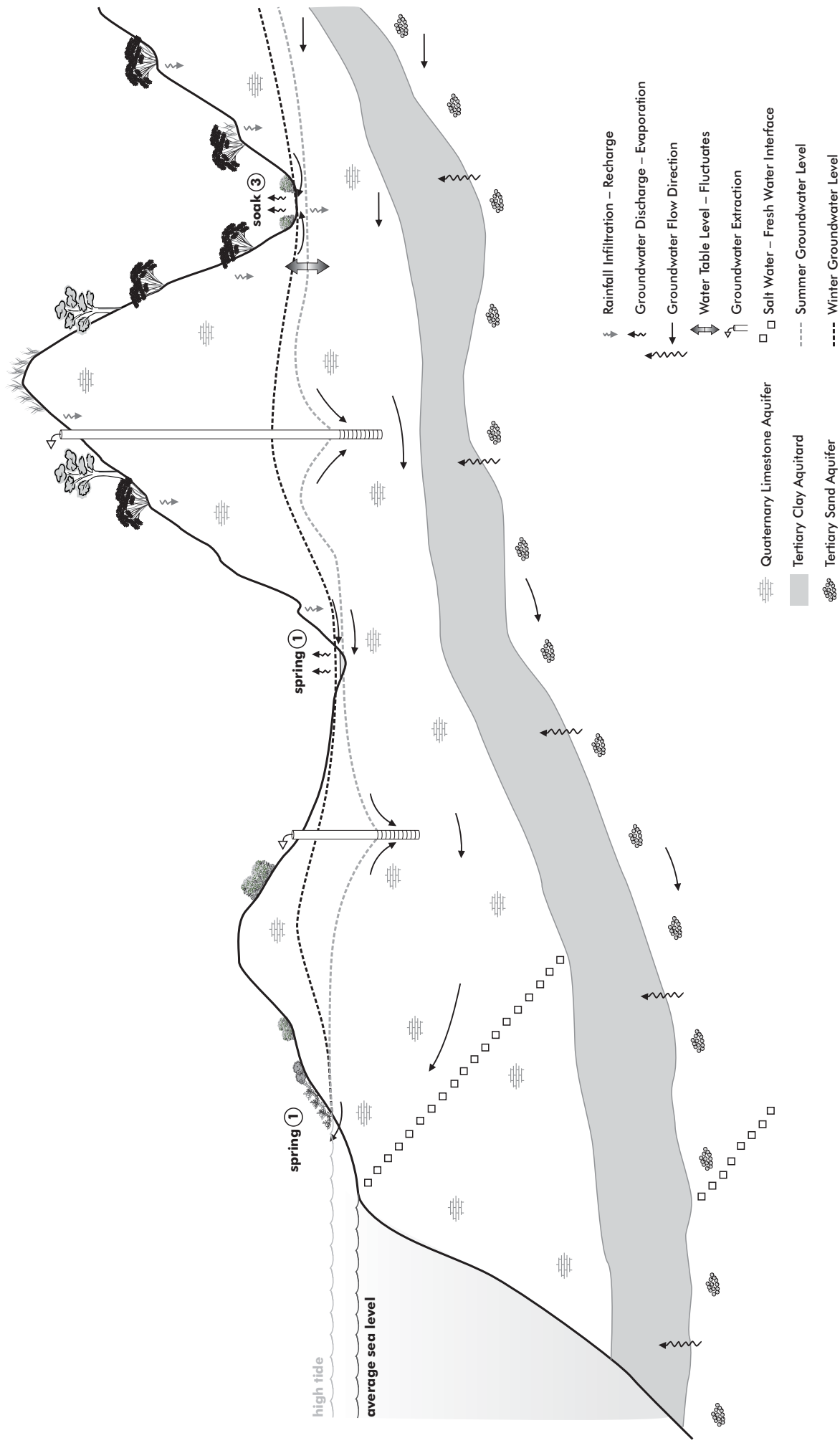


Figure 4.3 Springs and Soaks

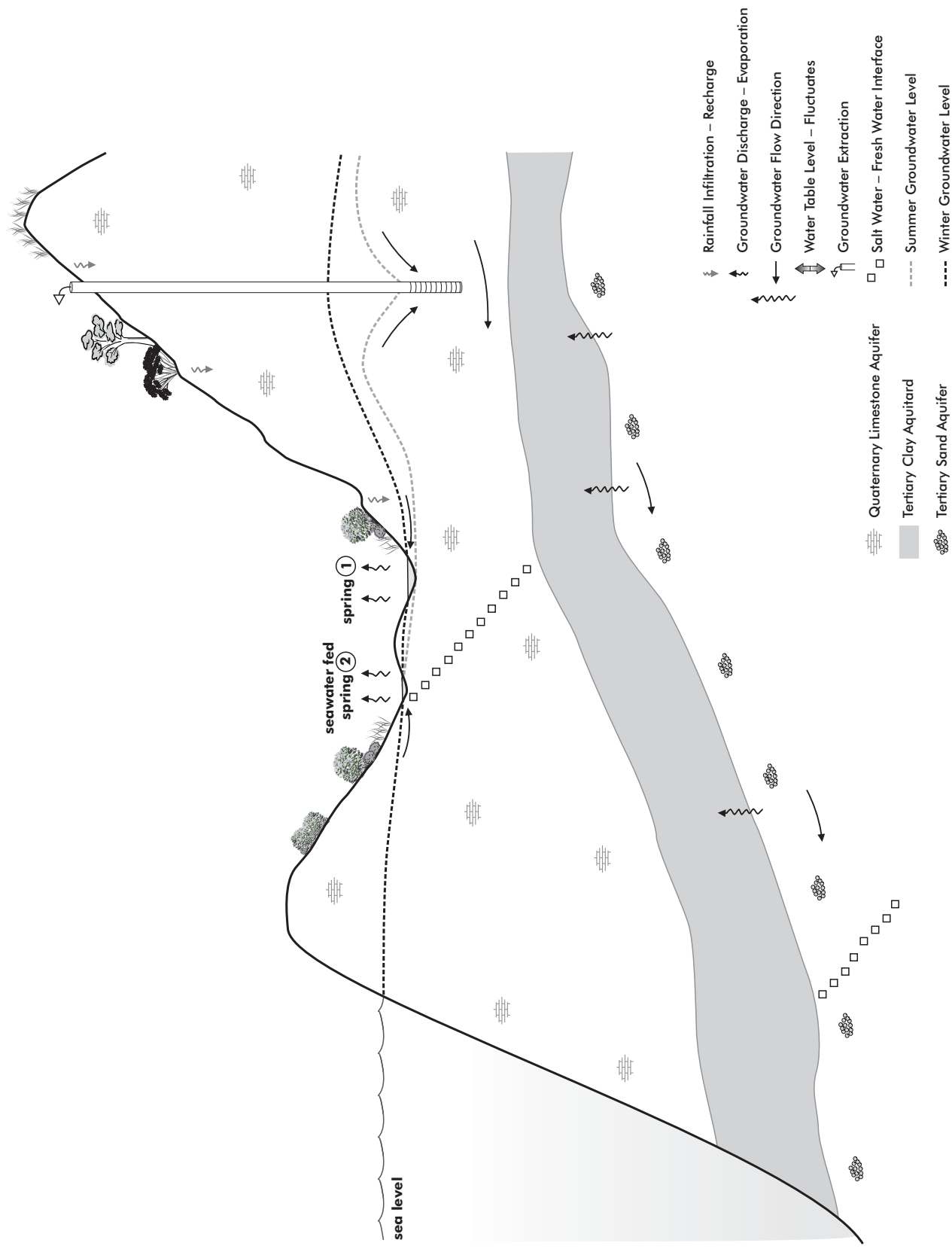


Figure 4.4 Springs



Soaks occur where groundwater seepage maintains waterlogged soils and it is assumed that they provide a similar habitat for wading birds and contain some high conservation value threatened plant species as saline swamps (Table 3.1).

4.4. Grasslands and sedgeland

There are three types of grasslands and sedgelands existing in the study areas (Figure 4.5). These are:

- 1) Sedgelands located on periodically inundated/waterlogged and wet areas. These are most commonly associated with seasonal freshwater ponds in the study areas, but also occur in seasonal saline swamps in the Musgrave PWA. Access to typically (either permanently or seasonally) water logged soils is likely to be critically important to their existence in a landscape. The level of groundwater dependence of sedgelands associated with wetlands is inherently linked to that of the adjacent/associated wetland system.
- 2) Tussock grasslands that occur in areas with shallow water tables. These are relatively sparse across the total area of mapped grassland in the study areas; the largest area overlying Poldia Basin in the Musgrave PWA. They generally occur at lower elevations but are also found to a lesser extent at higher topographies. They are found in areas that do not necessarily have shallow water tables year-round, and are often interspersed with grasslands that occur in areas with deep water tables. They are therefore likely to be facultative in nature; using groundwater on an opportunistic basis, and soil water when levels fall below the extent of their root system. That is, tussock grassland will be groundwater dependent in some circumstances and not in others.
- 3) Tussock grasslands that occur in areas with deep water tables. This grassland makes up the majority of the mapped areas. Occurring over water tables greater than 4 m below ground level, these grassland communities are thought to be non-dependent on groundwater for their water requirements. They typically form a mosaic with grasslands occurring over shallow water tables and likely comprise the same mix of species; taking advantage of shallow water tables when and where they occur.

Areas of tussock grassland growing above shallow water tables are likely to be more vulnerable to changes in groundwater condition than those growing over deeper water tables. Whilst groundwater is not critically important to the existence of tussock grassland in the landscape, if the groundwater conditions change at rates that they cannot adapt to, some dieback is likely to occur. The community as a whole is resilient and is likely to be able to germinate and thrive in affected areas, even if groundwater conditions do not return to what they were originally (depending on the moisture capacity of soils).

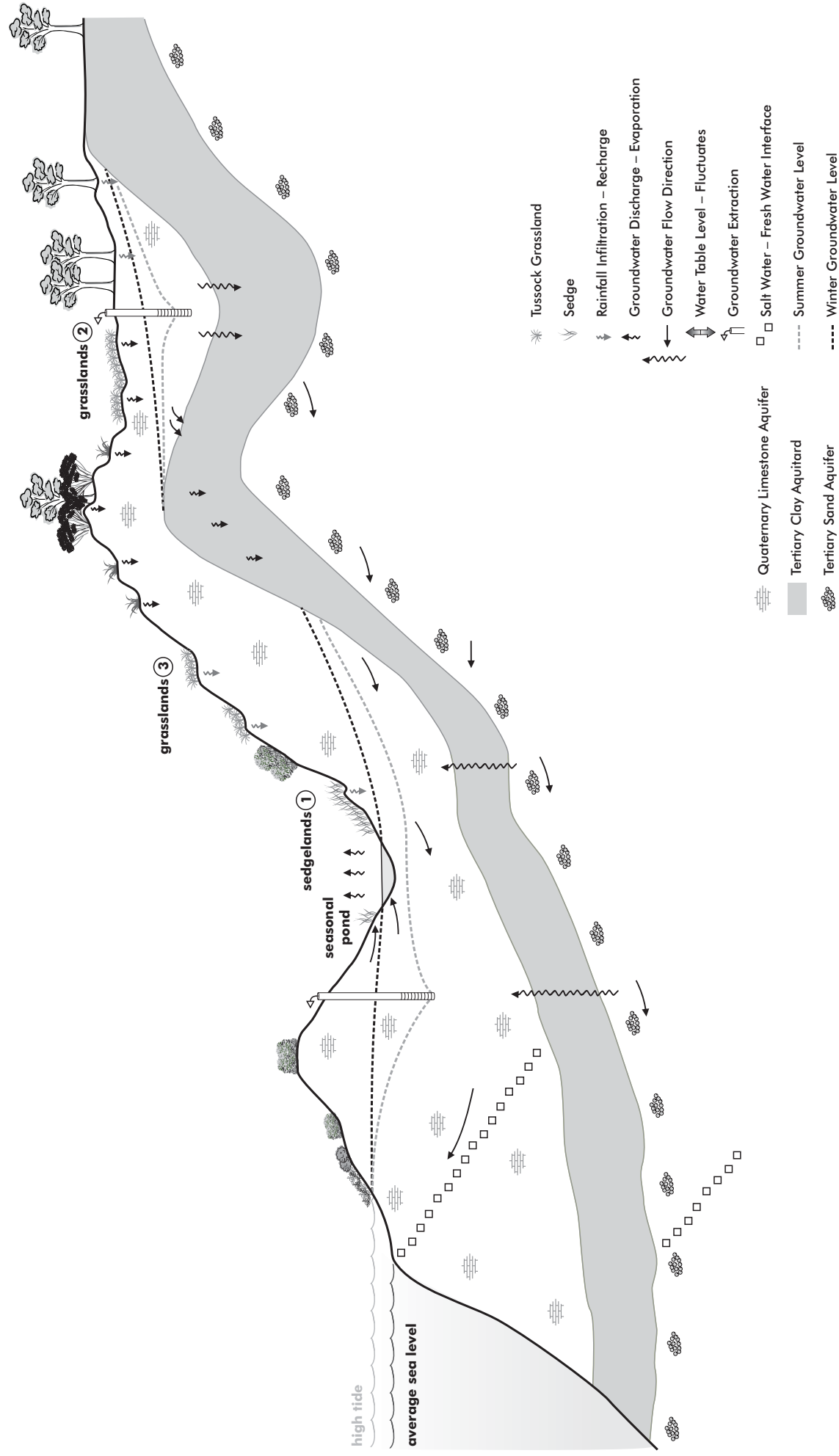


Figure 4.5 Grasslands/Sedgeland



Sedgelands are more vulnerable to changes in groundwater condition than grasslands because they appear to be limited to growing in water logged areas (at least part of the year) and specific groundwater conditions.

4.5. Hypogean, hyporheic and collapsed sinkhole ecosystems

Hypogean ecosystems exist in some saturated aquifer or cave environments (Figure 4.6). Hypogean ecosystems are thought to influence groundwater quality. There is very little known about them, or how extensive they are, but they provide habitat for unique macro- and micro-fauna and are completely dependent on groundwater. It is assumed that the fauna are mobile, to some extent, within the aquifer and are resistant to natural fluxes in groundwater conditions. Their resistance to changes in groundwater regime and their capability to repopulate when more favourable groundwater conditions return (resilience) is unknown.

Hyporheic zones occur where surface water and groundwater mix in the subsurface environment surrounding wetland, river and potentially collapsed sinkhole systems (Figure 4.6). Any activities that lower groundwater levels to the extent that surface water and groundwater connection is lost will impact hyporheic activity and threaten subsurface refuges for aquatic biota when surface waters dry out. The resilience of hyporheic fauna to repopulate an area once more favourable groundwater conditions return is unknown.

Collapsed sinkholes provide shady and moist environments for plant forms, including Rock Fern (*Cheilanthes austrotenuifolia*). These areas are likely to provide habitat for unique flora and fauna species on the peninsula. Some collapsed sinkholes may intersect the water table and act as drought refuge / watering areas (Figure 4.6), whilst others are likely to be elevated compared to the water table and rely on surface water inflows to maintain them and potentially dry out during summer or prolonged dry periods. The resistance and resilience of collapsed sinkhole flora and fauna to changes in groundwater condition are unknown.

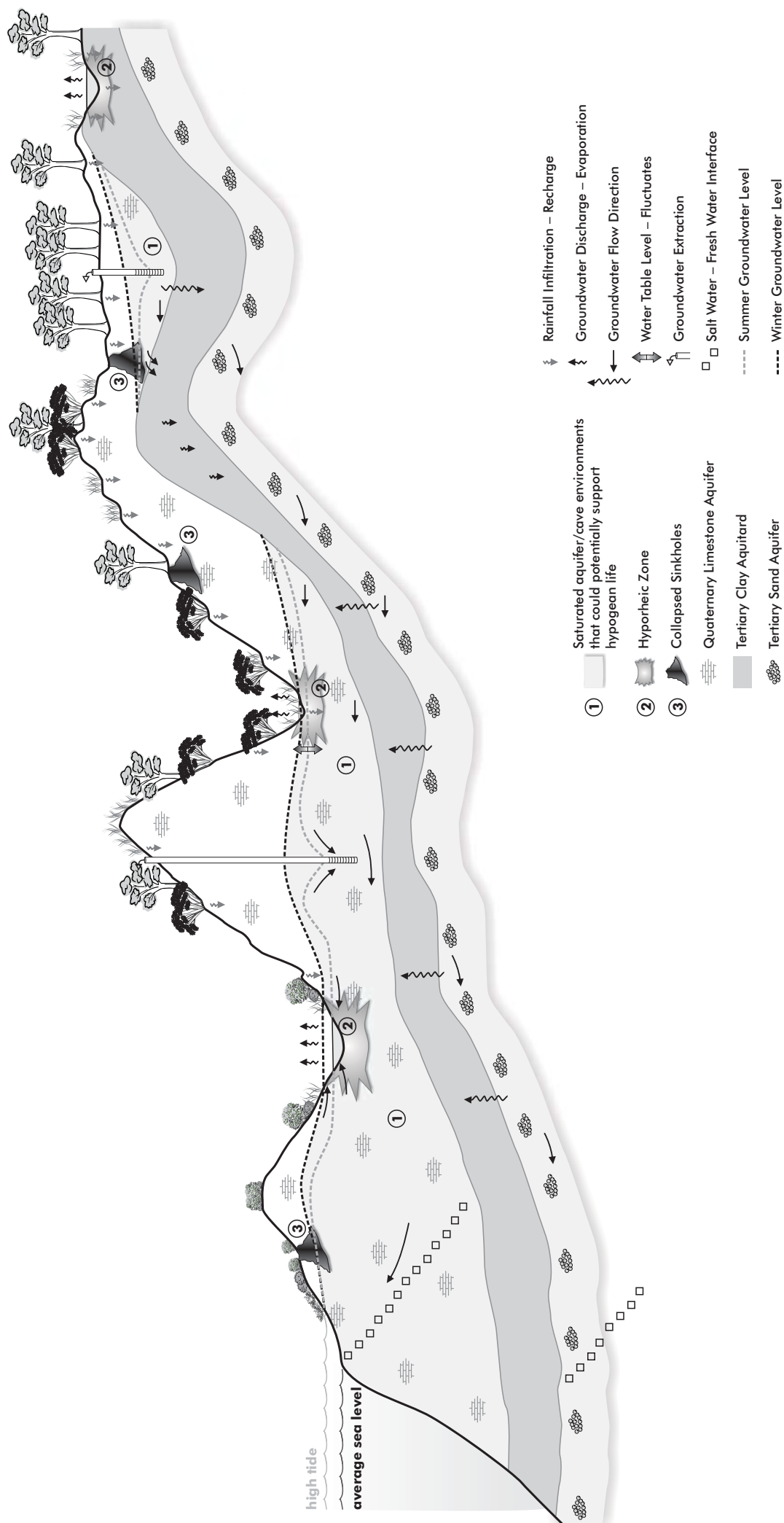


Figure 4.6 Hypogean, Hyporheic and Collapsed Sinkhole Ecosystems



4.6. Phreatophytes

There are two types of phreatophytes that occur within the study areas (Figure 4.7), these are:

- 1) Obligate phreatophytes, which are deep rooted plants that only inhabit areas where they can access groundwater, via the capillary fringe, to satisfy at least some proportion of their environmental water requirement. Access to groundwater is a critically important to their presence in a landscape; and
- 2) Facultative phreatophytes, which are deep rooted plant species that tap into groundwater, via the capillary fringe, to satisfy at least some portion of their environmental water requirement, but will also inhabit areas where their water requirements can be met by soil moisture reserves alone. That is, the species will be groundwater dependent in some environments, but not in others.

Trees have a range of strategies for dealing with water stress and some species are better adapted to deal with water stress than others, whether they are obligate or facultative phreatophytes. There is insufficient information available to assess whether facultative phreatophytes have a greater resistance to change in groundwater condition than obligate phreatophytes. However, obligate phreatophytes are less resilient than facultative phreatophytes and will only grow in areas where specific groundwater conditions exist.

Whilst facultative phreatophytes will dieback if the groundwater conditions change at rates that trees cannot adapt to, the species can often still germinate and thrive in these areas with juvenile trees having a greater capacity to adapt to different soil water / groundwater conditions. That is, while facultative phreatophytic trees may not have a high resistance to change in groundwater conditions, the species as a whole is resilient and can often re-colonise affected areas, even if groundwater conditions do not return to what they were originally (depending on the moisture capacity of soils) because access to groundwater is not critically important for the species persistence in the landscape.

Obligate phreatophytes are more vulnerable to changes in groundwater condition than facultative phreatophytes because they are limited to growing in areas with very specific ranges in groundwater condition. Juvenile obligate phreatophytes are likely to be better able to adapt to changed groundwater conditions than mature vegetation, but they will still require access to groundwater at critical times.

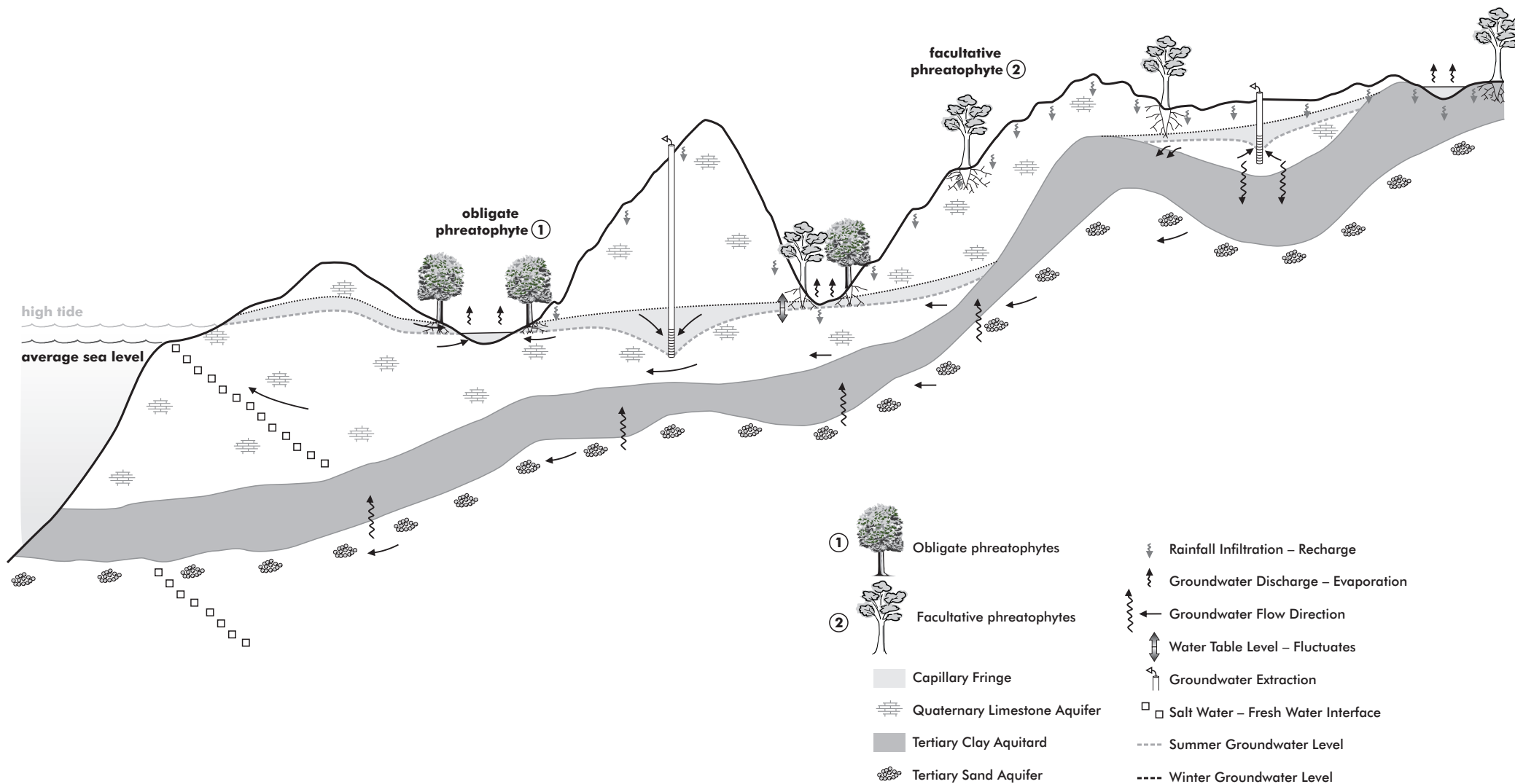


Fig 4.7 Phreatophytes



4.7. Freshwater lakes

There are two types of fresh water lakes that occur within the study areas (Figure 4.8), these are:

- 1) Seasonal/intermittent freshwater lakes which are connected to the Quaternary Limestone aquifer. These may recharge the Quaternary Limestone during inundation (losing conditions) and receive water back from bank storage as surface water levels recede (gaining conditions) extending the period of time that these lakes maintain a surface expression of water seasonally or episodically. Once surface water has dried, some species that exist within the seasonal / intermittent freshwater lake ecosystem (e.g. fringing Red Gum – obligate phreatophytes) are likely to be maintained by shallow water tables to sustain them during the dry periods since shallow soils are unlikely to hold sufficient moisture to sustain them for long periods; and
- 2) Seasonal/intermittent freshwater lakes that have a significant confining layer or occur beyond the extent of the Quaternary limestone aquifer are disconnected from and therefore do not access water from the Quaternary aquifer.

Seasonal / intermittent freshwater lakes that are disconnected from the Quaternary aquifer may receive groundwater inflow from perched aquifer systems, but will not be impacted by (are resistant to) groundwater extraction from the Quaternary aquifer. Seasonal / intermittent freshwater lakes that are connected to the Quaternary aquifer are less resilient to changes in groundwater condition due to groundwater extraction in the Quaternary aquifer.

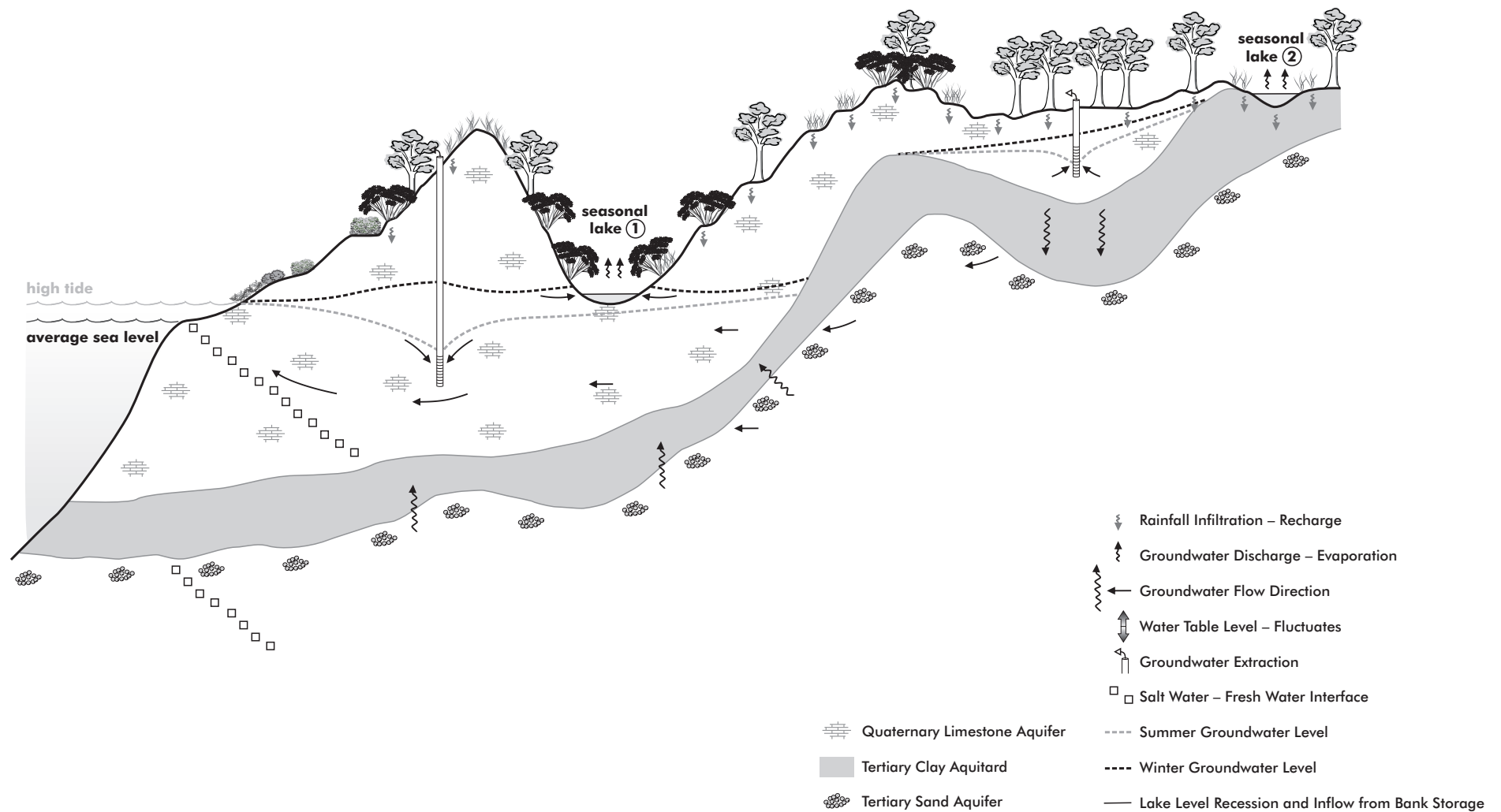


Figure 4.8 Freshwater Lakes



4.8. Damp coastal and sub-coastal heath

Damp coastal and sub-coastal heath are distinguished here by their distance from the coast; coastal heath being within 2 km of the shore. There is no obvious distinction in dominant species within the mapped areas of coastal and sub-coastal heath.

There are two types of damp coastal and sub-coastal heath within the study areas (Figure 4.9), these include:

- 1) Coastal and sub-coastal heath in areas with shallow water tables. These ecosystems appear to be relatively sparse in the landscape, typically occurring in low-lying areas. They do not necessarily occur in areas that have year-round shallow water tables, and are often interspersed with coastal and sub-coastal heath occurring in areas with deep water tables. They are therefore likely to be facultative in nature; using groundwater on an opportunistic basis, and soil water when levels fall below the extent of their root system.
- 2) Coastal and sub-coastal heath in areas with deep water tables are considerably more widespread than those overlying shallow water tables and occur over a much greater range of elevations.

Damp coastal and sub-coastal heath, similarly to grasslands, is thought to be facultative in nature. During periods, and in areas of shallow water tables, these communities will take advantage of extra water availability, particularly in times of low rainfall and hence surface runoff.

Areas of heath growing above shallow water tables are likely to be more vulnerable to changes in groundwater condition than those growing over deeper water tables. Whilst heath growing over shallow water tables will dieback if the groundwater conditions change at rates that they cannot adapt to, the community as a whole is resilient and can often re-colonise affected areas, even if groundwater conditions do not return to what they were originally (depending on the moisture capacity of soils) because access to groundwater is not critically important for the species' persistence in the landscape.

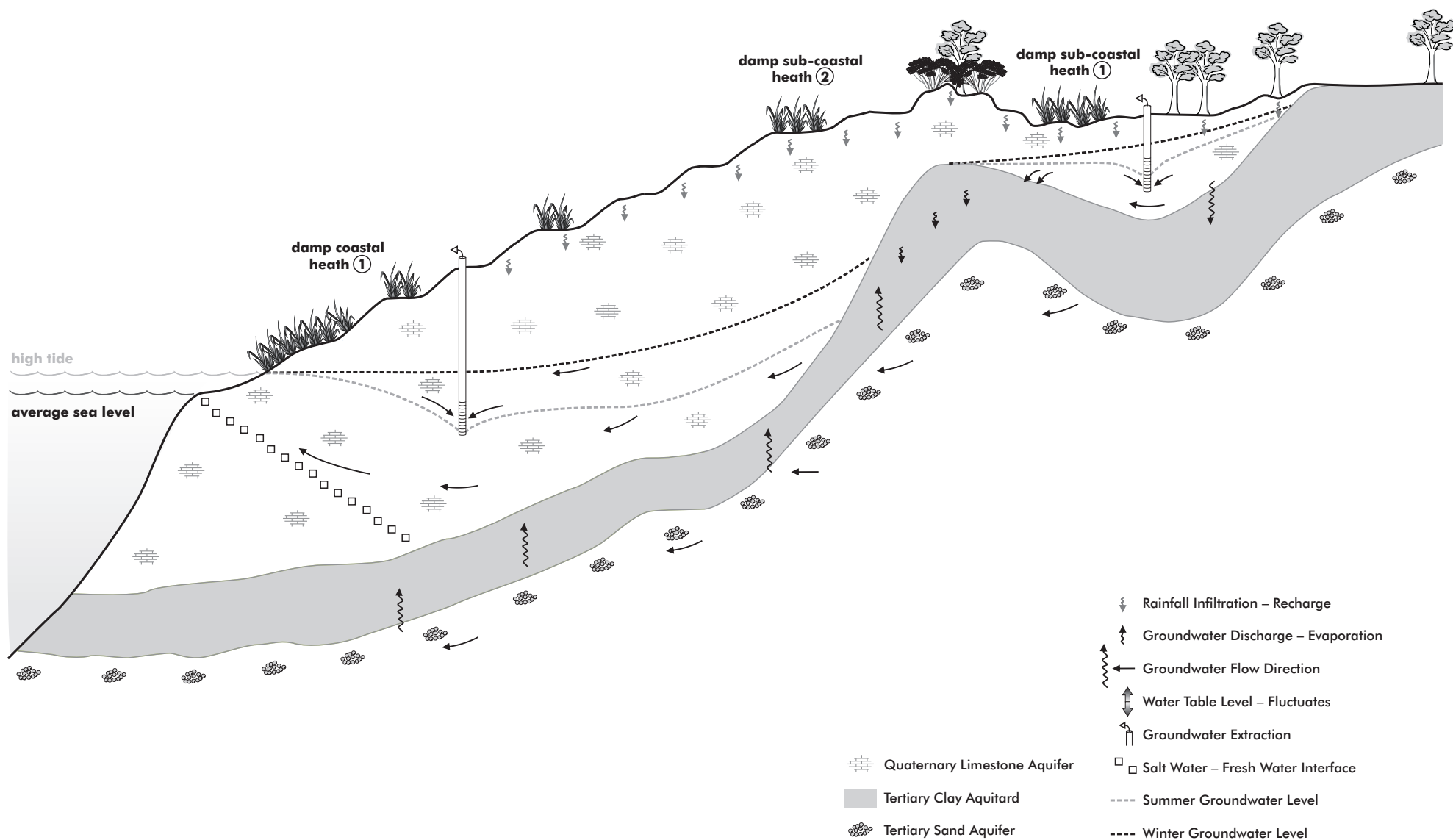


Figure 4.9 Damp Coastal and Sub-Coastal Heath



5. Mapping GDEs

5.1. Approach to identifying potential GDEs

The identification of potentially groundwater dependent wetlands in the study areas has been based on regional-scale wetland and vegetation mapping (from the Department of Environment and Heritage - DEH). These maps were refined based on available geological and hydrogeological information and the development of conceptual models of surface water – groundwater regimes for each potential GDE type (refer to section 3.2).

The source of water to all mapped wetlands was previously classified (by DEH) as “groundwater”. The occurrence of these mapped areas were compared to regional geology, lithological logs and depth to groundwater (based on groundwater monitoring data and topographical contours) to assess whether there was any potential for interaction to occur between the wetlands and the Quaternary aquifer.

The extent of potential groundwater dependent vegetation communities was initially classified by vegetation type. Based on previous experience in other areas and advice from DWLBC, CSIRO, SA Water, Flinders University and SKM, it was considered that the following vegetation communities could potentially access groundwater to meet some part of their environmental water requirement:

- Eucalyptus forest and woodland;
- Melaleuca forest and woodland;
- Melaleuca shrubland >1 m;
- Allocasuarina forest and woodland;
- Rushland / sedgeland;
- Tussock grassland; and
- Coastal shrubland

The occurrence of these mapped areas were compared to regional geology, lithological logs and depth to groundwater (based on obswell data and topographical contours) to assess whether they could potentially access groundwater from the Quaternary aquifer or not.

In addition, remote sensing technology (normalised difference vegetation index - NDVI) was implemented (25 m resolution) to identify areas where photosynthesis is highest during summer (imagery was sourced for late January 2009) as an indication of which vegetation experiences low water stress and hence may have access to groundwater.



The locations of springs, soaks, hypogean, collapsed sinkhole and hyporheic ecosystems could not be mapped based on pre-existing spatial datasets. The locations of some key springs are presented in Figure 5.7 and Figure 5.8. Whilst not mapped explicitly, hyporheic ecosystems are assumed to be associated with all surface water ecosystems that are continuously, seasonally or episodically connected to the water table via saturated soils.

5.2. Extent of saline swamps

Seasonal saline swamps occur within or in the vicinity of all three study areas (Figure 5.1, Figure 5.2 and Figure 5.3). Musgrave contains the largest expanse of saline swamp, located between Talia and Bramfield lenses. Smaller pockets were also identified in association with Lake Newland in the northwest of the area and other seasonal and permanent wetlands in the southwest. In the Southern Basins, seasonal saline swamps occur in smaller patches to the north of the area and to the east, where Pillie overlies Lincoln-C lens. There are three distinct seasonal saline swamps within 10 km of the Robinson lens.

