TECHNICAL REPORT

ENVIRONMENTAL WATER REQUIREMENTS OF GROUNDWATER DEPENDENT ECOSYSTEMS IN THE MUSGRAVE AND SOUTHERN BASINS PRESCRIBED WELLS AREAS ON THE EYRE PENINSULA

2012/16

Government of South Australia
Department for Water

ENVIRONMENTAL WATER REQUIREMENTS OF GROUNDWATER DEPENDENT ECOSYSTEMS IN THE MUSGRAVE AND SOUTHERN BASINS PRESCRIBED WELLS AREAS ON THE EYRE PENINSULA

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FOREWORD

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

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

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

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

Allan Holmes
CHIEF EXECUTIVE
DEPARTMENT FOR WATER

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- The EPNRM Board who funded the project
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SUMMARY

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

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

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

This project aims to document the current understanding on the distribution of groundwater dependent ecosystems (GDEs) within the Musgrave and Southern Basins PWAs on Eyre Peninsula; their ecological values; their environmental water requirements; and our best understanding on thresholds of change with respect to the relationship between groundwater regime and the Environmental Water Requirements (EWRs). The report provides information to support the environmental component of Environmental Water Provisions (EWPs – see Glossary), but does not specify them as social and economic considerations are outside the scope of this project.

The EWRs of Eyre Peninsula GDEs were determined using a five-step approach. Initially, all relevant information on the GDEs was collated, involving the identification, classification and mapping of the wetlands and describing the associated biota and ecological processes (ecological values). Secondly, Ecological Objectives were set to guide the determination of the EWRs. The relationship between the values used in objectives and their water requirements were described using conceptual models (how each GDE system "works") which are used to identify the critical characteristics of the water regime required to achieve the objectives. Finally, the water regimes that fulfil all of the objectives set for the different GDEs were determined.

The surface wetland systems have been well mapped in the Eyre Peninsula PWAs, but the dependence of some of them on groundwater sources has not been well demonstrated. It is assumed that without further evidence, all wetlands (apart from Big and Little Swamps – see Section 7.2) are dependent on regional groundwater and may be susceptible to impacts from groundwater development (e.g. decreased water availability and/or increased salinity) within the Prescribed area.

For GDEs other than wetlands which have been less well mapped, generic EWRs that are expected to apply to all situations where a particular class of GDE is identified are developed on the assumption that they will support a similar suite of vegetation.

For the purposes of determining Environmental Water Requirements, the GDEs in the study area were characterised into five distinct groups:

- Wetlands (divided into Wetland Groups based on the classification of Semeniuk and Semeniuk 2007a)
- Phreatophytes (concentrating on red gum woodlands)

- Springs and underground water soaks
- Hypogean, hyporheic and collapsed sinkhole ecosystems
- Marine discharges.

The objectives of the EWRs can be stated as providing:

> *… a watering regime that will promote self-sustaining populations of groundwater-dependent flora and fauna that currently exist within the area.*
>
> *The watering regime will reduce the likelihood of future degradation of assets and increase their resilience to future low rainfall periods.*
>
> *The current spatial distribution of groundwater-dependent flora and fauna will be maintained.*

Note that these objectives for EWRs may not reflect those adopted within the Water Allocation Plan after social and economic factors have been taken into consideration.

The majority of available data on biota in the two PWAs involve the presence of flora species. Plants are the biotic component that is most readily observable over time in the Eyre Peninsula GDEs. Relatively few studies have been conducted on more mobile or cryptic components such as aquatic macroinvertebrates, fish, birds and other vertebrates. Therefore, the EWRs were primarily determined by the water requirements of plants. However, it should be noted that many of the wetlands on Eyre Peninsula appear to be sub-optimal for the more aquatic (i.e. those that demand more permanent, deeper or more frequent inundation) or less salt tolerant species and appear to be persisting in conditions close to their limits of aquatic viability. The majority of wetlands in this study are dominated by more terrestrial and resilient vegetation with aquatic species inhabiting smaller and more marginal niches (e.g. small permanent springs).

The plants were classified into a variety of functional groups based on their similar hydroecological responses to water availability. Common plant species were selected to represent each functional group when determining EWRs. It is assumed that providing an adequate water regime for these representative taxa will adequately provide for other taxa in the same functional group that are less common and/or less well understood.

The taxa selected, functional group and water requirements for wetlands are shown below.

Taxon	**Functional group**	**Water requirements**
Wilsonia backhousei	Terrestrial Damp	Groundwater within 2-3 m of surface for at least 3 months each year for persistence and growth. Damp soil for at least 3 months of the year, at least 1 in 10 years for recruitment.
Melaleuca halmaturorum	Amphibious fluctuation tolerator woody	Groundwater within 2–3 m of surface for at least 3 months each year for persistence and growth. Damp soil for at least 3 months of the year, at least 1 in 10 years for recruitment.
Gahnia spp.	Amphibious fluctuation tolerator emergent	Groundwater within 3–4 m of surface for at least 2 months each year for persistence and growth.
Baumea juncea	Amphibious fluctuation tolerator emergent	Groundwater within 1 m of surface for at least 3 months each year for persistence and growth. Damp soil for at least 3 months of the year, at least 1 in 3 years for recruitment.
Samphires (*Sarcocornia* spp. and	Amphibious fluctuation	Surface water depth <500 mm for at least 6–9 months of the year for

Tecticornia spp.)	tolerator emergent	persistence and growth. Damp soil for at least 3 months of the year, at least 1 in 3 years for recruitment.
Triglochin striatum	Amphibious fluctuation tolerator emergent	Permanent shallow water or saturated soils all year.
Phragmites australis	Emergent	Permanent shallow water or saturated soils all year.
Ruppia tuberosa	Submerged r-selected	Surface water depth 20–30 mm for at least six months of the year at least 1 in 3 years for persistence, growth and recruitment
Chara spp.	Submerged r-selected	Surface water depth >250 mm for at least 16 weeks each year
Hydrocotyle spp.	Amphibious fluctuation responder plastic	Permanent shallow fresh water 20–100 mm deep.

An EWR was built for each Wetland Group by collating the various water requirements of the different plant functional groups. Plant data was derived from site investigations reported in Semeniuk and Semeniuk (2007a), SKM (2009) and site investigations.

Some groundwater dependent biota, such as red gums, occur outside of wetlands and required specific EWRs. The EWR for red gum (*Eucalyptus camaldulensis*) and the Eyre Peninsula blue gum or water gums (*E. petiolaris*) is to maintain the water regime within the limits of their capacity to adapt to changes in water regime (i.e. ability to change morphological and physiological characteristics). Further research into the water sources used by these phreatophytic eucalypts within the PWAs and their ability to switch water sources is needed to further refine this EWR for particular stands of gums (e.g. those occurring near the Polda Trench).

The only springs identified within the PWAs are those associated with Sleaford Mere and Lake Newland. EWRs for these systems are guided by the need to maintain flowing water to support associated vegetation communities, which in turn are assumed to support a wider diversity of other aquatic biota.

There are inadequate data to determine the location and the specific environmental assets of hypogean and hyporheic ecosystems and therefore, generic EWRs for these systems could not be developed.

For marine discharges, the groundwater level needs to be in direct contact with the marine discharge with a pressure at least sufficient to prevent seawater intrusion. Improved mapping of near-shore discharges is required to identify the discharge points and their dependent ecosystem assets and processes.

The Environmental Water Requirements presented here have been determined to maintain or improve the current environmental values into the future with a low level of risk. It is recognised that during dry periods, the quantity and quality of groundwater available to support environmental values may not always meet the recommended regime. This is seen as a natural occurrence, albeit one that may be exacerbated by climate change and the biota have adapted to survive some periods where water availability is lower than desirable. A process for assessing the risks to GDEs due to deviations from the described EWR is presented.

1. INTRODUCTION

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

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

This report is one component of the broader SSWAP project. It aims to document the current understanding on the distribution of groundwater dependent ecosystems (GDEs); their ecological values; their environmental water requirements; and our best understanding on thresholds of change with respect to the relationship between groundwater regime and the Environmental Water Requirements (EWRs).

Understanding environmental water requirements (EWRs) and their relationship with changes in groundwater regime is a key part of water allocation planning and licensing for prescribed water resources in South Australia. This report details current understanding on EWRs for the groundwater dependent ecosystems for the Musgrave and Southern Basins Prescribed Wells Areas (PWA) on Eyre Peninsula and the methods by which these EWRs have been developed.

The distinction needs to be made between EWRs and Environmental Water Provisions (EWPs). EWRs are defined as 'the water regime needed to sustain the ecological values of ecosystems, including their processes and biological biodiversity, at a low level of risk' (DWLBC 2006). EWPs are defined as 'those parts of environmental water requirements that can be met at any given time. This is what can be provided at that time with consideration of existing users' rights, social and economic impacts.' (DWLBC 2006). The development of EWPs is outside the scope of this project.

1.1. STUDY AREA

The study area is restricted to the Musgrave and Southern Basins Prescribed Wells Areas on the Eyre Peninsula in South Western South Australia (Figure 1). The Southern Basins PWA is located south-west of Port Lincoln and covers approximately 870 km^2. The Musgrave PWA is located further west around the township of Elliston and covers an approximate area of 3595 km^2.

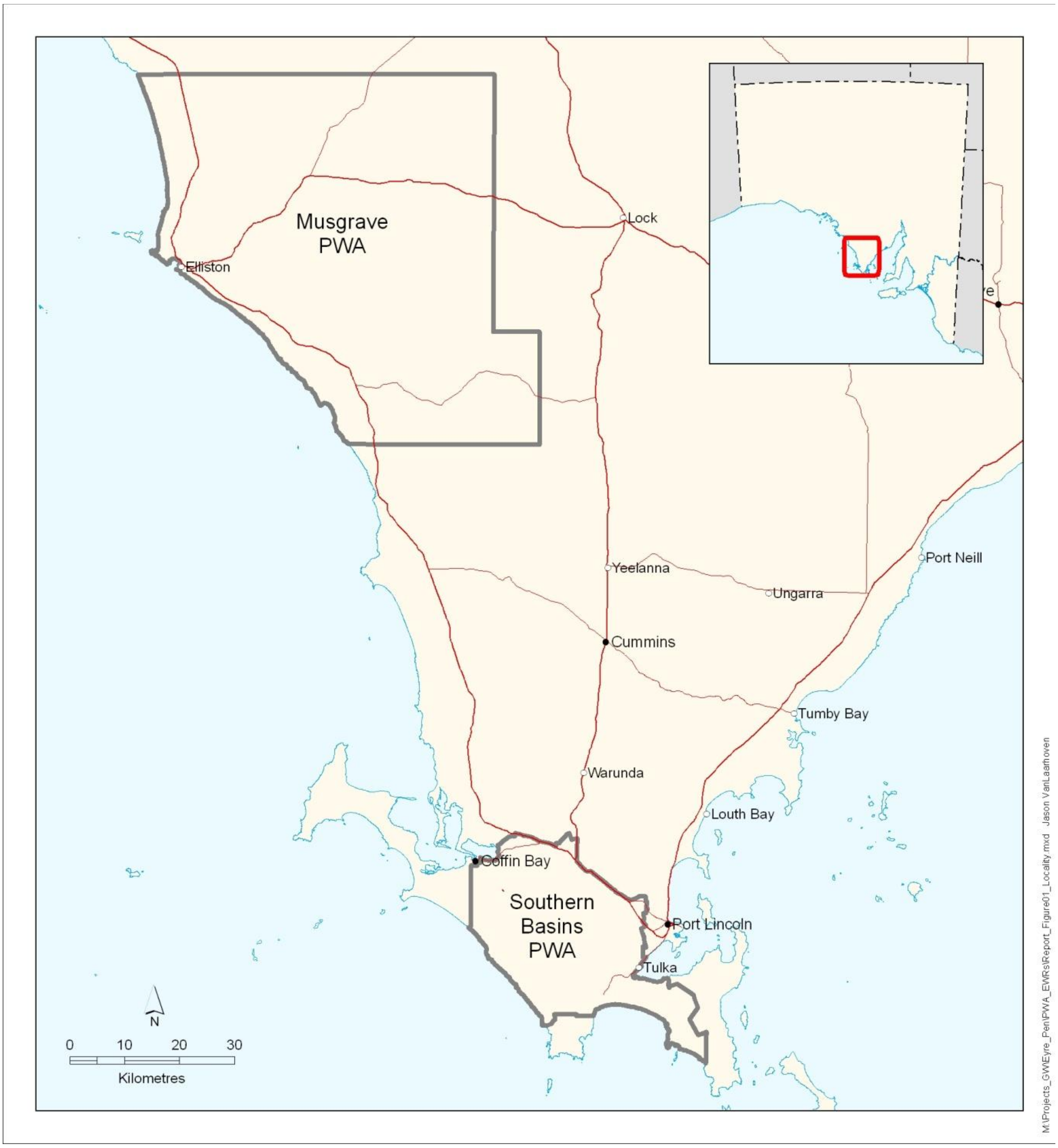


Figure 1. Musgrave and Southern Basins PWAs on Eyre Peninsula

1.2. *AIMS AND OBJECTIVES*

This project aims to document the current understanding on:

1. The distribution of groundwater dependent ecosystems within the Musgrave and Southern Basins PWAs on Eyre Peninsula
2. Their ecological values
3. Their environmental water requirements

4. Thresholds of change with respect to the relationship between groundwater regime and ecological responses.

The objective of the project is to provide EWRs for Groundwater Dependent Ecosystems located in the two Prescribed Wells Areas that can be used to inform the review of water allocation planning for the Eyre Peninsula. The information within this report will support all three Goals of the State NRM Plan (Government of South Australia, 2012) through informing a number of the guiding targets:

- Goal 1: People taking responsibility for natural resources and making informed decisions
    - Target 1: Ensure people are better informed and improve capacity in NRM decision making
- Goal 2: Sustainable management and productive use of land, water, air and sea
    - Target 5: All NRM planning and investment decisions take into account ecological, social and production considerations
    - Target 6: Maintain the productive capacity of our natural ecosystems
- Goal 3: Improved condition and resilience of natural systems
    - Target 9: Improve condition of terrestrial aquatic ecosystems.