Intertidal saline swamps only occur in the southern basins, with a small pocket to the north of Lincoln-B lens and south of Port Lincoln, outside of the study area.

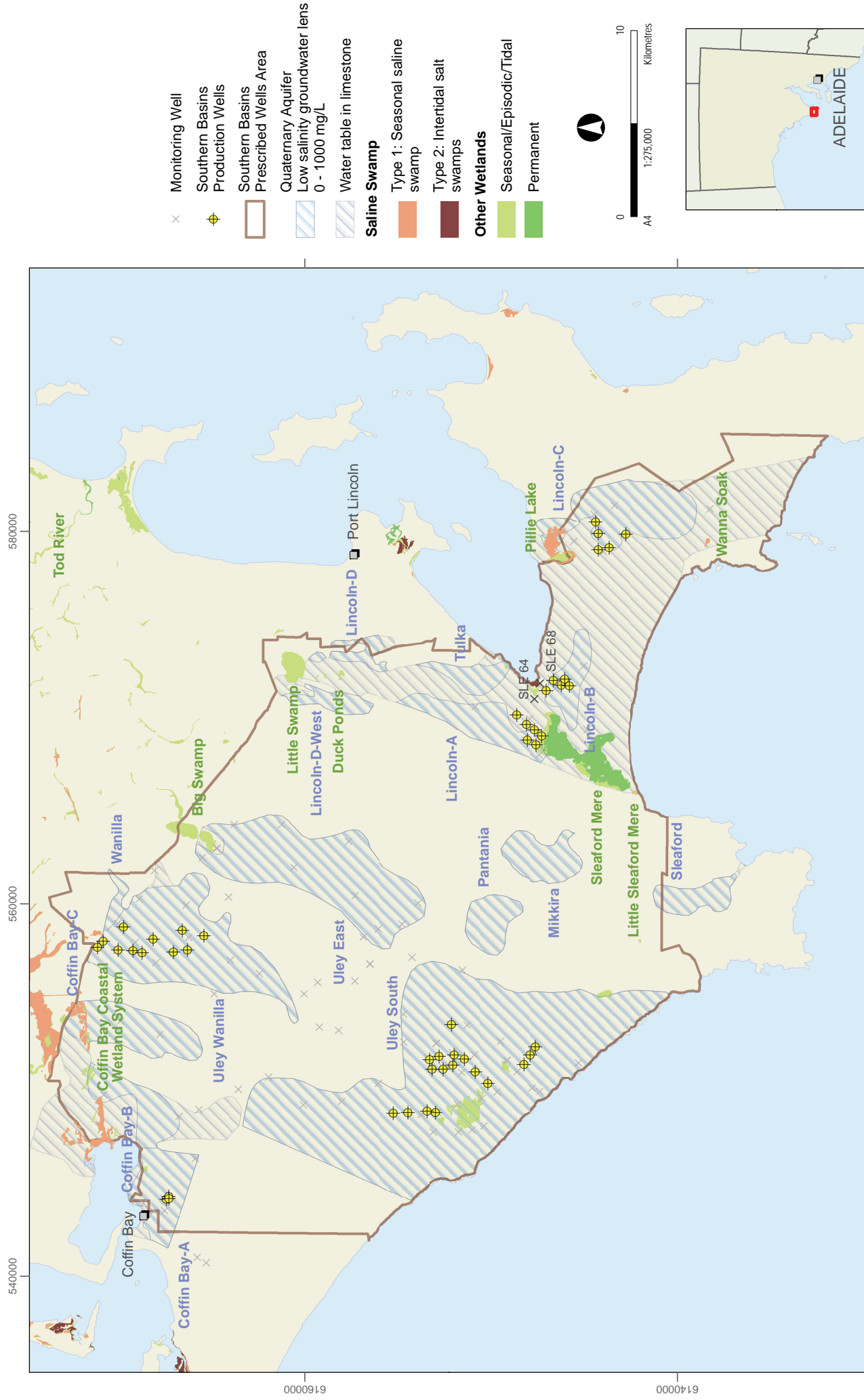
5.3. Extent of saline lakes

Saline lakes occur in all three study areas (Figure 5.4, Figure 5.5 and Figure 5.6). In Southern Basins PWA, Sleaford Mere is the only example of a permanent saline lake.

Seasonal saline lakes connected to the Quaternary aquifer were identified in all three study areas; the largest being Lake Newland in the Musgrave PWA. Several other smaller, seasonal examples are present within 2 km of the Musgrave coast; generally associated with other permanent and seasonal wetlands in the vicinity. In the Southern Basins, a small seasonal saline lake connected to the Quaternary aquifer is associated with Pillie Lake, west of Lincoln-C lens, and within the north of Coffin Bay basin, beyond the study area boundary. In the vicinity of Robinson lens, a saline lake connected to the Quaternary aquifer lies within 5 km of the lens. There is only one identified saline lake disconnected from the Quaternary aquifer in the three study areas. This is Little Swamp, which is located to the north of the Lincoln-D lenses in the Southern Basins PWA.

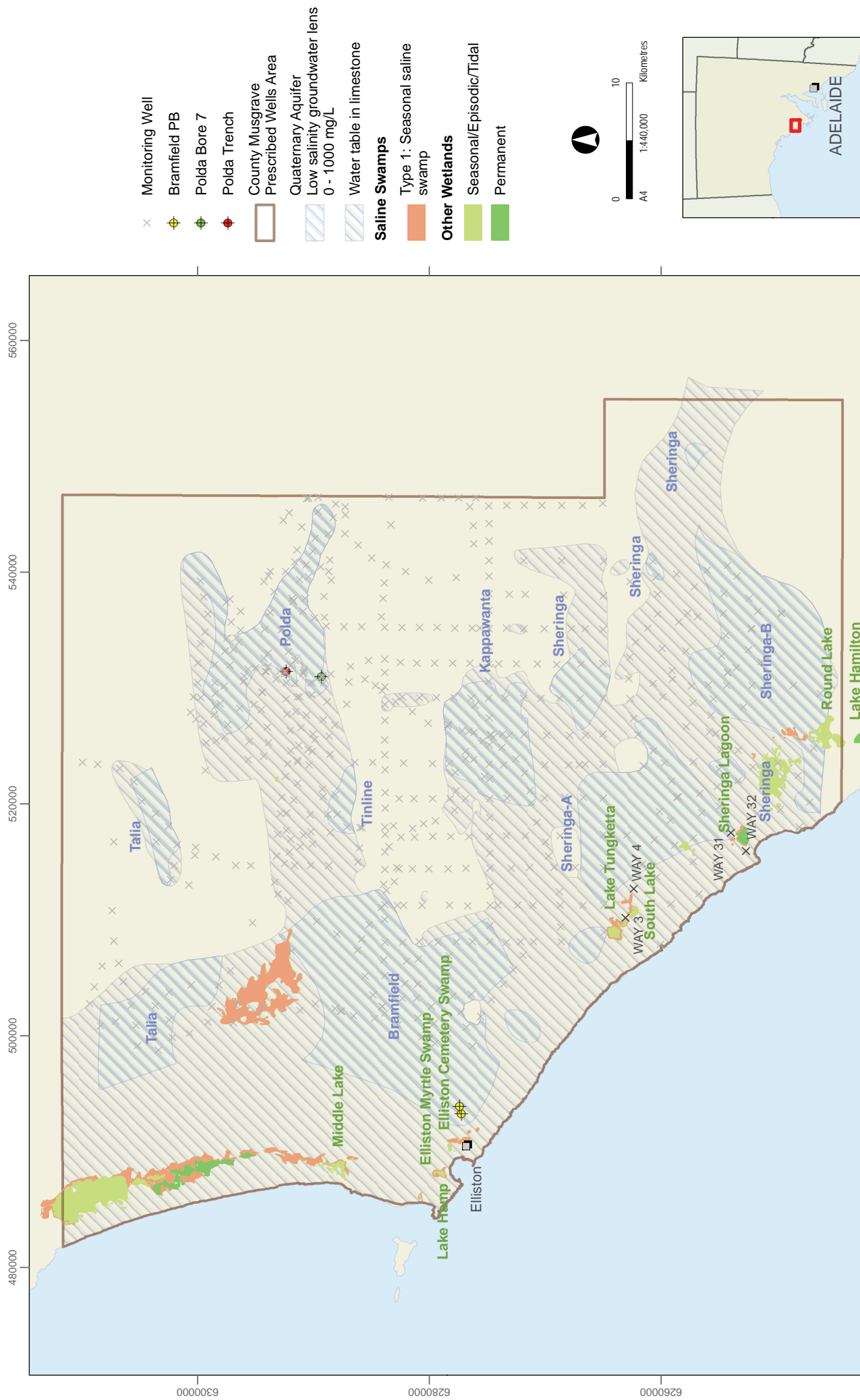
5.4. Extent of springs and underground water soaks

The locations of some key springs are presented in Figure 5.7 and Figure 5.8. Many more springs exist across the study areas, but there has not been any comprehensive mapping undertaken.



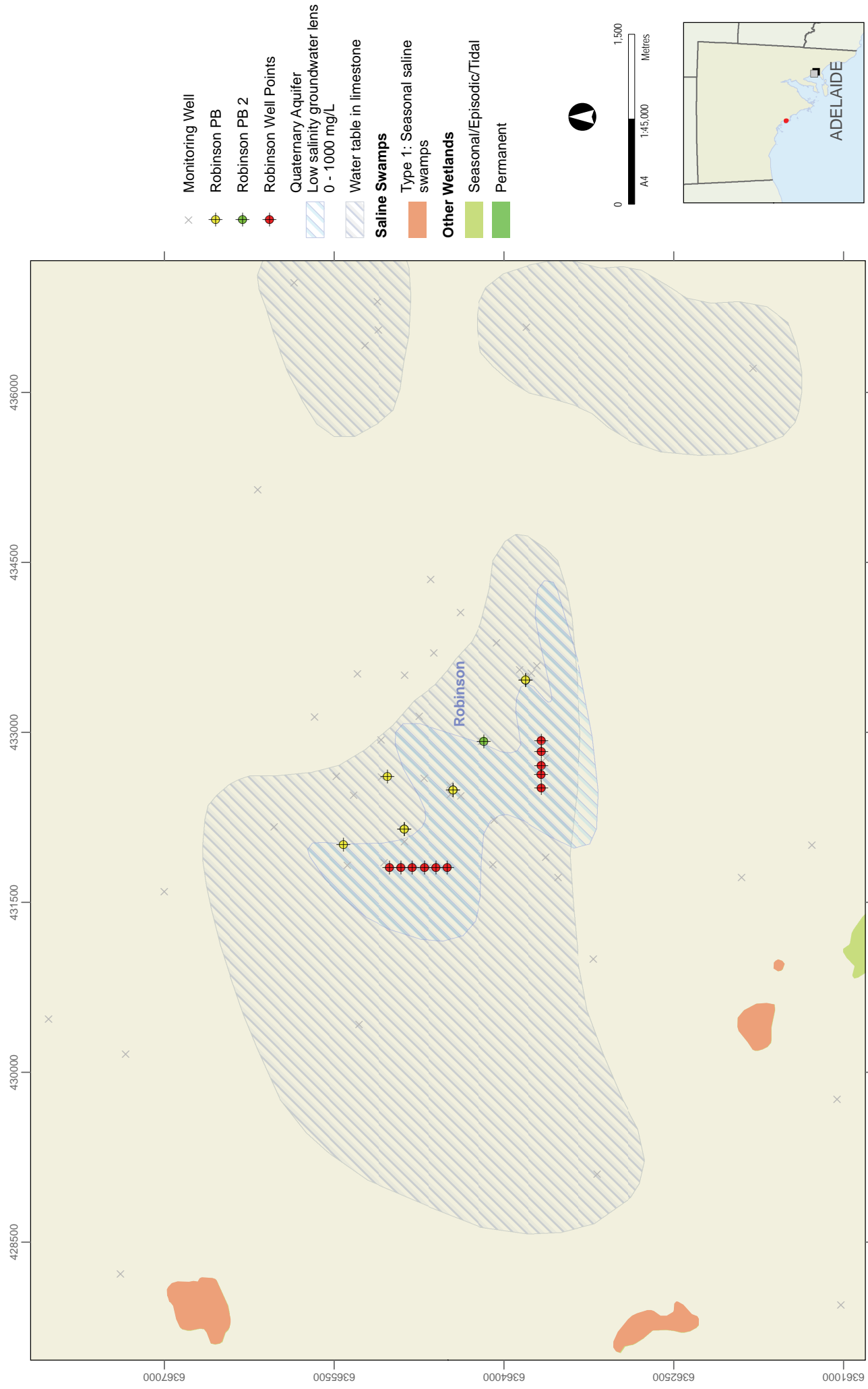
Southern Basins PWA

Figure 5.1: Permanent / Seasonal Saline Swamps



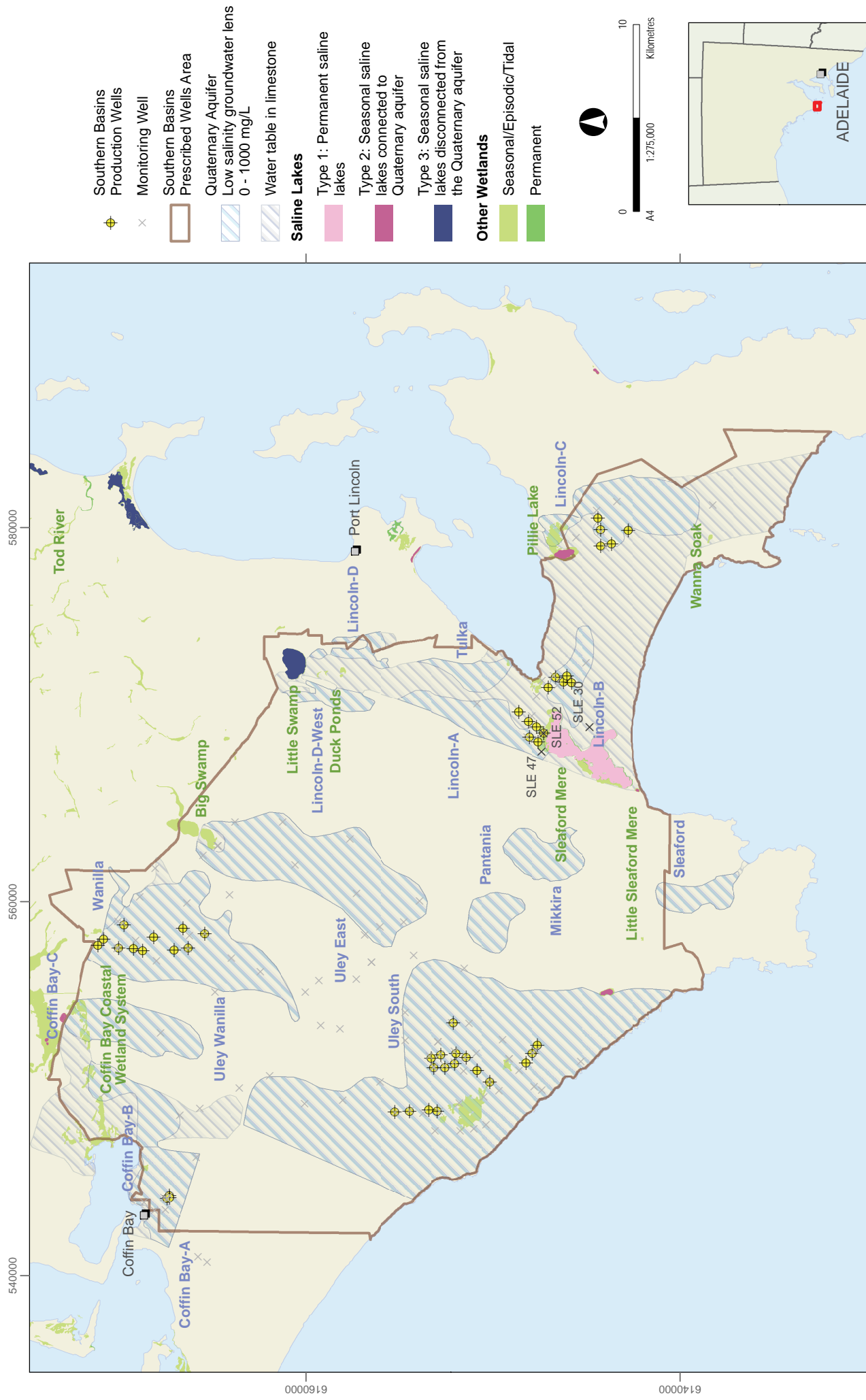
Musgrave PWA

Figure 5.2: Permanent / Seasonal Saline Swamps



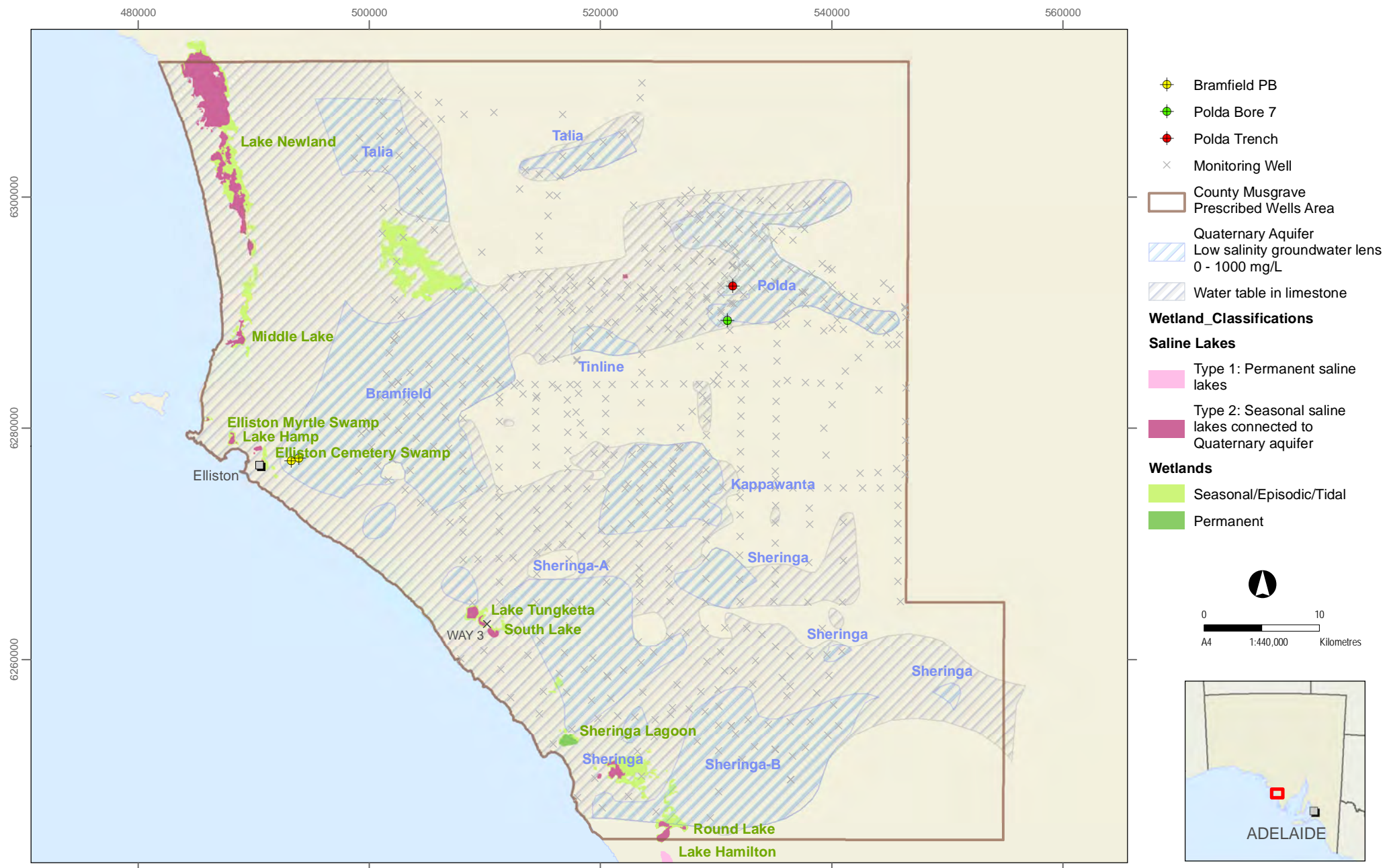
Robinson Basin

Figure 5.3: Permanent / Seasonal Saline Swamps



Southern Basins PWA

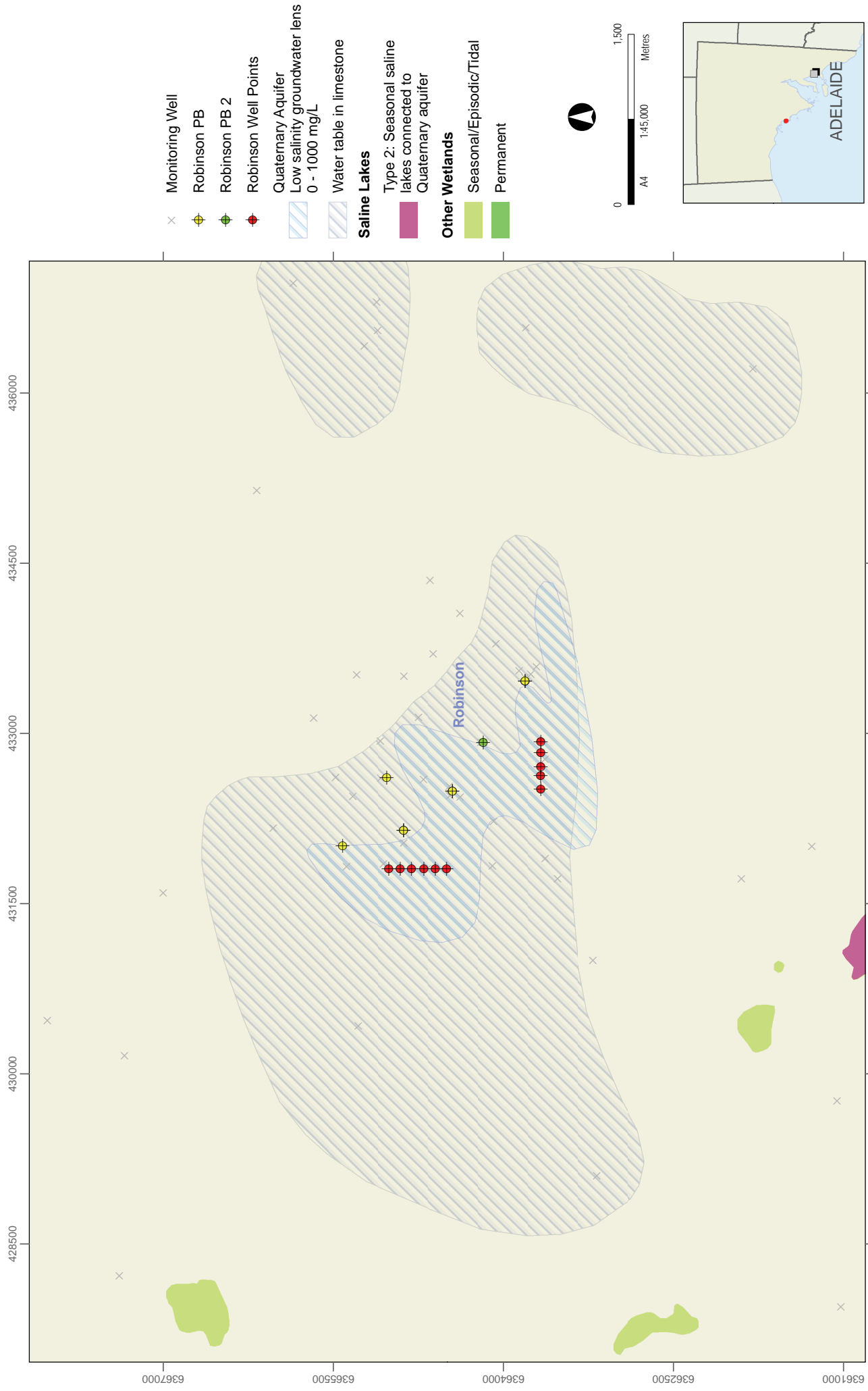
Figure 5.4: Permanent / Seasonal Saline Lakes



Musgrave PWA

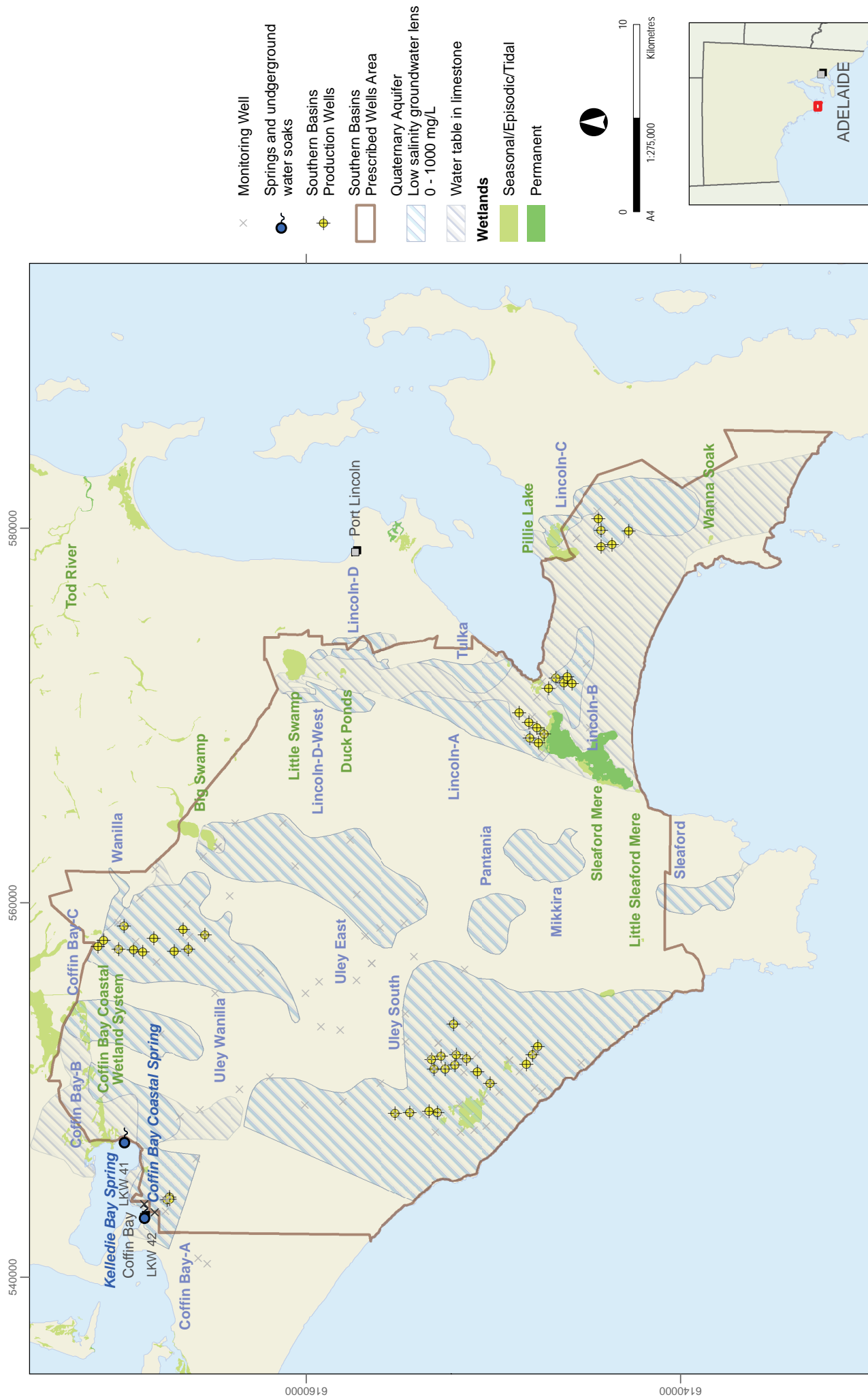
Figure 5.5: Permanent / Seasonal Saline Lakes

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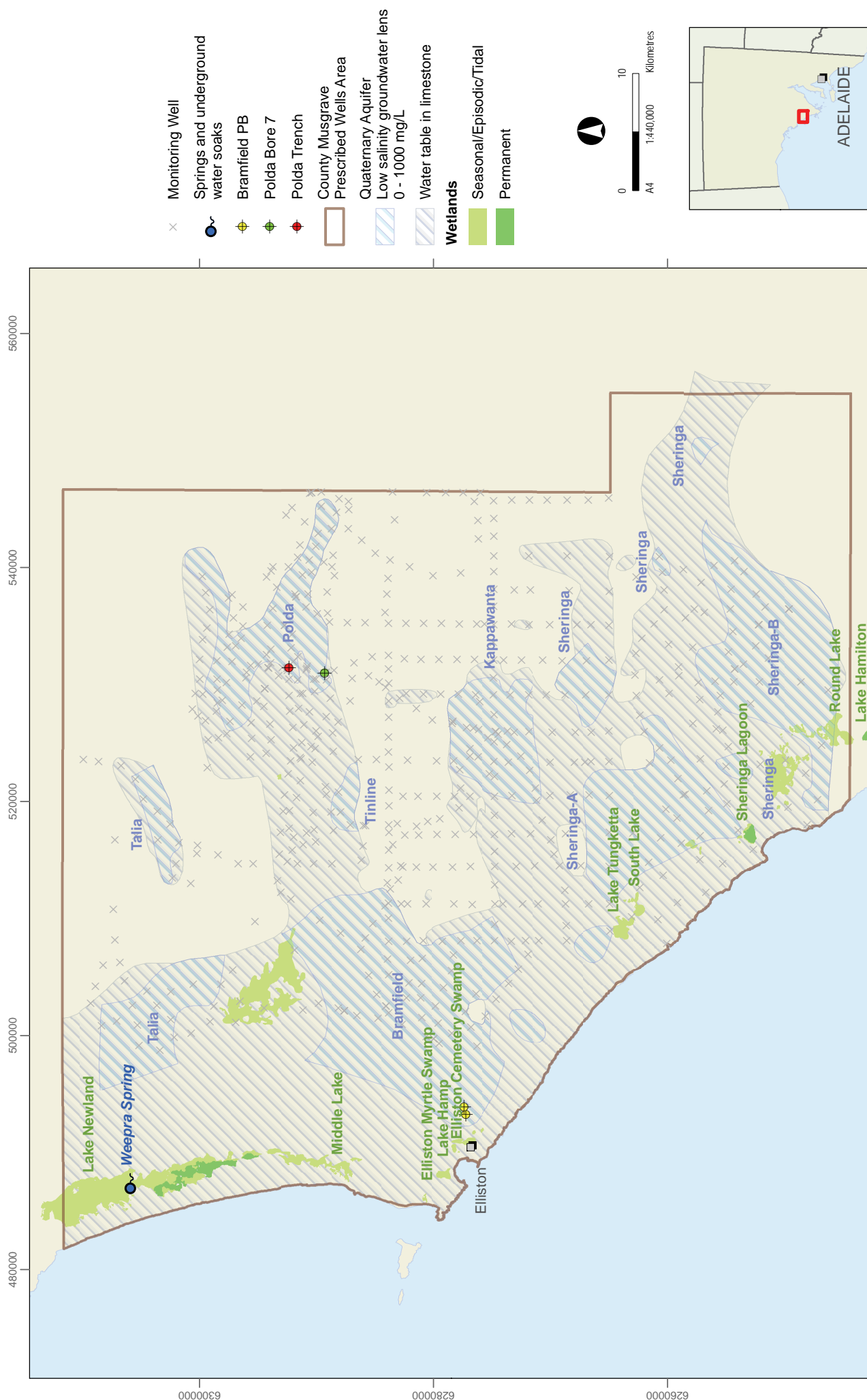
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Figure 5.6: Permanent / Seasonal Saline Lakes



Southern Basins PWA

Figure 5.7: Springs



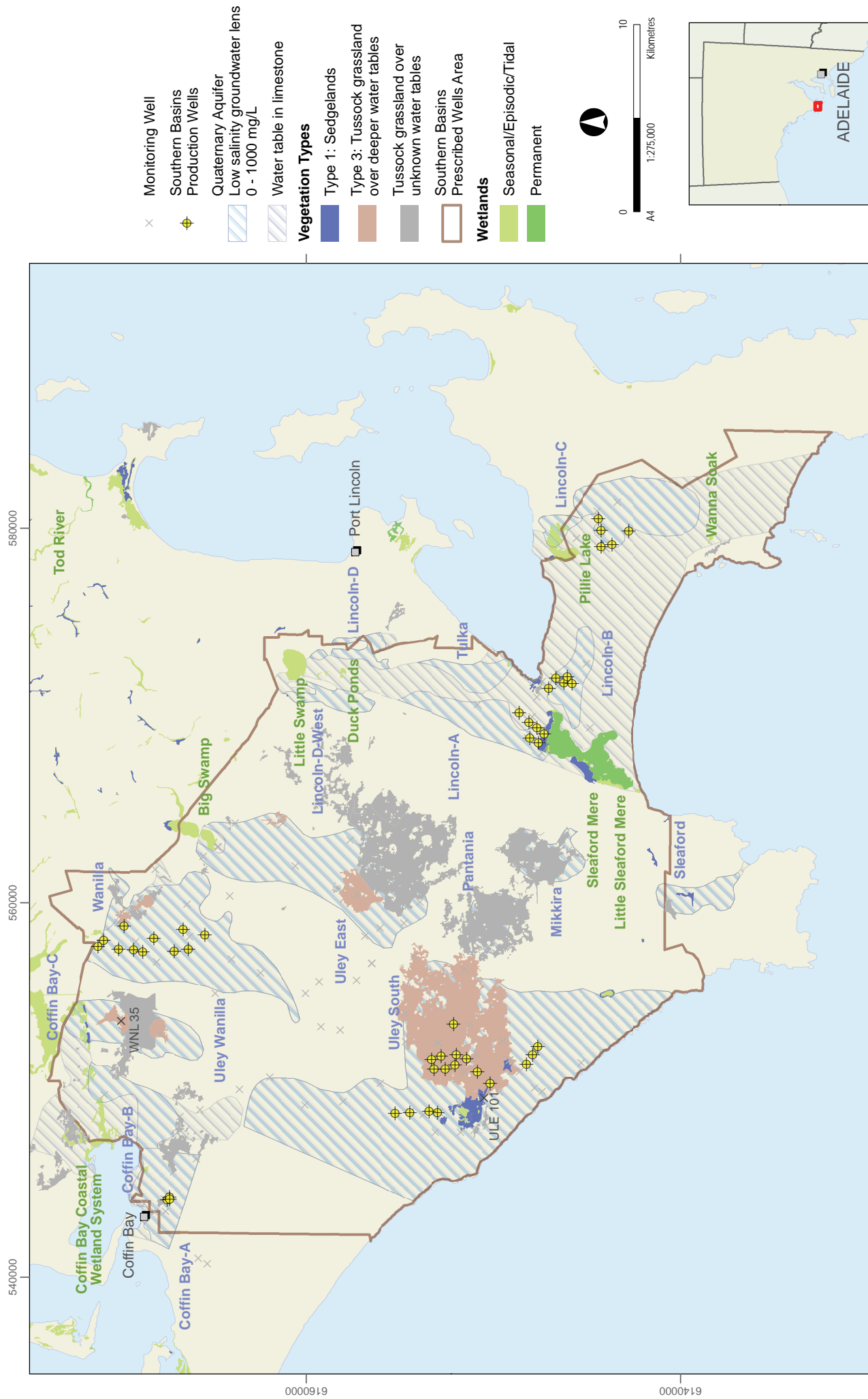


5.5. Extent of grasslands and sedgelands

Sedgelands are typically associated with wetlands and occur in Musgrave and Southern Basins PWAs but not in the vicinity of Robinson lens (Figure 5.9 and Figure 5.10). In Musgrave, sedgeland occurs within and the surrounds of a seasonal freshwater lake and the northern edges of the Lake Hamilton Complex in the south west of the PWA. In the Southern Basins PWA sedgelands are also associated with seasonal freshwater ponds that overlay Uley South lens, with small patches occurring on the northern and western edges of Sleaford Mere, which lies to the south of Lincoln-A lens.