2. METHODOLOGY

Developing techniques to estimate the environmental water requirements (EWRs) of wetlands (including groundwater dependent wetlands) has been attempted on a number of occasions (e.g. Roberts and Marston 2000, 2011; Davis *et al.* 2001; Froend *et al*. 2004; Hyde 2006). Techniques revolve about two different approaches – hydrological and ecological.

Hydrological approaches involve the provision of a particular watering regime (usually pre-development) with the assumption that the biota and ecological processes have adapted to this regime and will return to a healthy state once the regime is reinstated. Ecological techniques involve the determination of the water requirements of particular components of the ecosystem (biota or processes) that are desired end-points of management and the provision of that regime (Davis *et al*. 2001).

In the Eyre Peninsula, little is known of the pre-development state (both hydrological and ecological) so a purely hydrological determination cannot be adopted. Hence, the EWRs of Eyre Peninsula GDEs have been determined using a five-step ecological approach (Figure 2). A disadvantage of the ecological approach is the general lack of information on the water requirements of many Australian GDE biota. In the main, water requirements of some groundwater dependent biota have been determined, but mainly on the basis of observations, rather than scientific studies (Davis *et al*. 2001), so there is a large dependency on expert opinion.

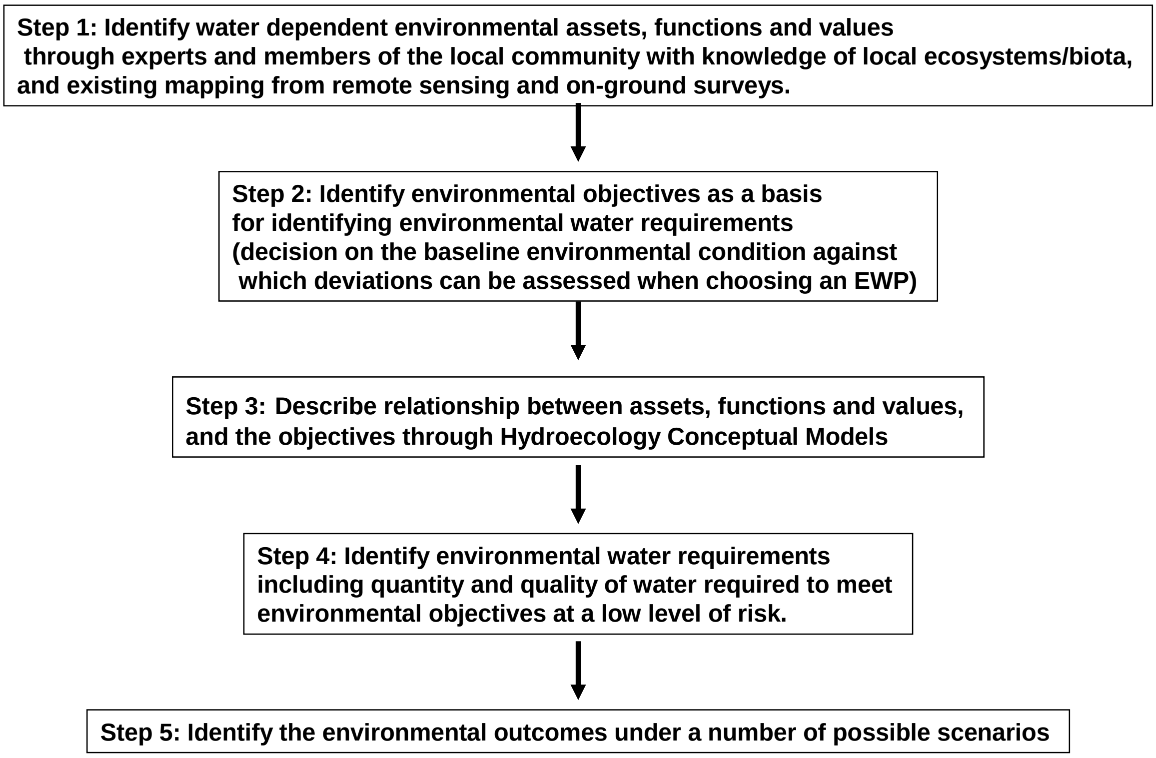


Figure 2. Process for establishing EWRs for GDEs on the Eyre Peninsula

Irrespective of the approach taken, the initial step of any technique is the collation of all relevant information on the GDEs and is the basis for the determination of appropriate EWRs. This involves the identification, classification and mapping of GDEs and describing the associated biota and ecological processes (ecological values).

Second, Ecological Objectives are set. These are not intended to be aspirational, but rather act to provide a meaningful context and baseline against which deviations from EWRs and consequential implications for aquatic ecosystem ‘condition’ can be measured. These may be on a broad spatial scale (e.g. no loss of ephemeral wetlands) or on a wetland specific scale (e.g. maintain or restore ecological values of Wetland B). They may also be on a broad biotic scale (e.g. maintain bird populations) or on a specific scale (e.g. self sustaining populations of Species A in Wetland B).

Third, the relationship between the values used in objectives and their water requirements are described. This is done partly through the construction of conceptual models (how the GDE system “works”) which are used to identify the critical characteristics of the water regime required to achieve the objectives.

The fourth stage is the determination of a water regime that will fulfil all of the objectives set for the GDE. This may involve simply “collating” all of the water requirements of individual values, or determining redundancies (e.g. the water requirements for fish may be more than for a certain plant species, so providing the regime for fish will ensure the plant objectives are met).

The final stage (before the determination of Environmental Water Provisions) is to consider the likely environmental outcomes under a range of possible future scenarios. This helps to identify how different scenarios could impact upon the achievement of the previously identified environmental objectives. Due to significant data and knowledge gaps, this step is not attempted in this report, but information on suitable approaches and assessment methods are provided.

3. IDENTIFYING GROUNDWATER DEPENDENT ECOSYSTEMS

Groundwater Dependent Ecosystems (GDEs) are defined as "natural ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their ecological processes" (EPNRMB 2010). Six main classes of GDEs have been identified (SKM 2001, 2009; Dresel *et al*. 2010), most of which are known to occur in the Musgrave and Southern Basins PWAs:

- Wetlands – wetland systems that receive ephemeral, seasonal or continuous groundwater contribution, including lakes, damplands and springs. Wetland GDEs include both saline wetlands, such as Lake Newland and Sleaford Mere and freshwater-brackish systems such as Myrtle Swamp and Lake Hamilton and springs such as the Weepra Spring at Lake Newland
- Aquifers and caves – habitats below the surface of the ground that depend on groundwater. Little is known about these systems on the Eyre Peninsula although some records of stygofauna have been identified from sampling of observation bores and caves (Leijs and Mitchell 2009). Tomlinson and Boulton (2008) provide a detailed description of subsurface GDEs
- Terrestrial vegetation (phreatophytes) – deep and/or shallow rooted vegetation communities that use groundwater to meet some or all of their water requirements. Vegetation communities which may depend on groundwater can be found in Red gum woodlands (such as Polda) and tussock grasslands
- Terrestrial fauna – native animals that directly use (e.g. drinking) groundwater rather than rely on it for habitat
- Estuarine and near-shore marine ecosystems – discharge of groundwater into coastal, estuarine and near-shore marine areas. These are poorly documented on the Eyre Peninsula although locals report they were and may still be common along the coastline. In Kelledie Bay groundwater discharge is readily visible in the shallow coastal waters particularly at low tide (Saunders 2009; SKM 2009)
- River Baseflow – ephemeral or permanent streams to which there is a continuous or seasonal groundwater contribution to flow. There are no River Baseflow GDEs known in the two PWAs on the Peninsula. The Tod River, the main riverine environment, lies outside the prescribed areas and is also not believed to be supplied from groundwater sources, being fed directly "by rainfall and by surface runoff and subsurface seepage" (Semeniuk and Semeniuk 2007a).

It should be noted that throughout this report, the term "groundwater" refers to water contained in the Quaternary Bridgewater Limestone Formation and the deeper Tertiary Sands Aquifers. It does not include transient water in overlying soil strata (recharge areas), or perched systems disconnected from the regional Bridgewater Formation aquifer.

Within each broad category of GDEs, further division can be made on the basis of the degree of dependence on groundwater sources or the chemistry of the water, primarily salinity (SKM 2009). Some systems may be "obligate" groundwater dependent, where the system would be lost if groundwater was no long available in a suitable regime. Other systems are described as "facultative" groundwater dependent, where other sources of water (e.g. rainfall, runoff) can be used in the absence of adequate groundwater.

Surface water salinity has been described in a number of classification systems based on total dissolved solids, from a simple division into freshwater or saline (SKM 2009 – although no clear salinity threshold is stated between the two), to more complex systems of fresh (<1000 mg/l), Subhaline (1000-3000 mg/l), Hyposaline (3000-20 000 mg/l), Mesosaline (20,000-50,000 mg/l) and Hypersaline (>50 000 mg/l – Semeniuk and Semeniuk (2007a).

A number of studies can be used to potentially identify, classify and map GDEs of the Eyre Peninsula (Seaman 2002; Semeniuk and Semeniuk 2007a; Wainwright 2008; SKM 2009). Of these, the first three concentrated only on wetlands or river baseflow systems across the whole peninsula (not addressing terrestrial flora and fauna, estuarine and marine and subterranean systems). Only SKM (2009) looked at all potential GDEs, concentrating on the two Prescribed Wells Areas.

Seaman (2002) surveyed 32 of the larger wetlands in the Eyre Peninsula (including some outside of the study area). These were classified into six different types (Table 1). While the majority of the wetlands surveyed lay over the Quaternary Bridgewater Foundation, no attempt was made to assess the groundwater dependence of the wetlands surveyed.

Table 1. Wetland types identified by Seaman (2002)

Wetland type	Examples of Wetlands on the Eyre Peninsula
Permanent freshwater lakes (8 ha) includes large oxbow lakes	Little Swamp
Seasonal/intermittent freshwater lakes (>8 ha) floodplain lakes	Big Swamp
Permanent saline /brackish lakes	Sleaford Mere, Sheringa Lagoon, Lake Newland, Lake Wangary, Duck Lake
Seasonal/intermittent saline lakes	Pillie Lake, Pillana Swamp, Malata Complex, Lake Hamilton, Round Lake, Middle Lake, Lake Tungketta, Elliston Myrtle Swamp, Three Lakes One, Three Lakes Three, Three Lakes Four, Greenly Complex, Lake Greenly, Big Lake Malata, Samphire Flat, Driver Salt Lake, Duck Ponds, Lake Baird
Seasonal/intermittent freshwater ponds and marshes	Taddie Pool, Meadow Pool
Seasonal saline marshes	Orana Swamp, Elliston Cemetery Swamp, Elliston Hamp Lake

Semeniuk and Semeniuk (2007a) concentrated only on wetland ecosystems and divided them into a number of “consanguineous suites” or groups. According to their report:

> *In this context, consanguinity intends to convey the notion of relationship between wetlands, relationship due to a similarity of causative factors and physical setting. Thus, if there is a similarity of climate, hydrology, geology and geomorphic processes, it may be expected that a suite of similar wetlands, or consanguineous wetlands, will result.* (Semeniuk and Semeniuk 2007a, p.18).

Seven criteria were used to establish members of a particular suite:

- Wetlands should occur in reasonable proximity
- Wetlands should be similar in size and shape
- There should be a recurring pattern of similar wetland types or a spectral range of inter-related wetland types resulting from a single dynamic process
- Wetlands should have a similar stratigraphy
- Wetlands should have similar water salinity regimes
- Wetlands should have similar hydrological dynamics
- Wetlands should have similar origin (Semeniuk and Semeniuk 2007a. p. 19).

Their assessment resulted in a number of primarily geographically separated suites of wetlands. Six suites were identified in the two PWAs (Figure 3 and Figure 4). Each suite contains one or more individual wetlands that may differ in type (e.g. permanent and ephemeral), but can be assumed to have similar hydrological drivers. Semeniuk and Semeniuk (2007a) identified one or more representative sites within each suite for further examination. For simplicity, in this report, the consanguineous suites are referred to as “Wetland Groups”. Note that the wetland group that Semeniuk and Semeniuk refer to as the Coffin Bay suite has been renamed as the Pillie wetland group for the purposes of this report.

While not always conclusive, Semeniuk and Semeniuk (2007a) provide an assessment of the hydrological regime and water source for the representative within each suite, which can be used to help identify groundwater dependence.

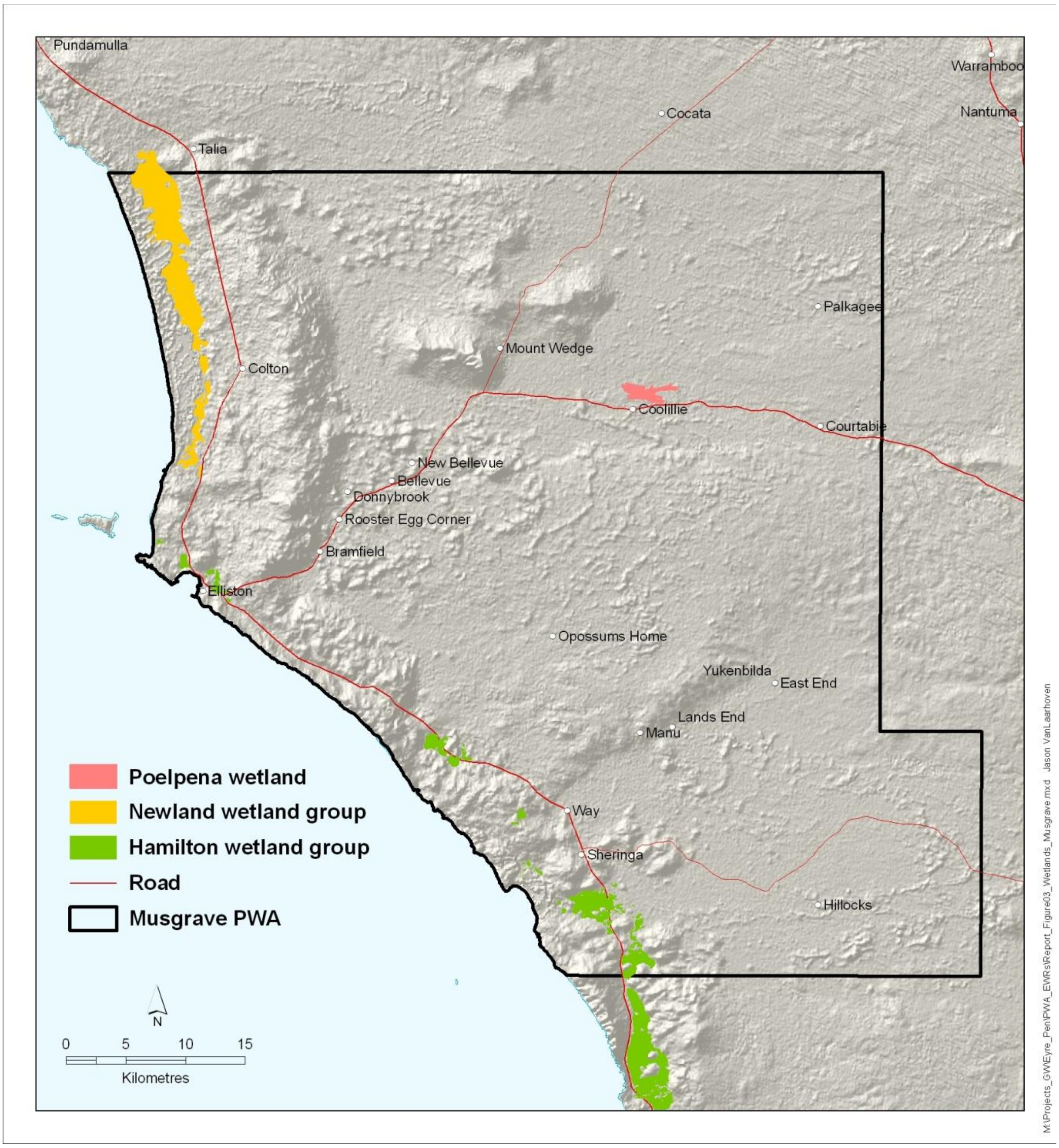


Figure 3. Musgrave PWA with Wetland Groups shown

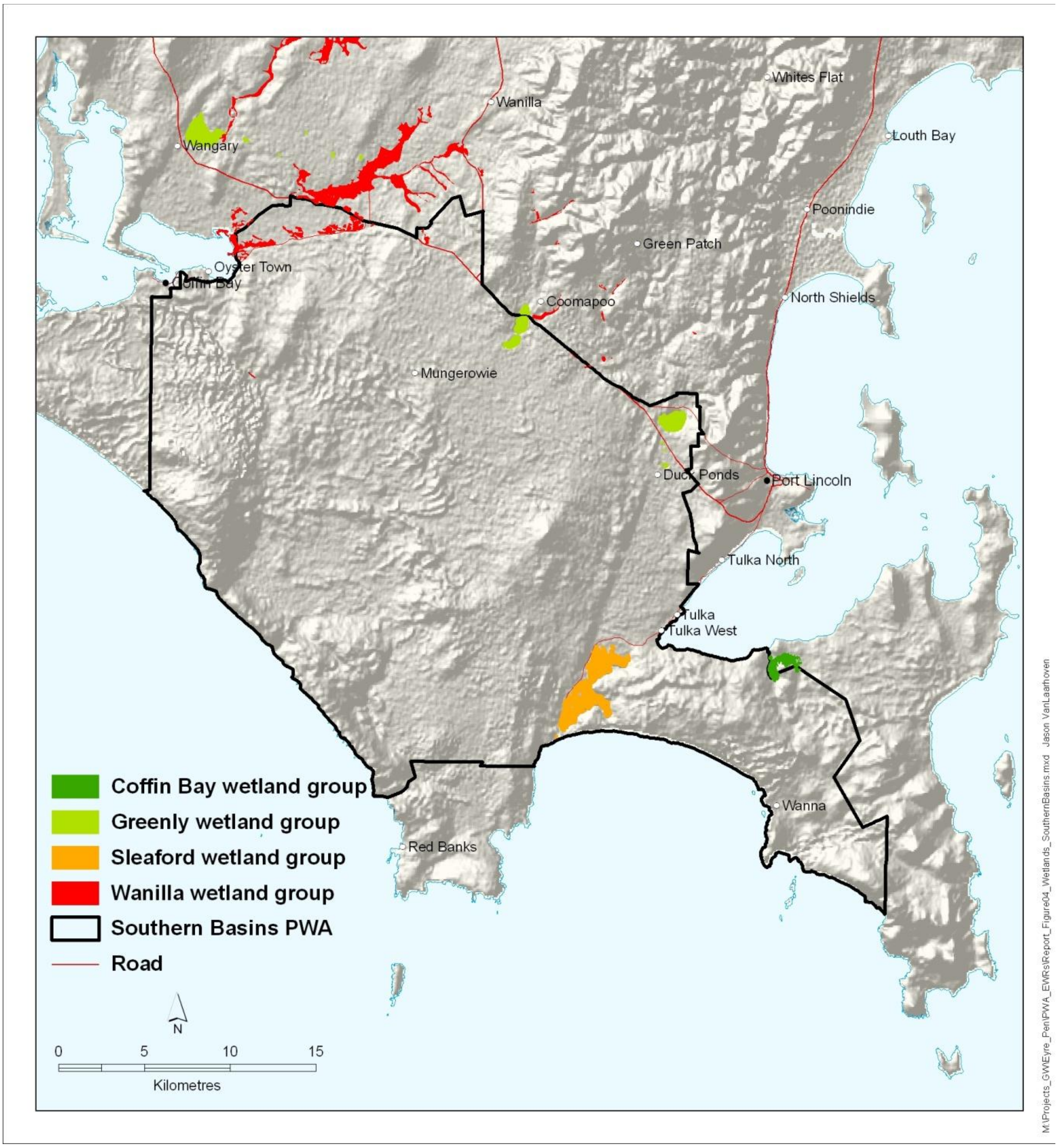


Figure 4 Southern Basins PWA with Wetland Groups shown

Wainwright (2008) used previous mapping, combined with Landsat satellite and aerial photographic imagery, vegetation mapping and field examinations to refine data on the extent, condition and persistence of wetlands across the Eyre Peninsula NRM region. Wetlands of the region were classified into eleven classes of wetland type, including riverine floodplains and subterranean karst systems. The water source of each wetland was not determined, but the comment was made that the "determination of water regime, water source, average depth when full and maximum depth when full was typically a "best guess" based on the evidence available (p. 13), leading to the conclusion that 89% of terrestrial wetlands were fed from groundwater" (p. 18).

SKM (2009) identified, classified and mapped potential GDEs in the two Prescribed Wells Areas on the Peninsula into eight groupings of GDE types:

- Saline swamps
- Saline lakes
- Freshwater lakes
- Springs (including freshwater and marine) and underground water soaks
- Hypogean, hyporheic and collapsed sinkhole ecosystems
- Phreatophytes (the term specifically refers to deep rooted plants that obtain water from the groundwater)
- Grasslands and sedgelands
- Damp coastal and sub-coastal heath.

To ascertain groundwater dependence, the mapped areas for the swamps and lakes 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" (SKM 2009, p. 40). From this, two wetlands (Little Swamp and Big Swamp) were found to be disconnected from regional groundwater systems and likely to lose water to the aquifer rather than gain water from the aquifer. That is, their water regime is not dependent on groundwater but they may be significant contributors of water to the regional groundwater system during periods of overflow. Semeniuk and Semeniuk (2007a) reports conflicting evidence that groundwater does rise to meet surface water. In light of this, water requirements for these wetlands are stated should future investigations find a level of dependence upon the Quaternary aquifer.

For phreatophytes, grasslands, sedgelands and damp coastal and sub-coastal heath, occurrences of a number of vegetation communities (e.g. red gum forests and woodlands) that were considered to be either facultative or obligate were identified. Again, regional geology, lithological logs and depth to groundwater were used to assess whether the mapped communities were likely to access the Quaternary aquifer.

In addition, a remote sensing spectral analysis (NDVI – Normalised Difference Vegetation Index) was used to identify areas where photosynthesis during summer is high. This is an indication that the plants in an area have access to water during periods when rainfall is unlikely to be a source and, hence may have access to groundwater. The analysis identified areas where potential groundwater dependent communities occurred which had high water use over the summer of 2009–10. This, however, does not discriminate between plants using regional groundwater as defined here (water contained in the Quaternary Bridgewater Limestone Formation and the deeper Tertiary Sands Aquifers) or perched rainfall (rainfall contained within the upper soil profiles by geological features). Eucalyptus forest and woodlands were considered to be the only obligate groundwater dependent vegetation community (SKM 2009).

SKM (2009) could not map the locations of all springs, soaks, hypogean, collapsed sinkhole, hyporheic ecosystems and marine discharges based on pre-existing spatial datasets. Some data on the presence of stygofauna are available (Leijs and Mitchell 2009), but this cannot be seen as a comprehensive assessment of all habitats of this kind in the study area.

In summary, the wetland systems in the PWA have been well mapped, but the dependence of some of them on groundwater resources has not been well demonstrated. For this report, it is assumed that without further evidence, all wetlands (apart from Big and Little Swamps – see Section 7.2) are dependent on groundwater and require determination of specific EWRs from this project.

The similar hydrological drivers present within each of the Wetland Groups of Semeniuk and Semeniuk (2007a) provides a convenient geographical division of wetlands for the purposes of determining EWRs.

For other GDEs which have been less well mapped, generic EWRs can be developed that can be applied to all situations where a particular class of GDE is identified.

For the purposes of determining Environmental Water Requirements, the GDEs in the study area were treated in five distinct groups:

- Wetlands (divided into Wetland Groups)
- Phreatophytes (red gum and water gum woodlands)
- Springs and underground water soaks
- Hypogean, hyporheic and collapsed sinkhole ecosystems
- Marine discharges.

4. ECOLOGICAL OBJECTIVES

Little is known about the historical composition and distribution of species that may have disappeared from the study area, so it is not feasible to describe a water regime that aims to restore conditions suitable for the re-establishment of those species. To this end, the project focuses on the hydrological regime required to maintain biota and ecosystems currently present in the region.

For the purposes of this project, the overall objective for EWRs is to propose:

> *A watering regime that will promote self-sustaining populations of groundwater dependent flora and fauna that currently exist within the area.*

A key aspect of self-sustaining populations is to promote their resilience to future disturbance and their ability to recover following disturbance. This is particularly relevant for future periods with low effective rainfall and/or recharge. Therefore:

> *The watering regime will reduce the likelihood of future degradation of assets and increase their resilience to future low rainfall periods.*

Resilience will be promoted through maintaining or increasing species population numbers, condition and spatial extent. Therefore:

> *The spatial distribution of groundwater-dependent flora and fauna will be maintained or increased.*

To maximise the usefulness of this information in the decision making process, EWRs will be presented in a way that allows the likely implications of water resource management decisions to be transparently reported on with regard to associated risks or impacts to GDEs.

5. CONCEPTUAL BASIS FOR DETERMINING EWRs

5.1. *HYDROGEOLOGY*

In broad geological terms, the Eyre Peninsula consists of pre-Cambrian basement rock (Hutchinson Group and Sleaford Complex) overlain by layers of Tertiary Sands (Wanilla Formation in the Uley and Lincoln basins and Poelpena Formation in the Musgrave PWA) and Quaternary Limestone (Bridgewater Formation) (Figure 5). These layers vary in thickness, depending on the formation of the basement rock, being thinner over basement highs and thicker in basement troughs (SKM 2009). In some areas of the PWAs, a clay layer aquitard (Uley Formation) lies between the Tertiary Sands and Quaternary Limestone, which acts as a near-impermeable barrier between the two aquifers. There is also a high-salinity Jurassic aquifer (Polda Formation) located within the Musgrave PWA. A comprehensive description of the hydrogeology of the PWAs is detailed in Stewart et al. (2012).

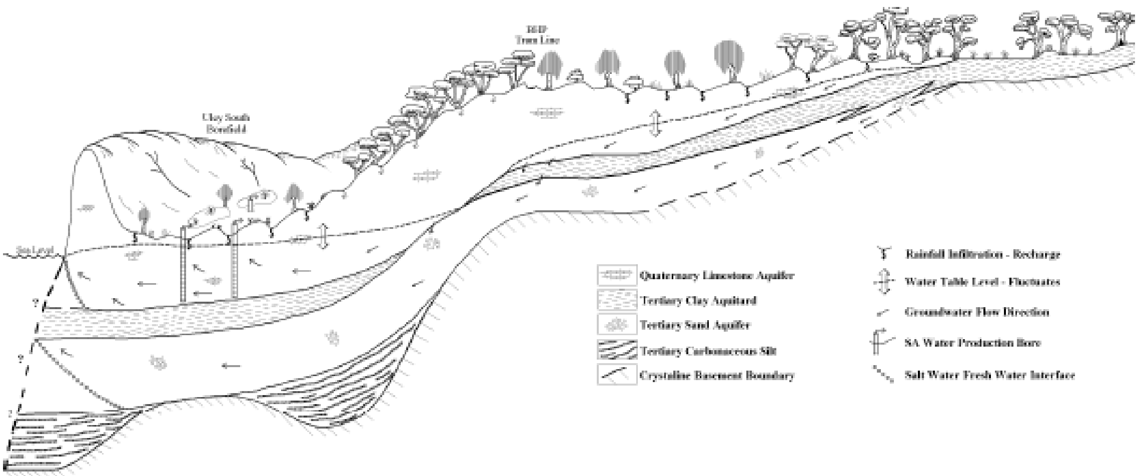


Figure 5. Typical model of main geological layers in the Eyre Peninsula (from ERWRPC 2000)

The Quaternary Limestone unconfined aquifer and to a lesser degree the Tertiary Sand aquifers form the major sources of water for domestic and irrigation use on Eyre Peninsula. Groundwater contained in the Quaternary Limestone aquifer is primarily recharged through the direct infiltration of rainfall (Evans *et al*. 2009a). The thin layer of soil and the presence of dissolution features (sinkholes) means that rainfall rapidly infiltrates the Quaternary Limestone aquifer and surface runoff is typically short-lived (Evans *et al*. 2009a; 2009b). In the Uley Basin, part of the Southern Basins Wells Area, recharge is thought to occur when more than 10 days of greater than 10 mm of rainfall falls between the months of May and October (Evans *et al*. 2009a). In the Musgrave Wells PWA, recharge of the Quaternary Limestone aquifer occurs when rainfall exceeds 60 mm/month during May to October (Evans *et al.* 2009b). Light rainfall events are rapidly evaporated and recharge is likely to be low

Movement of water through the aquifers leads to regular seasonal rises and falls in groundwater level related to the seasonal patterns of rainfall. This seasonality and changes in the depth of the watertable has implications for the hydro-ecology of GDEs on the peninsula. It is likely that the rate of recharge is a primary driver of groundwater availability for GDEs over time.