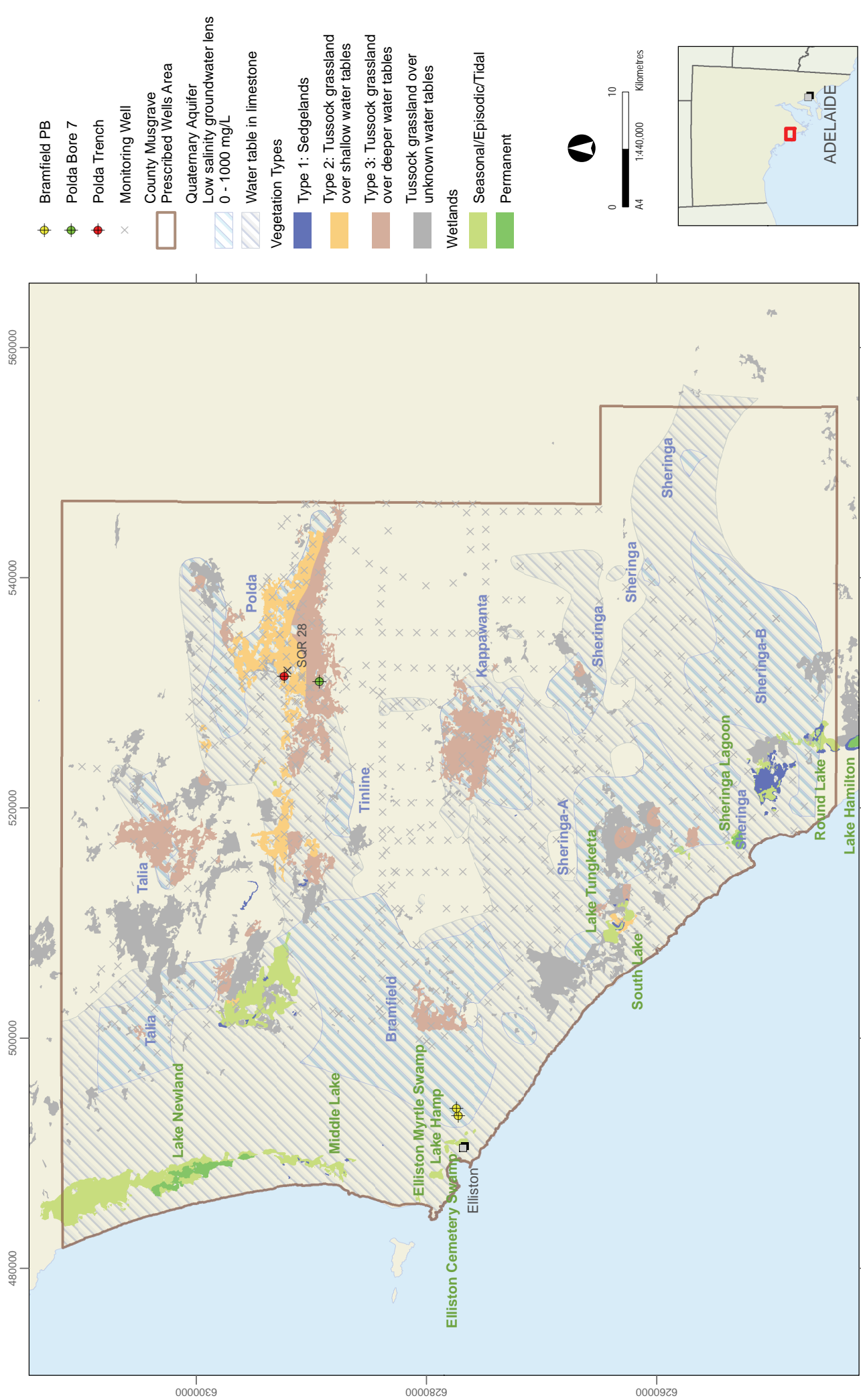
Grasslands have relatively extensive coverage within the two PWAs (Figure 5.9 and Figure 5.10) but there is no mapping of either grassland in or close to Robinson lens. Grasslands that exist over shallow water tables are sparse in relation to the total mapped area, occurring only within the Musgrave PWA. The largest single expanse of grassland over shallow water tables is located over the Polda lens, with further, smaller pockets occurring within a strip running west. This is indicative of shallow water tables in this area. Grasslands over deep water tables have a wider coverage; with the majority of monitoring wells within the mapped areas having deeper groundwater elevations. A significant area of mapped grassland did not have sufficient data for classification and hence these are potentially groundwater dependent. These are shown on the maps as having unknown water tables.

NDVI was calibrated so that areas of relatively high photosynthesis (interpreted low water stress) coincided with areas of sedgeland and with areas of tussock grassland over shallow water tables, and so that areas of relatively low photosynthesis (interpreted higher water stress) coincided with tussock grassland over deep water tables. The resulting NDVI for sedgeland and tussock grassland shows relatively good calibration to these areas (Figure 5.11 and Figure 5.12) and provides confidence in identifying areas where unclassified depth to groundwater tussock grassland may have access to groundwater. NDVI suggests that there are areas of tussock grassland and /or sedgeland near extraction wells in Uley South, Coffin Bay A, and Lincoln –A and B that potentially access groundwater and that there is very little tussock grassland or sedgeland that potentially accesses groundwater near groundwater extraction points in Musgrave PWA.



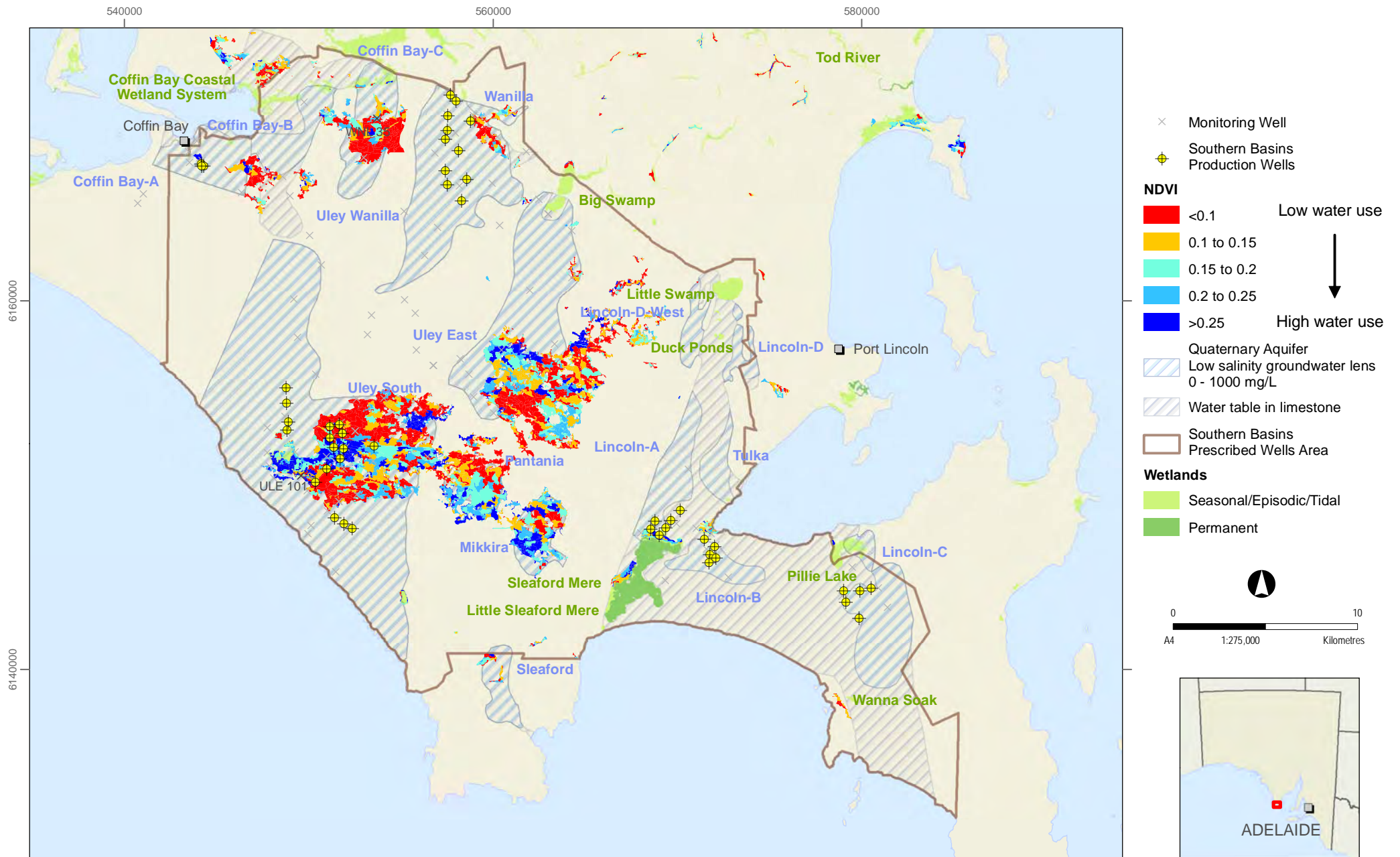
Southern Basins PWA

Figure 5.9: Grasslands and Sedgelands



Musgrave PWA

Figure 5.10: Grasslands and Sedgeland

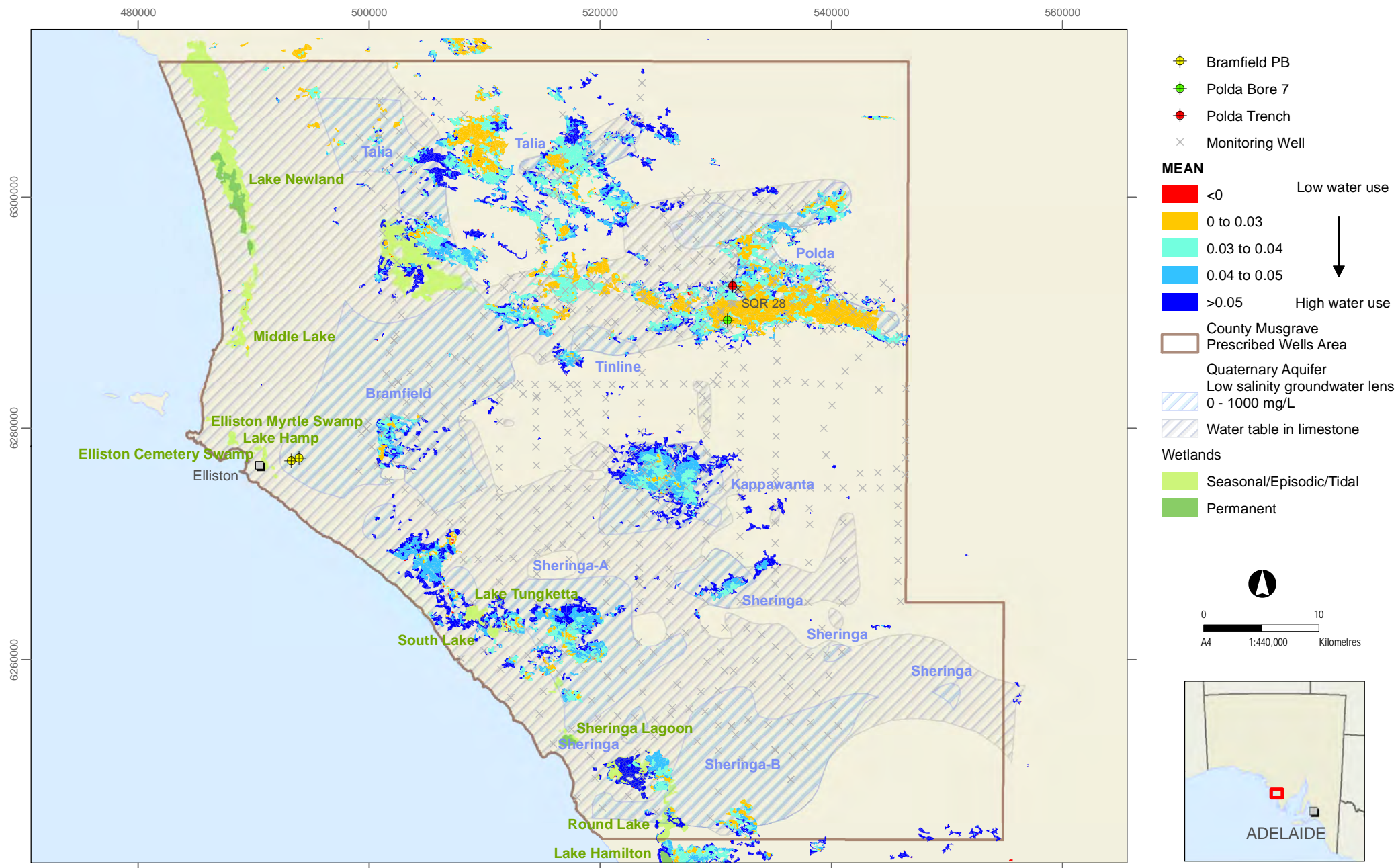


Southern Basins PWA

Figure 5.11: NDVI - Grasslands and Sedgeland

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Musgrave PWA

Figure 5.12: NDVI - Grasslands and Sedgeland

GDA 1994 MGA Zone 53



5.6. Extent of phreatophytes

Phreatophytes occur within all three study areas (Figure 5.13, Figure 5.14 and Figure 5.15), although they are most widespread in the vicinity of Robinson lens and the Southern Basins PWA. In the Southern Basins area, mapped areas inferred to be obligate phreatophytes are present in small pockets in the north and east of the region, overlying the northern edges of Uley Wanilla and Uley East, surrounding Big Swamp, as well as to the east near Lincoln-D and Tulka lenses. These obligate phreatophytes mainly occur outside the study area, beyond the northern boundary of the PWA. Facultative phreatophytes over deep water tables are common in the Southern Basins, with several relatively large expanses of mapped vegetation across the area. A significant portion of the mapped potentially phreatophytic vegetation in the area lies above unknown water tables and hence could potentially be groundwater dependent.

In the Musgrave area, obligate phreatophytes are the most common of those classified, mostly occurring as small pockets in the vicinity of Kappawanta and Sheringa lenses. Facultative phreatophytes are also present in this area; small pockets occurring over the shallow water tables that exist close to Poldia, Bramfield and Talia lenses. A significant portion of the phreatophytes identified in the Musgrave area have insufficient data to make conclusions about their dependence on groundwater and hence are potentially groundwater dependent.

In the vicinity of Robinson lens, facultative phreatophytes over shallow water tables are the most common, covering a significant portion of the lens itself. A small pocket of phreatophytes overlying deep water tables also lies just outside the lens, but the majority of the mapped area of potentially phreatophytic vegetation surrounding Robinson lens overlies unknown water tables and hence could be groundwater dependent.

NDVI was calibrated so that areas of relatively high photosynthesis (inferred low water stress) coincided with areas considered to contain obligate phreatophytes and facultative phreatophytes over shallow water tables, and so that areas indicative of relatively low photosynthesis (inferred higher water stress) coincided with potentially facultative phreatophytes over deep water tables (Figure 5.16, Figure 5.17 and Figure 5.18). The resulting NDVI for phreatophytes shows a relatively good match to groundwater conditions in the Musgrave PWA and Robinson Basin, but a poor match to groundwater conditions in the Southern Basins PWA.

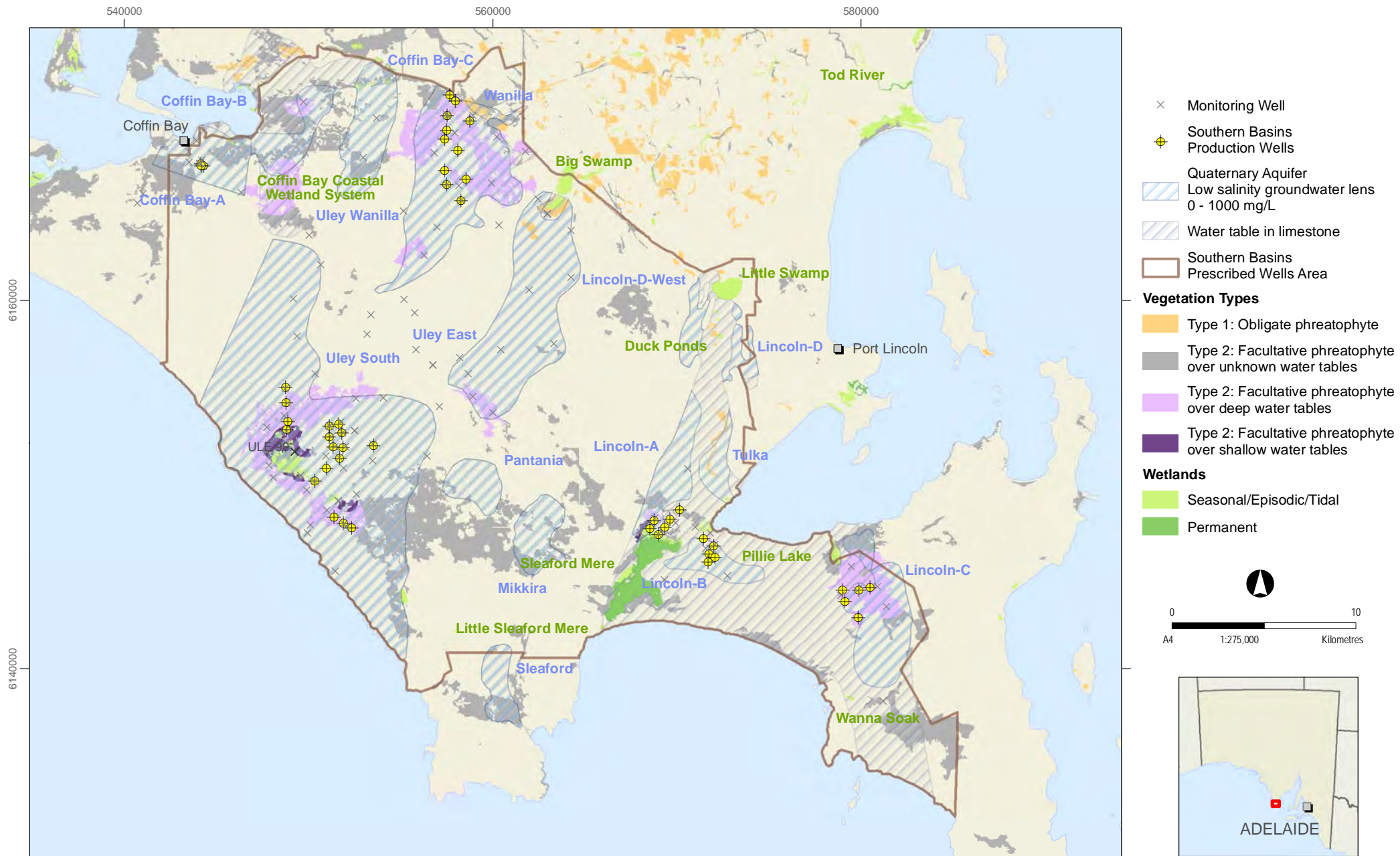
The poor match between NDVI and groundwater conditions beneath phreatophytes in the Southern Basins can be explained by a number of factors, including:

- Where there is high NDVI in areas of deep water tables (e.g. Lincoln-C lens), phreatophytes may be tapping into a perched groundwater source disconnected from the regional Quaternary Bridgewater Formation aquifer by a confining layer (there is little data available to confirm the presence or absence of such a confining layer);



- Where there is low NDVI in areas of shallow water tables (e.g. Uley South lens), phreatophytes may tap into the capillary fringe, but if the area is sparsely vegetated, the area as a whole will exhibit a lower inferred water use (i.e. lower photosynthesis as per NDVI). There is no information available to compare forest or woodland density throughout the study area; and
- Where there is low NDVI in areas of shallow water tables (e.g. Uley South lens), phreatophytes may be under stress regardless of the shallow water tables. It may be that phreatophytes in this area relied on a perched groundwater source that has become depleted due to lower than average annual rainfall (and therefore recharge conditions over the last 10 to 15 years).

There is no way of discerning which of these potential factors apply in different areas of the Southern Basin PWA without further investigations. The current NDVI analysis shows potential, but is not yet fit for widespread use to infer the presence or absence of groundwater dependent vegetation to inform the groundwater management process.



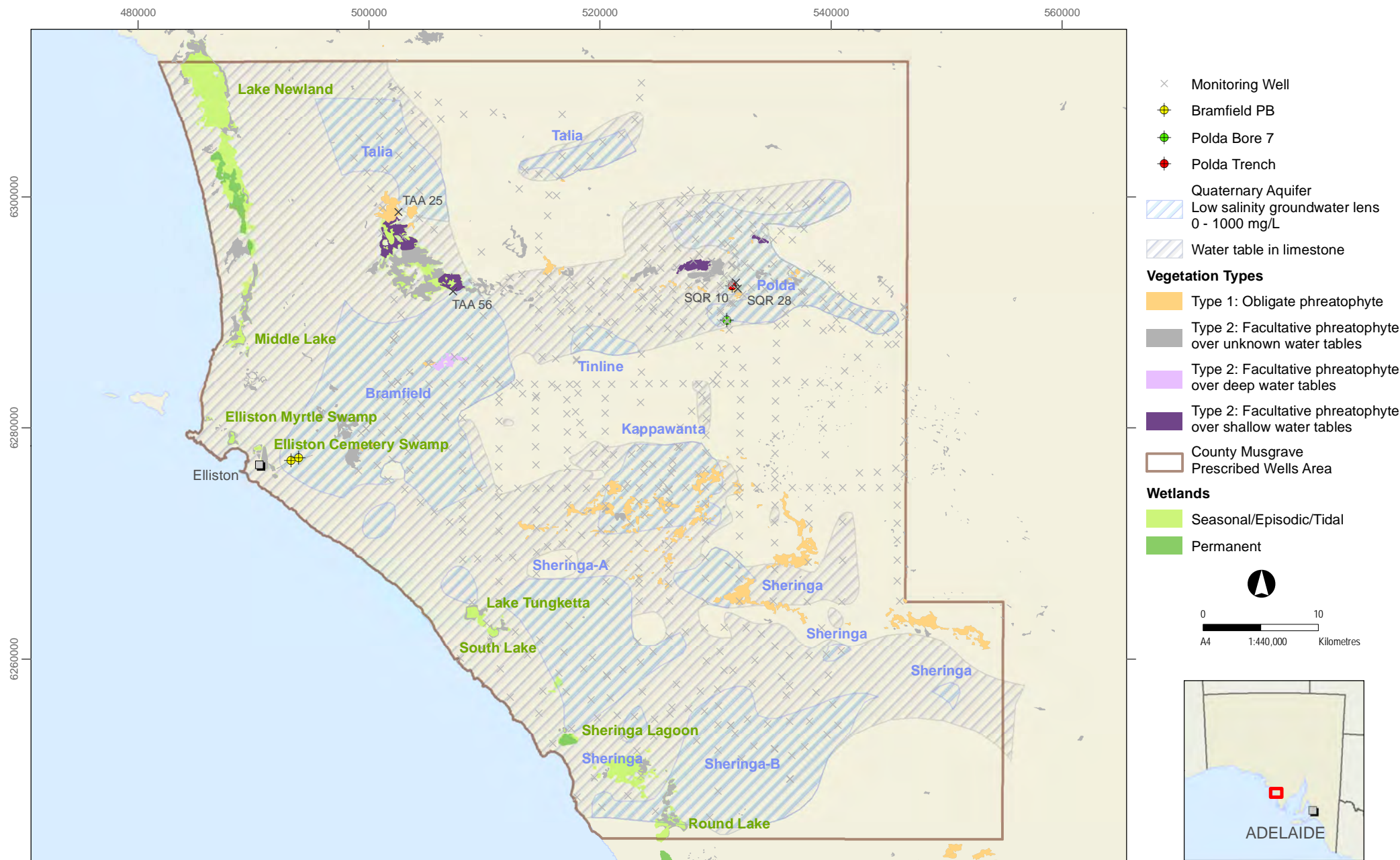
Southern Basins PWA

Figure 5.13: Potentially Phreatophytic Vegetation

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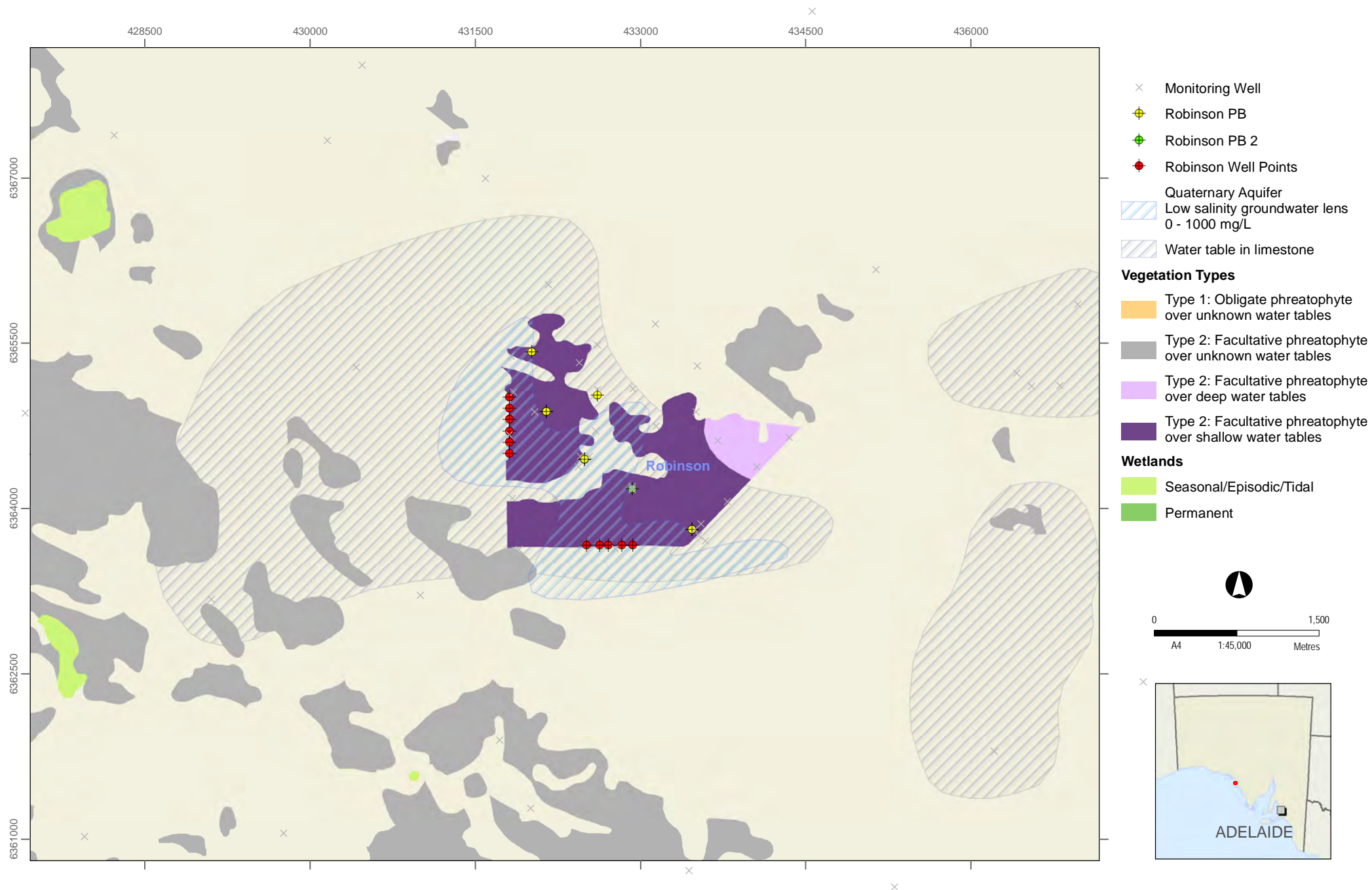
Musgrave PWA

Figure 5.14: Potentially Phreatophytic Vegetation

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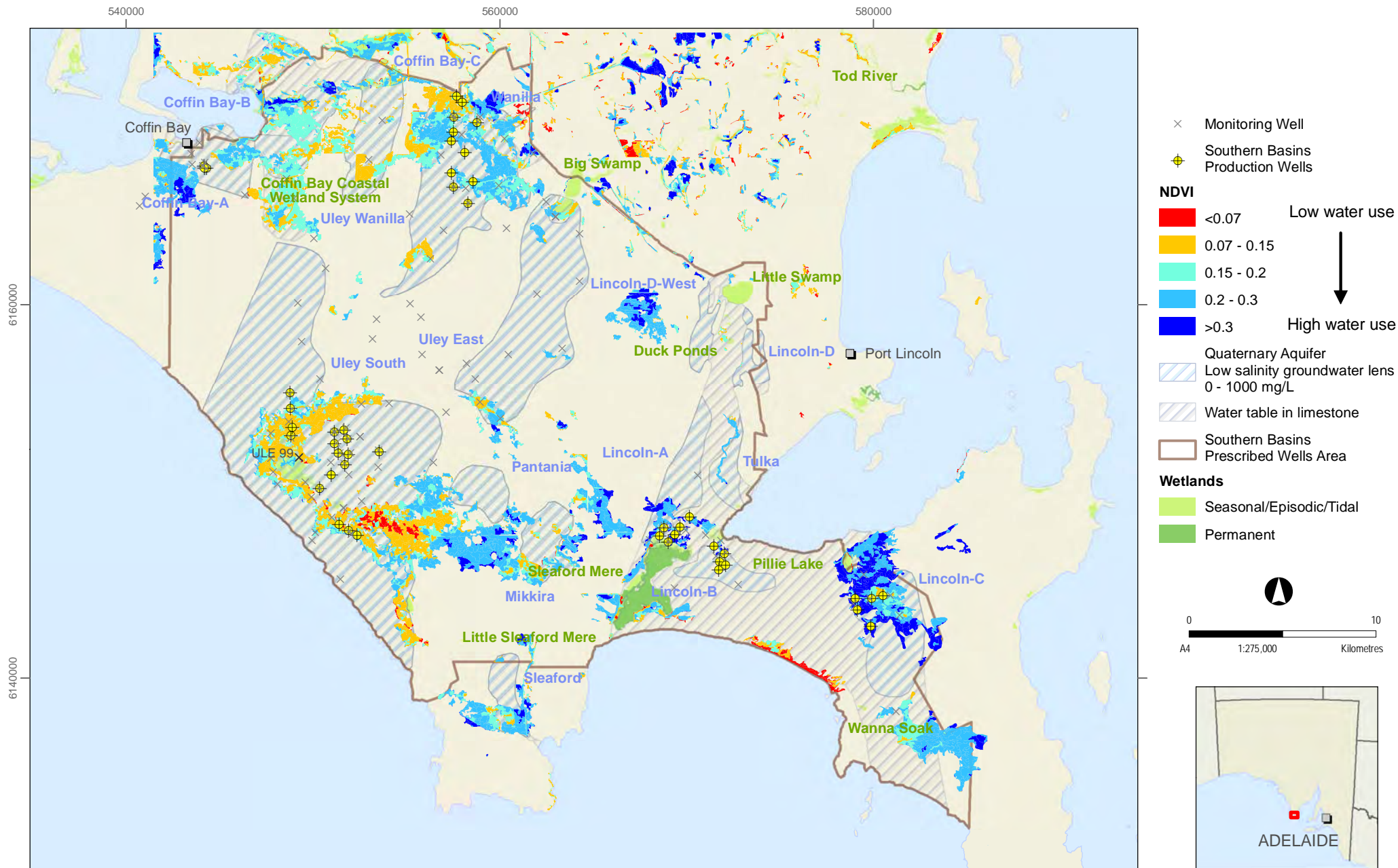
Robinson Basin

Figure 5.15: Potentially Phreatophytic Vegetation

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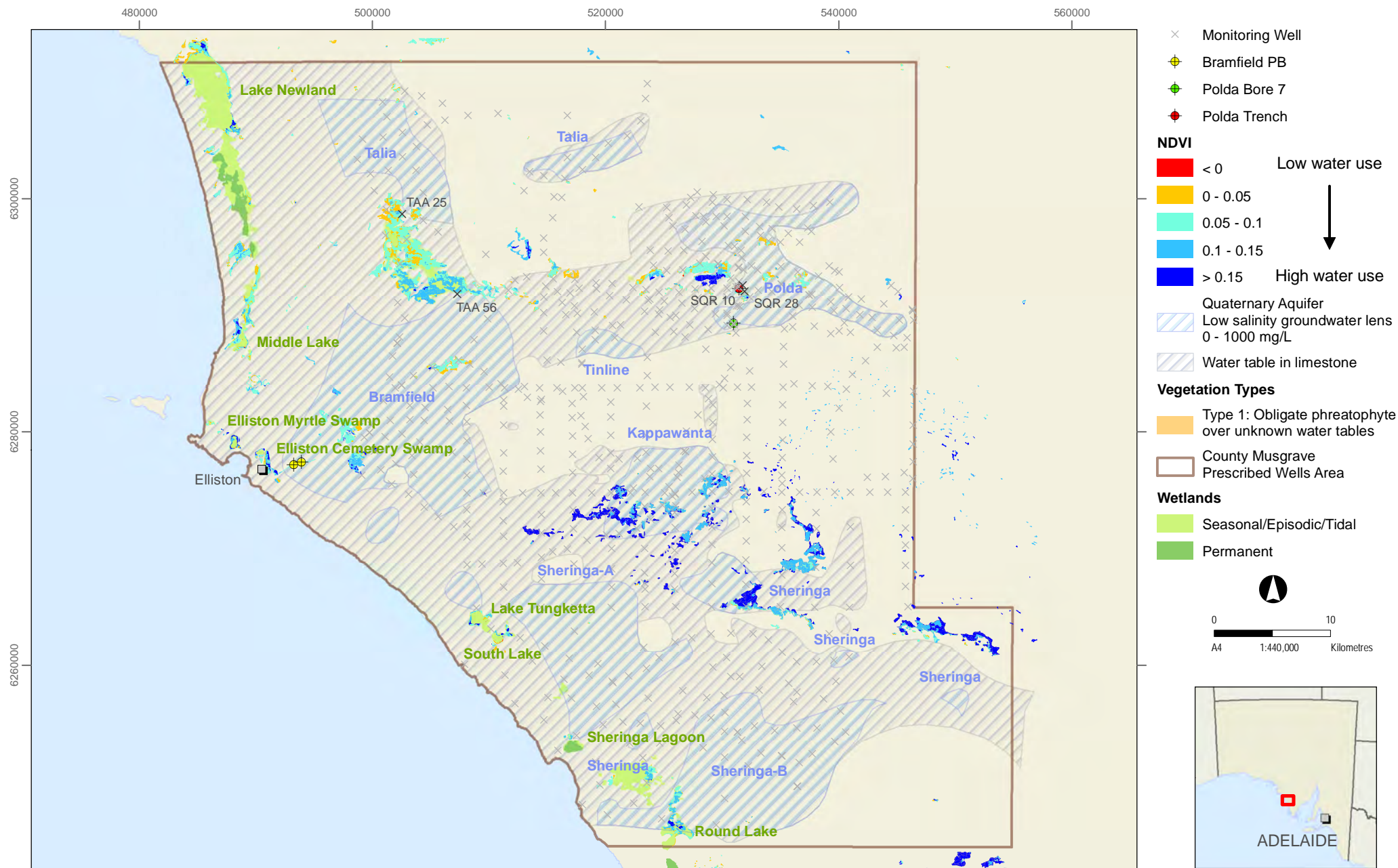


Southern Basins PWA

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Figure 5.16: NDVI - Potentially Phreatophytic Vegetation

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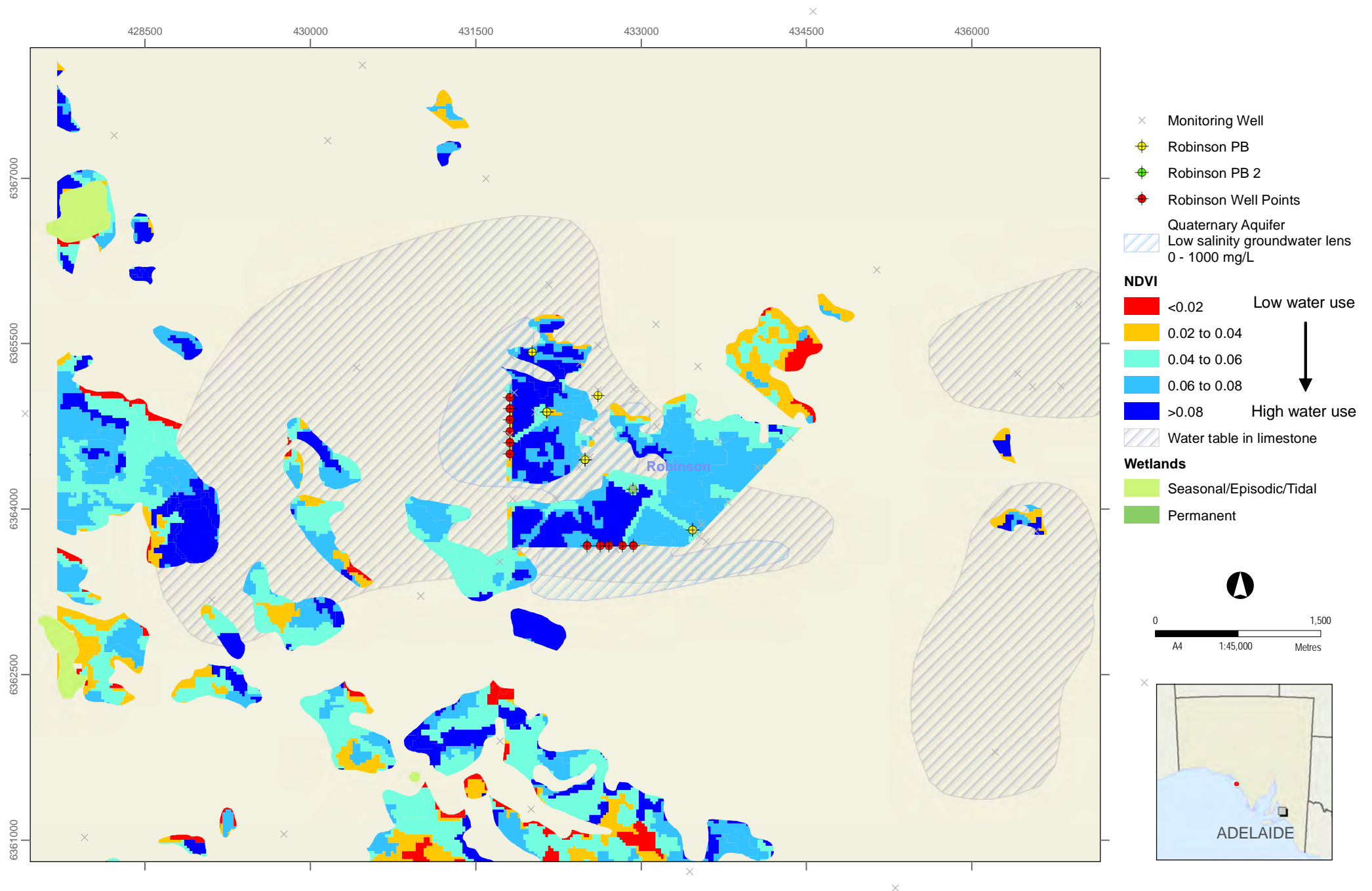
Musgrave PWA

Figure 5.17: Potentially Phreatophytic Vegetation

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Robinson Basin

Figure 5.18: NDVI - Potentially Phreatophytic Vegetation

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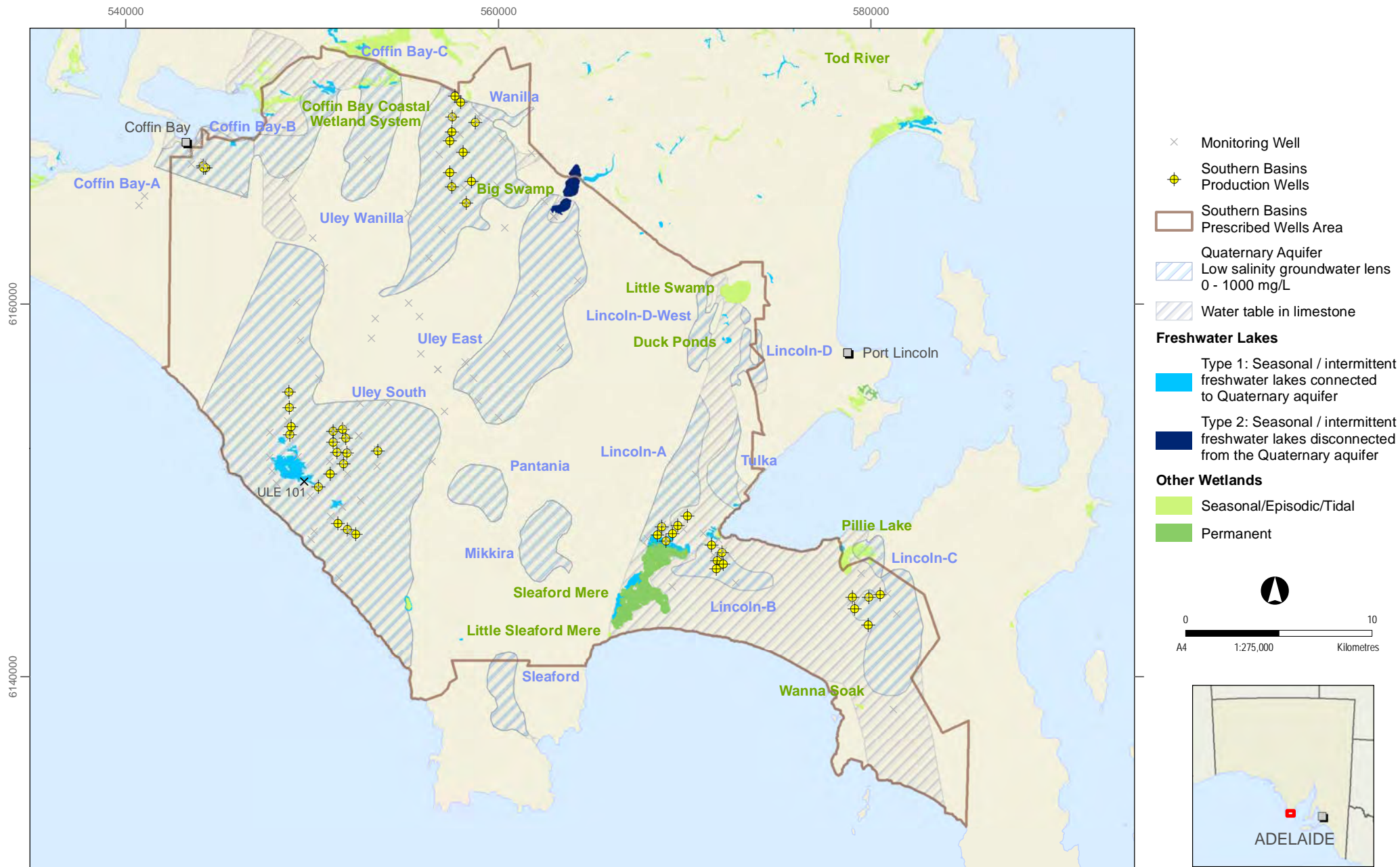
5.7. Extent of freshwater lakes

Freshwater lakes only occur within the Southern Basins and Musgrave PWA study areas (Figure 5.19 and Figure 5.20). In the Southern Basins, the largest seasonal/intermittent freshwater lake connected to the Quaternary aquifer overlies Uley South lens. Other smaller lakes are also present to the north of the area, near to Coffin Basin, and those with Sleaford Mere to the east of the area. In Musgrave PWA, seasonal/intermittent freshwater lakes mostly occur in the south of the area, in the vicinity of the Sheringa lenses, with one being associated with Lake Hamilton. A small pocket associated with Middle Lake also exists in the mid-coastal area. There is only one seasonal/intermittent freshwater lake disconnected from the Quaternary aquifer in the study areas. This is Big Swamp, which is located to the north of Southern Basins PWA, partially overlying the Uley East lens.