For groundwater-dependent systems, the hydro-ecology (and therefore the description of water requirements) is determined by one or more of four major characteristics of the groundwater regime (Froend *et al*. 2004):

- Level - the depth below the ground surface of the watertable (includes frequency, duration and seasonality of different levels)
- Flux - the rate of groundwater discharge or movement
- Pressure - the potentiometric head of the aquifer and its expression in groundwater discharge areas
- Quality - the chemical quality of groundwater.

There are often little or no data on the flux or pressure of groundwater resources in the Eyre Peninsula, so the water requirements of GDEs are necessarily determined based on water levels and salinities.

5.2. HYDRO-ECOLOGY

5.2.1. WETLANDS

Groundwater levels below wetlands naturally vary seasonally, being closer to the surface during the wetter months over winter and spring and declining to deeper levels in the drier summer and autumn. It is assumed here that the relationship between the wetland and the regional groundwater level determines the hydrological regime of the particular wetland and that the wetland gains water from the groundwater system.

The alternative is that the wetlands are ponding surface runoff from rainfall that is destined to evaporate or recharge the underlying aquifer. In this case, the wetlands may be losing water to groundwater. At this stage, there is no conclusive evidence either way for the majority of the wetlands in the PWAs.

Assuming that the other wetlands gain water from the regional groundwater, it can be reasoned that the relationship between the basin profile of the wetland itself (deep or shallow) and the minimum and maximum depths to groundwater will determine the frequency and duration of any surface water present in the wetland (see Figure 6 to Figure 8 below).

These differences in basin profile between the different regime wetlands can be relatively small. Cross-sections provided in Semeniuk and Semeniuk (2007a) show many of the wetlands have height differences of only a metre or so between the deepest point and the fringing vegetation zone. That is, small changes in groundwater levels can result in large changes in surface water regime (Hatton and Evans 1998). As a result of their relatively shallow depth, wetlands are vulnerable to relatively small changes in groundwater level that may not significantly affect other users.

The biotic assemblages in and around the wetland are determined by the presence and persistence of surface water, as well as the water chemistry (e.g. salinity). By far the most available data on biota in the two PWAs is that of the presence or absence of particular plant species. Plants are the most well-studied biotic component of Eyre Peninsula GDEs, with relatively few studies conducted on other components such as fish, birds and aquatic macroinvertebrates. Therefore, the EWRs will be primarily determined by the water requirements for plants.

A range of plants occur in Eyre Peninsula wetlands, from those that are wholly aquatic to those that are mostly terrestrial. It needs to be noted that the majority of wetland systems on Eyre Peninsula are dominated by terrestrial vegetation species or those that are highly resilient to periods of low water availability. The aquatic species with greater water needs tend to inhabit much smaller and more vulnerable niches. This configuration of terrestrially dominated vegetation suggests that these systems are sub-optimal for the majority of aquatic species and that the more aquatic biotic components are likely to be highly vulnerable to impact due to changes in water regime, whether it be climatic, surface or groundwater driven.

A large number of plant species have been recorded on the Eyre Peninsula and it would be impractical to determine EWRs for all species found. Instead, functional groups will be used as classified by Brock and Casanova (1997) and Casanova (2011) (Table 2). These functional plant groups have been developed based on their similar hydroecological responses to water availability. This allows us to select a subset of common plant species found on the Eyre Peninsula to act as surrogates (or “umbrella” species *sensu* Eamus and Froend 2006) for each functional group when determining EWRs. It is assumed that providing an adequate water regime for these taxa will adequately provide for other less common taxa in the same functional group.

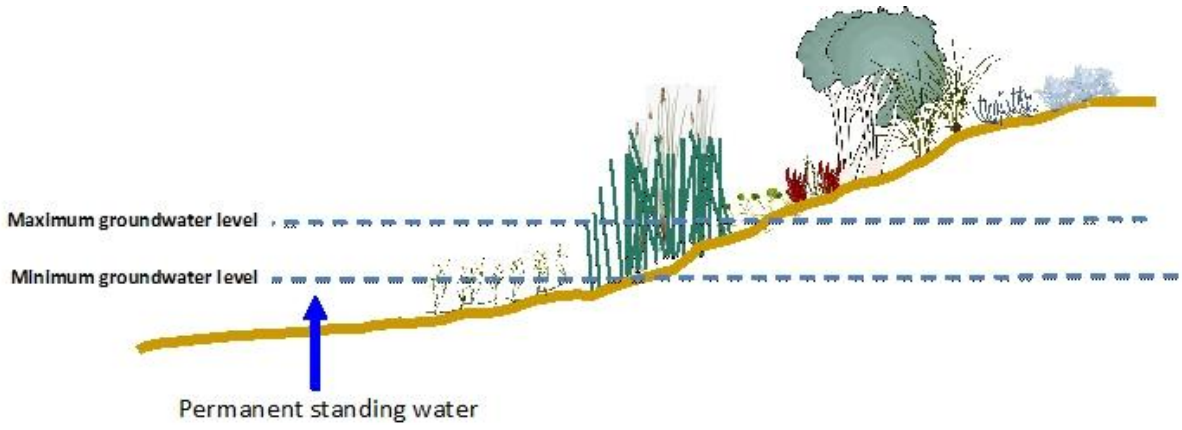


Figure 6. Deeper basin profile compared to the variation in watertable depth leading to permanent or persistent water in wetland over summer

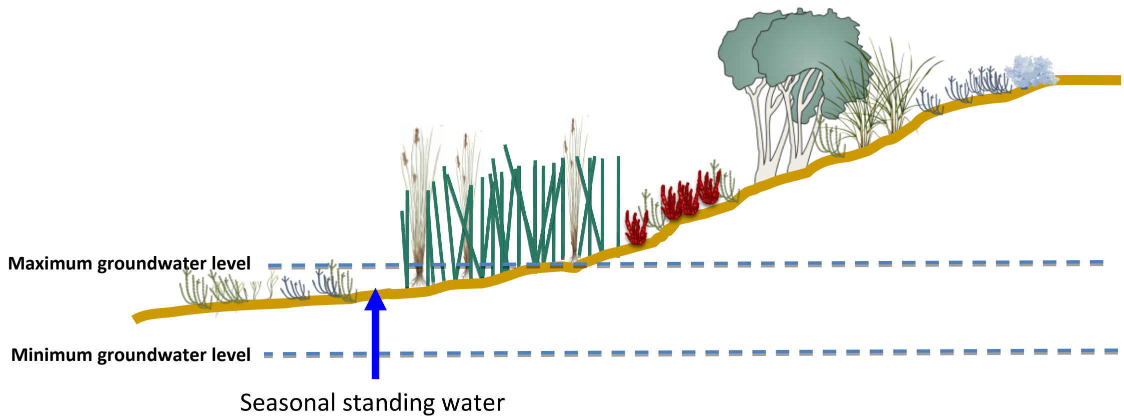


Figure 7. Shallow basin profile compared to the variation in watertable depth leading to a seasonal water regime, potentially drying over summer

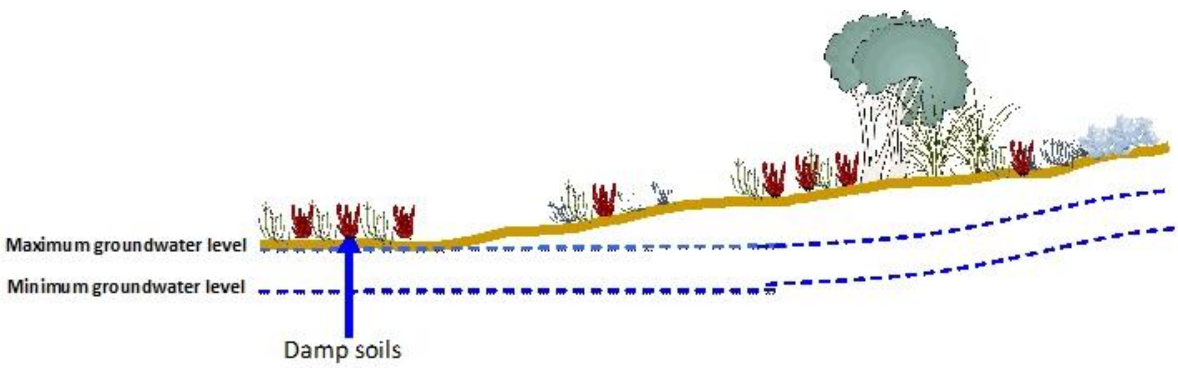


Figure 8. Shallow basin profile compared to the variation in watertable depth leading to little or no surface water over winter or summer, but periods of saturation (damplands)

Table 2. Plant functional groups with examples of water dependent taxa found in the PWAs on the Eyre Peninsula (adapted from Brock and Casanova 1997, Nicol *et al*. 2010 and Casanova 2011).

Functional Group	Code	Water Regime Preference	Eyre Peninsula Examples
Terrestrial dry	Tdr	Will not tolerate inundation and tolerates low soil moisture for extended periods.	Not considered to be GDEs in Eyre Peninsula
Terrestrial damp	Tda	Germinate and establish on saturated or damp ground, but cannot tolerate flooding in the vegetative state. Require high soil moisture throughout their life cycle.	*Wilsonia backhousei* *Wilsonia humilis*
Floodplain	Fp	Temporary inundation, plants germinate on newly exposed soil after flooding but not in response to rainfall.	Not considered relevant for Eyre Peninsula. Phreatophytes covered separately (see Section 5.2.2)
Amphibious fluctuation tolerator-emergent	ATe	Survive in saturated soil or shallow water but require most of their photosynthetic parts to remain above the water. They tolerate fluctuations in the depth of water, as well as water presence. They need water to be present for c. 8–10 months of the year and the dry time to be in the cooler times of the year	*Gahnia trifida* *Baumea juncea* *Sarcocornia quinqueflora* *Tecticornia pruinosa* *Triglochin striatum*
Amphibious fluctuation tolerator-woody	ATw	Require water to be present in the root zone all year round, but will germinate in shallow water or on a drying profile.	*Melaleuca halmaturorum*
Amphibious fluctuation tolerator-low growing	ATl	Germinate either on saturated soil or under water and grow totally submerged, as long as they are exposed to air by the time they start to flower and set seed. They require shallow flooding for c. 3 months.	None observed or recorded for Eyre Peninsula GDEs (Barker *et al*. 2005)
Amphibious fluctuation responder-plastic	ATp	Similar zone to the ATl group, except that they have a morphological response to water level changes such as rapid shoot elongation or a change in leaf type.	*Hydrocotyle* spp.
Amphibious fluctuation responder– floating	ATf	Grow underwater or float on the surface of the water or have floating leaves. They require the year-round presence of free water, but many can survive and complete their life cycle stranded on mud.	None observed or recorded for Eyre Peninsula GDEs (Barker *et al.* 2005).
Emergent	Se	Require permanent water in the root zone, but remain emergent.	*Phragmites australis*
Submergent k-selected	Sk	Require a site be flooded to >100 mm for at least six months for them to either germinate or reach sufficient biomass to start reproducing sexually. Many have asexual reproduction (fragmentation, rhizomes and turions).	*Ruppia megacarpa*
Submergent r-selected	Sr	Inhabit temporary waters with their habitats flooded from once a year to once a decade, to a depth >100 mm. Many require drying to stimulate high germination percentages and they frequently complete their life cycle quickly and die off naturally. They persist via a dormant, long-lived bank of seeds or spores in the soil.	*Chara* spp., *Ruppia tuberosa*

The classification of functional groups can be visualised as a theoretical zonation of plant communities along a transect in a permanent wetland (Figure 9) or as a relationship between the duration of inundation and the depth of inundation (Figure 10). Terrestrial Damp taxa (e.g. *Wilsonia backhousei*) are typically found higher on the banks of the wetland, above the high water mark. Only in exceptionally wet years will the water inundate that zone and then only for a short time. However, the plants there depend in part on the saturated soil beneath as a source of water.

Further down gradient, amphibious species (e.g. *Gahnia trifida*, *Melaleuca halmaturorum*) are more regularly flooded by increased wetland depth, but remain out of the water for the majority of the time. Again, the plants there depend on the saturated soil beneath as a source of water between inundation periods.

At the edge of the basin or creek, where soils remain permanently wet and inundation is common, emergent species (e.g. *Phragmites australis*, *Juncus*) can form a narrow to wide band, depending on the slope of the wetland shore, which determines the width of the band between the minimum and maximum water marks.

In the basin itself, where surface water is permanent, Floating and k-selected submergent species can be found (e.g. *Ruppia megacarpa*). If the water regime is temporary, submergent r-selected species replace the k-selected species (e.g. *Chara* and *Ruppia tuberosa*).

Therefore, the critical components of the water regime for wetlands are the:

- difference between the minimum and maximum levels of the watertable (determines the persistence of water and the functional groups present)
- frequency and duration of water levels that intersect with the wetland surface (determines the regularity of surface water and the time for evaporation to reduce surface water levels)
- water chemistry (particularly salinity).

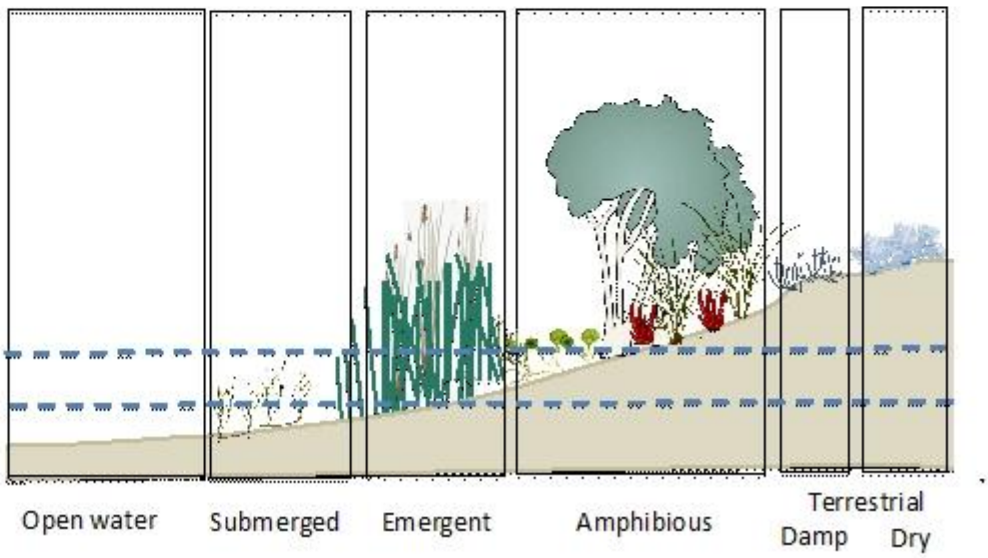


Figure 9. Typical zonation pattern of a permanent wetland

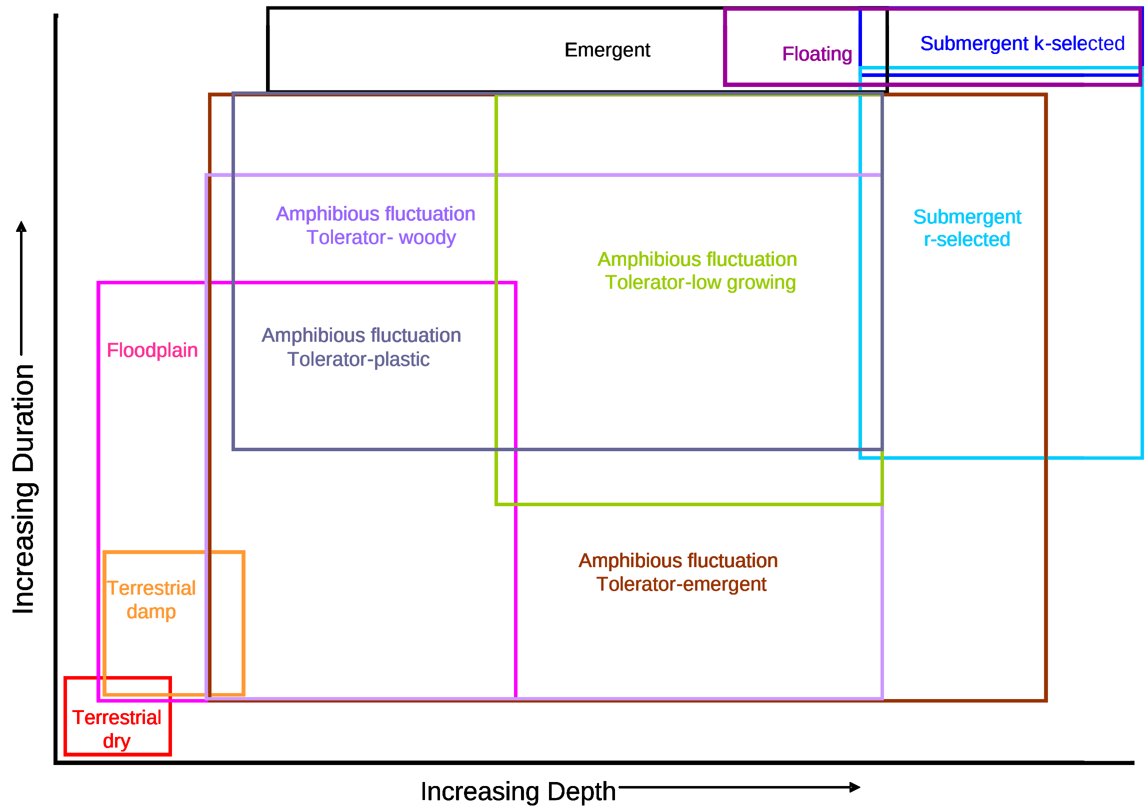


Figure 10. Plant functional groups in relation to depth and duration of inundation (from Nicol *et al.* 2010)

5.2.2. PHREATOPHYTES

Phreatophytes are deep rooted plants that obtain water from the groundwater (or some other permanent ground supply). In the study area, Eucalyptus forest and woodlands are considered to be the only obligate groundwater dependent vegetation community (SKM 2009). Phreatophytic eucalypts include *Eucalyptus camalduensis* (red gums) and *E. petiolaris* (Eyre Peninsula blue gum or water gums). *E. petiolaris* only occurs on the Eyre Peninsula (Brooker and Kleinig 2001) and very little is known about its ecophysiology. Given this, for the purposes of this report it is assumed to have similar water requirements to *E. camaldulensis*.

These tree communities access groundwater using deep root systems (Figure 11). Red gum roots use water in the unsaturated soil layers. They are not able to withstand long periods of soil anoxia caused by permanent waterlogging of the roots (Marcar 1993; Gehrig 2010). As such, red gum roots will not grow into the permanently wet (saturated) soil below the minimum groundwater level (Kienzle and Schulze 1992). Instead, their lateral roots grow in the surface subsoil that receives water from above (rainfall and dew) and their sinker roots grow in the unsaturated soils above the groundwater table that receive groundwater through capillary rise (Jolly and Walker 1996; Mensforth *et al*. 1994; Holland *et al*. 2006; Gehrig 2010; BenDavid-Novak and Schick 1997; Lubczynski 2009).

The typical water use requirements of red gums (Roberts and Marston 2011) are greater than that provided by average annual rainfall on Eyre Peninsula and thus their survival is dependent on additional water supplies (e.g. catchment run-off after summer storms or regional groundwater).

Their root structure allows red gums (and presumably water gums) to switch water sources depending on relative availability. It is likely that the trees become more dependent on groundwater during long periods of low rainfall and their long-term persistence will depend on reliable and accessible groundwater sources (Eamus *et al*. 2006b). If groundwater levels drop below the reach of the deeper sinker roots then the trees may show signs of dieback (e.g. shedding leaves and branches, Merchant *et al*. 2007) or may perish altogether.

In very wet years, rainfall can pond on the surface for days to weeks before it recharges the groundwater, but this is uncommon, occurring perhaps every 20 to 30 years (R. Coventry, EPNRMB, pers. comm.). Watercourse flooding is typically the trigger for recruitment in floodplain environments such as the Murray-Darling Basin (Roberts and Marston 2011), but the Eyre Peninsula red gum and water gum stands do not generally occur on defined watercourses and thus these flow events are not available to them. Therefore, it may be that the infrequent periods when rainfall ponds for extended periods are the key times for red gum recruitment. This hypothesis requires further investigation.

The critical components of the water regime for eucalypt phreatophytes are the:

- Frequency and duration of water levels that intersect with the root zone (determines the frequency and duration that the vegetation can access water through the roots and the duration that roots are inundated).

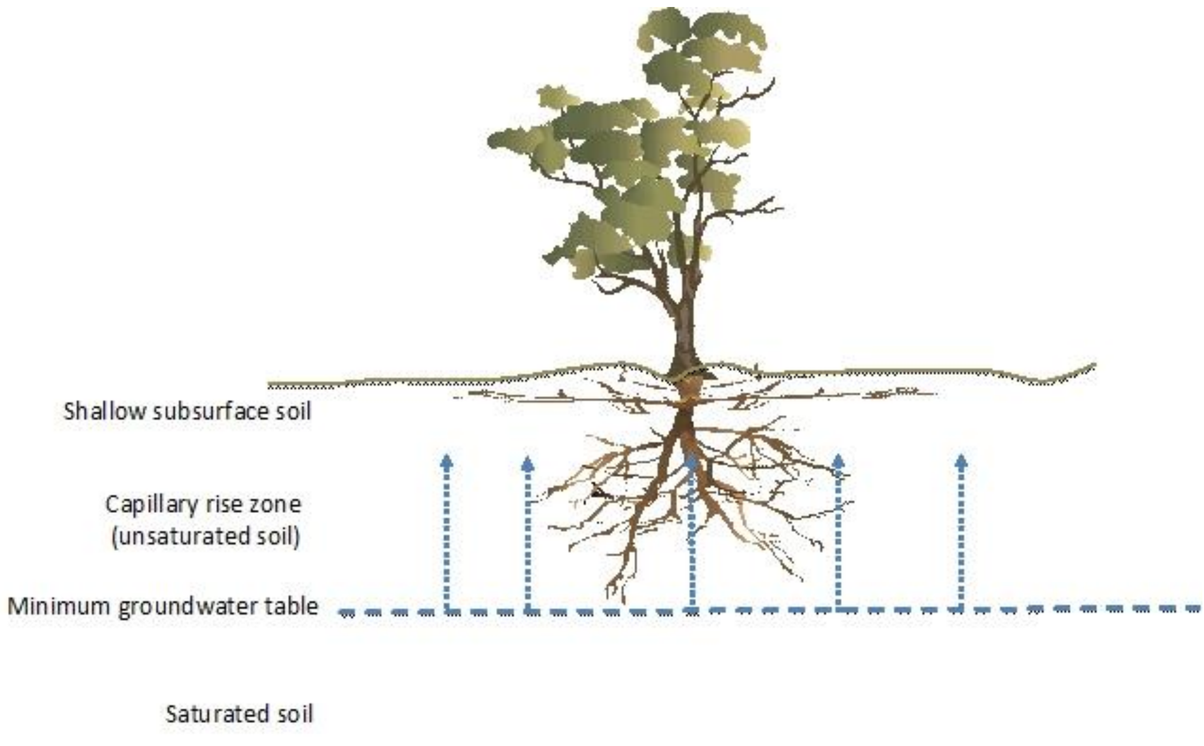


Figure 11. Groundwater level determines availability of water to the root system

5.2.3. SPRINGS

Springs are surface water expressions of groundwater and occur where the groundwater intersects with the surface and the pressure of the groundwater is sufficient to move water onto the surface. Therefore, they only occur where and when the groundwater table rises to the surface. Springs may be permanent where the groundwater is in constant contact with the surface, leading to the availability of permanent water, or may only be temporary when the watertable may drop and cease the surface flows. While springs may be permanent, the distance that the expressed water travels before it is recharged to the ground (and therefore the area affected by the springs) is a function of the flux and pressure of the groundwater (determining the discharge rate) and the porosity of the downslope soils (determining the rate of loss back into the ground).

Therefore, the critical components of the water regime for springs are the:

- Difference between the minimum and maximum levels of the watertable (determines the frequency and duration that the springs are active)
- Flux and Pressure (determines the rate that groundwater is expressed).

5.2.4. HYPOGEAN AND HYPORHEIC ECOSYSTEMS

There is a continuum of habitats from surface to groundwater environments. Some organisms will take refuge underground during dry conditions, whereas other organisms are obligate cave or aquifer biota. Hypogean and hyporheic ecosystems occur beneath the surface of the ground in saturated pore spaces, in cracks or fractures in consolidated material, or in caves formed below the surface. Hyporheic systems generally occur closer to the surface where there can be mixing of surface and groundwater, while hypogean systems occur deeper in the ground. These provide habitat for a diverse group of micro-organisms and minute invertebrates (Tomlinson and Boulton 2008) and even fish species can be found in underground caves (Romero 2001). The biota of these systems are obligate groundwater users that are isolated by physical and hydrological barriers to migration.

Therefore, the critical components of the water regime for hypogean and hyporheic systems is the difference between the minimum and maximum levels of the watertable. This determines the amount of available habitat, particularly in cave systems.

5.2.5. MARINE DISCHARGES

Like springs, marine discharges are surface water expressions of groundwater that occur under the ocean or near-shore marine environment. These can only occur where the terrestrial groundwater intersects with the marine bed and the pressure of the groundwater is sufficient to discharge water against the head of the seawater above it (Figure 12). The introduction of fresher water (depending on the salinity of the groundwater) into the marine environment creates a patch of habitat with different water chemistry to the surrounding areas and therefore can lead to a distinct biotic community adapted to that chemical regime (Kohout and Kolipinski 1967, cited in Simmons 1992). Alternatively, the fresh groundwater may prevent seawater contained in reverse estuaries reaching hypersaline concentrations as would occur due to evapotranspiration without freshwater inputs which is thought to be the case in Kelledie Bay (Saunders, pers. comm.).

Therefore, the critical components of the water regime for marine discharges are the:

- difference between the minimum and maximum levels of the watertable (determines the intersect with the marine system)
- pressure (determines whether groundwater can exceed the head of the seawater above it).