5.8. Extent of damp coastal and sub-coastal heath

Damp coastal and sub-coastal heath occurs in Musgrave and Southern Basins PWAs (Figure 5.21 and Figure 5.22). Damp coastal and sub-coastal heath over shallow water tables occurs within two distinct areas: on the southwestern coast of the Musgrave PWA and a small pocket to the north of Sleaford Mere, overlying Lincoln-A lens in the Southern Basins PWA. Damp coastal and sub-coastal heath over deep water tables is more common in the southern basins with relatively large expanses that overlie Uley South and Uley Wanilla lenses. However, there is not sufficient data for the majority of damp coastal and sub-coastal heath to classify. These areas have been mapped as having unknown water tables and hence are potentially groundwater dependent.

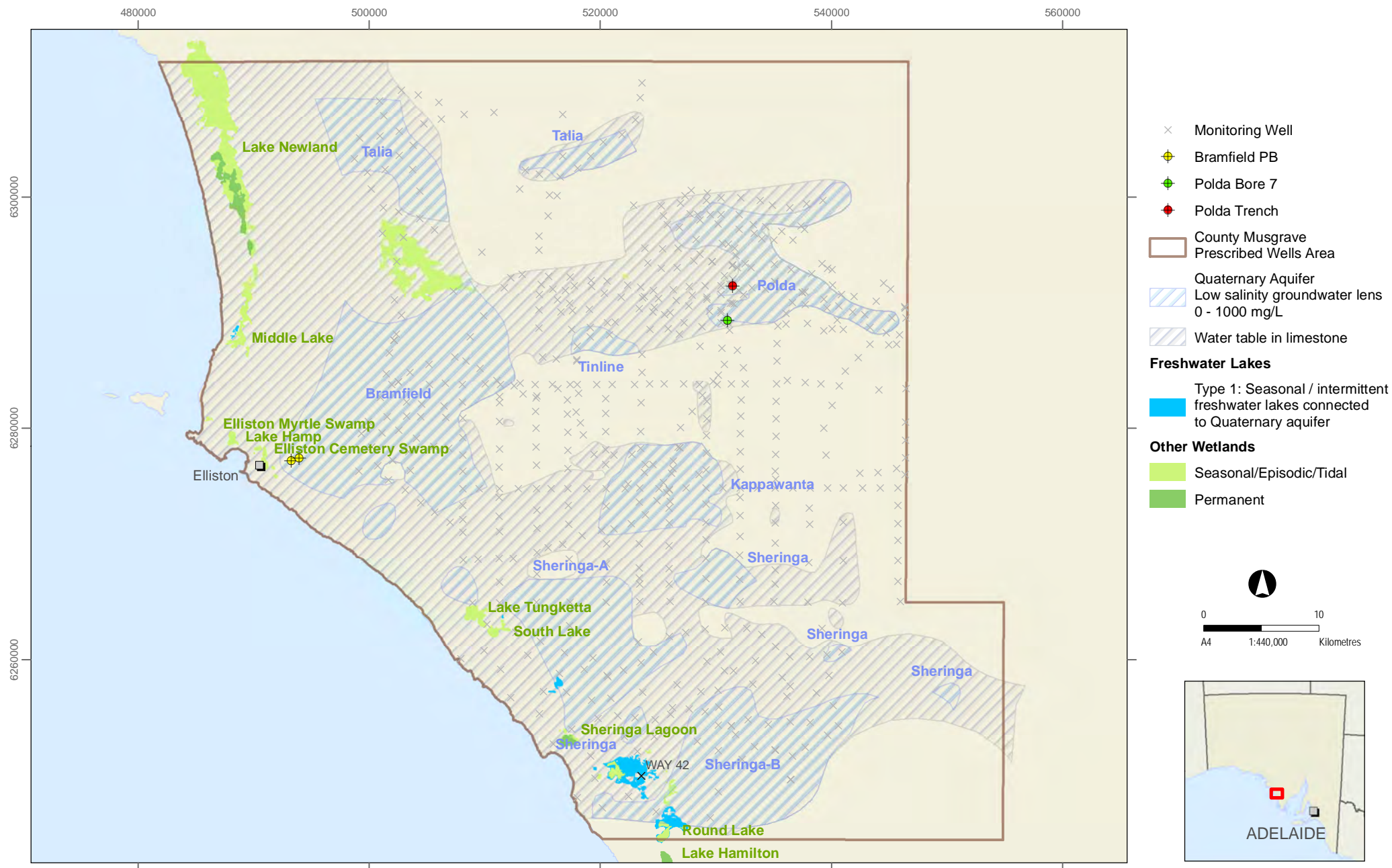
NDVI was calibrated so that areas of relatively high photosynthesis (interpreted low water stress) coincided with areas of damp coastal and sub-coastal heath over shallow water tables, and so that areas of relatively low photosynthesis (interpreted high water stress) coincided with damp coastal and sub-coastal heath over deep water tables. The resulting NDVI for damp coastal and sub-coastal heath shows relatively good calibration to these areas (Figure 5.23 and Figure 5.24) and provides confidence in identifying areas where damp coastal and sub-coastal heath that occur over unknown depths to water may have access to groundwater. NDVI suggests that there are areas of damp coastal and sub-coastal heath near extraction wells in Coffin Bay A, and Uley Wanilla that potentially access groundwater and that there is no damp coastal and sub-coastal heath that potentially accesses groundwater near groundwater extraction points in Musgrave PWA.



Southern Basins PWA

Figure 5.19: Permanent / Seasonal Freshwater Lakes

GDA 1994 MGA Zone 53



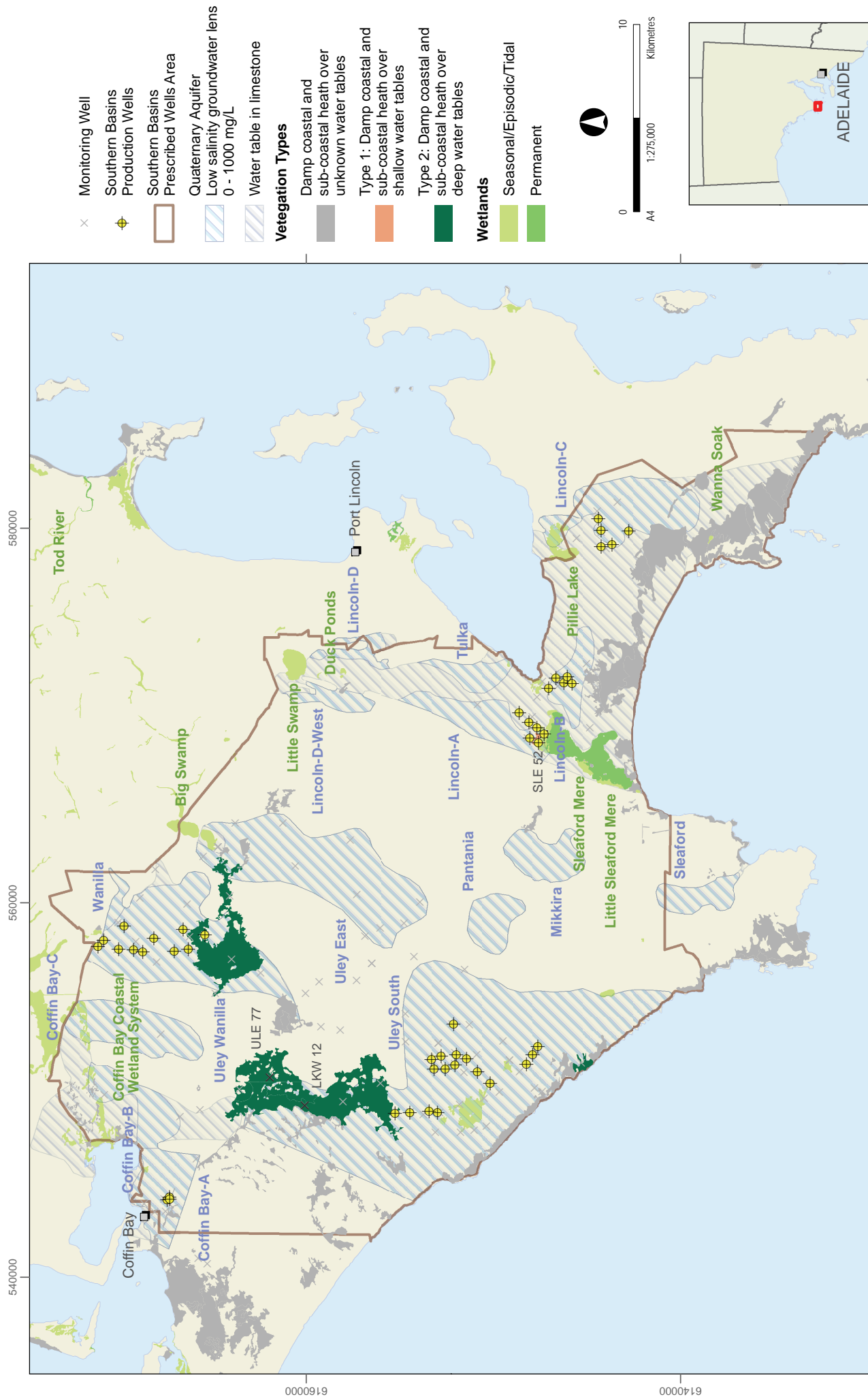
Musgrave PWA

Figure 5.20: Permanent / Seasonal Freshwater Lakes

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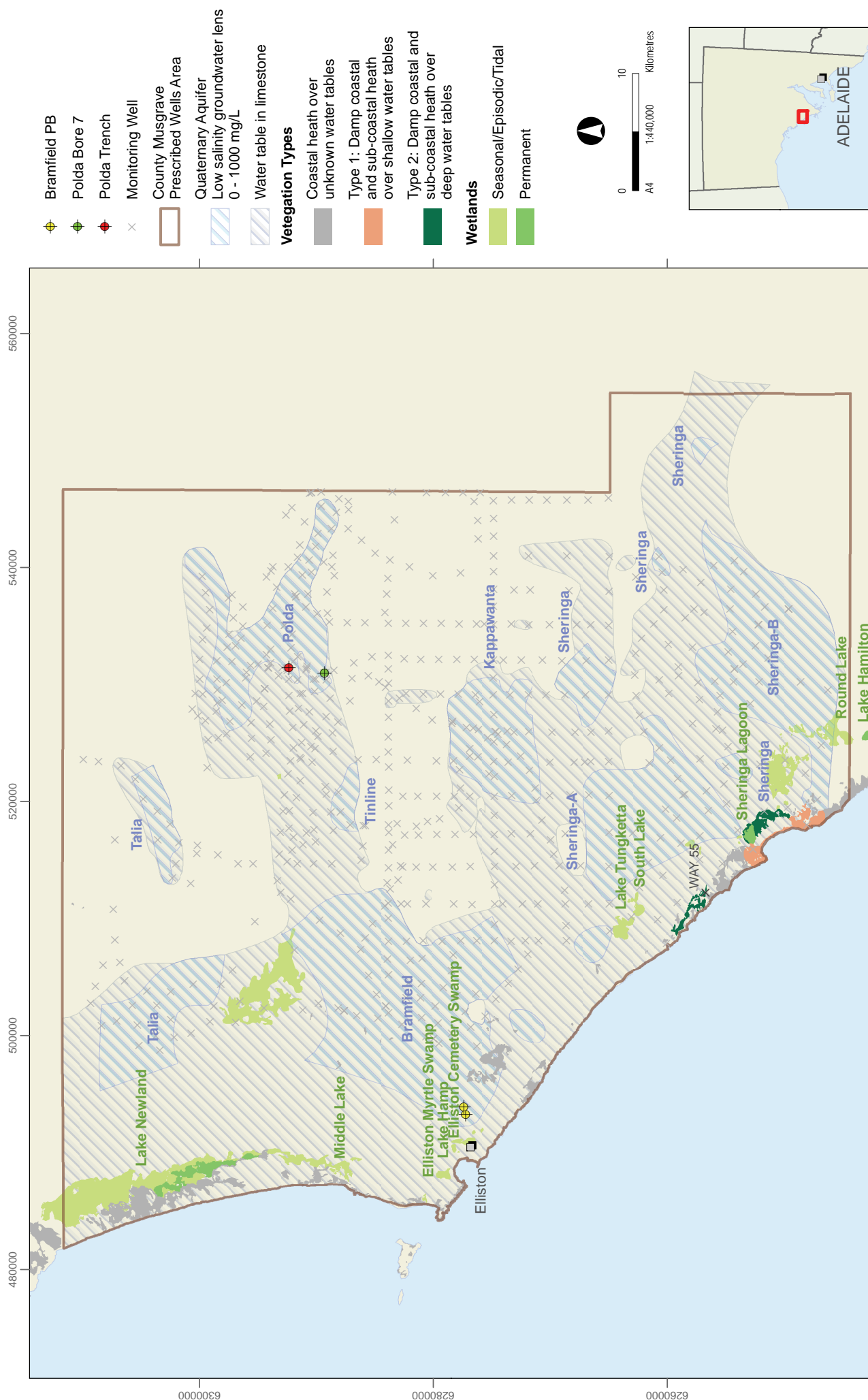
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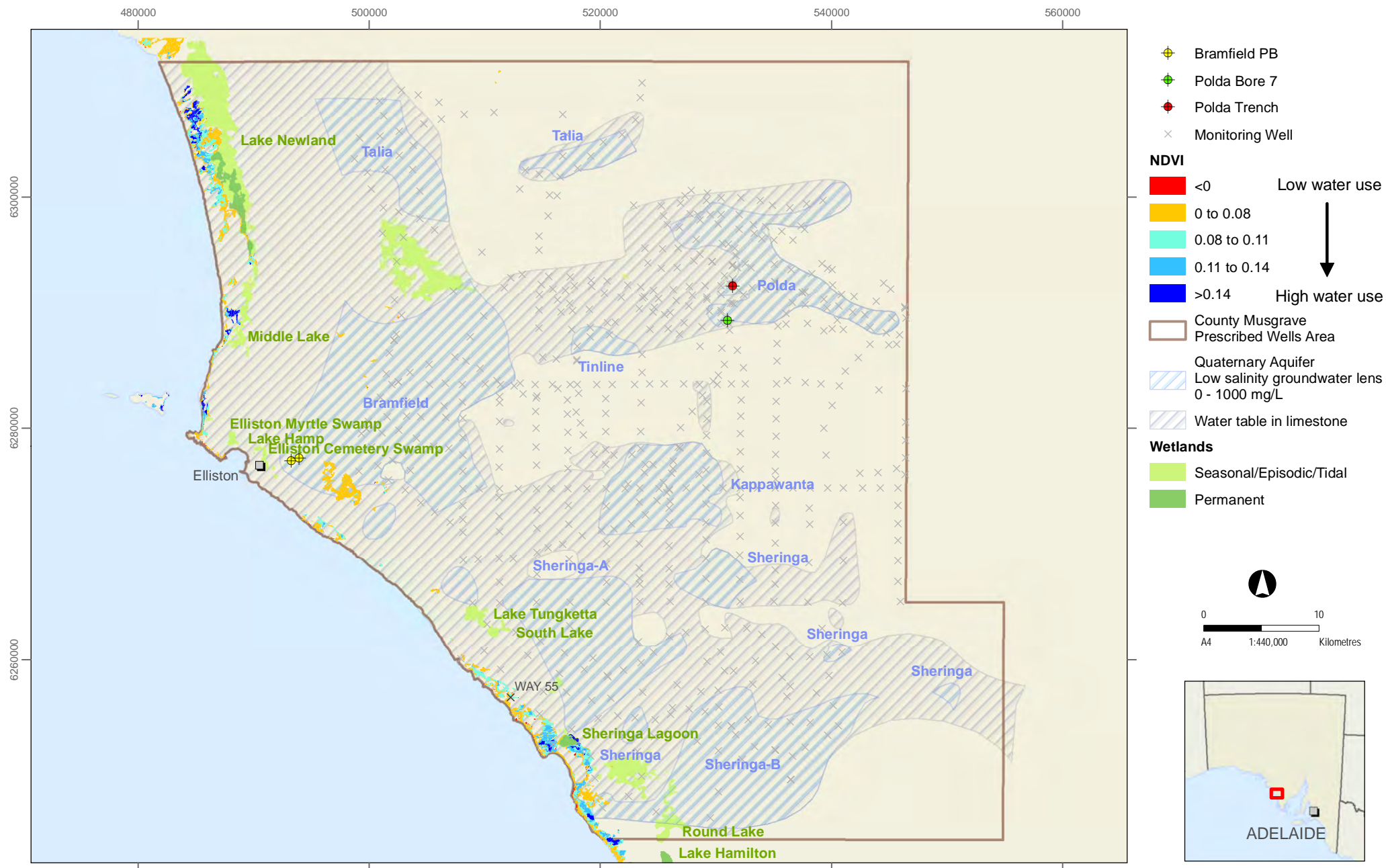
Southern Basins PWA

Figure 5.21: Damp Coastal / Sub-coastal Heath



Musgrave PWA

Figure 5.22: Damp Coastal / Sub-coastal Heath



Musgrave PWA

Figure 5.24: NDVI - Damp Coastal / Sub-coastal Heath

GDA 1994 MGA Zone 53



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5.9. Extent of GDEs

The Southern Basins PWA contains several different types of potential GDEs, covering a considerable portion of the landscape (Figure 5.25). In Uley and Coffin Bay Basins, the areas of potential GDEs mostly comprise tussock grassland and facultative phreatophytes over shallow water tables or unknown depths to water. In the Uley Basin the greatest expanse occurs to the east of Uley South, near to associated extraction wells, and in the south and to the east of Uley East. A seasonal / intermittent freshwater lake connected to the quaternary aquifer with adjacent obligate and facultative phreatophytes and sedgeland also overlies the centre of Uley South, near to extraction wells. In the Coffin Bay Basin, the majority of the landscape overlying the lenses contains potential groundwater dependent vegetation, with seasonal saline swamps occurring to the north of the area.

In the Lincoln Basin, potential GDEs lie mostly in the south relatively near to extraction wells. These mainly comprise areas of damp coastal and sub-coastal heath and facultative phreatophytes, with Sleaford Mere permanent saline lake lying just south of a cluster of wells in Lincoln-A.

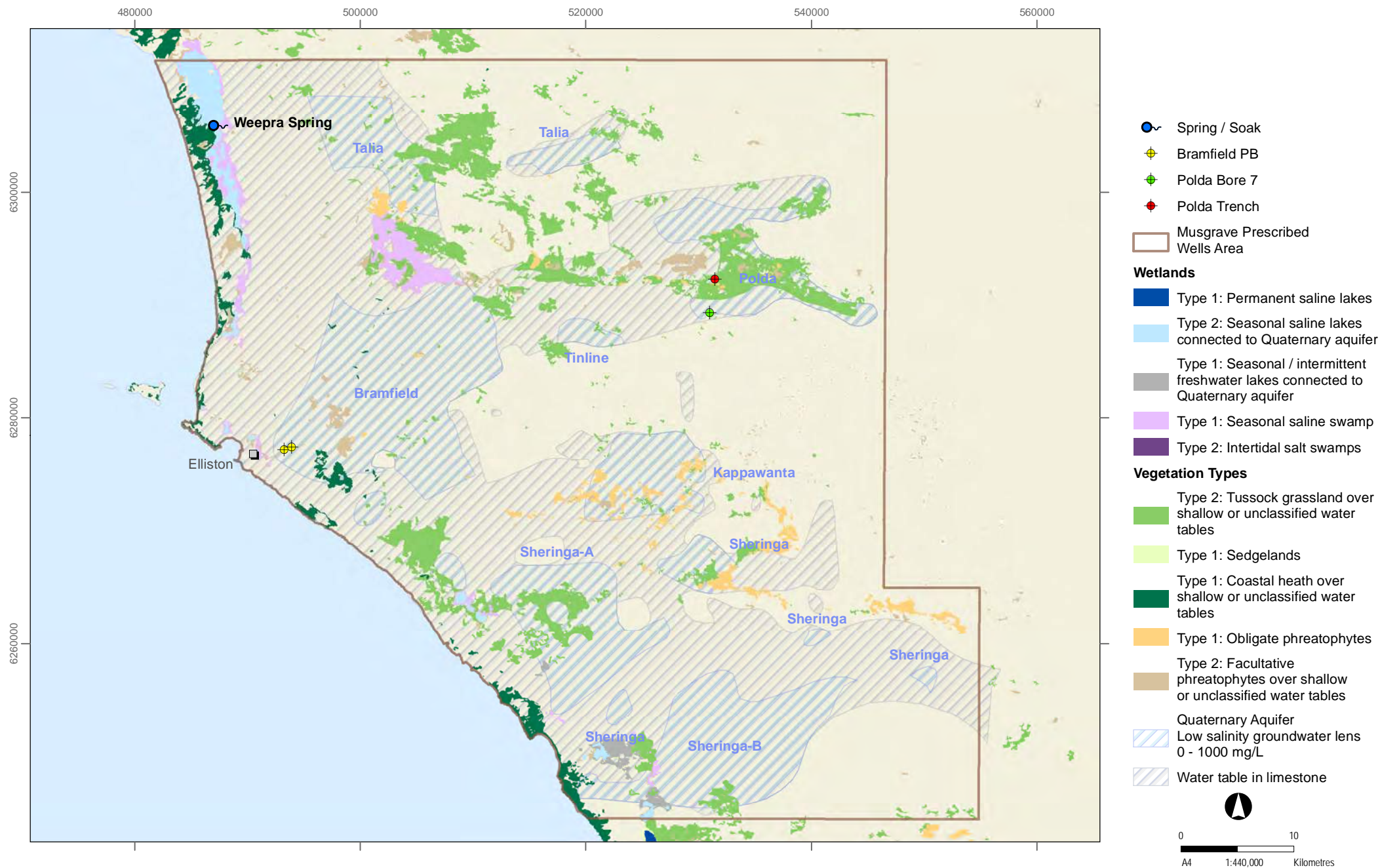
In Musgrave PWA, there are several types of potential GDEs present (Figure 5.26). The largest expanse is associated with grasslands over shallow watertables interspersed with obligate phreatophytes, with a significant portion overlying the Polda lens, near extraction wells. The largest mapped seasonal saline lake connected to the Quaternary aquifer, close to a known groundwater spring (Weepdra Spring), and seasonal saline swamp are also mapped within the Musgrave PWA. Several smaller areas of damp coastal heath, including near extraction wells, exist in the Bramfield lens.

There is a significant portion of the landscape overlying Robinson lens and the surrounding area to the east and south that could potential contains GDEs. Most commonly this includes facultative phreatophytes over shallow or unknown depth to water. There are also several saline swamps to the east and one saline lake to the south (Figure 5.27) of the lens that are potentially groundwater dependent.

5.10. Datasets used to define the location and extent of GDE types

The location and extent of each GDE type across the study areas were based on a range of spatial datasets, including:

- Department of Environment and Heritage wetland inventory;
- State-wide vegetation mapping;
- State-wide land use mapping;
- 10 m topography contours;



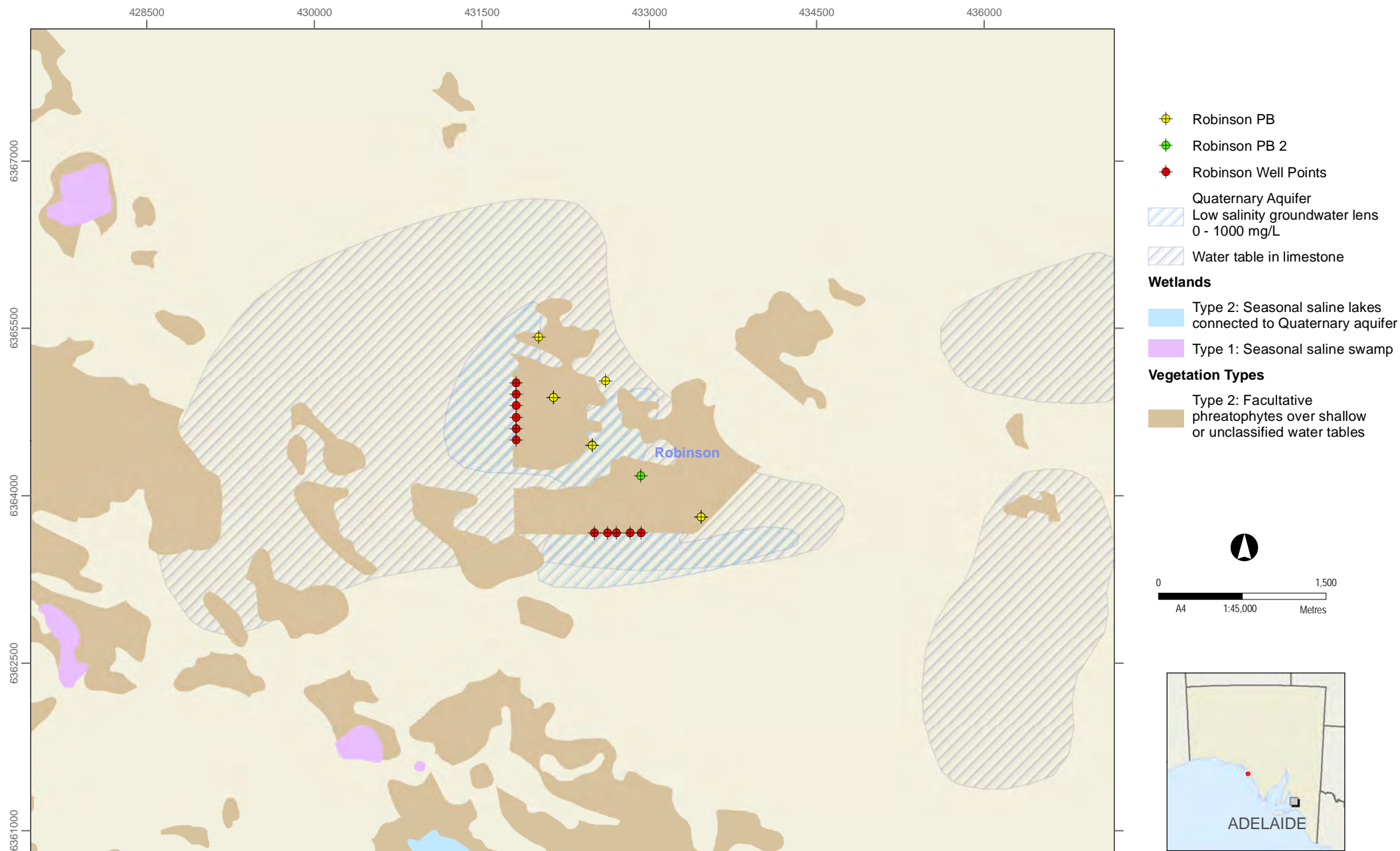
Musgrave PWA

Figure 5.26: Potential GDEs

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November 2009

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Robinson Basin

Figure 5.27: Potential GDEs

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- Regional geology mapping;
- Department of Water, Conservation and Biodiversity obswell groundwater level and salinity data archives;
- Department of Water, Conservation and Biodiversity drillhole lithology/drillers logs; and
- Remote sensing of vegetation vigour (NDVI).

Appendix A summarises how each dataset was used for assessing the location and extent of potential GDEs in the study areas and outlines the associated limitations in the current study.



6. Prioritisation of GDEs

6.1. Overview

A two tiered approach has been taken to prioritising GDEs. The first tier addresses ecosystems that have been identified for their high conservation value, which of these are most vulnerable to changed groundwater regimes and which are threatened by current or proposed groundwater affecting activities. The second tier addresses those ecosystems whose value has not been recognised, but are vulnerable to changes in groundwater regime and are threatened by current or proposed groundwater affecting activities.

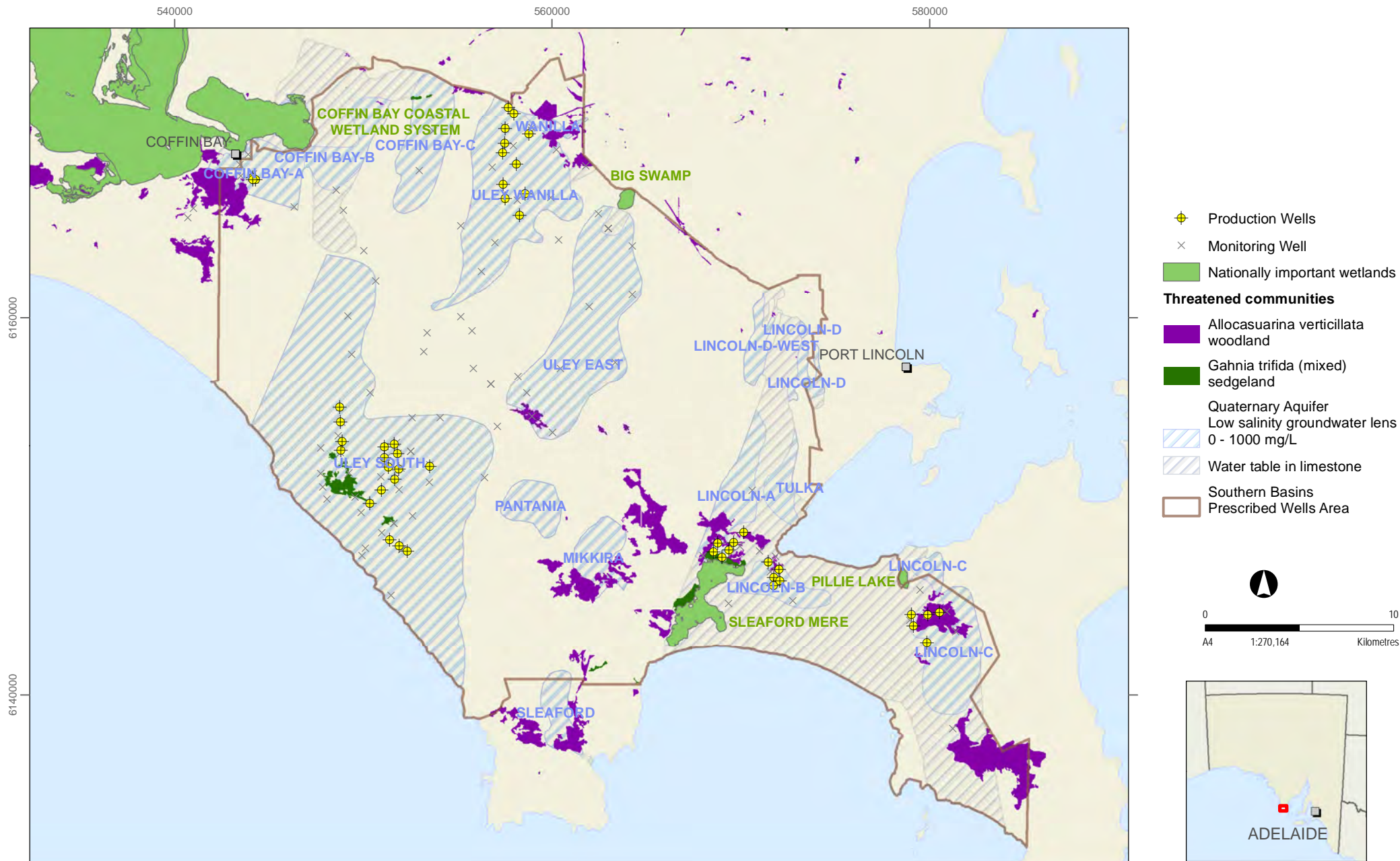
6.2. Tier 1 prioritisation of recognised high value GDEs

There are six wetlands that occur within and/or close to the study areas that are declared as nationally important through their inclusion in the *Directory of Important Wetlands in Australia*. These include: Big Swamp, Coffin Bay Coastal Wetland System, Lake Hamilton, Lake Newland, Pillie Lake and Sleaford Mere (Figure 6.1 and Figure 6.2).

Of these Sleaford Mere, Pillie Lake and the Coffin Bay Coastal Wetland System are closest to groundwater extraction and considered the most vulnerable to changes in groundwater conditions in the current environment.

There are four vegetation communities considered to be threatened in South Australia that occur within the study areas that are potentially components of GDEs. These are mapped in Figure 6.1, Figure 6.2 and Figure 6.3 and include *Gahnia trifida* Sedgeland which are classified as Endangered, and *G. filum* Sedgeland and *Allocasuarina verticillata* Grassy low woodland, which are classified as vulnerable (Matthews *et al.*, 2001).

Of these *G. trifida* sedgeland is considered the highest priority vegetation community since it is endangered and only occurs near groundwater extraction areas (Uley South lens and Lincoln-A lens fringing Sleaford Mere). The next highest priority vegetation community is *A. verticillata* grassy low woodland which occurs near groundwater extraction in Robinson Basin, Musgrave PWA (Bramfield lens) and Southern Basins PWA (Coffin Bay-A, Wanilla, Lincoln-A and Lincoln-C lenses). It is interpreted to occur over shallow water tables in most of the groundwater extraction areas, except near Lincoln-C where it is not considered to be dependent on groundwater. *A. verticillata* grassy low woodland is not limited to areas of groundwater extraction and is likely to be more resilient than *G. trifida* to changes in groundwater condition. *G. filum* sedgeland does not occur near groundwater extraction in the study areas and therefore is not currently considered at risk from groundwater extraction.

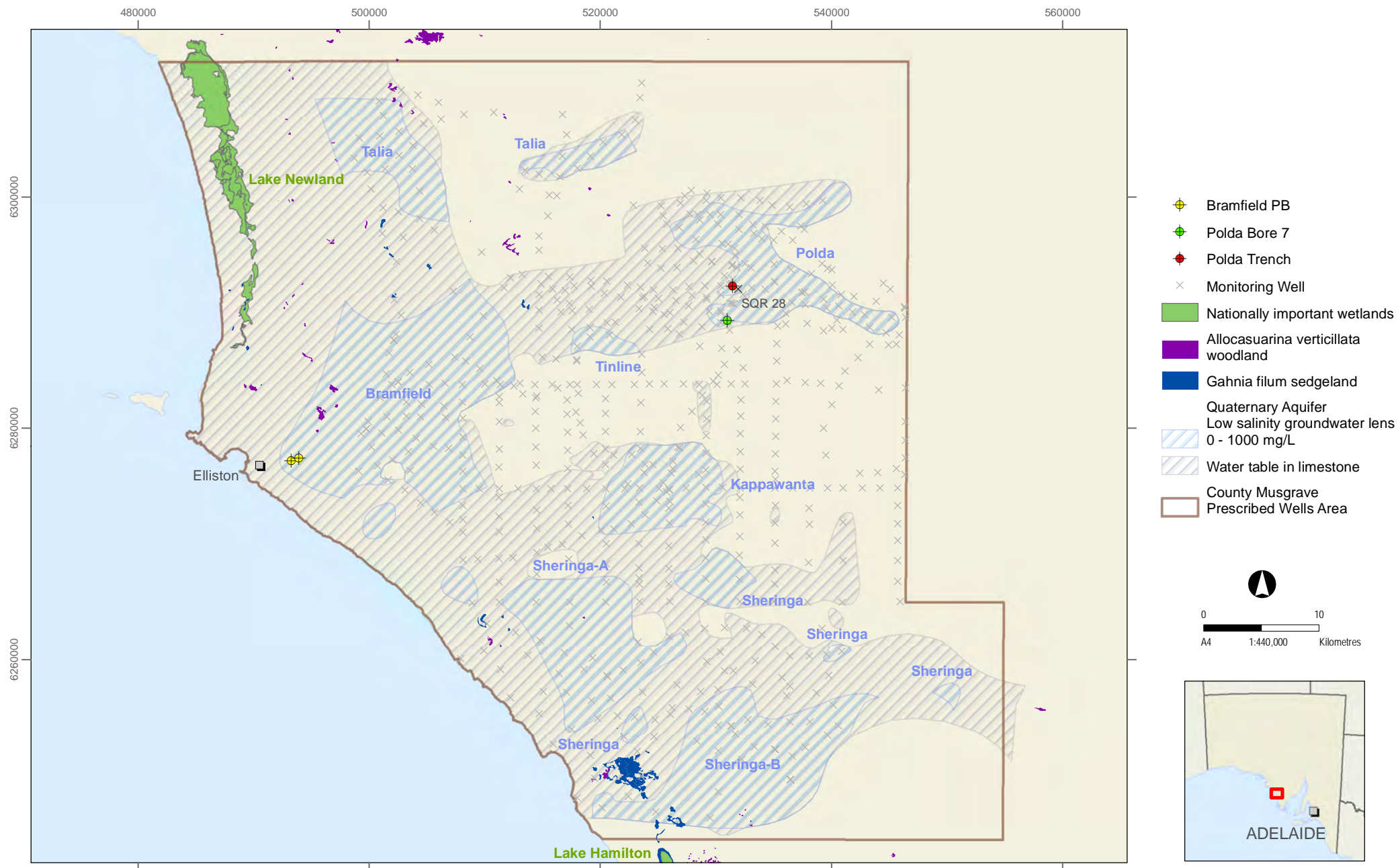


Southern Basins PWA

Figure 6.1: Threatened communities and nationally important wetlands

GDA 1994 MGA Zone 53

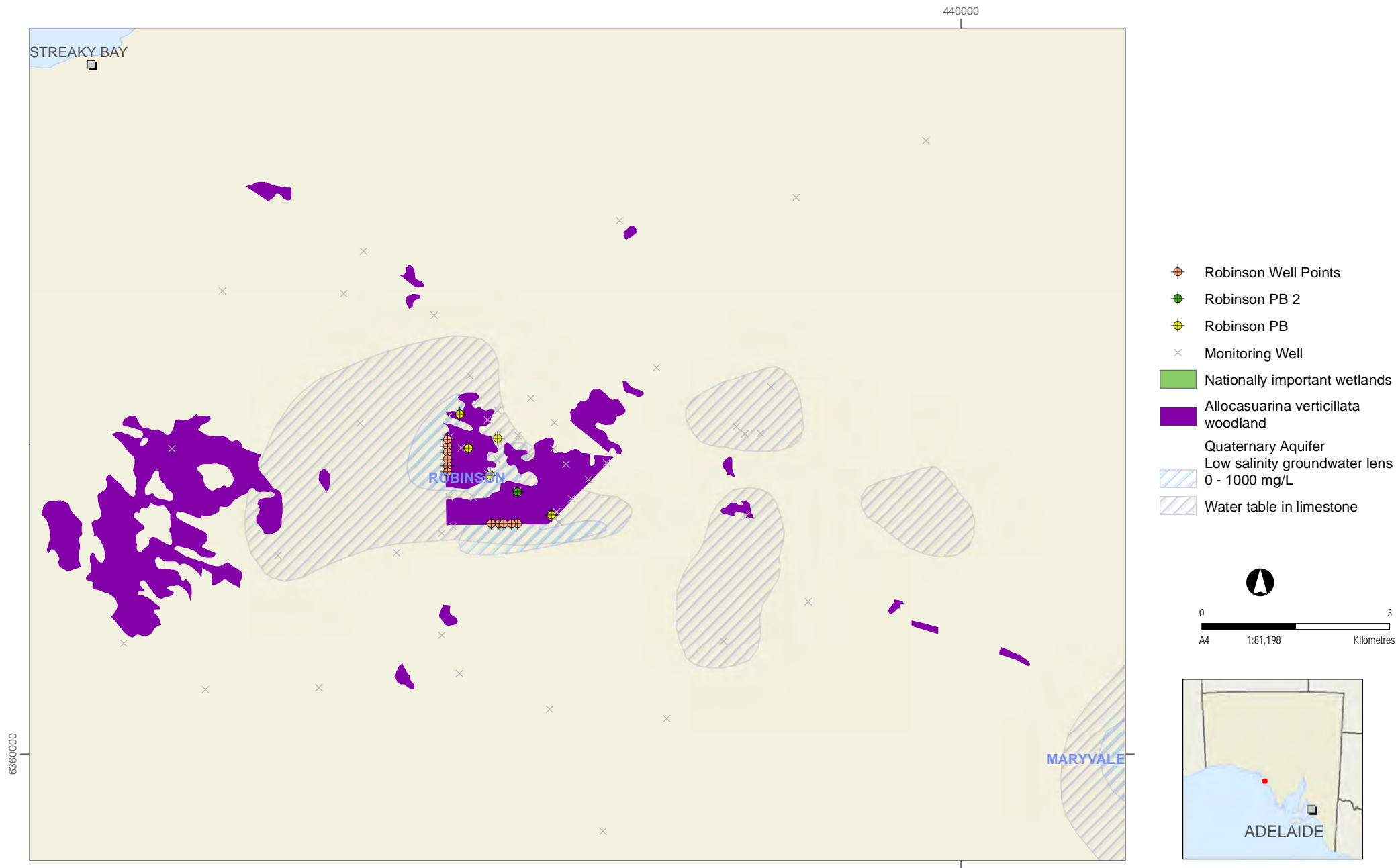
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Musgrave PWA

Figure 6.2: Threatened communities and nationally important wetlands

GDA 1994 MGA Zone 53





6.3. Tier 2 prioritisation of GDEs whose value has not been recognised

There are a number of potentially groundwater dependent ecosystems that are likely to have high conservation value, but are not currently formally recognised and protected. Table 6.1 provides a prioritisation of GDE types found in the study areas, based on (in order of significance): threat of change in groundwater condition induced by groundwater extraction; the inferred levels of resistance and resilience (form of dependence, Table 1.1) of the GDE to changes in groundwater condition; and whether or not the GDE is restricted to areas where it can access groundwater (obligate or facultative). For example, those potential GDEs that are likely to occur in areas where there is a high risk of change to the groundwater regime are ranked highest. Of these, the GDEs that have the least resistance and resilience to change in groundwater regime are ranked highest, and of these, the GDEs that are restricted to areas where they have access to groundwater (obligate) are ranked highest.

This method of prioritisation identifies springs, soaks, obligate phreatophytes and hyporheic ecosystems to be the most vulnerable to changes in groundwater conditions in the study areas. However, there is very little known about springs, soaks and hyporheic ecosystems on the Eyre Peninsula.



■ **Table 6.1 Ranking of GDE types based on form and type of groundwater dependence and threat of adverse groundwater conditions occurring within these GDE types in the study areas**

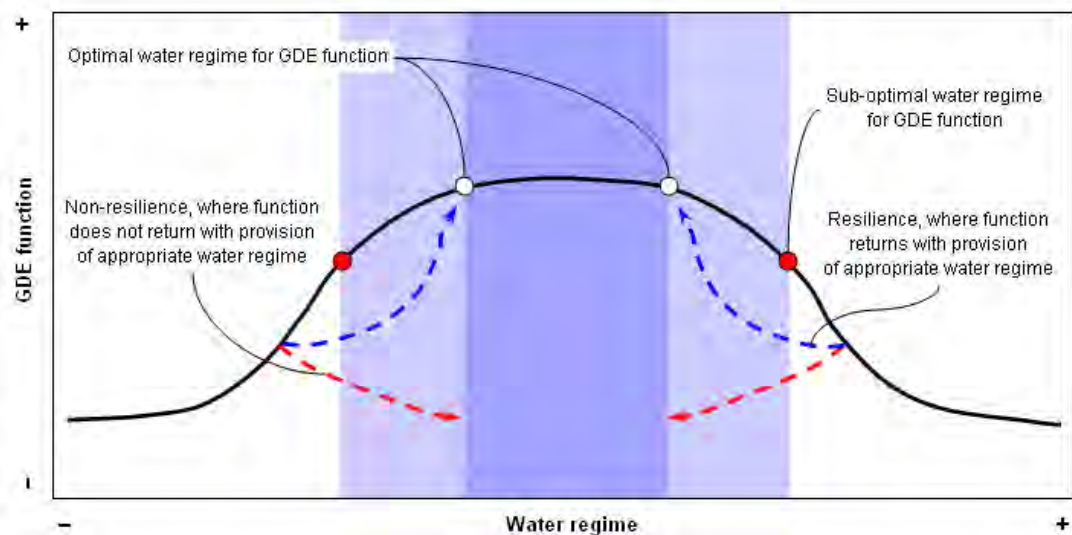
GDE type		Type of groundwater dependence	Form of groundwater dependence	Threat of change in groundwater condition	Rank
Saline swamps	Type 1: Seasonal saline swamps	Obligate	High	Medium	5
	Type 2: Intertidal salt swamps	Obligate	High	Low	12
Saline lakes	Type 1: Permanent saline lakes	Obligate	High	Medium	5
	Type 2: Seasonal saline lakes connected to the Quaternary aquifer	Obligate	Proportional	Medium	7
	Type 3: Seasonal saline lakes disconnected from the Quaternary aquifer	None apparent	None apparent	Low	14
Springs and underground water soaks	Type 1: Springs	Obligate	Total	High	1
	Type 2: Seawater-fed springs	None apparent	None apparent	Low	14
	Type 3: Soaks	Obligate	Total	High	1
Freshwater lakes	Type 1: Seasonal / intermittent freshwater lakes connected to Quaternary aquifer	Obligate	Limited	Medium	10
	Type 2: Seasonal / intermittent freshwater lake disconnected from the Quaternary aquifer	None apparent	None apparent	Low	14
Phreatophytes	Type 1: Obligate phreatophyte	Obligate	High	High	1
	Type 2: Facultative phreatophytes	Facultative	Proportional	High	2
Grasslands / Sedgelands	Type 1: Sedgelands	Facultative	High	Medium	6
	Type 2: Tussock grassland over shallow water tables	Facultative	Limited	Medium	11
	Type 3: Tussock grassland over deeper water tables	Facultative	None apparent	Low	13
Damp coastal and sub-coastal heath	Type 1: Coastal heath over shallow water tables	Facultative	Proportional	Medium	8
	Type 2: Coastal heath over deep water tables	Facultative	None apparent	Low	13
Hypogean, hyporheic and collapsed sinkhole ecosystems	Type 1: Hypogean	Obligate	Total	Medium	4
	Type 2: Hyporheic	Obligate	Total	High	1
	Type 3: Collapsed sinkhole ecosystems	Facultative	High	Medium	6



7. Environmental Water Requirements

7.1. Conceptual EWRs

The environmental water requirement of a GDE is the natural water regime that provides for the natural ecological function and the maintenance of the biodiversity and ecological significance of the GDE. The natural groundwater regime is dynamic and GDEs have a natural resistance and resilience to varying water availability/quality within that groundwater regime. This is depicted conceptually in Figure 7.1.



■ **Figure 7.1 Conceptual EWR (Howe *et al.*, 2007)**

For example, a wetland may depend on groundwater discharge to provide essential nutrients to aquatic species. Any changes in groundwater conditions that result in a change in the quantity or the quality of the groundwater discharged to the wetland may place the wetland ecosystem under stress. In some cases the change in groundwater condition may be within the resilience of the aquatic species, e.g. if there are insufficient nutrients delivered to the wetland in any one year, recruitment may not occur and the population of aquatic species will decline, but if more favourable conditions return in the following year, the population of the aquatic species will return to a growth phase. However, in other cases the change in groundwater condition may go beyond the resilience of the aquatic species, e.g. if high nutrient loads result in cyanobacteria blooms causing anoxic conditions in the wetland and leading to the annihilation of some aquatic species populations.

Given the climatic and groundwater systems are naturally dynamic, it is likely that the structure and function of GDEs in the Eyre Peninsula have changed and will change in the future. Groundwater management aims to protect GDEs within their resiliencies, which may change over time.



7.2. Method for describing EWRs

Ideally the groundwater component of the EWR of an ecosystem would be assessed based on how the ecosystem condition naturally responds to changes in hydrogeological conditions over a long period of record that includes variations in climatic conditions. There are some good hydrogeological records across the study areas on the Eyre Peninsula, but there is limited information regarding how ecosystem condition has responded to different hydrogeological regimes over time.

It has been assumed that, with one exception (refer to Appendix B.6), the hydrogeological regime has not adversely impacted upon the ecological condition of GDEs across the study areas; i.e. historic wetting and drying phases have been within the tolerance (resistance and resilience) range of GDEs. The one exception is Red Gum (within broad vegetation classification Eucalyptus forest and woodland) that occurs south of Mt Wedge in Musgrave PWA, where there has been an alarming dieback of mature Red Gum over the last few years, which might be related to a rapid decline in groundwater levels (2.3 m over 20 years) and lack of recruitment.

EWRs have been set assuming that the current ecosystem condition is acceptable, and that the EP NRM Board does not wish to return GDEs to the condition they experienced 10 to 20 years ago, when climatic conditions were more favourable.

The EWR is expressed as an annual minimum and annual maximum depth to groundwater and a maximum groundwater salinity that the ecosystem is naturally adapted to withstand in any one year across the study areas. Where hydrogeological records are available within a GDE type, the hydrographs with the greatest depth to water and the highest groundwater salinities were selected to represent the EWR. The maximum and minimum depths to water were selected from hydrographs as presented in Figure 7.2.

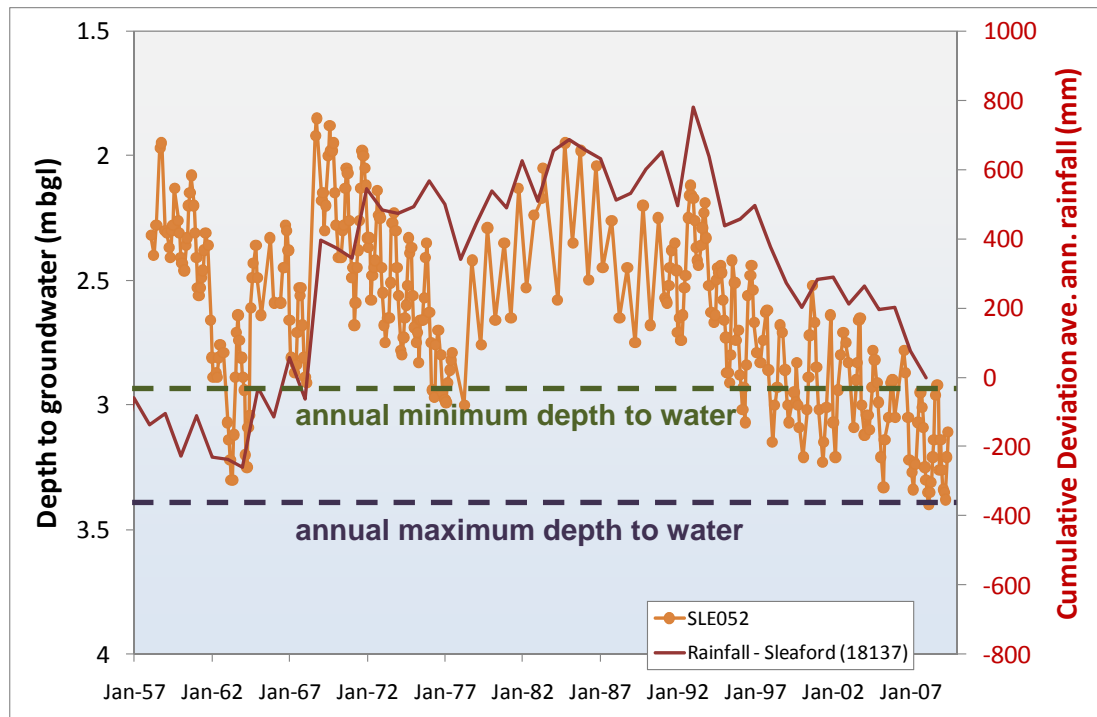
Where hydrogeological records are not available within a GDE type, the closest records to the GDE type were selected to analyse the EWR. In most cases these wells occurred in higher topographic positions than the GDEs themselves, in which case the wells that reported the shallowest depths to water near the GDEs were selected as most representative to define the annual minimum and maximum depths to water.

These provide a first-cut to setting bounds to thresholds of hydrogeological conditions that Eyre Peninsula GDEs are likely to withstand (thresholds), but do not represent static thresholds of depth to water. GDEs may be adversely impacted if depths to water are maintained at their limit for several consecutive years. Similarly, GDEs may be able to withstand greater annual minimum and maximum depths to groundwater if they are preceded and / or followed by years where the depth to water is much shallower. That is, GDEs may be able to withstand short-term deviations from these



groundwater conditions, but there is little to no evidence to suggest what the extent, timing or duration of such deviations or rates of change may be.

The EWRs defined for each potential GDE type mapped in the Southern Basins and Musgrave PWAs and Robinson Basin are presented as appendices to this report.



■ **Figure 7.2 Method for selection annual maximum and minimum depths to water**



8. Groundwater Management to Protect GDEs

8.1. Overview

The identification of an environmentally sustainable level of extraction (extraction limit) is an essential component of the water allocation planning process.

Approaches to setting an extraction limit have evolved from an historical approach of setting limits based only on a water balance (e.g. as a fraction of recharge), to one which recognises that the extraction limit is based on the notion of an *acceptable level of impact* to the groundwater resource (defined through a series of *resource condition limits*). The core element of this evolution is the recognition that any amount of groundwater extraction will have an impact on the resource and GDEs, and the process of defining a sustainable level of extraction is one of determining a balance between the needs of consumptive and environmental users. In that sense, the term *sustainable yield* is being replaced, at the management level at least, with the term *acceptable yield*.

It follows that the development of an appropriate and acceptable management approach for GDEs be developed with the best science available (explained within this document) and a consultative approach with key stakeholders representing the interests of consumptive and environmental uses. The discussion in this section is designed to raise issues and approaches that can be considered in the development of future water allocation plans.

The GDE type, suggested EWR and groundwater trends in each area have been tabulated in Table 8.1 as an aid to the discussion in this section.

8.2. Requirements of the National Water Initiative

The National Water Initiative (and programs of the National Water Commission) contains objectives that are important to the protection of GDEs.

One of the objectives of the National Water Initiative (NWI) is to return all currently overallocated or overused systems to environmentally-sustainable levels of extraction. The NWI defines environmentally sustainable level of extraction as: *the level of water extraction from a particular system which, if exceeded would compromise key environmental assets, or ecosystem functions and the productive base of the resource.*

■ **Table 8.1 Summary of GDEs potentially influenced of groundwater (GW) extraction and the GW component of their EWRs**

Lens	Trends in GW extraction	GDEs potentially influenced by GW extraction	Status of GW condition	^[1] GW level component of EWR	^[1] GW salinity component of EWR
Polda, Musgrave PWA	Currently 200 ML/yr Ranged from 200 to greater than 2000 ML/yr. General decline since 1988, stabilising at ~200 ML/yr	Type 2: Tussock grassland over shallow water tables	GW levels have declined by ~1.3 m since 1998. GW levels have been steadily declining since 1980.	Depth to water: annual min <4 m bgl; annual max <5 m bgl	<5 mS/cm
		Type 2: Facultative phreatophytes	GW levels have declined by 1 to 1.3 m since 1998. GW levels have declined ~2 m since 1989.	Depth to water: annual min <3.4 m bgl; annual max <3.9 m bgl	<24 mS/cm
		Type 1: Obligate phreatophytes	GW levels have declined by 1 to 1.5 m since 1998. GW levels have steadily declined ~2 m since 1980.	Depth to water is consistently <3.4 m bgl	<5 mS/cm
Bramfield, Musgrave PWA	Currently 80 ML/yr ~75 ML/yr since 1980 +/- 10 ML/yr	Type 2: Seasonal saline lakes connected to Quaternary aquifer	Regional GW levels have declined >3 m since 1980. From 1999 GW levels have declined ~1 m.	^[2] Depth to water: annual min <2.1 m bgl, annual max <2.5 m bgl	^[2] <32 mS/cm
		Type 1: Seasonal saline swamps	As above	^[2] Depth to water: annual min <1.5 m bgl, annual max <2.2 m bgl	^[2] <2 mS/cm
		Type 2: Facultative phreatophytes	As above	^[2] Depth to water <4m bgl	^[2] <24 mS/cm
		Type 1: Obligate phreatophytes	GW levels have declined by ~1 m over the last decade.	Depth to water: annual min < 3.6 m bgl; annual max <3.8 m bgl	^[2] <11 mS/cm
		Type 1: Coastal heath over shallow water tables	As above	^[2] Depth to water: annual min <3 m bgl, annual max <3.4 m bgl	^[2] <2.2 mS/cm
Coffin Bay A, Southern	Currently 100 ML/yr Commenced in 1986 at 50 ML/yr	Type 2: Facultative phreatophytes	GW levels have declined by 0.3 m since 1986 and have been stable since 1999.	^[2] Depth to water <4 m bgl	^[2] <24 mS/cm

Lens	Trends in GW extraction	GDEs potentially influenced by GW extraction	Status of GW condition	^[1] GW level component of EWR	^[1] GW salinity component of EWR
Basins PWA	and increased to 160 ML/yr until 2000, then decrease to 100 ML/yr	Type 2: Tussock grassland over shallow water tables	GW levels have declined by 0.3 m since 1986 and have been stable since 1999.	^[2] Depth to water: annual min <4 m bgl; annual max <5 m bgl	^[2] <5 mS/cm
		Type 1: Seasonal / intermittent freshwater lakes connected to Quaternary aquifer	GW levels appear to have been relatively stable since the late 1980s.	^[2] Depth to water : annual min <3.7 m bgl and annual max <4 m bgl	^[2] <2 mS/cm
		Type 1: Springs	GW levels appear to have been relatively stable since the late 1980s.	Depth to water <0 m bgl.	<1.5 mS/cm.
Uley South, Southern Basins PWA	<i>Currently 7500 ML/yr ~ 6000 ML/yr since 1976. Stabilised at 7500 ML/yr since 2000</i>	Type 2: Facultative phreatophytes	GW levels declined ~ 1 m since 1989, and have remained stable since 1999.	Depth to water: annual min <4 m bgl; annual max <4.4 m bgl. In the southern section of the borefield the phreatophytes overlie deeper water tables and are not GW dependent.	~ 1 mS/cm
		Type 1: Sedgeland	GW levels have declined ~0.2 m since 1998. Levels have declined by 1.4 to 2 m since 1995.	Depth to water: annual min <3.6 m bgl and annual max <4 m bgl	<1.5 mS/cm
		Type 1: Seasonal / intermittent freshwater lakes connected to Quaternary aquifer	GW levels have declined ~0.2 m since 1998. Levels have declined by 1.4 to 2 m since 1995.	Depth to water: annual min <3.7 m bgl and annual max <4 m bgl	<2 mS/cm
		Type 2: Seasonal saline lakes connected to Quaternary aquifer	Insufficient monitoring	^[2] Depth to water: annual min <2.1 m bgl, annual max <2.5 m bgl	<32 mS/cm
Lincoln A, Southern Basins PWA	<i>Currently 1000 ML/yr (in Lincoln A, B and C) Over 2000 ML/yr</i>	Type 1: Seasonal / intermittent freshwater lakes connected to Quaternary aquifer	GW levels have declined by ~0.5 to 1 m since 1985 and 0.3 since 1999.	Depth to water: annual min <2.8 m bgl, and annual max <3.5 m bgl	<2 mS/cm

Lens	Trends in GW extraction	GDEs potentially influenced by GW extraction	Status of GW condition	^[1] GW level component of EWR	^[1] GW salinity component of EWR
	until 1977. ~500 ML/yr until 1995 then stabilised at 1000 ML/yr	Type 2: Facultative phreatophytes	GW levels have declined by 1 m since 1985; and 0.5 m since 1999. Salinity has remained stable.	Depth to water: annual min <4.7 m bgl, and annual max <4.9 m bgl	<2 mS/cm
		Type 1: Coastal heath over shallow water tables	GW levels have declined by 0.5 to 1 m since 1985. Salinity has remained stable.	^[2] Depth to water: annual min <3 m bgl, annual max <3.4 m bgl	^[2] <2.2 mS/cm
		Type 1: Obligate phreatophytes	GW levels declined by ~ 1 m in the last decade.	^[2] Depth to water <4 m bgl	^[2] <11 mS/cm
		Type 1: Permanent saline lakes - Sleaford Mere	GW levels have declined by 0.5 to 1 m since 1995. GW salinity appears to have remained stable.	Depth to water: annual min <2.8 m bgl, and annual max <3.3 m bgl	~ 2 mS/cm on the northern edge and <9 mS/cm to the south and east
Lincoln B, Southern Basins PWA		Type 1: Seasonal / intermittent freshwater lakes connected to Quaternary aquifer	GW levels have declined by ~0.5 to 1 m since 1985 and 0.3 since 1999.	Depth to water: annual min <2.8 m bgl, and annual max <3.5 m bgl	<2 mS/cm
		Type 1: Permanent saline lakes - Sleaford Mere	GW levels have declined by 0.5 to 1 m since 1995. GW salinity has remained stable.	Depth to water: annual min <2.8 m bgl, and annual max <3.3 m bgl	~ 2 mS/cm on the northern edge and <9 mS/cm to the south and east
		Type 2: Facultative phreatophytes	GW levels have declined by 0.5 to 1 m in the last decade.	^[2] Depth to water <4 m bgl	^[2] <24 mS/cm
		Type 1: Sedgelands	GW levels have declined by 0.5 to 1 m since 1989 and by 0.1 to 0.5 m since 1999. GW salinity has remained stable.	Depth to water: annual min <2.8 m bgl; and annual max <3.3 m bgl	~ 2 mS/cm

Lens	Trends in GW extraction	GDEs potentially influenced by GW extraction	Status of GW condition	^[1] GW level component of EWR	^[1] GW salinity component of EWR
Lincoln C, Southern Basins PWA		Type 1: Coastal heath over shallow water tables	GW levels have declined by 0.5 to 1 m since 1985. Salinity has remained stable.	^[2] Depth to water: annual min <3 m bgl, annual max <3.4 m bgl	^[2] <2.2 mS/cm
		Type 1: Seasonal / intermittent freshwater lake connected to Quaternary aquifer - Pillie Lake	GW levels have declined by ~0.5 to 1 m since 1984 and have declined by 0.2 to 0.3 m since 2000.	^[2] Depth to water: annual min <3.7 m bgl and annual max < 4 m bgl	^[2] <2 mS/cm
		Type 2: Facultative phreatophytes	GW levels have declined by ~0.5 to 1.7 m since 1984 and by < 0.5 since 2000.	Depth to water consistently >7 m bgl and assumed to satisfy its EWR from the soil store	Not GW dependent
		Type 1: Sedgelandes	No representative monitoring wells	^[2] Depth to water: annual min <3.6 m bgl and annual max <4 m bgl	^[2] <1.5 mS/cm
		Type 1: Coastal heath over shallow water tables	No representative monitoring wells	^[2] Depth to water: annual min <3 m bgl, annual max <3.4 m bgl	^[2] <2.2 mS/cm
		Type 1: Seasonal saline swamps	No representative monitoring wells	^[2] Depth to water: annual min <1.5 m bgl, annual max <2.2 m bgl	^[2] <2 mS/cm
		Type 2: Seasonal saline lakes connected to Quaternary aquifer	GW levels have declined by 1 to 0.5 m since 1984 and 0.2 to 0.3 m since 2000.	^[2] Depth to water: annual min <2.1 m bgl, annual max <2.5 m bgl	^[2] <32 mS/cm
Uley Wanilla, Southern Basins PWA	Currently 250 ML/yr Fluctuated until late 1970 then decreased to 500 ML/yr. Peaked at 1500 ML/yr in early 1990, then	Type 2: Facultative phreatophytes	GW levels have declined by 0.5 to 0.7 m since 1999.	Depth to water is consistently >6 m bgl and vegetation is assumed to access its EWR from the soil store	Not GW dependent
		Type 1: Obligate phreatophytes	GW levels have declined by up to 4 m since 1987. Since 1999 GW levels have remained relatively stable.	^[2] Depth to water <4 m bgl	^[2] <11 mS/cm

Lens	Trends in GW extraction	GDEs potentially influenced by GW extraction	Status of GW condition	^[1] GW level component of EWR	^[1] GW salinity component of EWR
	decreased and stabilised at ~300 ML/yr during 2000	Type 2: Tussock grassland over shallow water tables	GW levels have declined by up to 4 m since 1987. Since 1999 GW levels have remained relatively stable.	^[2] Depth to water: annual min <4 m bgl; annual max <5 m bgl	^[2] <5 mS/cm
		Type 2: Seasonal saline lakes connected to Quaternary aquifer	GW levels have declined by up to 4 m since 1987. Since 1999 GW levels have remained relatively stable.	^[2] Depth to water: annual min <2.1 m bgl, annual max <2.5 m bgl	^[2] <32 mS/cm
Robinson Basin	Currently <50 ML/yr. Commenced in 1973 at 250 ML/yr. Rates of extraction remained ~200 ML/yr to 300 ML/yr until 2003. In 2004 rates decreased dramatically stabilising at less than 50 ML/yr	Type 2: Facultative phreatophytes	Overall GW levels have declined by ~ 0.5 m since the 1980s. GW salinity has typically become more brackish since 2000.	East of the lens depth to water >4 m bgl. Elsewhere depth to water is typically <4 m bgl. Annual min <4.3 m bgl, annual max <4.6 m bgl	<13 mS/cm
		Type 2: Seasonal saline lakes connected to Quaternary aquifer	GW levels have steadily declined by ~ 1 m since the 1980s.	Depth to water: annual min <2.1 m bgl, annual max <2.5 m bgl	<32 mS/cm
		Type 1: Seasonal saline swamps	No representative monitoring wells	^[2] Depth to water: annual min <1.5 m bgl, annual max <2.2 m bgl	^[2] <2 mS/cm

^[1] Site specific information included where available

^[2] Site specific information not available and regional values assumed, refer to Appendix B



Under the banner of Environmental Water, the National Water Initiative requires that:

- environmental and other public benefit outcomes for water systems identified with as much specificity as possible in water plans;
- management practices and institutional arrangements in place to achieve environmental outcomes;
- accountable environmental water managers established and equipped with the necessary authority and resources to provide sufficient water at the right times and places to achieve identified outcomes, including across state boundaries where relevant; and
- cost-effective measures to provide water for environmental outcomes.

Paragraphs 78 and 79 of the NWI outline the provisions relating to integrated management of environmental water.

Clause 35 of the Intergovernmental agreement on a National Water Initiative goes further to require that water provided to meet environmental and other public benefit outcomes is to have *at least* the same security as entitlements provided to consumptive users.

Water market and trading arrangements must protect the needs of the environment.

In the 2009 Biennial Assessment the National Water Commission recommends that:

'all jurisdictions put in place systematic and transparent processes to determine environmental water outcomes and requirements'; and

'the identification and assessment of the water needs of GDEs need to be brought into the planning and allocation process, just as for surface water systems'

8.3. Current approach to GDE management in water allocation plans

A primary consideration of the water allocation process for the groundwater resources of the Southern Basins and Musgrave PWAs is to ensure that the volume allocated to licensed users considers the need to maintain a level of saturation within the aquifer and maintain a rate of groundwater discharge to ecosystems. The general principle of management to achieve this objective is to apportion usage from the recharge component of the water budget.

This is based on a recharge rate which reflects the variability of annual recharge; the groundwater response to precipitation less the precipitation lost to evaporation and transpiration. The allocation process thus takes into account significant seasonal variations in water levels and strong relationships with seasonal rainfall patterns.

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The Southern Basins PWA WAP provides 60% of the annual recharge for GDEs. In effect this means that for the post-development steady-state condition there is 40% less discharge from the Quaternary groundwater system than occurred under natural pre-development conditions.

Similarly 90% and 50% of recharge to the Tertiary and basement aquifers is provided to maintain aquifer pressures and meet needs of GDEs. The Musgrave PWA WAP provides for 60% of recharge to the Quaternary aquifers for GDEs and 90% of the recharge to the Tertiary aquifer.

Qualitative descriptions of GDEs are provided in the WAP and the supporting documents with limited information regarding the quantity of water needed (small, moderate or large), timing of needs and water quality requirements.

There appears to be no analysis available which links the allocation regime to a groundwater condition. For example, there is no quantification of the impact of allocation of 40% of rainfall recharge on discharge rates and on groundwater levels and salinity.

The volumetric allocations are supported by additional policy that limits allocations further where there are:

- unacceptable trends in salinity (more than 0.15 mS/cm from the baseline); or
- reductions in saturated thickness (more than 10% in a 12 month period at the point of extraction and 5% reduction within 500 metres).

The approach adopted for the Southern Basins and Musgrave PWA is an effective approach to the management of groundwater systems that are highly sensitive to annual recharge (that is where the ratio of aquifer storage to recharge is relatively small). The use of rules that link allocations to resource conditions (e.g. saturated thickness and salinity) is also supported.

However, there are areas where further development of a management response could occur, including:

- Set clear management objectives related to the required condition of the resource, health and characteristics of GDEs and needs of consumptive users;
- Link annual allocations to discharge rates as well as recharge rates;
- Quantify the linkage between the percentage of recharge allocated annually and changes to the resource condition (water level and salinity);
- Consider a tiered management response which ensures appropriate responses are applied to the highest priority GDE assets and develop a flexible approach for consumptive users;



- Investigate and account for environmental water requirements and provisions under a variable (and drier) climate scenario; and
- Set environmental water provisions in the broader context of balancing needs of consumptive and environmental users, as well as accounting for climate variability at the inter-annual and inter-decadal time scales.

A discussion of these issues is captured briefly in the following sections.

8.4. Management objectives

The current water allocation plans are not explicit in relation to the management objective (especially as it relates to GDE values), although the policy appears to support an objective to maintain groundwater conditions in a steady-state condition that existed at the time of the preparation of the WAPs (2000). If this is the case then it can be assumed the objective is also to maintain the health of GDEs at 2000 levels.