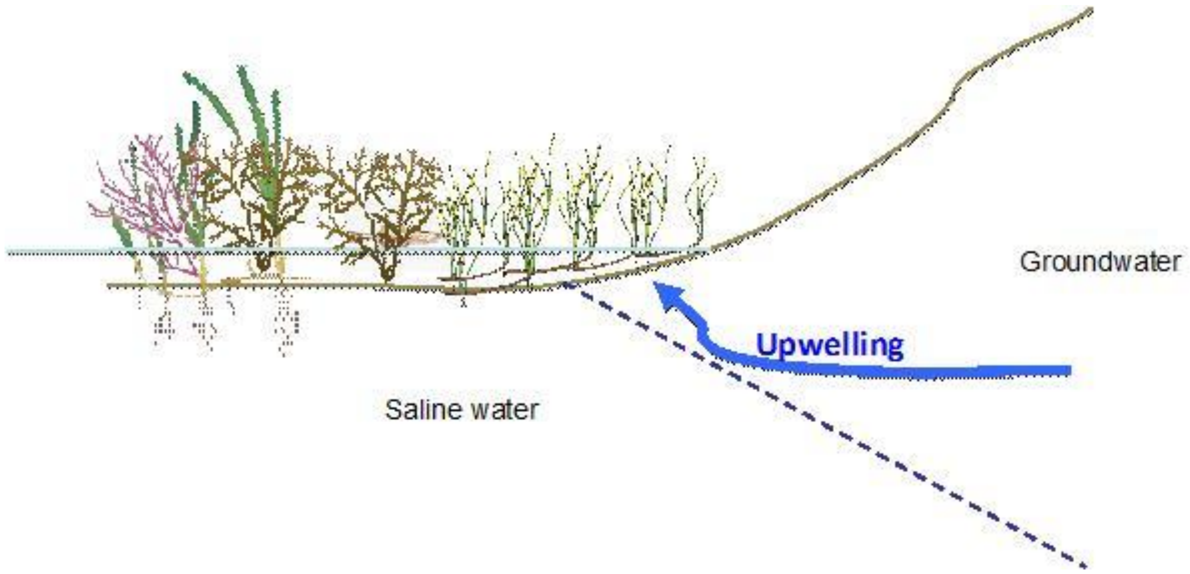


Figure 12. Schematic diagram of a marine discharge

6. ENVIRONMENTAL WATER REQUIREMENTS

In determining Environmental Water Requirements for environmental assets, a distinction needs to be made between "tolerances", "preferences" and "requirements". Tolerances represent the upper and lower bounds of some environmental condition (e.g. water depth, salinity) that beyond which, the asset will decline in health and reproductive ability such that, if maintained beyond those bounds, the asset can be expected to decline to extinction. Preferences represents the range of environmental conditions where the asset can be expected to survive into the future, but with a variable level of health or reproductive ability and a variable chance of extinction through random events. Requirements represent either the environmental conditions that supports the health and reproductive ability of the asset at a low level of risk, minimising the risk of future extinction, or particular environmental conditions that are essential for the completion of a particular stage of the life cycle.

This can be visualised in Figure 13 where the health of the asset can be mapped against the range of some environmental variable. Outside of the tolerance limits, the health of the asset is effectively zero, so that the asset can be expected to be lost if those conditions are maintained. Between the tolerance limits, the preference range allows the asset to continue, but at variable levels of health. The requirement range will support asset health at a level that will allow it to persist with a low level of risk of degrading to an unhealthy state (as in the environmental objective for the EWRs).

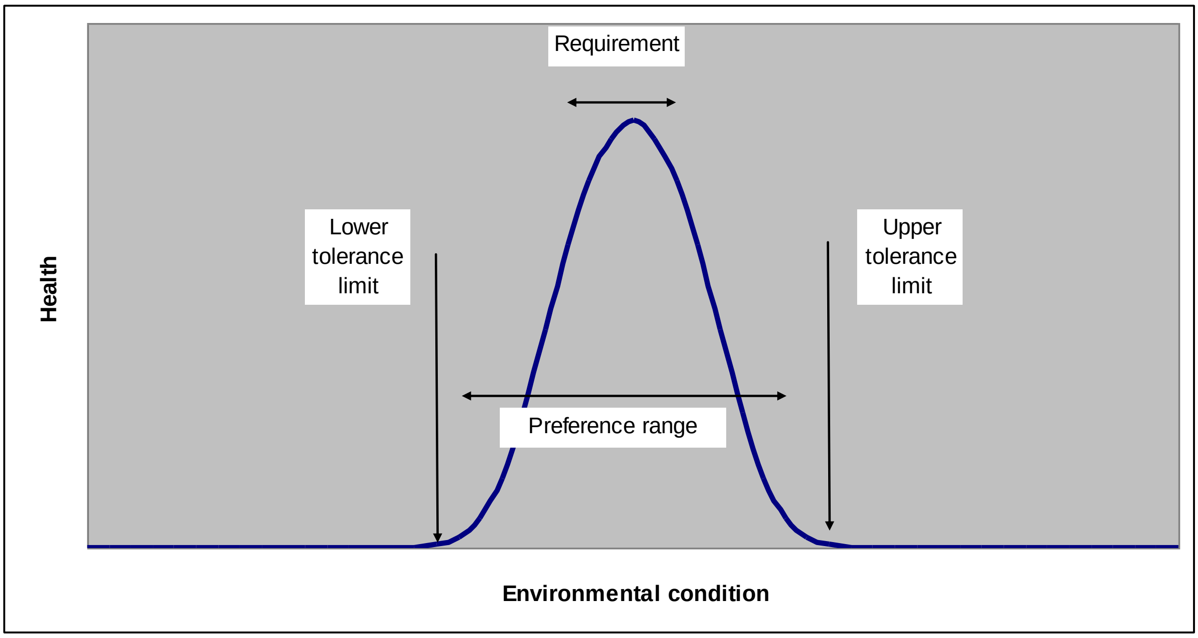


Figure 13. Conceptual model of health against the range of an environmental variable

The environmental condition may represent a variety of environmental variables such as water depth, duration of flooding, duration of drying, frequency of inundation or salinity levels. Different species may have different ranges of tolerances, preferences and requirements for the same variable. The Environmental Water Requirements outlined below represent the best estimate of the conditions that will maximise the health, reproductive capacity and resilience of species found in the Eyre Peninsula GDEs.

6.1. EWRs OF WETLANDS

From the information gained from surveys of wetlands and observations during field inspections, a number of common or widespread plant taxa were identified across the study area, or species that are restricted to particular habitats within the study area. These were selected as the surrogate taxa for particular functional groups (Table 2) and are shown in Table 3. Providing for the water requirements of these species is assumed to provide an adequate regime for other, less common species within the same functional group.

Table 3. Taxa used as surrogates for different functional groups of wetland plants (Codes from Casanova 2011)

Taxa/taxon	Functional group	Rationale for selection
Wilsonia backhousei	Terrestrial damp (Tda)	Indicative of the highest elevation that retains damp soil.
Melaleuca halmaturorum	Amphibious fluctuation tolerator woody (ATw)	Dominant tree species. Decline suggests change from wetland to terrestrial.
Gahnia trifida	Amphibious fluctuation tolerator emergent (ATe)	Indicates periodic waterlogging in the root zone (surface to ~3 m)
Baumea juncea	Amphibious fluctuation tolerator emergent (ATe)	Most sensitive of the emergent plants to water source variations.
Samphires	Amphibious fluctuation tolerator emergent (ATe)	Dominant shrub species. Only vegetation in most saline wetlands. Indicative of wet, saline areas. Decline suggests change from wetland to terrestrial.
Triglochin striatum	Amphibious fluctuation tolerator emergent (ATe)	Indicative of permanently damp brackish areas.
Hydrocotyle spp.	Amphibious fluctuation responder plastic (ARp)	Desiccation and salt intolerant. Indicative of fresher and permanently wet habitats (e.g. springs at Sleaford Mere).
Phragmites spp.	Emergent (Se)	Indicative of fresher and permanently wet or damp habitats (e.g. Merintha Creek).
Ruppia tuberosa	Submerged r-selected (Sr)	Indicative of periodic inundation. Significant food resource for birds and other fauna.
Chara spp.	Submerged r-selected (Sr)	Indicative of periodic inundation. Significant food resource for birds and other fauna.

The EWRs for the surrogate plant taxa were derived from available literature (e.g. Roberts and Marston 2000, 2011; Davis *et al*. 2001; Froend *et al*. 2004) or from expert opinion sourced at a workshop held in Adelaide on 9–10 August 2011 (see Appendix A). Most of the literature sources were based on plant requirements in floodplain environments that experience periods of overland flows and often have requirements for depth, frequency and duration of flooding regimes. Surface flooding flows such as these are rare in the study area, so a large degree of expert opinion was needed to transfer any published data to the Eyre Peninsula situation.

Relevant experts in hydrology, hydrogeology, geomorphology and ecology attended the August workshop and used a multidisciplinary approach to evaluate available life-history, habitat types and water requirement data for the study region. The panel used their professional and local knowledge and experience to determine water requirements for various plant species identified. Where possible, thresholds or ranges for EWRs were also determined.

All the wetland GDEs showed the typical zonation of plant types along the elevation gradient (Figure 9). This zonation is common in other Australian wetlands, including saltmarshes (Laegdsgaard 2006):

> *The zones can be described as lower, mid and upper levels, usually each with a distinct mosaic of species that is often complicated by small-scale patchiness. Succulents dominate the lower marsh (e.g. Sarcocornia spp.), while the mid-marsh usually contains species such as Sporobolus spp. and Samolus spp. The upper marsh is a mosaic of species including Juncus kraussii and Baumea juncea. The area behind the upper marsh is filled with terrestrial vegetation such as eucalypts, melaleucas and casuarinas.*

Whether a particular zone is present at a particular wetland depends on the persistence and depth of water in the wetland. While some species in each zone may partially utilise rainwater as a source, with predicted reductions in future rainfall (Green *et al.* 2011) species will become increasingly reliant on groundwater as a source, or the location of the zone may change position in the landscape, moving to where the hydrological regime is more suitable.

6.1.1. EWRs OF FLORA TAXA

A consistent component of the vegetation zonation in the PWAs (irrespective of the persistence of surface water) is the presence of fringing vegetation composed primarily of Amphibious species. These lie above the regular high water mark on the exposed slopes of permanent wetlands (Figure 9), but are also found in seasonal and ephemeral wetlands where the groundwater level is high enough to provide for a source of water to the root system.

Across the PWAs, the zone of Amphibious species commonly consist of bands of *Baumea* species (usually *B. juncea*), *Melaleuca halmaturorum* and *Gahnia* species (usually *G. trifida* or *G. filum*). *Baumea* is found closest to the wetland basin, with *M. halmaturorum* and *Gahnia* in bands found with increasing distance from the wetland edge. Other species may be present in the fringing vegetation, but those three groups seem to be consistently present.

Submerged and emergent vegetation may or may not be present depending on the persistence of water in the wetland and the degree of saturation of the soils in this zone or the salinity (see section 8.2). Where these occur, bands or patches of Samphires can be found extending across the basin, particularly in the more seasonal wetlands.

Environmental Water Requirements for the surrogate taxa used in this study are shown in Table 4.

The consistent presence of *Baumea*, *Melaleuca halmaturorum* and *Gahnia* at wetlands across the PWAs allows us to set a broad scale initial EWR for wetlands with fringing zonation:

- The groundwater table needs to be maintained within 1 m of the *Baumea* zone for at least three months of the year (at any time)
- The groundwater table needs to be maintained within 2–3 m of the *Melaleuca halmaturorum* zone for at least three months of the year (at any time)
- The groundwater table needs to be maintained within 3–4 m of the *Gahnia* zone for at least two months of the year (at any time)

- Over spring (one in three years), the groundwater table needs to be maintained within 250 mm[1] of the *Baumea* zone for a period of at least three months
- Over spring (one in 10 years), the groundwater table needs to be maintained within 250 mm of the *Melaleuca* zone for a period of at least three months

The broad water requirements above can be modified for individual wetlands or wetland groups by the presence of emergent or submerged taxa (see Section 7)

6.1.2. EWRs BASED ON PERSISTENCE OF WATER

The relationship between the location of the fringing vegetation zone and the broad hydrological regime classification (permanent, seasonal, ephemeral) of the wetland (Figures 6 to 8), suggests that by maintaining the condition and particularly the location of the fringing vegetation zonation (expressed as a required depth to the groundwater in summer and winter), will also provide an adequate regime to maintain the remaining water dependent biota.

6.1.2.1. Permanent Wetlands

For permanent wetlands (Figure 6), such as Sleaford Mere and Lake Newland, the summer groundwater level needs to intersect with the shore of the wetland (or not be below the deepest point of the wetland for long enough to allow evaporation to dry the wetland and increase salinity to above tolerance levels). An adequate depth of water to support fish (e.g. small-mouthed hardyhead) and submerged vegetation requiring permanent water (e.g. *Chara*, *Ruppia*) is in the range of 100–200 mm continuously throughout the year. Thus for permanent wetlands, an additional EWR can be added to the generalised EWRs above:

- The groundwater table needs to maintain a depth of surface water of 100–200 mm throughout the year.

Given the shallow nature of most of the permanent wetlands, this depth would provide a large area of open water for vegetation, fish and waterbirds

6.1.2.2. Seasonal Wetlands

For seasonal wetlands (Figure 7), such as Lake Hamilton and Round Lake, the summer groundwater level does not always intersect with the shore of the wetland. The persistence of water (length of inundation) depends on the time that the wetland is connected to the summer groundwater and the evaporation rate once the water is disconnected from the groundwater. This duration of inundation varies from wetland to wetland and from year to year.

Maintaining the winter-spring groundwater levels at levels suitable for the fringing vegetation should ensure that, at the start of summer, water levels in the wetland are within a normal range. Over the summer, the wetland can then reduce in depth and volume at a natural rate. Therefore, for seasonal wetlands, the EWR for *Baumea* recruitment should ensure that water levels remain within the natural range:

- In Spring, the groundwater table needs to reach within 250 mm of the *Baumea* zone for three months.

[1] An assumption is made that when the groundwater is within 250 mm of the soil surface, the soil will remain damp and not dry out.

6.1.2.3. Ephemeral Wetlands

For damplands (Figure 8) such as Pillie Lake, the groundwater remains close to the surface through much of the year, providing for extended periods of damp soil with no surface water. In the main, the basin surface of these wetlands is relatively flat, with little variation in surface elevation across the wetland. In these wetlands, the groundwater needs to be close enough to the surface for capillary action to draw the water to the surface. Only in wet years does the water level rise above the surface. Therefore:

- The groundwater table needs to be maintained at least within 250 mm of the sediment surface of the basin throughout the year.

Table 4. Environmental Water Requirements of surrogate taxa

Taxa and Process	Functional Group	Water Level requirement (Surface or Groundwater)	Minimum Duration	Timing	Frequency	Comments/Source
Wilsonia backhousei or W. humilis	Tda	Groundwater within 250 mm of surface leading to damp soil (no surface water)	3 months	Any time	Annual	**Source:** VRO Website **Comments:** Good to High tolerance of waterlogging and seasonal and longer-term inundation over a few months (VRO website 1)
Melaleuca halmaturorum Persistence and growth	ATw	Groundwater within 2–3 m of surface based on assumed root depth	3 months	Any time	Annual	**Source:** Davis *et al*. 2001; J. Nicol, SARDI, pers. com.; Denton and Ganf 1994 **Comments:** Can persist with rainfall and surface water run-off, so not entirely dependent on groundwater. But with future declines in rainfall, may become more dependent on groundwater sources. Health of stands reduced if inundated for more than 6-9 weeks (Davis *et al*. 2001). In its juvenile stage, recovers from short floods of three weeks or less but performs poorly if floods exceed six to nine weeks (Denton and Ganf 1994)
Melaleuca halmaturorum Recruitment		Groundwater within 250 mm of surface leading to damp soil (no surface water)	3 months without drying	Spring	Once every 10–25 years	
Gahnia trifida Persistence and growth	ATe	Groundwater within 3–4 m of surface based on assumed root depth	2 months	Any time	Annual	**Source:** J. Nicol, SARDI, pers. com. **Comments:** Can persist with rainfall and surface water run-off, so not entirely dependent on groundwater. But with future declines in rainfall, may become more dependent on groundwater sources.
Baumea juncea Persistence and growth	ATe	Groundwater within 1 m of surface based on assumed root depth	3 months	Any time	Annual No rarer than once every 3 years	**Source:** Davis *et al*. 2001; J. Nicol, SARDI, pers. com. **Comments:** Range of depth occurrence ± 1 m (Davis *et al*. 2001). Recession rate no greater than 10 mm/day (J. Nicol, SARDI, pers. comm.)
Baumea juncea Recruitment		Groundwater within 250 mm of surface leading to damp soil (no surface water)	3 months	Spring – early summer (optimal)	Once every 3 years No rarer than once every 5–10 years	

Taxa and Process	Functional Group	Water Level requirement (Surface or Groundwater)	Minimum Duration	Timing	Frequency	Comments/Source
Samphires Persistence and growth	ATe	Saturated soil or surface water depth <200 mm	3–6 months	Any time	Annual No rarer than once every 2 years	**Source:** Davis *et al*. 2001; J. Nicol, SARDI, pers. com.; Laegdsgaard 2006 **Comments:** Will not germinate under water. Seed bank allows survival through dry years with no surface water. Seed bank depleted if frequency more than 1 in 10 years. *Sarcocornia* can only withstand short periods of inundation before the plants quickly rot and decompose (Adams and Bate 1994, cited in Laegdsgaard 2006).
Samphires Recruitment		Groundwater within 250 mm of surface leading to damp soil (no surface water)	3 month	Any time	1 in 3 years	
Triglochin striatum Persistence and growth	ATe	Wetland margins with damp soil to shallow water (20–100 mm)	3 months	Any time	Annual No rarer than once every 3 years	**Source:** Laegdsgaard 2006; Naidoo and Naicker 1992 **Comments:** Plants die down to underground rhizomes in dry conditions and will only flower once they are flooded (Laegdsgaard 2006). Seeds remain dormant in saline soils, germinating rapidly when salt stress reduced (Naidoo and Naicker 1992).
Triglochin striatum Recruitment		Freshening of saline soils by inundation	3 months	Spring – early summer (optimal)	Once every 2 years No rarer than once every 3-5 years	
Hydrocotyle spp.	ARp	Permanent shallow (20–100 mm) fresh water	12 months	Continuous	Annual	**Source:** J. Nicol, SARDI, pers. com. **Comments:** Very sensitive to salt intrusion and will die-off within weeks if salt inundated. Seed persistence is unknown – expert opinion suggests 5 years.
Phragmites spp. Persistence and growth	Se	Permanent shallow water (200–450 mm) or saturated soils	12 months	Continuous	Annual	**Source:** Davis *et al*. 2001; J. Nicol, SARDI, pers. com.; MFAT website; Roberts and Marston 2000, 2011 **Comments:** Rhizomes can persist over one consecutive dry summer (J. Nicol, SARDI, pers. com.). Tolerant of fluctuating water levels (Roberts and Marston 2000). No germination and seeding establishment under water. Shoot density and height and biomass greatest at depths 200–40 mm (Roberts and Marston 2011). Growth rates are highest when water levels are only a few centimetres deep (MFAT website).
Phragmites spp. recruitment		No surface water	<4 weeks inundation of seedlings	Any time	1 in 7 years	
Ruppia tuberosa	Sr	Surface water depth 20–30 mm	6 months	Any time	1 in 3 years	**Source:** Nicol 2005

Taxa and Process	Functional Group	Water Level requirement (Surface or Groundwater)	Minimum Duration	Timing	Frequency	Comments/Source
Persistence, growth and recruitment						**Comments:** Annual species, propagules bank allows survival through dry years with no surface water. Seed propagule depleted if frequency less than 1 in 10 years
Chara spp. Persistence, growth and recruitment	Sr	Surface water depth >250 mm	>16 weeks	Any time	Annual	**Source:** J. Nicol, SARDI, pers. com.; Roberts and Marston 2000 **Comments:** Dependent on surface water to grow and reproduce (Roberts and Marston 2000). Germination of oospores occurs underwater. Duration of inundation to establish 10 months for *Chara australis* (Roberts and Marston 2000). Seed persistence unknown – expert opinion suggests 5 years.

6.2. EWRs OF SPRINGS

Springs associated with the Sleaford Mere and Lake Newland need to maintain flowing water to support the associated vegetation community. Flowing water at Sleaford Mere also prevents the ingress of salty water into the seepage area which would rapidly kill off the freshwater community if allowed to ingress. The known springs in the study area are all permanent. Therefore, for spring areas:

- For the entire year, the groundwater level needs to be in direct contact with the spring source.

6.3. EWRs OF PHREATOPHYTES

The majority of the phreatophytes in the Musgrave and Southern Basins PWAs are scattered across the prescribed areas. They were identified using Normalised Difference Vegetation Index (NDVI) techniques (SKM 2009) based upon the assumption that overall soil moisture in the summer of 2009–10 was low, therefore plants with low water stress signatures at that time were likely to be accessing groundwater. NDVI is typically high where potentially groundwater dependent vegetation (obligate and facultative) communities are mapped over shallow watertables suggesting that these vegetation communities have access to groundwater. Where facultative groundwater dependent vegetation occurs over deep watertables, NDVI is typically low, suggesting that these vegetation communities do not have access to groundwater and the soil water store is low. This technique could not distinguish between plants using regional groundwater or perched rainfall.

Red gums and water gums are the only obligate groundwater dependent vegetation communities so far identified in the PWAs, which is supported by their consistent occurrence over shallow watertables that are likely to be connected to the Quaternary Bridgewater Formation aquifer (SKM 2009). A number of potentially facultative groundwater dependent vegetation community types such as *Melaleuca* forests, woodlands and shrublands, *Allocasuarina* forest and woodland, sedgelands/rushlands, Tussock grassland and coastal shrubland were identified by NDVI. In many areas they occurred over deep or perched watertables, indicating that these vegetation communities may only be dependent on groundwater in specific locations or they occur in recharge areas and intercept downward moving water.

There are, however, some inconsistencies between NDVI and facultative phreatophytes in the Southern Basins PWA. There are a number of factors (such as vegetation condition and density, or locations of 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. Any potentially facultative GDEs that occur over deep watertables have been removed from the GDE spatial dataset used here.

The trees we commonly refer to as red gums (*Eucalyptus camaldulensis*) consist of seven identified subspecies (McDonald *et al*. 2009) that are all typically found in riverine or floodplain habitats. Indeed, most research on their water needs comes from riparian or floodplain environments, or forestry (see Roberts and Marston 2011 for review). Red gums are very long-lived trees, typically living for over 100 years and possibly up to 950 years (Ogden 1978).

They are known to:

- exhibit considerable morphological differences between individual trees, provenance types and subspecies (Brooker *et al*. 2002)
- have very high rates of hydraulic conductivity through their roots (Heinrich 1990)

- switch between different water sources (Mensforth *et al*. 1994; Thorburn and Walker 1994; Overton and Doody 2007)
- transfer water from areas of high to low availability via their root system (Burgess *et al*. 1998; Eamus *et al*. 2006)
- allocate more biomass to root systems (Gibson *et al*. 1994, 1995) when water availability is poor
- avoid severe water deficit by shedding leaves, minimising transpiration and adjusting their osmotic tension (Merchant *et al*. 2007; Roberts and Marston 2011).

Mature trees can harvest water from an area up to 40 m around the tree (Dexter 1978) using their dual lateral-sinker root system. The fine lateral roots (<2 mm diameter, Jonsson *et al*. 1988; Nasra *et al*. 2005) are primarily concentrated in the upper 100 mm of the profile (Tedala 2004) and extend out from the central trunk. The sinker roots penetrate deeper into the soil (around 9 m in floodplain trees; Horner *et al*. 2009) and provide a resilient connection to deeper groundwater and a strong anchor against wind or other physical disturbances. Taproots may be damaged or stunted by localised high watertables and often, when mature trees are uprooted on the Eyre Peninsula, they show a very shallow and wide root system (Musgrave WAPCC members, pers. comm.).

Red gums roots do not possess air-carrying tissue (aerenchyma) although they are able to produce adventitious roots in response to flooding (Marcar 1993). In general, they can survive long periods of flooding or permanent watertable position (2–4 years of inundation or submergence; Chesterfield 1986; Bren 1987). They depend on water in the unsaturated soil layers, but will use water opportunistically, transpiring freely when water is available (Heinrich 1990, Holland *et al.* 2009; Gehrig 2010). The use of available water sources will be governed by factors such as the ability of an individual or species to access the water source and the reliability and quality of the water source (Stromberg and Patten 1996).

The red gums and water gums that occur in the Musgrave and Southern Basins PWAs are not riparian, that is, they are scattered and do not exclusively occur along surface water drainage lines. Therefore much of the research into environmental water needs is inappropriate for direct application. A generalized EWR could be determined by assuming that because red gums are very long-lived they are likely to use their morphological and physiological plasticity (described above) to adapt to changes in water regime over time. That is, they have the capacity to adapt to changes in the frequency, extent, timing and period of water availability. However, there will be limits to that adaptability. If these limits are breached injury or loss may result because the tree will be unable to adapt its root harvesting mechanisms to match the new water regime. Therefore, the EWR for red gums and water gums is:

- to maintain the water regime within the limits of their adaptability (as indicated by the historic groundwater regime). Further research into the water sources used by red gums and water gums within the PWAs and their ability to switch sources is needed to refine this EWR for particular stands of eucalypts (e.g. the red gums occurring near the Polda Trench).

6.4. EWRs OF HYPOGEAN AND HYPORHEIC ECOSYSTEMS

Subsurface groundwater dependent ecosystems are completely dependent on groundwater, but there are inadequate data to determine the location, environmental assets and therefore, specific EWRs for these systems.

6.5. EWRs OF MARINE DISCHARGES

Plants and animals that inhabit the zones affected by marine discharges typically differ from the surrounding marine environment (e.g. Miller and Ullman 2004) and can represent a significant and irreplaceable contribution to the biodiversity and functioning of marine embayments within which they live. Marine discharges are thought by locals to be common along the Eyre Peninsula coastline particularly in Kelledie Bay, Proper Bay (Tulka) and where the Uley South groundwater lens meets the coast (WAPCC members, pers. comm.). Of these, the discharges at Kelledie Bay are still readily observable (K. Muller, field observation, November 2011). Discharges at the other sites are less readily observable but their ecological effects can be distinguished by changes in fish communities targeted by local fishers (WAPCC members, pers. comm.).

Kelledie Bay is the most inland of the bays in the estuarine complex of Coffin Bay. No major rivers run into the Coffin Bay estuary with freshwater inputs being provided instead by several small creeks (e.g. Merintha and Minniribbie Creeks) and groundwater discharges (such as the upwelling observable in Kelledie Bay). There are strong hydrological restrictions in the bays that result in a salinity gradient from near seawater concentrations at the opening to the sea at Point Longnose to more saline concentrations closer to the land (further from the sea) except for after heavy winter rains. This suggests that the bays are acting as 'inverse' estuaries for at least part of the year. As a consequence, the salinity variation is greatest in areas closest to land where the diversity of plants and animals is least. In the case of Kelledie Bay the discharging groundwater is likely to act to keep salinities lower than otherwise expected. During winter this may still be seawater or greater concentrations due to the inverse estuarine nature of the bay (Saunders 2009).

Most notable among the flora of Coffin Bay is *Ruppia* spp., a species indicative of seawater and freshwater mixing which occurs at the mouth of Merintha Creek and in Dutton Bay. *Ruppia* spp. has declined over time and reduced in cover having previously occurred at Long Beach as well (Saunders 2009). *Triglochin striatum,* also indicative of fresher than seawater salinities, occurs near the mouth of Salt Creek (Saunders pers. comm.). A range of saltmarsh plants occur with *Sarcocornia quinqueflora* dominating the seaward edge, *S. blackiana* being less common and on the landward side, *Tecticornia halocnemoides* in areas of occasional inundation and *T. arbuscula* in areas with daily inundation up gradient to above high tide mark (Saunders 2009). Other key flora are *Melaleuca halmatuorum* (saltmarshes, limestone ledges) and *Juncus kraussii* (protected sandy shores), although *J. kraussii* is common at the base of sand dunes throughout the region and may associate with areas of rainfall collection rather than specifically occurring areas of groundwater discharge.