A clear statement of the objective (water management and ecological) is essential to the proper framing of management responses. It is recommended that the Board undertake a consultative process to establish management objectives taking into account:

- Value of the groundwater resources to environmental and consumptive users;
- Guiding principles for groundwater management
- Influence of climate variability and change to GDEs; and
- Trends in groundwater condition.

8.5. Potential Management responses

There are a range of management responses that could be considered in the evaluation of management approaches. Many of the preferred approaches are partly captured by the current WAP policies. The following issues are explored:

- Alignment of management response to risk;
- Adaptive management;
- Using resource condition limits;
- Triggers;
- Buffers;
- Response to climate variability and change; and
- Monitoring and evaluation.

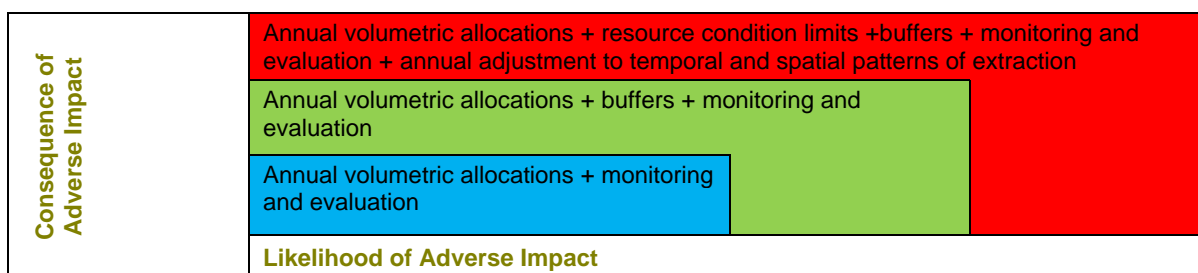


8.5.1. Aligning management response with risk

The prioritisation of GDEs based on risk provides an opportunity to target management approaches (geographically and by level of restriction).

Greatest response in management and investigation should go where the greatest risk to GDEs occur. The level of risk to GDEs can be conceptualised in a variety of ways such as quantitative analysis of threats and values and ‘best guesses’ by workers with knowledge of local conditions.

It is recommended that prioritisation of the GDEs occur based on value of the GDE, sensitivity of change to groundwater conditions and magnitude of the threat from extraction. The concept of linking management response to risk is shown schematically in Figure 8.1.



■ **Figure 8.1 Concept of how management response can be aligned with risk (as defined by likelihood and consequence)**

8.5.2. Setting volumetric allocations adaptively

Adaptive groundwater management should be viewed as a flexible approach to achieving acceptable levels of extraction whilst being able to respond to external influences, whether they are controllable (e.g. demand, markets) or uncontrollable (climate variability and change).

An adaptive management approach means that allocations can be set at shorter timeframes (annual) and can provide a flexible approach for licensed users. A more flexible approach may allow greater extraction volumes at locations further from priority GDEs and lesser extraction volume near priority GDEs.

The current approach of setting annual allocations that reflect variability in rainfall recharge is supported. However, the question of what proportion of recharge to set aside for the needs of the environment remains. This can only be answered by developing a tool that links the water balance to groundwater condition (e.g. a numerical groundwater flow model) – with inferences for GDE health.

The approach of setting annual extraction limits based on recharge should be extended to more explicitly manage GDEs by responding to changes in annual discharge rates (as indicated by



groundwater levels) at GDE sites. A tool should be developed that quantifies the dynamic relationships between recharge, extraction and discharge. This will also allow calculations of the lags between changing recharge and changing discharge to be calculated.

As a conservative approach (and given the climate-driven declines in groundwater levels) it is recommended the current volumetric allocations are maintained. This is especially the case where GDEs are susceptible to a declining groundwater condition (such as the phreatophytic vegetation).

It is important to understand when ecosystems require access to groundwater, especially where other sources of water (e.g. soil water) are available on an annual basis. The level of tolerance of an ecosystem may allow ecological function to be maintained by providing groundwater at critical times, e.g. periods of dry conditions.

8.5.3. Resource condition limits (thresholds)

It is recommended that volumetric allocations are supported by resource condition limits.

Resource condition limits (RCL) are upper levels of impact on selected indicators of groundwater resource condition that cannot be exceeded due to the extraction of groundwater. For example a resource condition limit could relate to acceptable groundwater level or groundwater salinity in a particular zone (as compared to a rate of change in these parameters). Another resource condition limit could relate to an acceptable rate of groundwater level drawdown.

The limit may be chosen to be different to the EWR (as presented in Section 7); however, there is a need to be clear about the consequence (positive and negative) of choosing a particular resource condition limit. It is likely that a combination of indicator limits will be required.

The current WAPs contain policy related to limits on saturated thickness of the aquifer and salinity.

The advantages of the RCL approach are:

- It explicitly ties policy to the condition of groundwater;
- It provides a clear mechanism for changes to management approaches; and
- It is easily communicated as a management concept to stakeholders.

The dis-advantages of the RCL approach are:

- There is a greater level of management effort associated with collection and evaluation of monitoring data; and
- That RCLs can be exceeded due to climate variability and there is a need to differentiate the effects of climate from extraction.



It is recommended that RCLs are developed to support the volumetric allocations for the highest priority areas. The RCLs should be developed with consideration of the needs of consumptive users, current trends in groundwater condition and the suggested EWR for GDEs.

It is also recommended that RCLs be set to take into account adverse impacts associated with potential salinity increases.

RCLs should be used to guide where extraction can occur in each year. Exceedence of an RCL in one location may trigger a shift in extraction to a location where conditions are within the threshold set by the RCL. This approach will provide flexibility for licensed users.

Further consideration of the influence of climate variability and climate change on the management response is required.

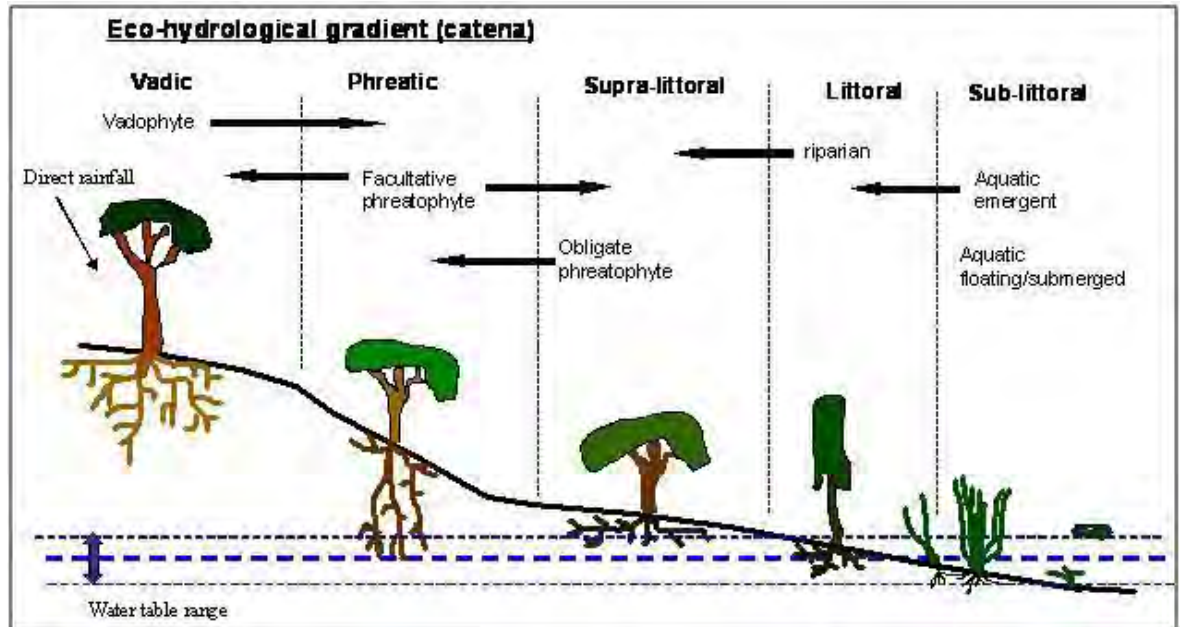
8.5.4. Managing to RCLs where climate variability is influential

Recent experience in other groundwater management areas such as Gnangara (north of Perth) is that the approach of using water level criteria (RCLs) is problematic where declines in levels are mainly driven by reduced rainfall and a drying climate. That is, thresholds have been set and then exceeded due to processes outside the control of a water allocation plans.

In the case of the Eyre Peninsula PWAs climate has a major influence on groundwater levels and inter-annual trends can be managed to some extent with the existing policy of allocation of a portion of recharge. However, the data suggests this approach has not arrested a climate decline in groundwater levels in many of the lenses. There are practical limits to a policy that seeks to offset climate effects on water levels.

It is recommended that RCLs are not used as water allocation triggers in areas where the water level trend is driven mainly by climate, and that further analysis of climate driven trends is undertaken.

In managing GDEs in a climate driven system the question moves from one that seeks to maintain conditions to a managed or 'orderly' transition to a new 'eco-hydrological' state. This concept has been progressed by work such as Petit *et al.* (2007) and considers the concept that changes in eco-hydrological state can occur for example, from terrestrial vegetation highly dependent on groundwater (phreatophytic) to terrestrial vegetation that are only dependent on soil water (vadec; Figure 8.2).



■ **Figure 8.2 Possible transitions in eco-hydrological state e.g. from phreatophytic to vadic vegetation communities (from Petit *et al.*, 2007)**

8.5.5. Buffers

A buffer or setback distance is the separation between a point of groundwater extraction and the GDE. Buffers are used in water allocation planning policy to minimise the impact of the drawdown of groundwater levels. The current water allocation plan policy has a buffer concept through a policy principle which limits the allocation of groundwater where there is more than 5% decline in the saturated thickness in the aquifer within 500 metres of the groundwater extraction well.

It is recommended that buffers are used in the management of GDEs on Eyre Peninsula. Buffer policy could be used to guide the location of new extraction wells, guide the extraction rate in wells that are close to GDEs.

Calculation of the buffer distance should take into account local aquifer properties, allowable drawdown, timeframes for impacts and likely range of extraction rates.

8.5.6. Monitoring and evaluation

Monitoring and evaluation is a key part of the proposed management approach. There is good groundwater monitoring undertaken, however there is a need to link the groundwater monitoring to a broader scope of environmental monitoring.



It is recommended that the Board design an environmental monitoring program which will provide information to implement the preferred policy, evaluate policy effectiveness and provide information to guide future evaluations of GDE water requirements and water provisions.



9. Conclusions and Recommendations

9.1. Conclusions

Investigations into GDEs in the Southern Basins and Musgrave PWAs and Robinson Basin have lead to the following conclusions:

Extent of GDEs

- Potential GDEs extend across vast regions of the study areas, including saline swamps, saline lakes, freshwater lakes, grasslands and sedgeland, phreatophytes and coastal shrubland.
- Groundwater dependent springs also occur across the region, but are not well documented and therefore could not be comprehensively mapped.
- Groundwater dependent hypogean ecosystems have been shown to exist on the Eyre Peninsula (pers. comm. Remko Leij, Adelaide Museum), but their extent is poorly understood.
- Hyporheic ecosystems are assumed to be associated with groundwater dependent swamps, lakes, soaks and springs, but their extent across the region is poorly understood.
- It is thought that there are soaks and collapsed sinkholes across the region that could potentially be dependent on groundwater, but since their locations have not been mapped, their potential dependence on groundwater could not be assessed in this study.
- NDVI shows good potential to be used as an indicator of groundwater use by vegetation across the study area, but interpretation requires ground-truthing to explain some observed inconsistencies.

EWRs of GDEs

- The composition and structure of some GDEs throughout the region are likely to have changed due to the lower than average rainfall over the last 10 to 15 years. With this change in structure and composition, the environmental water requirements are also likely to have changed.
- The environmental water requirements of GDEs on Eyre Peninsula are dynamic. Thresholds of depth to water and groundwater salinity that a GDE can withstand in any one year, will depend on its condition when it is placed under water stress, its resistance and resilience to water stress and the duration and frequency that it suffers from water stress.
- EWRs have been expressed as minimum and maximum depths to water and maximum groundwater salinities that have been experienced by GDEs in the study areas. The timing



and duration that these minimum and maximum depths to water and groundwater salinities can be withstood by GDEs and their impacts on GDE condition remain unknown.

Threats to GDEs

- Under current conditions, climate appears to be the over-riding factor contributing to groundwater level declines.
- Groundwater extraction or land uses that impact on groundwater conditions in vulnerable areas are likely to worsen the water stress suffered by GDEs.
- Springs, soaks, obligate phreatophytes and hyporheic ecosystems were interpreted to be the most vulnerable GDEs to changes in groundwater conditions in the study areas. However, there is very little known about springs, soaks and hyporheic ecosystems on the Eyre Peninsula.

Options for managing groundwater to protect GDEs

The approach adopted for the Southern Basins and Musgrave PWA is an effective approach to the management of groundwater systems that are highly sensitive to annual recharge (that is where the ratio of aquifer storage to recharge is relatively small). The use of rules that link allocations to resource conditions (e.g. saturated thickness and salinity) is also supported.

However, there are areas where further development of a management response could occur, including:

- Set clear management objectives related to the required condition of the resource, health and characteristics of GDEs and needs of consumptive users;
- Link annual allocations to discharge rates as well as recharge rates;
- Quantify the linkage between the percentage of recharge allocated annually and changes to the resource condition (water level and salinity);
- Consider a tiered management response which ensures appropriate responses are applied to the highest priority GDE assets and develop a flexible approach for consumptive users;
- Investigate and account for environmental water requirements and provisions under a variable (and drier) climate scenario; and
- Set environmental water provisions in the broader context of balancing needs of consumptive and environmental users, as well as accounting for climate variability at the inter-annual and inter-decadal time scales.

9.2. Recommendations

The following recommendations aim to improve the understanding of GDEs on Eyre Peninsula:



- NDVI requires ground-truthing to explain some observed inconsistencies before it can be used as an indicator of groundwater use by vegetation across the study area.
- EWRs should be refined by linking changes in groundwater condition to changes in ecosystem condition.
- It appears that some of the GDEs that are most vulnerable to changes in groundwater condition are those that we know the least about. Further investigations need to target these vulnerable ecosystems under threat from changes in groundwater condition.

The following actions are recommended to progress development of appropriate management responses:

- Develop agreed management objectives – balancing consumptive and environmental uses;
- Develop a framework that allows alignment of management response to risk/priority;
- Quantitatively link allocations based on rainfall recharge to changes in discharge rates, including estimation of lag times;
- Develop resource condition limits to support volumetric allocations. The resource condition limits should take into account suggested EWRs and current trends in groundwater condition;
- Develop an analysis of the influence of inter-decadal climate variability and change on the preferred management response – especially where climate is a primary driver on the management approach; and
- Develop an integrated groundwater – environmental monitoring and evaluation scheme.



10. References

Boggon T & Evans I (2006). A Coordinated Cpproach to Wetland Management on Eyre Peninsula. Eyre Peninsula Natural Resources Management Board. South Australia.

Brown KG & Harrington GA, 2001. A preliminary investigation into the groundwater salinity of the Robinson Basin, Streaky Bay, South Australia. SA Department for Water Resources Report Book DWR 2001/019.

Brown KG & Harrington GA, 2002. The dynamic behaviour of a stressed, semi-arid groundwater basin, Streaky Bay, South Australia. Department of Water, Land and Biodiversity Conservation. Report DWLBC 2003/8.

Canadell J, Jakson RB, Ehleringer JB, Mooney HA, Sala OE & Schulze E-D, 1996 Maximum rooting depth of vegetation types at a global scale. *Oecologia* **108**(4): 583-595.

Clarke, DS, Berens, V and Dennis, KJ, 2003. Uley South – Coffin Bay Observation Well Network Review. South Australia. Department of Water, Land and Biodiversity Conservation. Report, DWLBC 2003/04.

Clifton C, Cossens B, McAuley C, Evans R, Cook P, Howe, P & Boulton A, 2007 A Framework for assessing the Environmental Water Requirements of Groundwater Dependent Ecosystems, Report 1 Assessment Toolbox. Prepared for Land & Water Australia.

Department for Environment and Heritage, 2002. Biodiversity Plan for Eyre Peninsula. South Australia, DEH South Australia. Adelaide.

DWE, 2001. Understanding the Musgrave Prescribed Wells Area. Department of Water Resources.

Evans, SL, 1997. Estimating long term recharge to thin, unconfined carbonate aquifers using conventional and environmental isotope techniques: Eyre Peninsula, South Australia. Finders University (South Australia). M.Sc. thesis (unpublished).

Evans, S.L., 2002. Southern Basins Prescribed Wells Area Groundwater Monitoring Status Report 2002. DWLBC Report 2002/13.

Eyre Region Water Resources Planning Committee, 2000. Water Allocation Plan for the Southern Basins Prescribed Wells Area. Department for Water Resources. Adelaide.

Eyre Region Water Resources Planning Committee, 2001. Water Allocation Plan for the Musgrave Prescribed Wells Area. Department for Water Resources. Adelaide.



Eyre Peninsula Catchment Water Management Board, 2005. Eyre Peninsula Catchment Water Management Plan. Port Lincoln. South Australia.

Harrington G, Evans S & Zulfic D, 2006. Uley Basin Groundwater Modelling Project Volume 1: Project Overview and Conceptual Model Development. DWLBC Report 2006/01.

Howe B & Clark J, 2009. Monitoring Report: Volume 1. Eyre Peninsula Groundwater Allocation and Planning Project. Eyre Peninsula Natural Resources Management Board.

Howe P, Cook P, O'Grady A & Hillier J, 2006 Pioneer Valley Groundwater Consultancy Report 3 Analysis of Groundwater Dependent Ecosystem Water Requirements. Prepared for the Queensland Department of Natural Resources and Mines.

Howe P, Pritchard J, Cook P, Evans R, Clifton C & Cooling M, 2007. A Framework for assessing the Environmental Water Requirements of Groundwater Dependent Ecosystems, Report 3 Implementation. Prepared for Land & Water Australia.

Matthews E, Oppermann A & Inns RW, 2001. Biodiversity Plan for Eyre Peninsula. Department for Environment and Heritage, South Australia.

Pettit NE, Edwards T, Boyd TC & Froend RH, 2007. Ecological Water Requirement (Interim) Framework Development: A conceptual framework for the maintenance of groundwater dependent ecosystems using state and transition modelling. A report to the Dept. of Water. Centre for Ecosystem Management report # 2007-14.

Seaman, RL, 2002. Wetland Inventory for Eyre Peninsula, South Australia. Department for Environment and Heritage.

Wainright, 2008. 2007 Wetland Inventory Eyre Peninsula. Draft. Department for Environment and Heritage.



LIMITATION STATEMENT

The sole purpose of this report and the associated services performed by Sinclair Knight Merz (“SKM”) is to identify and develop an understanding of the spatial distribution of potentially groundwater dependent ecosystems, their environmental water requirements and developing policy options for managing GDEs through water allocation planning in prescribed wells areas in accordance with the scope of services set out in the contract between SKM and the Client. That scope of services, as described in this report, was developed with the Client.

In preparing this report, SKM has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, SKM has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

SKM derived the data in this report from information sourced from the Client (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. SKM has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by SKM for use of any part of this report in any other context.

It is recognised that GDEs are not only threatened by groundwater affecting activities. They are also vulnerable, for example, to grazing, disease, weed infestation, climate change, land use change, natural disasters, surface water diversion, pollution. As such GDE condition cannot be protected by affective groundwater management strategies alone. Broader ecosystem management also needs to be considered, such as land management, and pest control. This report however, is limited to the identification of threats to GDEs due to groundwater affecting activities in the study areas on Eyre Peninsula, including the Southern Basins and Musgrave Prescribed Wells Areas, and Robinson lens, near Streaky Bay. Mapped layers show the possible existence of GDEs outside these areas, however, they are beyond the scope of this study and as such, their accuracy have not been scrutinised for further classification.

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Identification of GDEs within the study areas is limited to pre-existing ecological, hydrogeological and geological datasets. Ground-truthing the accuracy of these datasets was not within the scope of the analysis. The scope of work involved interpretation of these datasets, not the assessment of their accuracy. The suitability of these datasets for identifying and assessing GDEs is reported on to a limited extent.

A key factor in defining the environmental water requirements of GDEs is being able to assess how resistant and resilient ecosystems are to water stress. There is, however, limited information regarding ecosystem condition. There is evidence that the current groundwater conditions (lowest on record) and/or other factors are already placing GDEs under stress (Red Gum die-back in Musgrave PWA). The aim here is to set EWRs that will prevent further GDE degradation. It does not attempt to set EWRs to attempt to return ecosystems to the composition and structure that they possessed a decade ago.

This report has been prepared on behalf of, and for the exclusive use of, SKM's Client, and is subject to, and issued in accordance with, the provisions of the agreement between SKM and its Client. SKM accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.



Appendix A Datasets used to define the location and extent of potential GDEs

Table A.1 Datasets used to define the location and extent of potential GDEs

GDE type		DEH wetland mapping classification	Regional vegetation mapping	Regional Geology	Lithological or drillers logs	Depth to groundwater	Comments
Saline swamps	Type 1: Seasonal saline swamps	Seasonal saline marshes, Shrub swamps			Absence of significant confining layer	Shallow water tables	
	Type 2: Intertidal salt swamps	Intertidal salt marshes					
Saline lakes	Type 1: Permanent saline lakes	Permanent saline / brackish lakes			Absence of significant confining layer	Shallow water tables	
	Type 2: Seasonal saline lakes connected to the Quaternary aquifer	Seasonal / intermittent saline lakes		Overlies Quaternary Formation	Absence of significant confining layer	Shallow water tables	Excludes Little Swamp
	Type 3: Seasonal saline lakes disconnected from the Quaternary aquifer	Seasonal / intermittent saline lakes		Directly overlies Tertiary sediments	Presence of confining layer	Deep water tables	Little Swamp only
Springs and underground water soaks	Type 1: Springs					Shallow water tables	No available spatial datasets
	Type 2: Seawater-fed springs					Shallow water tables	No available spatial datasets
	Type 3: Soaks					Shallow water tables	No available spatial datasets
Freshwater lakes	Type 1: Seasonal / intermittent freshwater lakes connected to Quaternary aquifer	Seasonal / intermittent freshwater ponds, Seasonal / intermittent freshwater lakes >8 ha		Overlies Quaternary Formation	Absence of significant confining layer	Shallow water tables	Excludes Big Swamp
	Type 2: Seasonal / intermittent freshwater	Seasonal / intermittent		Directly overlies	Presence of	Deep water	Big Swamp

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GDE type		DEH wetland mapping classification	Regional vegetation mapping	Regional Geology	Lithological or drillers logs	Depth to groundwater	Comments
lakes disconnected from the Quaternary aquifer		freshwater lakes >8 ha		Tertiary sediments	confining layer	tables	only
Phreatophytes	Type 1: Obligate phreatophyte		Eucalyptus forest and woodland	Overlies Quaternary Formation	Absence of confining layer (potential for perched groundwater levels)	Water tables typically < 4 m bgl	Compared to NDVI
	Type 2: Facultative phreatophytes		Melaleuca forest & woodland, Melaleuca shrubland >1 m, Allocasuarina forest & woodland	Overlies Quaternary Formation	Absence of confining layer (potential for perched groundwater levels)	Water tables often < 4 m bgl in some areas & consistently >6 m bgl in other areas	Compared to NDVI
Grasslands / Sedgeland	Type 1: Sedgeland		Rushland / sedgeland	Overlies Quaternary Formation	Absence of confining layer (potential for perched groundwater levels)	Water tables typically <4 m bgl	Compared to NDVI
	Type 2: Tussock grassland over shallow water tables		Tussock grassland	Overlies Quaternary Formation	Absence of confining layer (potential for perched groundwater levels)	Water tables typically <4 m bgl	Compared to NDVI
	Type 3: Tussock grassland over deeper water tables		Tussock grassland	Overlies Tertiary sediments	Presence of confining layer (potential for perching)	Consistently > 5 m bgl	Compared to NDVI
Damp coastal and sub-coastal heath	Type 1: Damp coastal and sub-coastal heath over shallow water tables		Coastal shrubland	Overlies Quaternary Formation	Absence of confining layer (potential for perched groundwater levels)	Water tables typically <4 m bgl	Compared to NDVI
	Type 2: Damp coastal and sub-coastal heath over deep water tables		Coastal shrubland	Overlies Tertiary sediments	Presence of confining layer (potential for	Consistently > 5 m bgl	Compared to NDVI



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GDE type		DEH wetland mapping classification	Regional vegetation mapping	Regional Geology	Lithological or drillers logs	Depth to groundwater	Comments
Hypogean, hyporheic and collapsed sinkhole ecosystems	Type 1: Hypogean ecosystems				perching)		No available spatial datasets
	Type 2: Hyporheic ecosystems						No available spatial datasets
	Type 3: Collapsed ecosystems						No available spatial datasets



Appendix B Summary of GDEs, threats and EWRs



Saline Swamps	Discussion	GDE Status ^[1]	Potential Threats to GDEs	Level of Threat ^[2]	Observations	EWR ^[5]
	<p>Type 1: Seasonal saline swamps occur where a shallow water table or groundwater discharge maintains saturated soils during winter.</p> <p>Typically occur in low-lying (<10 mAHD), near-coastal regions, overlying the Bridgewater Formation Limestone.</p> <p>Refer to Figure 4.1 ①</p>	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	Land use ^[3]	●	Saline swamps near Robinson Basin and in Southern Basins PWA are within conservation areas. Most saline marshes in the Musgrave PWA are surrounded by areas where the land use classified as “production from dryland agriculture and plantations” ^[7] .	The best available data for assessing EWRs for seasonal saline swamps are in the swamp adjacent Middle Lake, which suggest that the following ranges in groundwater conditions have historically maintained them:
			Groundwater extraction ^[4] from Bridgewater Formation Limestone	●●	Pumping from Robinson Basin (Figure 5.3) and Southern Basins PWA (Figure 5.1) has occurred > 2 km away from seasonal saline swamps. Pumping from Bramfield in Musgrave PWA (Figure 5.2) occurs about 1.5 km away from some seasonal saline swamps. It is assumed there is hydraulic connection between the water table at Sheringa Lagoon and Sheringa A Basin. There is no lithological data available to determine whether there is hydraulic connection between the swamps and the water table elsewhere in the study areas. It is therefore conservatively assumed that all swamps are connected to the Quaternary Bridgewater Formation aquifer.	<ul style="list-style-type: none">Depth to groundwater: annual minimum <1.5 m bgl^[6], annual maximum <2.2 m bgl; andGroundwater salinity (as EC): <2 mS/cm.
			Climate variability	●●●	Groundwater level trends appear to be dominated by climate variability rather than groundwater extraction.	Seasonal saline swamp ecosystems may be able to withstand short-term deviations from these groundwater conditions, but there is no evidence to suggest the extent, timing or duration of such deviations or rates of change. It can only be assumed, due to lack of monitoring data in seasonal saline swamps, that these ranges in depth to groundwater and groundwater salinity will also maintain seasonal saline swamps in other areas of Eyre Peninsula. Data are presented in Appendix C.
	<p>Type 2: Inter-tidal salt swamps are infrequently inundated by sea water and soils remain moist during low tide due to shallow water tables or groundwater discharge.</p> <p>Typically occur in low-lying (<5 mAHD) coastal regions, overlying the Semaphore Sand Member.</p> <p>Refer to Figure 4.1 ②</p>	<input checked="" type="checkbox"/>	Land use	●	The one inter-tidal swamp mapped within the study areas is located within a conservation area.	The only available data for assessing EWRs for inter-tidal swamps are near the Tulka coastal wetland area, which suggest that the following ranges in groundwater conditions have historically maintained it:
			Groundwater extraction from Bridgewater Formation Limestone	●	Pumping from Lincoln-B is near the Tulka coastal wetland. It is assumed there is hydraulic connection between the water table at Tulka and the aquifer pumped at Lincoln B. Groundwater elevations in near coastal zones are expected to be buffered by seawater levels.	<ul style="list-style-type: none">Depth to groundwater annual minimum <5.7 m bgl, annual maximum <5.9 m based on a monitoring well located about 70 m upgradient from Tulka coastal wetland area; andGroundwater salinity (as EC) 1.5 to 16 mS/cm.
			Climate variability	●●●	Groundwater level trends appear to be dominated by climate variability rather than groundwater extraction	Inter-tidal salt swamp ecosystems may require the depth to water to be shallower than presented here, since the available data is from a higher topographic position in the landscape than where the Tulka coastal wetland (inter-tidal salt swamp) is located. Data are presented in Appendix C.

^[1]GDE Status:

☒☒ Groundwater dependence likely

☒ Some groundwater dependence likely, supported by surface water inundation

☒ Groundwater dependence unlikely

^[2]Level of threat based on how activities affect groundwater (i.e. excluding threats such as grazing pressure, weed infestation, disease)

Short term (annual to inter-annual): low ●; medium ●●; high ●●●

Long term (decades): low ●; medium ●●; high ●●●



^[3]Changes in land use can increase or decrease groundwater recharge changing the flux and timing of groundwater availability to GDEs and potentially altering the quality of water available to GDEs at critical times

^[4]Groundwater extraction can cause groundwater elevations to decline, potentially decreasing availability of good quality water (e.g. relatively low salinity, contaminant-free) to GDEs at critical times

^[5]Environmental Water Requirements (EWR) were assessed based on available groundwater level and salinity monitoring data. Data were only available for a small number of sites. Due to shortage of information, it is assumed that types of GDEs have similar groundwater requirements

^[6]m bgl – metres below ground level

^[7]Whilst land use mapping includes a classification referring to plantations, it is recognised they few of these exist within the study areas

Saline Lakes	Discussion	GDE Status ^[1]	Potential Threats to GDEs	Level of Threat ^[2]	Observations	EWR ^[5]
 <p>■ Permanent saline lake: Sleaford Mere, Southern Basins PWA</p>	<p>Type 1: Permanent saline lakes that typically intercept the regional groundwater system (Quaternary Limestone).</p> <p>Typically occur in low-lying (<10 mAHD), near-coastal regions, overlying the Bridgewater Formation Limestone.</p> <p>Refer to Figure 4.2 ①</p>	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	Land use ^[3]	●	There are two permanent salt lakes mapped in/near the study areas. The majority of the land surrounding Sleaford Mere is within a conservation area. On the western side of Sleaford Mere some of the land use is classified as “production from dryland agriculture and plantations” ^[7] , and some as “intensive uses” and surrounding Lake Hamilton (just south of Musgrave PWA) land use is classified as “production from dryland agriculture and plantations”.	<p>The only available data for assessing EWRs for permanent saline lakes are near Sleaford Mere which suggest that the following ranges in groundwater conditions have historically maintained it:</p> <ul style="list-style-type: none"> Depth to groundwater annual minimum <2.8 m bgl^[6] (this was <2.5 m bgl during the 80s when rainfall was higher), annual maximum <3.3 m bgl (this was <2.8 m bgl during the 80s) based on a monitoring well located about 200 m north of Sleaford Mere; and Groundwater salinity (as EC) <2 mS/cm around the northern and western perimeter of Sleaford Mere, and ranging from 2 to 9 mS/cm to the south and east. <p>Permanent saline lake ecosystems may be able to withstand short-term deviations from these groundwater conditions, but there is no evidence to suggest the extent, timing or duration of such deviations or rates of change.</p> <p>It can only be assumed, due to lack of monitoring data around permanent saline lakes, that these ranges in depth to groundwater and groundwater salinity will also maintain Lake Hamilton.</p> <p>Data are presented in Appendix C.</p>
			Groundwater extraction ^[4] from Bridgewater Formation Limestone	●●	Pumping from Lincoln-A groundwater lens (Figure 5.4) is near Sleaford Mere (assumed to be connected to Quaternary Limestone aquifer pumped). Pumping from Musgrave PWA (Figure 5.5) has occurred > 2 km away from salt lakes.	
			Climate variability	●●	Groundwater level trends appear to be dominated by climate variability rather than groundwater extraction.	
 <p>■ Seasonal saline lake: Lake Tungketta, Musgrave PWA</p>	<p>Type 2: Seasonal saline lakes that are connected to the Quaternary Limestone aquifer. These may recharge the Quaternary Limestone during inundation (losing conditions) and receive groundwater discharge as surface water levels recede (gaining conditions), being only seasonally or episodically connected to the regional aquifer.</p> <p>Typically occur in low-lying (<10 mAHD), near-coastal regions, overlying the Bridgewater Formation Limestone.</p> <p>Conceptually occurring where there is a greater depth to water than beneath permanent lakes and / or where the lakebed sediments have low permeability and minimise surface water – groundwater interaction.</p> <p>Refer to Figure 4.2 ②</p>	<input checked="" type="checkbox"/>	Land use	●	Many of these lakes are within conservation areas. Most salt lakes in the Musgrave PWA are surrounded by land use classified as “production from dryland agriculture and plantations”. The western side of Lake Newland is prescribed for conservation. Most of the salt lakes near Robinson Basin are within conservation areas, but some fall within “dryland agriculture and plantation” land use classified areas.	<p>The best available data for assessing EWRs for seasonal saline lakes are within a seasonal saline lake near Robinson Basin and near Middle Lake, which suggest that the following ranges in groundwater conditions have historically maintained them:</p> <ul style="list-style-type: none"> Depth to groundwater annual minimum <2.1 m bgl (this was <1.1 m bgl during the 80s when rainfall was typically above average, and <1.4 m bgl during the 90s when rainfall was slightly lower), annual maximum <2.5 m (this was <1.8 m bgl in the 80s and < 2.1 m bgl during the 90s) based on a monitoring well within a seasonal saline lake near Robinson Basin; and Groundwater salinity (as EC) ranging from 1.5 to 32 mS/cm. <p>Seasonal saline lake ecosystems may be able to withstand short-term deviations from these groundwater conditions, but there is no evidence to suggest the extent, timing or duration of such deviations or rates of change that can occur without impacting ecosystem condition.</p> <p>It can only be assumed, due to lack of monitoring data around seasonal saline lakes, that these ranges in depth to groundwater and groundwater salinity will also maintain other seasonal saline lakes in the study areas.</p> <p>Data are presented in Appendix C.</p>
			Groundwater extraction from Bridgewater Formation Limestone	●●	Pumping from in the study areas has occurred > 2 km away from seasonal salt lakes (Figure 5.4, Figure 5.5, Figure 5.6).	
			Climate variability	●●●	Groundwater level trends appear to be dominated by climate variability rather than groundwater extraction.	



Saline Lakes	Discussion	GDE Status ^[1]	Potential Threats to GDEs	Level of Threat ^[2]	Observations	EWR ^[5]
	<p>Type 3: Seasonal saline lakes that are disconnected from the Quaternary Limestone aquifer by a confining layer. These rely on perched groundwater systems that are sustained by recharge during surface water inundation and are disconnected from the regional aquifer.</p> <p>Typically occur in topographic depressions, at higher elevations in the landscape, beyond the extent of the Bridgewater Formation Limestone.</p> <p>Refer to Figure 4.2 ^③</p>	<div><input checked="" type="checkbox"/></div>	Land use	●	Little Swamp is completely surrounded by areas classified with land uses as “production from dryland agriculture and plantations”, and “intensives uses”.	There are no observation wells near Little Swamp. However, it is assumed that seasonal saline lakes that are disconnected from the Quaternary Limestone aquifer in the study area only depend on rainfall and surface water runoff to satisfy their EWRs.
			Groundwater extraction from perched groundwater system	●	There are no production wells near Little Swamp (Figure 5.4).	
			Climate variability	●●●	Groundwater level trends are dominated by climate variability.	

^[1]GDE Status:

- ☒☒ Groundwater dependence likely
- ☒ Some groundwater dependence likely, supported by surface water inundation
- ☒ Groundwater dependence unlikely

^[2]Level of threat based on how activities affect groundwater (i.e. excluding threats such as grazing pressure, weed infestation, disease)

Short term (annual to inter-annual): low ●; medium ●●; high ●●●

Long term (decades): low ●; medium ●●; high ●●●


^[3]Changes in land use can increase or decrease groundwater recharge changing the flux and timing of groundwater availability to GDEs and potentially altering the quality of water available to GDEs at critical times

^[4]Groundwater extraction can cause groundwater elevations to decline, potentially decreasing availability of suitable quality water to GDEs at critical times

^[5]Environmental Water Requirements (EWR) were assessed based on available groundwater level and salinity monitoring data. Data were only available for a small number of sites. Due to shortage of information, it is assumed that types of GDEs have similar groundwater requirements

^[6]m bgl – metres below ground level

^[7]Whilst land use mapping includes a classification referring to plantations, it is recognised they few of these exist within the study areas

Springs and Underground Water Soaks	Discussion	GDE Status ^[1]	Potential Threats to GDEs	Level of Threat ^[2]	Observations	EWR ^[5]
 <p>Coastal spring: Upwelling freshwater spring on foreshore at Coffin Bay</p>	<p>Type 1: Springs that occur in parts of the landscape where groundwater rises or seeps to the ground surface and maintains a surface expression of groundwater. This typically occurs at breaks in slope or low-lying areas of the landscape.</p> <p>Refer to Figure 4.3 ①</p>	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<p>Land use^[3];</p> <p>Groundwater extraction^[4] from Bridgewater Formation Limestone</p>	<p>●●</p> <p>●●●</p>	<p>Most of the identified springs (Kelledie Bay – type 1 coastal, Figure 5.7; Weepdra Springs – type 1 inland at Lake Newland, Figure 5.8) occur within conservation areas, however, there are also springs on the foreshore in the township of Coffin Bay. Groundwater recharge conditions may be altered by the town landscape, potentially affecting the quantity and quality of groundwater discharging at the springs.</p> <p>The springs at the Coffin Bay foreshore occur within 0.5k m of Coffin Bay-A freshwater lens (TDS<1000 mg/L). Groundwater extraction occurs within 1.5 km of these springs. Regional-scale geological mapping suggests that the springs are likely to be connected to the pumped aquifer, but there is no lithological information available.</p> <p>Other springs in Kelledie Bay are known to occur within 0.7 km of Coffin Bay-B freshwater lens (TDS<1000mg/L), however, there are no production wells within this basin. Regional-scale geological mapping suggests that the springs are likely to be connected to the Bridgewater Formation aquifer, but there is no lithological information available.</p> <p>Weepdra Spring occurs ~9 km away from Talia freshwater lens (TDS<1000mg/L) and ~30 km away from any production wells. Regional-scale geological mapping suggests that the springs are likely separated from the Bridgewater Formation by lakebed sediments. The extent of this potentially confining layer is unknown.</p> <p>Groundwater level trends appear to be dominated by climate variability rather than groundwater extraction.</p>	<p>The best available data for assessing EWRs of springs are near the costal springs near the township of Coffin Bay, which suggest that the following ranges in groundwater conditions have historically maintained them:</p> <ul style="list-style-type: none"> Depth to groundwater <0 m bgl^[6] based on extrapolation from monitoring wells located ~0.5 km away from the springs; and Groundwater salinity (as EC) <1.5 mS/cm. <p>Spring ecosystems may be able to withstand short-term deviations from these groundwater conditions, but there is no evidence to suggest the extent, timing or duration of such deviations or rates of change that can occur without impacting ecosystem condition. It can only be assumed, due to lack of spring mapping and monitoring data near springs, that these depth to groundwater and groundwater salinity conditions will also maintain other springs in the study areas. Background information is presented in Appendix C.</p>
	<p>Type 2: Sea water-fed springs that occur in near coastal regions where sea water flows through the aquifer system and discharges inland to the ground surface and maintains a surface expression of groundwater.</p> <p>Refer to Figure 4.4 ②</p>	<input checked="" type="checkbox"/>	<p>Land use;</p> <p>Groundwater extraction from Bridgewater Formation Limestone</p> <p>Climate variability</p>	<p>●</p> <p>●</p> <p>●</p>	<p>It is assumed that any existing seawater springs occur within conservation areas.</p> <p>It is assumed that groundwater extraction is unlikely to affect seawater inflows to inland coastal springs due to a low demand for high salinity groundwater.</p> <p>It is assumed that seawater inflow to springs is more likely to be impacted by sea level rise/fall than by groundwater extraction.</p>	<p>There are no data available to identify EWRs for seawater springs on Eyre Peninsula. However, it is presumed that this is dictated by sea level.</p>
	<p>Type 3: Soaks occur in parts of the landscape where the water table lies very close to or at the ground surface.</p> <p>Refer to Figure 4.3 ③</p>	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<p>Land use;</p> <p>Groundwater extraction from Bridgewater Formation Limestone</p> <p>Climate variability</p>	<p>●●</p> <p>●●●</p> <p>●●●</p>	<p>It is assumed that soaks occur in similar parts of the landscape as swamps (refer to saline swamps for details).</p>	<p>No data are available to identify the location or EWRs of soaks on Eyre Peninsula. It is assumed that soaks require water tables to remain within a metre or so of the ground surface.</p>



^[1]GDE Status:

- ☒☒ Groundwater dependence likely
- ☒ Some groundwater dependence likely, supported by surface water inundation
- ☒ Groundwater dependence unlikely

^[2]Level of threat based on how activities affect groundwater (i.e. excluding threats such as grazing pressure, weed infestation, disease)

Short term (annual to inter-annual): low 🔴; medium 🔴🔴; high 🔴🔴🔴



Long term (decades): low ⬛; medium ⬛⬛; high ⬛⬛⬛

^[3]Changes in land use can increase or decrease groundwater recharge changing the flux and timing of groundwater availability to GDEs and potentially altering the quality of water available to GDEs at critical times

^[4]Groundwater extraction can cause groundwater elevations to decline, potentially decreasing availability of good quality water (e.g. relatively low salinity, contaminant-free) to GDEs at critical times

^[5]Environmental Water Requirements (EWR) were assessed based on available groundwater level and salinity monitoring data. Data were only available for a small number of sites. Due to shortage of information, it is assumed that types of GDEs have similar groundwater requirements

^[6]m bgl – metres below ground level

Grasslands/Sedgeland	Discussion	GDE Status ^[1]	Potential Threats to GDEs	Level of Threat ^[2]	Observations	EWR ^[5]
 <p>■ Figure 0.1 Sedgeland, Musgrave PWA</p>	<p>Type 1: Sedgelands are located on seasonally or periodically inundated waterlogged and wet areas. They are most commonly associated with seasonal freshwater ponds in the study areas, but also occur in seasonal saline swamps in the Musgrave PWA. They typically reside in shallow Holocene playa sediments overlying the Bridgewater Formation Limestone. There are a few locations where they overlie the Glanville Formation.</p> <p>Refer to Figure 4.5 ①</p>	☑	Land use ^[3]	●●	There are numerous, small pockets of sedgeland in the study areas; mainly occurring within conservation areas in the Southern Basins and within areas with land use classified as “production of dryland agriculture and or plantations” ^[7] in the Musgrave PWA.	<p>The best available data for assessing EWRs for sedgeland are from a mapped area associated with the seasonal swamp, which overlies Uley South lens. These data suggest that the following ranges have historically maintained them:</p> <ul style="list-style-type: none"> Depth to groundwater: annual minimum <3.6 m bgl (this was 2.7 m bgl during the period of average (higher) rainfall between late 1970s and mid 1990s); annual maximum <4 m bgl (<3.2 m bgl between 1970s and mid 1990s); and Groundwater salinity (as EC) <1.5 mS/cm <p>Sedgeland ecosystems may be able to withstand short-term deviations from these groundwater conditions and data from other monitoring wells near mapped sedgeland areas showing them to occur where depth to groundwater could be ~8 m bgl. However, it is evident that they are generally associated with other wetland ecosystems such as saline lakes and seasonal swamps.</p> <p>Data are presented in Appendix C.</p>
			Groundwater extraction ^[4] from Bridgewater Formation Limestone	●●	There is one production well 150 m away from a large area mapped as sedgeland in the Uley South Lens and two production wells <100 m away from sedgeland in the Lincoln A Lens adjacent Sleaford Mere in the Southern Basins PWA. In some areas the Holocene playa sediments may locally confine the Bridgewater Formation aquifer, and the sedgelands may rely on water that is stored within or perched on top of these sediments, rather than the water table aquifer.	
			Climate variability	●●	Groundwater level trends appear to be dominated by climate variability rather than groundwater extraction.	
 <p>■ Figure 0.2 Tussock Grasslands, Musgrave PWA</p>	<p>Type 2: Tussock grasslands occur in areas with shallow water tables. These are relatively sparse across the study areas, generally occurring at elevations between 10 and 60 mAHD covering lower elevations of valleys and to a lesser extent higher topographies, overlying the Bridgewater Formation.</p> <p>Refer to Figure 4.5 ②</p>	☑	Land use	●	The majority of tussock grasslands occur within conservation areas in the Southern Basins PWA and to a lesser extent in the Musgrave PWA where grassland within or surrounded by land use classified as “production from dryland agriculture or plantations” is more common. There is no tussock grassland mapped near Robinson lens.	<p>The best available data for assessing EWRs for type 2 grasslands are from an area mapped within Musgrave PWA, which overlies the Poldia lens. These data suggest the following ranges in groundwater conditions have historically maintained them:</p> <ul style="list-style-type: none"> Depth to groundwater: annual minimum <4 m bgl; annual maximum <5 m bgl; and Groundwater salinity (as EC) <4.2 mS/cm. <p>Type 2 grasslands are likely able to withstand deviations from these groundwater conditions and there are areas of type 3 grassland within 2 km (see below). Type 2 grasslands are likely to be opportunistic in their use of shallow water tables, making use of soil water during dryer periods.</p> <p>Data are presented in Appendix C.</p>
			Groundwater extraction from Bridgewater Formation Limestone	●●	Production wells in the study areas are within mapped areas of tussock grassland, within the Uley South lens in the Southern Basins PWA and Poldia lens in the Musgrave PWA. Grassland in this area may seasonally tap into capillary fringe through shallow (skeletal) soils overlying the Bridgewater Formation when the depth to water is shallow.	
	<p>Type 3: Tussock grasslands in areas with deep water tables. These are relatively extensive across the study areas, generally occurring at elevations between 20 and 100 mAHD covering lower elevations of valleys and to a</p>	☒	Climate variability	●●	Groundwater level trends appear to be dominated by climate variability rather than groundwater extraction.	<p>Depth to groundwater in Type 3 grasslands is > 6 m bgl and hence the EWRs of these ecosystems are unlikely to have a groundwater component from the Bridgewater Formation aquifer.</p> <p>Data are presented in Appendix C.</p>
			Land use	●	The majority of grasslands occur within conservation areas or surrounded by land use classified as “production from dryland agriculture or plantations”, however land use derived impacts on groundwater poses negligible threat to type 3 grasslands as they are assumed not to be dependent on groundwater.	



Grasslands/Sedgeland	Discussion	GDE Status ^[1]	Potential Threats to GDEs	Level of Threat ^[2]	Observations	EWR ^[5]
	lesser extent higher topographies (>100 mAHD), overlying the Bridgewater Formation. Refer to Figure 4.5 ③		Groundwater extraction from Bridgewater Formation Limestone Climate variability	● ●	Some type 3 grasslands do occur within 2 km of production wells but are not considered to be dependent on groundwater due to the large depth to groundwater and the ephemeral nature of the grassland. Groundwater level trends appear to be dominated by climate variability rather than groundwater extraction. As type 3 grasslands are considered to not be dependent on groundwater, the affects of climate variability on groundwater poses low threat to these ecosystems, although they may be impacted by climate variability directly.	

^[1]GDE Status:
☒ ☒ Groundwater dependence likely
☒ Some groundwater dependence likely, supported by surface water inundation
☒ Groundwater dependence unlikely

^[2]Level of threat based on how activities affect groundwater (i.e. excluding threats such as grazing pressure, weed infestation, disease)
Short term (annual to inter-annual): low ●; medium ●●; high ●●●
Long term (decades): low ●; medium ●●; high ●●●

^[3]Changes in land use can increase or decrease groundwater recharge changing the flux and timing of groundwater availability to GDEs and potentially altering the quality of water available to GDEs at critical times

^[4]Groundwater extraction can cause groundwater elevations to decline, potentially decreasing availability of good quality water (e.g. relatively low salinity, contaminant-free) to GDEs at critical times

^[5]Environmental Water Requirements (EWR) were assessed based on available groundwater level and salinity monitoring data. Data were only available for a small number of sites. Due to shortage of information, it is assumed that types of GDEs have similar groundwater requirements

^[6]m bgl – metres below ground level

^[7]Whilst land use mapping includes a classification referring to plantations, it is recognised they few of these exist within the study areas



Hypogean, Hyporheic and Collapsed Sinkhole Ecosystems	Discussion	GDE Status ^[1]	Potential Threats to GDEs	Level of Threat ^[2]	Observations	EWR ^[5]
	Type 1: Hypogean fauna (stygofauna) occur in the subsurface environment, in some aquifer and cave systems. Refer to Figure 4.6 ①	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	Land use ^[3] Groundwater extraction ^[4] from Bridgewater Formation Limestone Climate variability	 	Recent surveys on the Eyre Peninsula found stygofauna present in calcrete/limestone aquifers in some areas, but absent in other areas (pers. comm. Remko Leijds, South Australian Museum, 2009). There is currently insufficient information available about stygofauna to speculate why they occur in some places and not others or how resilient they may be to changes in groundwater condition induced by land use change, groundwater extraction or climate variability.	The current status of hypogean ecosystem research is at the identification phase. Their environmental water requirements and potential resilience to changes in groundwater regime are likely to remain unknown for many years to come. Given the current lack of understanding about these ecosystems, the most common strategy for managing them, in the context of groundwater plans, is to assume that groundwater management designed to maintain the EWRs of wetland, river baseflow and terrestrial vegetation GDEs, is also sufficient to maintain subsurface GDEs. That is, maintaining groundwater elevations and groundwater quality within threshold ranges over specified timeframes that resemble natural variability.
	Type 2: The hyporheic zone occurs where mixing of surface water and groundwater occurs in the subsurface environment. The mixing between oxygen-rich surface water and oxygen-poor subsurface water are major sites for the transfer and transformation of solutes and nutrients that may be essential to the function of surface or subsurface environments. Hyporheic fauna move between underground and surface environments, usually macro-invertebrates or micro-organisms. Refer to Figure 4.6 ②	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	Land use Groundwater extraction from Bridgewater Formation Limestone Climate variability	 	Hyporheic zones occur where there is subsurface connection between surface water and groundwater systems. Any activities that lower groundwater levels to the extent where surface water and groundwater connection is lost will impact hyporheic activity and threaten subsurface refuges for aquatic biota when surface waters dry out. Similarly, if groundwater levels are elevated to the extent that the direction of surface water – groundwater exchange is reversed for extended periods of time, the function of the subsurface environment will be modified.	
	Type 3: Collapsed sinkholes Refer to Figure 4.6 ③	<input checked="" type="checkbox"/>	Land use Groundwater extraction from Bridgewater Formation Limestone Climate variability	 	Potentially groundwater dependent flora and fauna may exist in sinkholes that intersect the water table. Any changes in groundwater regime that prevent access to a suitable quality or quantity of water will threaten such ecosystems.	

^[1]GDE Status:
☒☒ Groundwater dependence likely
☒ Some groundwater dependence likely, supported by surface water inundation
☒ Groundwater dependence unlikely

^[2]Level of threat based on how activities affect groundwater (i.e. excluding threats such as grazing pressure, weed infestation, disease)

Short term (annual to inter-annual): low ; medium ; high
Long term (decades): low ; medium ; high
^[3]Changes in land use can increase or decrease groundwater recharge changing the flux and timing of groundwater availability to GDEs and potentially altering the quality of water available to GDEs at critical times
^[4]Groundwater extraction can cause groundwater elevations to decline, potentially decreasing availability of suitable quality water to GDEs at critical times

^[5]Environmental Water Requirements (EWR) were assessed based on available groundwater level and salinity monitoring data. Data were only available for a small number of sites. Due to shortage of information, it is assumed that types of GDEs have similar groundwater requirements
^[6]m bgl – metres below ground level
^[7]Whilst land use mapping includes a classification referring to plantations, it is recognised they few of these exist within the study areas

Phreatophytes	Discussion	GDE Status ^[1]	Potential Threats to GDEs	Level of Threat ^[2]	Observations	EWR ^[5]
 <p>■ Red Gum, Musgrave PWA highland. This is an obligate phreatophyte and is included in the “Eucalyptus woodland and forest” classified areas in state-wide vegetation mapping.</p>	<p>Type 1: Obligate phreatophytes are deep rooted plants that only inhabit areas where they can access groundwater, via the capillary fringe, to satisfy at least some proportion of their environmental water requirement. Access to groundwater is a critically important to their presence in a landscape.</p> <p>Refer to Figure 4.7 ①</p>	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	Land use ^[3]	●	<p>The potentially obligate groundwater dependent mapped vegetation units (Eucalyptus forest and woodland, Melaleuca shrubland >1 m) exist within conservation and natural environments, although much of the Melaleuca shrubland within Musgrave PWA is surrounded by land use classified as “production from dryland agriculture and plantations”^[7].</p>	<p>Available data near mapped areas of Eucalyptus forest and woodland in the Musgrave and Southern Basins PWAs suggest that it is an obligate phreatophyte and the following ranges in groundwater conditions have historically maintained it:</p> <ul style="list-style-type: none"> Depth to groundwater <4 m bgl; and Groundwater salinity (as EC) <11 mS/cm. <p>Eucalyptus forest and woodland may be able to withstand deviations from these groundwater conditions. Studies on the Murray River floodplain suggest that red gum may be able to withdraw groundwater with salinities up to 30 mS/cm (Overton and Jolly 2004). However, it appears that the rate of groundwater level decline south of Mt Wedge (2.3 m over 20 years) was greater than mature red gum could withstand.</p> <p>Background information is presented in Appendix C.</p>
	<p>Type 2: Facultative phreatophytes are deep rooted plant species that tap into groundwater, via the capillary fringe, to satisfy at least some portion of their environmental water requirement, but will also inhabit areas where their water requirements can be met by soil moisture reserves alone. That is, the species will be groundwater dependent in some environments, but not in others.</p> <p>Refer to Figure 4.7 ②</p>	<input checked="" type="checkbox"/>	Groundwater extraction ^[4] from Bridgewater Formation Limestone	●●●	<p>Most potentially obligate groundwater dependent vegetation is mapped in areas where the water table is within the Bridgewater Formation limestone aquifer (Figure 5.13, Figure 5.14, Figure 5.15). In the Musgrave PWA, Eucalyptus forest and woodland tends to sit within the freshwater lenses (TDS<1000 mg/L), whereas Melaleuca shrubland tends to occur where the groundwater in the limestone aquifer is more brackish (TDS: 1000 to 5000 mg/L). In the Southern Basins PWA, both Eucalyptus forest and woodland, and Melaleuca shrubland are mainly mapped within the freshwater lenses. Much of the Melaleuca shrubland near Robinson lens occurs beyond the mapped extend of where the water table sits within the Bridgewater Formation limestone aquifer.</p> <p>Very little potentially groundwater dependent vegetation species mapped within 2 km of production wells in Musgrave PWA. However, there is significant Melaleuca shrubland >1 m mapped within 1 km of production wells within the Southern Basins PWA and some Melaleuca shrubland mapped within 1 km of production wells within Robinson freshwater lens.</p>	<p>Melaleuca shrubland has, for the most part, been mapped in areas of the landscape where it has access to groundwater, but also in areas where it does not. It is therefore considered a facultative phreatophyte (assuming that Melaleuca shrubland is in good condition in all of these areas) on Eyre Peninsula and the groundwater component of its EWR varies depending on where it is located in the landscape, for example, where:</p> <ul style="list-style-type: none"> Depth to groundwater: <3 m bgl, groundwater salinity (as EC) <3 mS/cm; Depth to groundwater <4 m bgl, groundwater salinity (as EC) <24 mS/cm; or Depth to groundwater >50 m bgl, groundwater is not accessed to satisfy the EWR. <p>Species of Melaleuca have been found to be obligate phreatophytes in other parts of Australia (SKM 2008).</p>
			Climate variability	●●●	<p>Groundwater level trends appear to be dominated by climate variability rather than groundwater extraction, however groundwater levels appear to have recovered slightly in Robinson lens since groundwater extraction was radically reduced.</p>	<p>Allocasuarina forest and woodland has been mapped in areas of the landscape where it has access to groundwater, but also in areas where it does not. It is therefore considered a facultative phreatophyte (assuming that Allocasuarina forest and woodland is in good condition in all of these areas) on Eyre Peninsula and the groundwater component of its EWR varies depending on where it is located in the landscape, for example, where:</p> <ul style="list-style-type: none"> Depth to groundwater: <2 m bgl, groundwater salinity (as EC) <13 mS/cm; Depth to groundwater <5 m bgl, groundwater salinity (as EC) <50 mS/cm; or Depth to groundwater >6 m bgl, groundwater is not accessed to satisfy the EWR. <p>If groundwater conditions change, causing mature Melaleuca shrubland or Allocasuarina forest and</p>



Phreatophytes	Discussion	GDE Status ^[1]	Potential Threats to GDEs	Level of Threat ^[2]	Observations	EWR ^[5]
						woodland to die back on Eyre Peninsula, it is possible, since it is a facultative phreatophyte, that it will regenerate in the same area and the juvenile vegetation would adapt to the new groundwater condition and flourish. This has been observed for facultative phreatophytes (banksia species) in Western Australia (lead by Ray Froend, Curtin University WA). However, the success of juvenile Melaleuca shrubland or Allocasuarina forest and woodland in reaching maturity is likely to be limited by some land uses (particularly stock grazing) and by soil capacity to store sufficient water. Melaleuca shrubland and Allocasuarina forest and woodland may be able to withstand short-term deviations from these groundwater conditions, but there is no evidence to suggest the extent, timing or duration of such deviations or rates of change that can occur without impacting ecosystem condition. Background information is presented in Appendix C.


^[1]GDE Status:
☒☒ Groundwater dependence likely
☒ Some groundwater dependence likely, supported by surface water inundation
☒ Groundwater dependence unlikely

^[2]Level of threat based on how activities affect groundwater (i.e. excluding threats such as grazing pressure, weed infestation, disease)

Short term (annual to inter-annual): low 🔴; medium 🔴🔴; high 🔴🔴🔴
Long term (decades): low ⬛; medium ⬛⬛; high ⬛⬛⬛
^[3]Changes in land use can increase or decrease groundwater recharge changing the flux and timing of groundwater availability to GDEs and potentially altering the quality of water available to GDEs at critical times
^[4]Groundwater extraction can cause groundwater elevations to decline, potentially decreasing availability of suitable quality water to GDEs at critical times

^[5]Environmental Water Requirements (EWR) were assessed based on available groundwater level and salinity monitoring data. Data were only available for a small number of sites. Due to shortage of information, it is assumed that types of GDEs have similar groundwater requirements
^[6]m bgl – metres below ground level
^[7]Whilst land use mapping includes a classification referring to plantations, it is recognised they few of these exist within the study areas



Freshwater Lakes	Discussion	GDE Status ^[1]	Potential Threats to GDEs	Level of Threat ^[2]	Observations	EWR ^[5]
	Type 1: Seasonal/intermittent freshwater lakes. These may recharge the Quaternary Limestone during inundation (losing conditions) and receive water back from bank storage as surface water levels recede (gaining conditions). The lakes in the Southern Basins PWA are considered to be seasonally or episodically connected (losing) to the Quaternary limestone aquifer where they directly overly the Bridgewater or Glanville Formations. In the Musgrave PWA the lakes may be disconnected from the Quaternary limestone by the presence of Holocene playa sediments. Refer to Figure 4.8 ①	☒	Land use ^[3]	●●	Seasonal freshwater lakes in the Southern basins PWA are located within conservation areas, whereas freshwater lakes in Musgrave PWA are surrounded by land use classified as “dry land agriculture and plantations” ^[7] .	<p>The best available data for assessing EWRs of freshwater lakes are near the seasonal lake in Uley South, which suggest that the following ranges in groundwater conditions have historically maintained them:</p> <ul style="list-style-type: none">Depth to groundwater: annual minimum <3.7 m bgl^[6] (this was <1.9 m bgl pre-1977 and <2.7 m bgl from 1977 to 1993); annual maximum <4 m bgl (this was <2.3 m bgl pre-1977 and < 3.2 m bgl from 1977 to 1993); andGroundwater salinity (as EC) <2 mS/cm. <p>Freshwater lake ecosystems may be able to withstand short-term deviations from these groundwater conditions, but there is no evidence to suggest the extent, timing or duration of such deviations or rates of change that can occur without impacting ecosystem condition.</p> <p>It can only be assumed, due to lack of monitoring data around seasonal freshwater lakes, that these depth to groundwater and groundwater salinity conditions will also maintain other freshwater lakes in the study areas.</p> <p>Background information is presented in Appendix C.</p> <p>Groundwater within the Quaternary Bridgewater Formation Limestone is not considered to form a component of the EWR for this type of freshwater lake.</p>
			Groundwater extraction ^[4] from Bridgewater Formation Limestone	●●	Two production wells in Lincoln Basin A are located within 65 m of seasonal freshwater lakes bordering Sleaford Mere. One production well Lincoln Basin B is within 400 m of seasonal freshwater lakes bordering Tulka coastal wetland. There is one production well within 150 m of seasonal freshwater lakes in Uley South Basin, and four more within 800 m.	
			Climate variability	●●	There are no production wells near seasonal freshwater lakes in Musgrave PWA. Groundwater level fluctuations appear to be dominated by climate variability rather than groundwater extraction.	
	Type 2: Seasonal/intermittent freshwater lakes that have a significant confining layer or occur beyond the extent of the Quaternary limestone aquifer and are disconnected from the regional aquifer. Typically occur in topographic depressions, at higher elevations in the landscape. Refer to Figure 4.8 ②	☒	Land use	●	Big Swamp freshwater lake is situated near land use classified as “dry land agriculture and plantations”.	
			Groundwater extraction from perched groundwater system	●	Production wells are >5 km away from Big Swamp and tap into the Bridgewater Formation aquifer.	
			Climate variability	●●●	Groundwater level trends are dominated by climate variability rather than groundwater extraction.	
■ Big Swamp, Southern Basins PWA						

^[1]GDE Status:
☑☑ Groundwater dependence likely
☑ Some groundwater dependence likely, supported by surface water inundation
☒ Groundwater dependence unlikely

^[2]Level of threat based on how activities affect groundwater (i.e. excluding threats such as grazing pressure, weed infestation, disease)
Short term (annual to inter-annual): low ●; medium ●●; high ●●●
Long term (decades): low ●; medium ●●; high ●●●
SINCLAIR KNIGHT MERZ

^[3]Changes in land use can increase or decrease groundwater recharge changing the flux and timing of groundwater availability to GDEs and potentially altering the quality of water available to GDEs at critical times
^[4]Groundwater extraction can cause groundwater elevations to decline, potentially decreasing availability of suitable quality water to GDEs at critical times
^[5]Environmental Water Requirements (EWR) were assessed based on available groundwater level and salinity monitoring data. Data were only

available for a small number of sites. Due to shortage of information, it is assumed that types of GDEs have similar groundwater requirements
^[6]m bgl – metres below ground level
^[7]Whilst land use mapping includes a classification referring to plantations, it is recognised they few of these exist within the study areas



Damp Coastal and sub-Coastal Heath	Discussion	GDE Status ^[1]	Potential Threats to GDEs	Level of Threat ^[2]	Observations	EWR ^[5]
■	Type 1: Coastal and sub-coastal heath in areas with shallow water tables is relatively sparse; typically in low-lying areas (0-10 mAHD). Areas of type 1 coastal heath in the Musgrave PWA is underlain with Semaphore Sand Member, whereas sub-coastal heath in this area, similar to that seen associated with Sleaford Mere, overlies Bridgewater Formation Limestone. Coastal heath is defined here as occurring within 2 km of the coast. Sub-coastal heath communities are seen further inland, where ocean spray has a lower influence. Vegetation mapping shows sub-coastal heath communities to be more common in the Southern Basins, with relatively large communities found up to 15 km inland. There is no obvious distinction between the dominant species found within the coastal versus sub-coastal heath types, based on vegetation mapping in the study areas.	<input checked="" type="checkbox"/>	Land use ^[3]	●	Type 1 coastal heath within the Musgrave PWA exists mainly within a conservation area, fringing land use is classified as for “production from dryland agriculture and plantations” ^[7] . Type 1 sub-coastal heath in Musgrave lies wholly within land use classified as “production from dryland agriculture and plantations”, whereas the pocket of Type 1 heath associated with Sleaford Mere lies within a conservation area.	<p>The best available data for assessing type 1 damp coastal and sub-coastal heath are taken from mapped areas associated with Sleaford Mere, which overlies the Lincoln-A lens. These data suggest that the following ranges have historically maintained these ecosystems:</p> <ul style="list-style-type: none">• Depth to groundwater: annual minimum <3 m bgl; annual maximum <3.4 m bgl.• Groundwater salinity <2.2 mS/cm <p>It is likely that type 1 damp coastal and sub-coastal heath is able to withstand deviations from these groundwater conditions. The sparseness of this ecosystem type relative to the total area of mapped coastal and sub-coastal heath, and the lack of clear distinction between species composition within type 1 and type 2 heath suggests that they are likely to be opportunistic in their use of shallow water tables. That is, they are facultative GDEs.</p> <p>Data are presented in Appendix C.</p> <p>Depth to groundwater in Type 3 coastal and sub-coastal heaths is > 6 m bgl, and often >22 m bgl. Although these areas may be reliant on shallow, perched water, EWRs of these ecosystems are unlikely to be connected to the Bridgewater Formation aquifer.</p> <p>Data are presented in Appendix C.</p>
			Groundwater extraction ^[4] from Bridgewater Formation Limestone	●●	Two production wells are located within the mapped area of type 1 heath associated with Sleaford Mere in the Southern Basins PWA. In Musgrave, there are no production wells within 2 km of mapped type 1 heath, with the nearest existing 2.2 km away from the patch of sub-coastal heath.	
			Climate variability	●●●	Groundwater level trends are dominated by climate variability.	
	Type 2: Coastal and sub-coastal heaths in areas with deep water tables are considerably more widespread than type1 heath and occur at elevations of 0 to >100 mAHD. Coastal heaths in this category are mainly underlain by the Semaphore Sand Member, with small pockets occurring in areas overlaying Bridgewater Formation Limestone, which is also the case for sub-coastal heath.	<input checked="" type="checkbox"/>	Land use ^[3]	●	The majority of type 2 heath exists within conservation areas, with relatively small pockets of coastal heath in the Musgrave PWA and in the northwest of the Southern Basins PWA occurring in land use classified as “production from dryland agriculture and plantations”.	
			Groundwater extraction ^[4] from Bridgewater Formation Limestone	●	Although some type 2 coastal and sub-coastal heathland occurs <1km from pumping wells, they are not considered to be dependent on groundwater due to the large depths to the water table.	
			Climate variability	●	Groundwater level trends appear to be dominated by climate variability rather than groundwater extraction. As type 2 heath is considered to not be dependent on groundwater, the affects of climate variability on groundwater poses low threat to these ecosystems, although they may be impacted by climate variability directly.	

^[1]GDE Status:

- ☒☒ Groundwater dependence likely
- ☒ Some groundwater dependence likely, supported by surface water inundation
- ☒ Groundwater dependence unlikely

^[2]Level of threat based on how activities affect groundwater (i.e. excluding threats such as grazing pressure, weed infestation, disease)

Short term (annual to inter-annual): low ●; medium ●●; high ●●●

Long term (decades): low ●; medium ●●; high ●●●

^[3]Changes in land use can increase or decrease groundwater recharge changing the flux and timing of groundwater availability to GDEs and potentially altering the quality of water available to GDEs at critical times

^[4]Groundwater extraction can cause groundwater elevations to decline, potentially decreasing availability of suitable quality water to GDEs at critical times



^[5]Environmental Water Requirements (EWR) were assessed based on available groundwater level and salinity monitoring data. Data were only available for a small number of sites. Due to shortage of information, it is assumed that types of GDEs have similar groundwater requirements

^[6]m bgl – metres below ground level

^[7]Whilst land use mapping includes a classification referring to plantations, it is recognised they few of these exist within the study areas



Appendix C Supporting information for defining EWRs

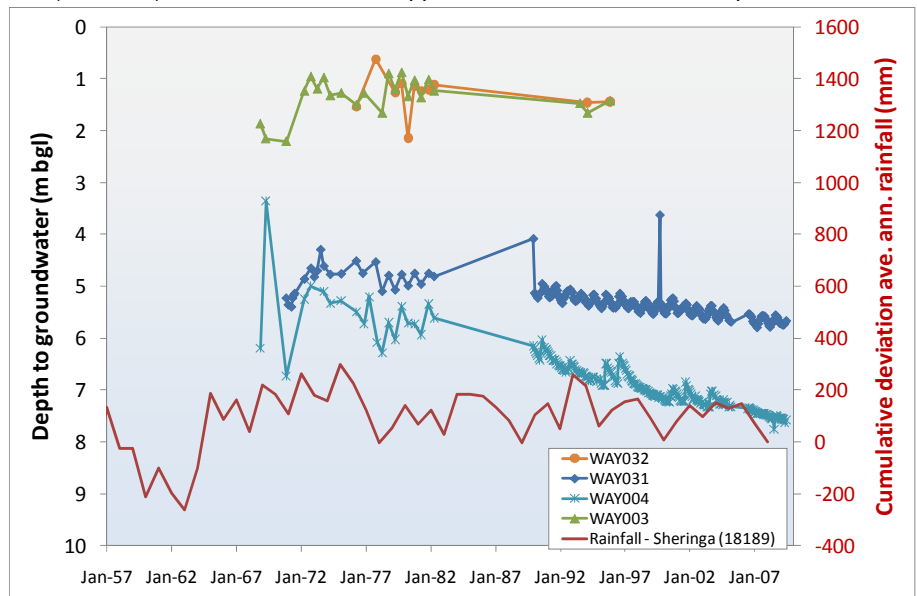


Saline Swamps

Information available to define EWRs

Type 1:
Seasonal saline
swamp

- Figure C.1 presents best available data for assessing the depth to water component of the EWRs of seasonal saline swamps. Only one of the wells (WAY003) falls within an area mapped as seasonal saline swamp.



- Figure C.1 Depth to groundwater near seasonal saline swamps (WAY003: in swamp adjoining Middle Lake; WAY004: 0.5 km upgradient from swamp adjoining South Lake; WAY031: 0.5 km upgradient from swamp adjoining Sheringa Lagoon; WAY032: 0.5 km downgradient from swamp adjoining Sheringa Lagoon) compared to cumulative deviation from average annual rainfall at Sheringa**

- The depth to groundwater in the seasonal saline swamp adjacent Middle Lake varied between 0.9 and 2.2 m bgl throughout the sporadic monitoring record (1968 – 1995).
- The trends in depth to groundwater were fairly stable from the late 60s to the early 80s, but have consistently increased since the early 90s near Sheringa and South Lake. The depths to the water table vary between 5 and 5.8m bgl (Sheringa), and 6 to 7.8m bgl (South Lake) since 1990 in observation wells located ~0.5km from the swamps.
- There is no significant groundwater pumping reported in the South Lake-Middle Lake-Sheringa Lagoon region, therefore the increasing depths to groundwater 0.5 km upgradient from South Lake and Sheringa Lagoon are assumed to be due to the regional-scale declines in groundwater level as a result of the lower than average rainfall over the last 20 years (Figure C.2) which are not reflected in the coastal weather station at Sheringa (Figure C.3).
- The same increases in depth to groundwater are not apparent at the saline swamp adjacent to Middle Lake (WAY003). There are several possible explanations for this:
 - Increases in the depth to groundwater are buffered by sea water levels closer to the coast and monitoring wells 0.5 km upgradient of the saline swamps are more representative of the regional inland groundwater system than the groundwater system beneath the saline swamps (near coastal groundwater system);
 - Seasonal saline swamps potentially occur in areas where perched water tables have developed over low permeability sediments/calcrete and are



Saline Swamps	Information available to define EWRs
	<p>isolated from the regional groundwater system. There is no lithological information in this area to prove or disprove this;</p> <ul style="list-style-type: none"> Groundwater monitoring within the seasonal saline swamp adjoining Middle Lake may have ceased too early to show increases in the depth to the water table over the last 20 years. Groundwater salinity (as EC) in the observation wells (WAY004 and WAY031) near to seasonal saline swamps is consistently <2 mS/cm, however historic drillhole data suggests that groundwater salinity within seasonal saline swamps adjacent Lake Newland can be as high as 10 mS/cm.
Type 2: Inter-tidal salt swamp	<ul style="list-style-type: none"> Figure C.2 presents best available data for assessing the depth to water component of the EWRs of inter-tidal swamps. Only one well (SLE0268 falls within 100 m of an area mapped as inter-tidal swamp. <div data-bbox="561 779 1487 1370"> </div> <ul style="list-style-type: none"> Figure C.2 Depth to water near Tulka coastal wetland (SLE068: ~70 m upgradient; SLE064: ~700 m upgradient) compared to cumulative deviation from average annual rainfall at Sleaford. <ul style="list-style-type: none"> The depth to groundwater within 100 m of the mapped inter-tidal swamp varied between 5.4 to 5.9 m bgl since 1990. Tulka coastal wetland has experienced annual groundwater level fluctuations of ~0.2 m, and groundwater levels have declined by ~0.4 m since monitoring began (1991). Groundwater levels appear to be buffered by proximity to the sea (groundwater level decline in response to dry climate over the last decade is lower than further inland). Groundwater elevations remain at ~3.5 mAHD (5.4 to 5.9 m bgl) in an observation well within 100 m of Tulka, but groundwater elevations in Lincoln Basins A & B have been consistently lower and regularly fall below 0mAHD. There is potential for movement of groundwater from the coastal region toward Lincoln Basins A & B. There is no consistent groundwater salinity monitoring near Tulka coastal wetland. Historic drillhole data suggests that groundwater can be fresh to brackish within 100m of the swamp (1.5 to 16 mS/cm).

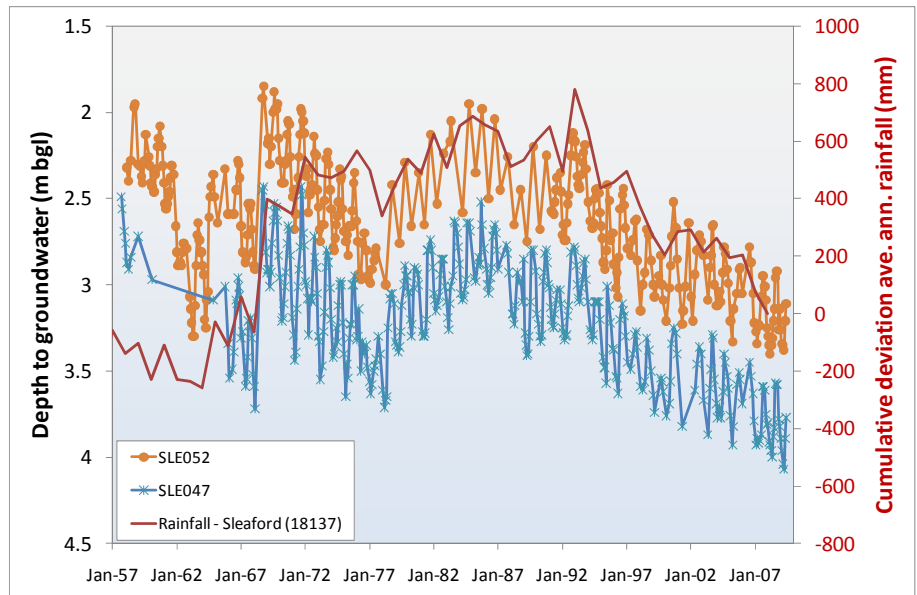


Saline Lakes

Information available to define EWRs

Type 1:
Permanent
saline lakes

- Figure C.3 and Figure C.4 present the best available data for assessing the depth to water component of the EWRs for permanent saline lakes. Monitoring well, SLE052 (~200 m north of Sleaford Mere), is the closest well and probably the most representative of groundwater conditions occurring at Sleaford Mere, permanent saline lake.



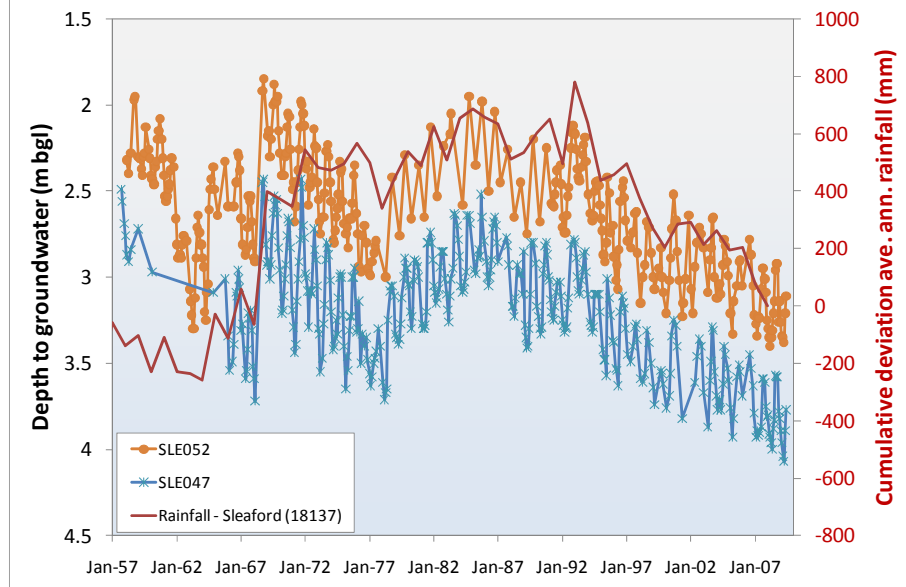
- Figure C.3 Depth to water near Sleaford Mere (SLE052: ~200 m north; SLE047: ~300 m north) compared to cumulative deviation from average annual rainfall at Sleaford.**

- The depth to groundwater at SLE052 has typically ranged between 2 and 3.5 m bgl over the last 50 years (this is likely to be shallower closer to Sleaford Mere), groundwater elevations fluctuate by 0.2 to 0.6 m annually, and groundwater levels have declined by 0.5 to 1 m since 1985.
- Groundwater elevations are typically < 1 m AHD, but north of Sleaford Mere they have consistently dropped below 0 m AHD annually since 1996.
- Historic groundwater salinity data (recorded when hole is drilled, since 1957) suggests that groundwater is typically fresh (<2 mS/cm) around the northern and western perimeter of Sleaford Mere, becoming more brackish (2 to 9 mS/cm) to the south and east. Groundwater salinity has remained consistently fresh to brackish in monitoring wells to the north of Sleaford Mere since monitoring began (1990).
- Since groundwater extraction near Sleaford Mere does not appear to have induced any increases in groundwater salinity in the area, it has been suggested that Sleaford Mere is disconnected from the Quaternary Limestone aquifer by a clay confining layer. There is, however, no evidence in available lithological records of such a confining layer. Whether or not a confining layer exists, it is likely that groundwater discharges to the lake at least episodically.
- The only other permanent saline lake mapped near the study areas is Lake Hamilton, which is located about 1 km south of the Musgrave PWA where there are no observation wells.



Saline Swamps

Information available to define EWRs



■ **Figure C.4 Depth to water near Sleaford Mere (SLE030: ~700 m east) compared to cumulative deviation from average annual rainfall at Sleaford.**

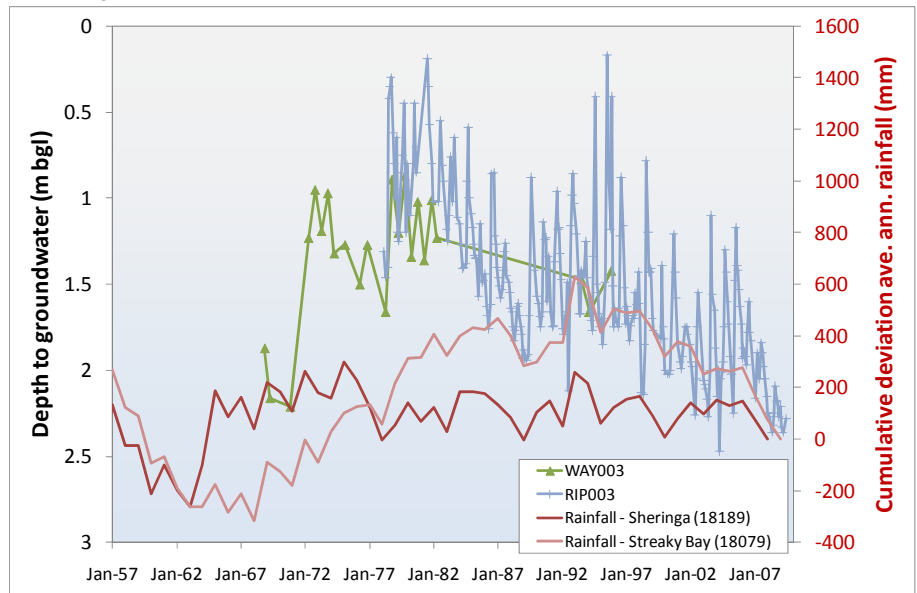
Type 2:
Seasonal saline
lakes that are
connected to the
Quaternary
aquifer

- Figure C.5 presents the best available data for assessing the depth to water component of the EWRs of seasonal saline swamps in the study areas. Monitoring well RIP003 is located within a seasonal saline lake near Robinson Basin and WAY003 is closest to any seasonal saline lakes within Musgrave PWA. RIP003 probably contains the most representative records of groundwater conditions required to sustain seasonal saline lakes.
- The depth to groundwater at RIP003 has varied between 0.2 and 2.5 m bgl since monitoring began (1978) and the depth to groundwater near Middle Lake (WAY003) has varied between 0.9 and 2.2 m bgl throughout the sporadic monitoring record (1968 – 1995).
- The annual minimum depth to groundwater (RIP003) is <2.1 m bgl and the annual maximum depth to groundwater is <2.5 m bgl for RIP003 since monitoring began (1978), but these depths to groundwater have tended to increase over the last 30 years. Between 1978 and 1986, the annual minimum depth to groundwater was <1.1 m bgl and the annual maximum depth to groundwater was <1.8 m bgl; whereas between 1987 and 1999, the annual minimum depth to groundwater was <1.4 m bgl and the annual maximum depth to groundwater was <2.1 m bgl.
- Groundwater levels near Robinson Basin have typically declined by 0.6 to 1.3 m since 1996. Some of the increases in depth to groundwater are likely to be partially induced by groundwater extraction in Robinson Basin, but the overriding influence appears to be climatic (Figure C.5; Streaky Bay).
- Assuming that it is the climatic conditions that have predominantly been the cause of declining groundwater levels at RIP003 suggests that the changes in depth to groundwater that have occurred over the last 30 years are within the range of conditions that seasonal saline lake ecosystems would naturally have needed to adapt to.
- Natural changes in groundwater condition over time may cause a shift in the structure of an ecosystem and consequently the EWR may also change. As such, EWRs may be transient depending on ecosystem adaptations to a variable

**Saline Swamps****Information available to define EWRs**

climate.

- Groundwater salinity (as EC) in the observation well (WAY004) is consistently <1.5 mS/cm, however historic drillhole data suggests that groundwater salinities within seasonal saline lakes range from about 3 to 32 mS/cm throughout the Musgrave PWA and Robinson Basin area.



- Figure C.5 Depth to groundwater within (RIP003: near Robinson Basin) and near seasonal saline lakes (WAY003: ~150 m upgradient of Middle Lake) compared to cumulative deviation from average annual rainfall at Sheringa and Streaky Bay.**

Type 3:
Seasonal saline
lakes that are
disconnected
from the
Quaternary
aquifer

There are no observation wells near Little Swamp. However, it is assumed that seasonal saline lakes that are disconnected from the Quaternary Limestone aquifer in the study area only depend on rainfall and surface water runoff to satisfy their EWRs.

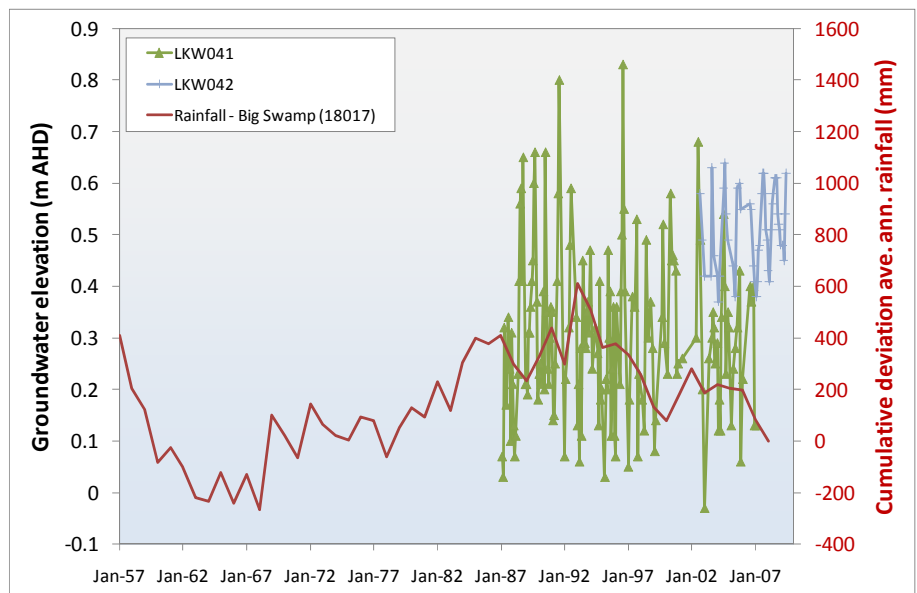


Springs and underground water soaks

Information available to define EWRs

Type 1: Springs that occur in parts of the landscape where groundwater rises or seeps to the ground surface

- Many springs and soaks are reported to occur on the Eyre Peninsula, but their occurrence has not been comprehensively mapped.
- Analysis is limited to those springs shown in Figure C.6.
- Annual groundwater levels in monitoring wells near Coffin Bay springs (~0.5 km) fluctuate by ~0.2 m annually, typically ranging between 0 and 0.5 m AHD (Figure C.6) and appear to be largely buffered by seawater levels. Groundwater in the Bridgewater Formation (pumped aquifer) appears to be at the ground surface in this area (based on extrapolation of groundwater elevation data and topographical contours). Groundwater salinity is <1.5 mS/cm (as EC) in monitoring wells, but historic drillhole information suggests that it can also be brackish (typically <4 mS/cm) near the springs.
- Groundwater levels in Coffin Bay B freshwater lens also appear to fluctuate by ~0.2 m annually, but range between 7 and 11 m AHD and have declined by ~2 m since 1991. Historic drillhole information suggests that groundwater salinity tends to be brackish (~5 mS/cm) near the Kelledie Bay springs.
- There are no monitoring wells within 10 km of Weepdra Spring. Although historic drillhole data shows groundwater is highly brackish (~9.5 mS/cm) in this area.



■ **Figure C.6 Groundwater elevation near Coffin Bay coastal springs (~0.5 km inland) compared to cumulative deviation from average annual rainfall at Big Swamp.**

Type 2: Springs that occur in near coastal regions where sea water flows through the aquifer system and discharges inland to the ground surface

There are no data available to identify EWRs for seawater springs on Eyre Peninsula. However, it is presumed that this is dictated by sea level.



Sinks and underground water soaks	Information available to define EWRs
Type 3: Soaks occur in parts of the landscape where the water table lies very close to or at the ground surface	No data are available to identify the location or EWRs of soaks on Eyre Peninsula. It is assumed that soaks require water tables to remain within a metre or so of the ground surface.

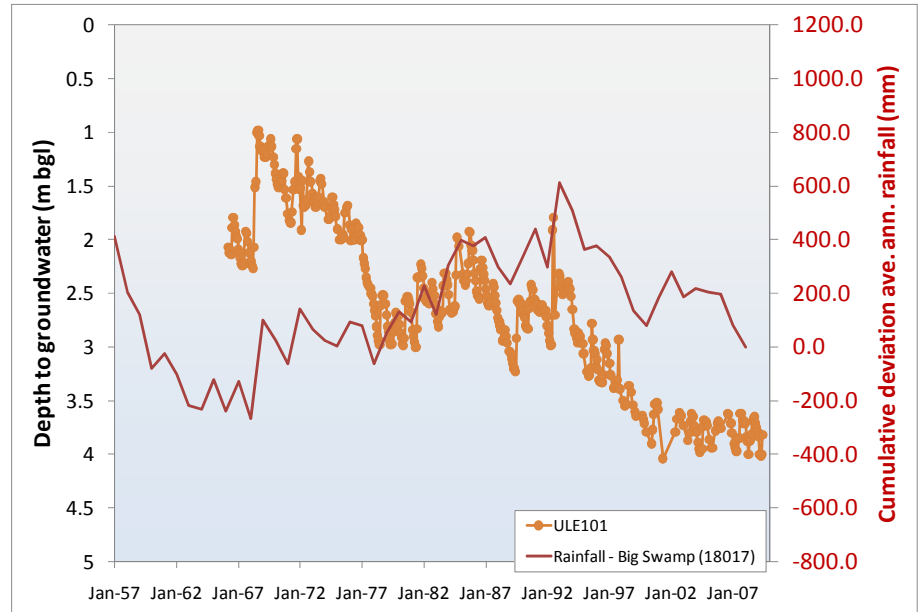


Grasslands / Sedgeland

Information available to define EWRs

Type 1: Sedgeland located on periodically inundated/waterlogged and wet areas

- Figure C.7 presents the best available data for assessing the depth to water component of EWRs of sedgeland. Monitoring well ULE101 is located on the edge of mapped sedgeland associated with seasonal swamp, which overlies Uley South lens and is the most representative hydrograph of the groundwater conditions required to sustain this type of ecosystem.



- Figure C 7 Depth to groundwater near Sedgeland (ULE101: on the edge of sedgeland overlaying Uley South lens) compared to cumulative deviation from average annual rainfall at Sleaford.**
 - The depth of groundwater at ULE101 varied between 1 and 4 m bgl throughout the monitoring record (1966-2009).
 - The annual minimum depth to groundwater in this well is 3.6 m bgl and maximum depth to groundwater is 4 m bgl. However, between the late 1970s and mid 1990s, which was a period of average rainfall, annual minimum and maximum depth to groundwater were 2.7 m bgl and 3.2 m bgl respectively, and levels were generally more stable.
 - Groundwater elevations in the sedgeland underlying Uley South lens fluctuate between 0.3 and 1 m annually, although seasonal variation has decreased over the last 15 years. Groundwater levels have seen a decrease of between 1.4 and 2 m over the last four to five decades, with depth to groundwater in the area historically ranging between 2 and 5 m bgl. Groundwater salinity is <1.2 mS/cm.
 - Figure C.7 illustrates the correspondence of groundwater levels with rainfall variability. Depth to groundwater in the last decade have remained stable, >3.5 m bgl, in a period of relatively average rainfall.
 - Elsewhere on the Eyre Peninsula, data is more sporadic and often not available in close proximity to mapped areas of sedgeland. Groundwater elevations near sedgeland at Sleaford Mere fluctuate by 0.2 to 0.6 m annually, and groundwater levels have declined by 0.5 to 1 m since 1985. Depth to groundwater in this area typically ranges between 2 and 4 m bgl. Groundwater salinity is ~2 mS/cm.
 - Sedgeland associated with the seasonal swamp near South Lake in Musgrave PWA have experienced annual groundwater level fluctuations of 0.2 to 0.4 m, and groundwater level declines of 1.4 m since 1991. Depth to water table has

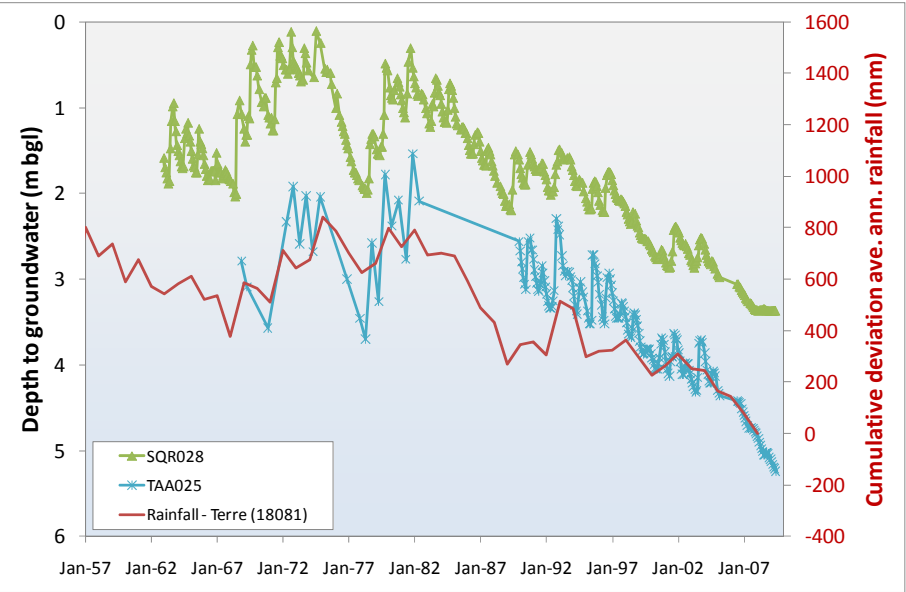


Grasslands / Sedgeland	Information available to define EWRs
	<p>varied between 6 and 8 m bgl since 1990 in observation wells located ~0.5 km from the sedgeland. Groundwater salinity in the observation well is consistently ~1.5 mS/cm.</p>
<p>Type 2: Tussock grasslands that occur in areas with shallow water tables</p>	<ul style="list-style-type: none"> Figure C.8 presents the best available data for assessing the depth to water component of the EWRs of type 2 grasslands in the study areas. Monitoring wells SQR009, located within an area mapped as tussock grassland which overlies the Poldia lens in Musgrave PWA and are the most representative hydrographs of the range of groundwater conditions required to sustain this type of ecosystem. <div data-bbox="596 719 1508 1328"> </div> <ul style="list-style-type: none"> Figure C.8 Depth to groundwater within type 2 grasslands (SQR009, which overlay Poldia lens) compared to cumulative deviation from average annual rainfall at Elliston. Depth to groundwater has historically remained <4 m, although groundwater levels have been declining steadily since 1980 and have been consistently deeper than 4 m since 2000. The water table beneath these grasslands generally varies between 0.1 and 0.5 m annually. The annual minimum depth to groundwater in monitoring well SQR009 is <4 m bgl, and annual maximum depth is <5 m bgl. Depths have tended to increase over the last 30 years, corresponding with an extended period of lower than average rainfall. Groundwater salinity in this area (SQR028) is consistently < 4.2 mS/cm, however data available from a bore within 1.3 km from SQR028 and <100 m from the Poldia Trench pumping well shows levels consistently >12 mS/cm where depth to groundwater is typically <3 m. Groundwater levels in the Uley South lens below type 2 grasslands historically ranged between 2.8 and 5.8 m (ULE184). Although levels have declined ~0.4m since 1992, they have remained relatively stable since 2002. Groundwater salinity in this area is <1.3 mS/cm. Areas of type 2 and type 3 grasslands tend to exist as mosaics; occurring within the same expanse of mapped grassland, within metres of each other. It is likely that grasslands are opportunistic in nature; taking advantage of shallow water



Grasslands / Sedgeland	Information available to define EWRs
	<p>tables when and where they occur, and relying on soil water in dryer periods when coverage is likely to be sparser. The species density and composition of these areas is likely to change with changing depths to groundwater.</p>
<p>Type 3: Tussock grassland in areas with deep water tables</p>	<ul style="list-style-type: none"> Figure C.9 presents the best available data for assessing the depth to water component of the EWRs of type 3 grasslands. Monitoring well WNL035 is located within an area of mapped tussock grassland, which overlies Coffin Bay-C lens in the Southern Basins PWA and is the most representative hydrograph of the groundwater conditions required to sustain this type of ecosystem. <div data-bbox="596 689 1508 1301"> </div> <ul style="list-style-type: none"> Figure C 9 Depth to groundwater near type 3 grasslands (WNL035, which overlies Coffin Bay-C lens) compared to cumulative deviation from average annual rainfall at Big Swamp. Depth to groundwater is generally >4 m bgl, and often >15 (as in Figure C.9) with seasonal fluctuations generally between 0.1 and 1.1 m. There is a large range of groundwater elevations in grasslands across the study areas. Groundwater salinity is generally fresh (<1.6 mS/cm). Type 3 grassland is unlikely to be dependent on groundwater due to the associated large depths to water table. They most likely rely on soil water.

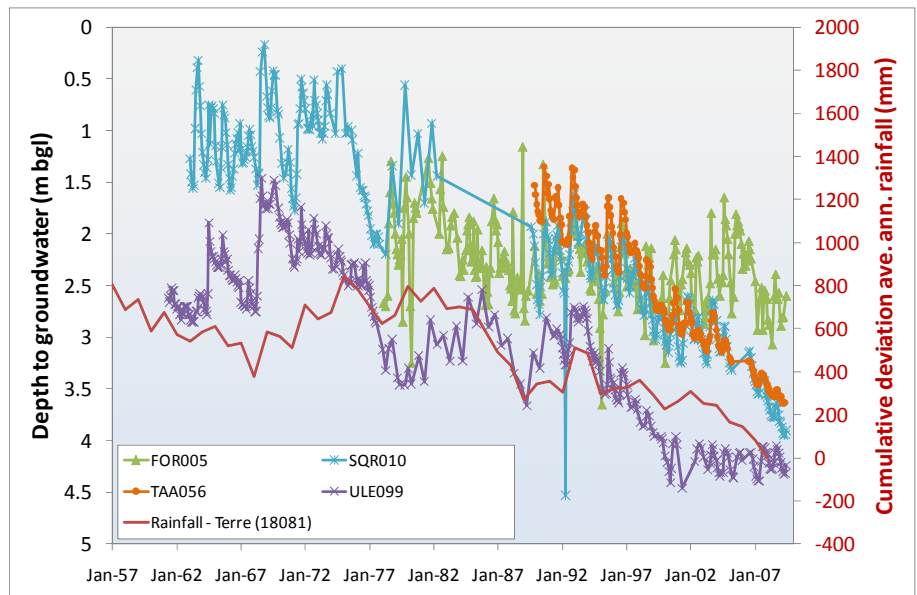


Phreatophytes	Information available to define EWRs
Type 1: Obligate phreatophytes	<ul style="list-style-type: none"> Eucalyptus forest and woodland is less widespread than Melaleuca shrubland and Allocasuarina forest and woodland, occurring where the depth to groundwater is typically <4 m bgl. In Musgrave PWA, the depth to groundwater pre-1990s beneath Eucalyptus forest and woodland was typically <4 m bgl with annual fluctuations in groundwater level of ~0.5 m and groundwater salinities ranging from fresh to brackish (1 to 11 mS/cm as EC). Since 1990, groundwater levels have typically declined by ~2 m, resulting in red gum die-back in some areas (particularly in an area south of Mt Wedge – this is >15 km away from production wells; Figure C.10). Eucalyptus forest and woodland in Southern Basins PWA occurs along ephemeral creek lines through Tulka Basin (west PWA) and in the higher parts of the landscape in the northern section of the PWA in Uley East and Uley Vanilla Basins where groundwater salinity is historically fresh (<2 mS/cm). Prior to 1990, groundwater levels were typically <5 m bgl, but annual maximum groundwater levels have declined by ~2.5 since 1989.  <p>■ Figure C 10 Depth to groundwater near Eucalyptus forest and woodland where vegetation has remained healthy (SQR028) and where there has been significant die-back (TAA025) compared to cumulative deviation from average annual rainfall at Terre rain station (18081).</p>
Type 2: Facultative phreatophytes	<ul style="list-style-type: none"> Melaleuca shrubland in the Robinson Basin area exists over shallow water tables (1 to 3 m bgl), where groundwater levels typically fluctuate by ~0.5 m annually. Groundwater levels in this area have declined by ~0.5 m since the 1990s. Groundwater salinity is typically brackish (2 to 3 mS/cm), and appears to have been increasing since ~2000. Melaleuca shrubland in the Musgrave PWA tends to exist where the depth to groundwater is slightly deeper (<4 m bgl; e.g. Figure C.11), with annual fluctuation in groundwater levels ~0.5 m and groundwater salinities highly brackish (ranging from 11 to 24 mS/cm). Since 1990, groundwater levels have typically declined by ~2 m. In the Southern Basins PWA, some Melaleuca shrubland occurs where the depth to groundwater is consistently <4.5 m bgl, and are likely to access groundwater to meet some part of their EWR. In other areas the depth to groundwater has consistently been much deeper (some consistently >50 m bgl) and are likely to access their EWR from water stored in the soil profile above the capillary fringe. The Melaleuca

**Phreatophytes****Information available to define EWRs**

shrubland over shallow water tables are likely to be more vulnerable to changes in groundwater condition. In these areas groundwater salinity is <1 mS/cm, annual fluctuations in groundwater level are typically 0.5 to 1 m, and groundwater levels have declined by 1 to 4 m since 1990.

- Figure C.11 presents the hydrographs that are the most representative of groundwater conditions required to sustain this type of ecosystem in each of the study areas.



- Figure C.11 Depth to groundwater beneath Melaleuca shrubland near Robinson Basin (FOR005), Poldas Basin (Musgrave PWA; TAA025, SQR010) and Uley South (Southern Basins PWA; ULE099) compared to cumulative deviation from average annual rainfall at Terre rain station (18081; near Poldas Basin).**

- Allocasuarina forest and woodland within the Robinson lens area has existed where the depth to groundwater has typically ranged between 2 and 4 m bgl. Rainfall has typically been below average since 1993 and groundwater levels declined correspondingly. Groundwater extraction from Robinson lens decreased dramatically around 2004 and groundwater levels showed some recovery in response to this, however, overall groundwater levels have continued to decline and since 2000 the depth to groundwater has typically ranged between 2.5 and 4.5 m bgl. Figure C.12 presents depth to groundwater data from wells located amongst Allocasuarina forest and woodland.
- Groundwater salinity (as EC) was typically about 1.5 mS/cm. Since the 1990s groundwater has become more brackish and is up to 4.5 mS/cm in some areas – particularly near the edge of the lens.
- There is considerable groundwater monitoring in Allocasuarina forest and woodland surrounding (but outside) Robinson lens. This shows that this vegetation type exists over a range of groundwater conditions – where the depth to groundwater is consistently <2 m bgl with highly variable groundwater salinity (0.5 to 13 mS/cm); where depth to groundwater typically ranged between 3 and 5 m bgl and groundwater salinity has increased markedly from typically fresh to brackish (<4 mS/cm) pre-1990s to brackish to saline (up to 50 mS/cm) since the 1990s; and where depth to groundwater has consistently been >6 m bgl with groundwater salinities between 1.5 and 15 mS/cm pre-1990s and up to 35 mS/cm since 1990.



Phreatophytes	Information available to define EWRs
	<ul style="list-style-type: none"> There is no groundwater monitoring within Allocasuarina forest and woodland in Musgrave PWA. Allocasuarina occur within the Bramfield lens where groundwater levels have declined by 2.8 m since 1990. Allocasuarina forest and woodland occurs across a wide range of hydrogeological conditions in the Southern Basins PWA. It occurs in Coffin Bay-A lens within 500 m of extraction wells. There are no monitoring wells inside this type of vegetation in the vicinity of the Coffin Bay lens, but the depth to water appears to be stable in this area, fluctuating by up to 0.3 m annually and the depth to water is consistently <4 m bgl within 200 m of this vegetation in the Coffin Bay lens. Allocasuarina forest and woodland also occurs in Wanilla lens within 750 m of extraction wells. Groundwater levels within this area decreased by about 2 m during the 1990s and have remained relatively stable since 2000. The depth to groundwater was typically <5 m bgl pre-1990 and has been consistently >6 m bgl since 1997. Allocasuarina forest and woodland that occurs in Uley East lens is > 5 km from any extraction wells and the depth to water is consistently > 20 m bgl. Allocasuarina forest and woodland occurs within 20 m of extraction wells in Lincoln-A lens. Prior to the 1900s, the depth to groundwater was < 4 m bgl. Since 1990 groundwater levels have fallen by ~0.7 m. Outside of Lincoln-A lens Allocasuarina forest and woodland occurs where the depth to groundwater is typically > 6 m bgl. Groundwater extraction inside the Lincoln-B lens occurs within Allocasuarina forest and woodland where the depth to groundwater is consistently >36 m bgl. Groundwater extraction inside the Lincoln-C lens occurs within Allocasuarina forest and woodland where the depth to groundwater is consistently >7 m bgl.
	<p>■ Figure C.12 Depth to groundwater beneath Allocasuarina forest and woodland in Robinson Basin (FOR026), Bramfield Basin (Musgrave PWA; WAD030), Coffin Bay-A (Southern Basin PWA; LKW043), Wanilla Basin (WNL043) and Lincoln-A lens (Southern Basins PWA; SLE047) compared to cumulative deviation from average annual rainfall at Big Swamp.</p>



Freshwater Lakes	Information available to define EWRs
<p>Type 1: Seasonal/intermittent freshwater lakes that are connected to the Quaternary Bridgewater Formation aquifer</p>	<ul style="list-style-type: none"> Groundwater elevations near seasonal freshwater lakes bordering Sleaford Mere fluctuate by 0.2 to 0.6 m annually, and groundwater levels have declined by 0.5 to 1 m since 1985. Groundwater elevations in this area are typically <1 m AHD, but they have consistently dropped below 0 m AHD annually since 1996 and the depth to groundwater typically ranges between 2 and 4 m bgl. Groundwater salinity is ~2 mS/cm. Groundwater elevations underlying seasonal freshwater lakes in the Uley South Basin generally fluctuate between 0.3 and 1 m annually. Groundwater levels have decreased by between 1.4 and 2 m over the last four to five decades, typically being >1.5 m AHD over the last decade. The depth to groundwater in the area historically ranges between 1 and 4 m bgl (Figure C.13), but have been consistently >3.5 m bgl in the last decade. Groundwater elevations in Uley east, near the intermittent freshwater lake south of Big Swamp fluctuate by 0.5 to 1 m annually and groundwater levels have declined by >2.5 m since 1990. Minimal historic data suggests the groundwater beneath the lakebed is typically brackish. The depth to groundwater beneath seasonal/intermittent freshwater lakes in southern Musgrave PWA was <2 m bgl and groundwater salinity was fresh (<2 mS/cm) during the 1970s, but no more recent information exists.
	<p>■ Figure C.13 Depth to groundwater near freshwater lakes compared to cumulative deviation from average annual rainfall at Big Swamp</p>
<p>Type 2: Seasonal/intermittent freshwater lakes that are disconnected from the Quaternary Bridgewater Formation aquifer</p>	<p>There are no monitoring wells near Big Swamp. Historical groundwater salinity data suggests that groundwater in the vicinity is fresh to brackish.</p>

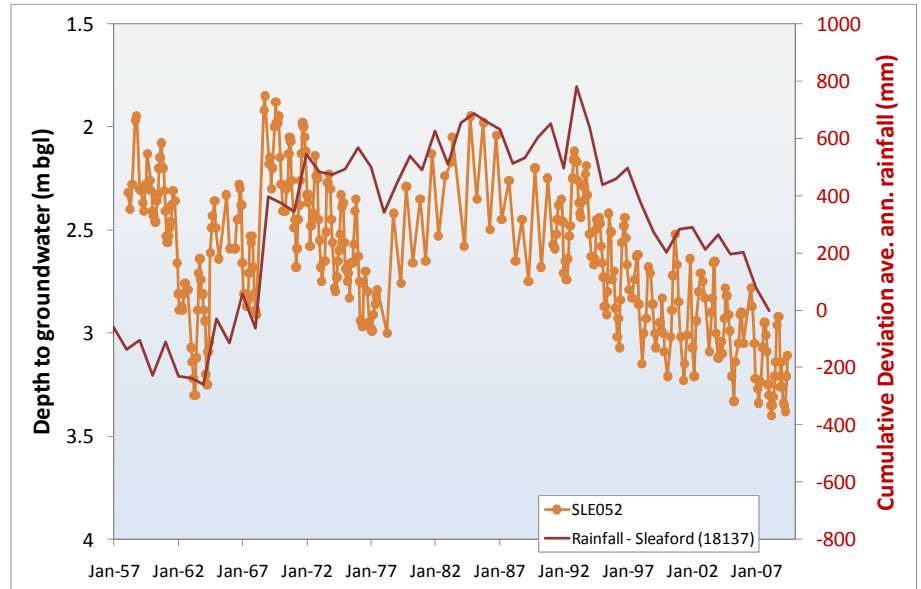


Damp Coastal and sub-Coastal Heath

Information available to define EWRs

Type 1: Damp coastal and sub-coastal heath in areas with shallow water tables

- Figure C.14 presents available data for assessing the depth to groundwater component of the EWRs of damp coastal and sub-coastal heath in areas with shallow water tables. Monitoring well SLE052 is located within an area of mapped sub-coastal heath which overlies the Lincoln-A lens, north of Sleaford Mere.



■ **Figure C.14 Depth to water within damp coastal and sub-coastal heath (SLE052) compared to cumulative deviation from average annual rainfall at Sleaford.**

- Depth to groundwater in this well historically ranges from 2 to 3.3 m bgl. Groundwater levels fluctuate by 0.2 to 0.6 m annually and have declined by 0.5 to 1 m since 1985, corresponding with a period of below average rainfall since that time. Annual minimum depth to groundwater is <3 m bgl and annual maximum is <3.4 m bgl.
- Groundwater salinity in this area has historically ranged between 1.9 mS/cm and 2.2 mS/cm (SLE052).
- There are few other areas with data from monitoring wells within mapped coastal and sub-coastal heath, which overlies shallow water tables (defined as <4 m bgl). Groundwater level records in the coastal heath within Musgrave PWA are relatively sparse. However, in the south west of the defined PWA it is evident that these communities exist across areas with considerable variation in depth to water table over a short distance (ranging from ~0.6 m to >21 m bgl) and hence appear interspersed with type 2 coastal heath (discussed below). Groundwater taken from a monitoring well (WAY055) within this type 1 heath show levels have generally remained stable since records began in the late 1990s, with fluctuations of <0.5 m annually.
- Groundwater salinity in this area (WAY055) has typically ranged between 5.7 and 30 mS/cm since 1992 when records began.
- Areas of type 1 damp coastal and sub-coastal heath appear relatively sparse throughout the study areas, although data needed to assess the presence of these ecosystems is limited. Those identified are either in relatively small pockets, or interspersed with type 2 damp coastal and sub-coastal heaths (below). This suggests that they are opportunistic in nature; taking advantage



	<p>of shallow water tables where they exist, such as heath adjacent Sleaford Mere in the Southern Basins PWA, and likely to be reliant on soil water where levels decline and/or during dryer periods.</p>
<p>Type 2: Damp coastal and sub-coastal heaths in areas with deep water tables</p>	<ul style="list-style-type: none"> Figure C.15 presents data for assessing the depth to groundwater component of the EWRs of damp coastal and sub-coastal heaths in areas with deep water tables. Monitoring wells ULE077 and LKW012 are located within an area of mapped sub-coastal heath which overlies the Uley South lens in the Southern Basins PWA. <div data-bbox="595 616 1509 1207"> </div> <ul style="list-style-type: none"> Figure C.15 Depth to groundwater near type 2 coastal and sub-coastal heath (ULE0747 and LKW012, which overlay Uley South lens) compared to cumulative deviation from average annual rainfall at Big Swamp. The data available suggests that damp coastal and sub-coastal heath which overlies areas with deep water tables is by far the most common type of coastal heath in the study areas, with the limited data highlighting type 1 heath discussed above. Depth to groundwater in these areas is defined here as being consistently >4 m bgl. However, data from wells in these mapped areas suggest the majority to lie above groundwater levels of > 22 m bgl and in some cases > 131 m bgl. Data available, suggest that groundwater salinities in these areas are typically quite fresh, being consistently <1.3 mS/cm. Type 2 damp coastal and sub-coastal heath is unlikely to be dependent on groundwater due to the associated large depths to water table. They most likely rely on soil water.