Overall, very little is known about the locations, extent and ecological composition of these communities on the Eyre Peninsula. Only a qualitative EWR can therefore be developed:

- to maintain the water regime within the natural limits. The groundwater level needs to be in direct contact with the marine discharge with a pressure at least sufficient to prevent seawater intrusion.

7. EWRs OF WETLAND GROUPS

For each of the wetland groups as defined by Semeniuk and Semeniuk (2007a), an EWR was built up by collating the various EWRs of the different plant components recorded in the group. Some EWRs for individual taxa were redundant (the requirements were more than covered by the requirements of another functional group or taxon) and so these were left out of the final EWR.

7.1. SLEAFORD WETLAND GROUP

Description: The Sleaford Group is located on the south-eastern tip of the Eyre Peninsula and consists of two basins, Sleaford Mere and Little Sleaford Mere. Sleaford Mere is a permanently inundated, shallow saline lake, while Little Sleaford Mere is ephemeral.

Hydrology: Recharge appears to be via direct rainfall and groundwater recharge. At the northern end of Sleaford Mere, permanent freshwater soaks can be located.

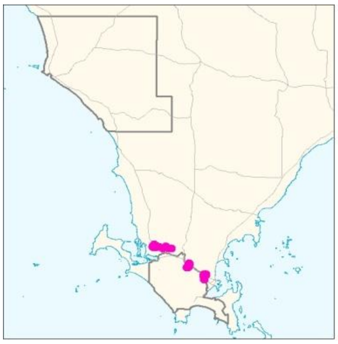
Vegetation: Sleaford Mere displays the typical fringing zonation of *Gahnia trifida* or *G. filum*, *Melaleuca halmaturorum, M. lanceolata*, *M. cassytha* and *Baumea*. On the damp littoral edges of the lake, a diverse community includes *Wilsonia*. The permanent freshwater soaks provide habitat for a number of restricted plant taxa including *Hydrocotyle* and *Triglochin striatum*.

Other significant environmental values: Sleaford Mere is a site of national and international importance for shorebirds and is nationally important through its inclusion in the Directory of Important Wetlands in Australia (Environment Australia 2001). Sleaford Mere provides important habitat for a wide range of waders, shorebirds and other waterbirds.

Environmental Water Requirement: Based on the presence of different vegetation components and persistence of water, the EWR for Sleaford Mere can be described as:

- For the entire year, the groundwater level needs to be in direct contact with the sources of the freshwater soaks.
- The groundwater table needs to maintain the surface water to a depth of 100–200 mm throughout the year.
- For at least three months of the year (at any time), the groundwater table needs to be maintained within 1 m of the *Baumea* zone.
- For at least three months of the year (at any time), the groundwater table needs to be maintained within 2–3 m of the *Melaleuca* zone.
- For at least two months of the year (at any time), the groundwater table needs to be maintained within 3–4 m of the *Gahnia* zone.
- For at least three months of the year over spring (one in three years) the groundwater table needs to be maintained within 250 mm of the *Baumea* zone.
- For at least three months of the year over spring (one in 10 years) the groundwater table needs to be maintained within 250 mm of the *Melaleuca* zone.

7.2. GREENLY WETLAND GROUP



Description: The Greenly Group consists of a number of widely spread individual basins and small scale connecting, inflowing or outflowing channels. Most of the main wetlands – Lake Greenly, Duck Lake, Big Swamp and Little Swamp – are seasonally inundated, but Lake Wangary has become permanently inundated by damming the head of the southern exit channel (Semeniuk and Semeniuk 2007a).

Hydrology: Analyses on the correlations between swamps and lake location and regional geology, lithological logs and depth to groundwater (SKM 2009) suggests that Little and Big Swamps within the Greenly Group are disconnected from the Quaternary aquifer and therefore, are not considered to be GDEs within the context of this report. However alternative evidence by Semeniuk and Semeniuk (2007a) suggests that groundwater does rise to meet surface water. Further studies are required to definitively ascertain the hydrological processes maintaining these ecosystems. The following EWRs are only applicable should future investigations find a level of dependence upon the quaternary aquifer for these systems.

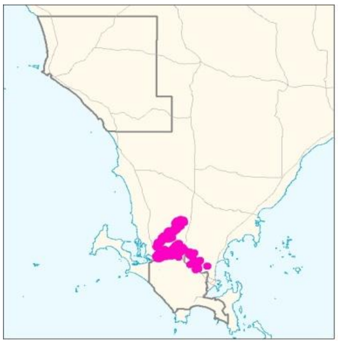
Vegetation: The centres of the basins are generally unvegetated but the margins display the typical zonation of *Melaleuca halmaturorum* and *Gahnia trifida*, with open ground cover of *Sarcocornia* and *Tecticornia* species (Semeniuk and Semeniuk 2007a). Aquatics included species of *Chara*.

Other significant environmental values: Big Swamp is listed as a nationally important wetland in the Directory of Important Wetlands in Australia (Environment Australia 2001). The listing identifies it as a good example of a wetland type occurring within a biogeographic region in Australia and as important habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge during adverse conditions such as drought.

Environmental Water Requirement: Based on the presence of different vegetation components, the EWR for wetlands in the Greenly Group can be described as:

- For three to six months of the year, saturated soil or surface water depth <200 mm needs to be maintained in the basin for *Sarcocornia* and *Tecticornia*.
- For at least 16 weeks, a water depth of greater than 250 mm needs to be maintained in the basin for *Chara*.
- For at least three months of the year (one in three years), no surface water should be present, but the groundwater table needs to maintain damp soil within the parts of the basin where *Sarcocornia* and *Tecticornia* are located for recruitment.
- For at least three months of the year (at any time), the groundwater table needs to be maintained within 2–3 m of the *Melaleuca* zone.
- For at least two months of the year (at any time), the groundwater table needs to be maintained within 3–4 m of the *Gahnia* zone.
- For at least three months of the year over spring (one in 10 years) the groundwater table needs to be maintained within 250 mm of the *Melaleuca* zone.

7.3. WANILLA WETLAND GROUP



Description: The Wanilla Group consists of a number of short channels, originating in the Lincoln Hills, that flow into waterlogged flats. These channels are seasonally inundated or seasonally waterlogged. The two main wetlands are Merintha Creek and Wanilla.

Hydrology: There is some doubt about the contribution of groundwater to the hydrology of the creeks. According to Semeniuk and Semeniuk (2007a), the creeks are shallow (200 mm), have flow periods of approximately five months, are recharged by direct rainfall and runoff from Lincoln Hills and are losing systems to the groundwater. As for the Greenly Group above, the following EWRs apply only if future investigations find a level of dependence upon the Quaternary aquifer for these systems.

Vegetation: *Phragmites* (or *Carex*) surrounded by *Melaleuca brevifolia*

Other significant environmental values: None

Environmental Water Requirement: Based on the presence of different vegetation components, the EWR for wetlands in the Wanilla Group can be described as:

- For the entire year, the groundwater table needs to maintain damp soil throughout the creekline for *Phragmites* species.
- For at least three months of the year (at any time), the groundwater table needs to be maintained within 2–3 m of the *Melaleuca* zone.
- For at least three months of the year over spring (one in 10 years) the groundwater table needs to be maintained within 250 mm of the *Melaleuca* zone.

7.4. PILLIE WETLAND GROUP

Description: The Pillie Group consists of a number of small elongate dampland basins. The selected representative site is Lake Pillie.

Hydrology: Recharge appears to be via direct rainfall and groundwater recharge.

Vegetation: The vegetation community at Pillie Lakes consist of a simple zonation, with *Wilsonia backhousei* and *Sarcocornia quinqueflora* found on the shoreline and basin floor with open heath of *Melaleuca brevifolia* and *Gahnia trifida* further up the slope. *Chara* is found in the basin itself.

Other significant environmental values: None known.

Environmental Water Requirement: Based on the presence of different vegetation components, the EWR for Pillie Lake can be described as:

- For three to six months of the year, saturated soil or surface water depth <200 mm needs to be maintained in the basin for *Sarcocornia*.
- Where present, a surface water depth >250 mm needs to be present for at least 16 weeks for *Chara*.

- For at least three months of the year (one in three years), no surface water should be present, but the groundwater table needs to maintain damp soil within the parts of the basin where *Sarcocornia* is located.
- For at least three months of the year (at any time), the groundwater table needs to be maintained within 2–3 m of the *Melaleuca* zone.
- For at least two months of the year (at any time), the groundwater table needs to be maintained within 3–4 m of the *Gahnia* zone.
- For at least three months of the year over spring (1 in 10 years) the groundwater table needs to be maintained within 250 mm of the *Melaleuca* zone.

7.5. HAMILTON WETLAND GROUP

Description: The Hamilton Group consists of a single large elongate basin (Lake Hamilton) and a number of smaller associated basins. All are seasonally inundated. The selected representative sites are Lake Hamilton and Round Lake.

Hydrology: In Lake Hamilton, recharge appears to be via several pathways. Fresh water from the eastern and western limestone ridges discharges into the lake. Vents occur on the western side of the lake, which appear to be the outlet for marine waters and tidal channels transport this water from the western edge to the central basin.

In Round Lake, recharge appears to be via direct rainfall and groundwater recharge.

Vegetation: Lake Hamilton supports the typical vegetation zonation, including fringing *Melaleuca brevifolia* with an understorey of *Gahnia trifida* and *Sarcocornia quinqueflora*. In waterlogged areas this is replaced with pure stands of *Gahnia trifida*. *Gahnia trifida* occur around freshwater seepages and springs. Within the basin, *Tecticornia* spp. and *Sarcocornia* spp. cover the exposed flats and the aquatic vegetation consists of *Chara* spp. and *Ruppia* spp.

Round Lake displays the typical fringing zonation of *Gahnia*, *Melaleuca* and *Baumea*, with *Tecticornia* spp. and *Sarcocornia* spp. in the lower portions of the basin fringe.

Other significant environmental values: Lake Hamilton is listed as a nationally important wetland in the Directory of Important Wetlands in Australia (Environment Australia 2001) as a good example of a wetland type occurring within a biogeographic region in Australia.

Environmental Water Requirement: Based on the presence of different vegetation components, the EWR for Lake Hamilton can be described as:

- For the entire year, the groundwater level needs to be in direct contact with the spring source.
- For three to six months of the year, saturated soil or surface water depth <200 mm needs to be maintained in the basin for *Sarcocornia* and *Tecticornia*.
- For six months of the year, a water depth of 20–30 mm needs to be maintained in the basin for *Ruppia*.
- For at least three months of the year (one in three years), no surface water, with groundwater sufficiently shallow to maintain damp soil within the parts of the basin where *Tecticornia* and *Sarcocornia* are located (for recruitment).

- Where present, a surface water depth >250 mm needs to be present for at least 16 weeks for *Chara*.
- For at least three months of the year (at any time), the groundwater table needs to be maintained within 2–3 m of the *Melaleuca* zone.
- For at least two months of the year (at any time), the groundwater table needs to be maintained within 3–4 m of the *Gahnia* zone.
- For at least three months of the year over spring (one in 10 years) the groundwater table needs to be maintained within 250 mm of the *Melaleuca* zone.

The EWR for Round Lake can be described as:

- For three to six months of the year, saturated soil or surface water depth <200 mm needs to be maintained in the basin for *Sarcocornia* and *Tecticornia*.
- For at least three months of the year (one in three years), no surface water should be present, but the groundwater table needs to maintain damp soil within the parts of the basin where *Tecticornia* and *Sarcocornia* are located (for recruitment).
- For at least three months of the year (at any time), the groundwater table needs to be maintained within 1 m of the *Baumea* zone.
- For three months of the year over spring (one in three years) the groundwater table needs to be maintained within 250 mm of the *Baumea* zone.
- For at least three months of the year (at any time), the groundwater table needs to be maintained within 2–3 m of the *Melaleuca* zone.
- For at least two months of the year (at any time), the groundwater table needs to be maintained within 3–4 m of the *Gahnia* zone.
- For at least three months of the year over spring (one in 10 years) the groundwater table needs to be maintained within 250 mm of the *Melaleuca* zone.

7.6. NEWLAND WETLAND GROUP

Description: The Newland wetland group consists of a complex of large wetland basins, with the main body of water (Lake Newland) being a relatively permanent salt lake with freshwater springs. Parts of the lake system dry over the summer period.

Hydrology: Fresh water is delivered into the Newland Lake by rainfall and groundwater (Semeniuk and Semeniuk 2007b). The saline lakes become shallower and more saline in summer, but are renewed by winter rain and by a number of fresh water springs and seepages, which enter the lakes at their edges.

Vegetation: As a mostly permanent system, Lake Newland system supports the typical vegetation zonation, including fringing *Gahnia*, *Melaleuca halmaturorum* and *Baumea*. Within the basin, *Tecticornia* and *Sarcocornia* cover most exposed flats and there is aquatic vegetation consisting of *Chara*, *Ruppia* and filamentous algae.

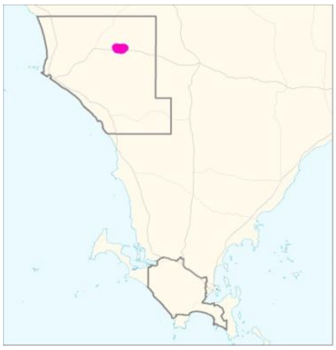
Site investigations of freshwater springs and seepage areas around the lake found *Cyperus*, *Triglochin*, *Juncus*, *Ficinia nodosa*, *Baumea* and *Sarcocornia* (J. Nicol, field observations, November 2011). These findings are supported by earlier surveys conducted by Semeniuk and Semeniuk (2007b).

Other significant environmental values: Lake Newland is one of the most ecologically important wetlands on the Eyre Peninsula. It attracts bird species considered vulnerable in South Australia and has an important role as a drought refuge for waterfowl. It is also considered to be of international importance for Banded Stilt and of national importance as a summer feeding habitat for the vulnerable Hooded Plover (Wainwright 2008). It is listed as a nationally important wetland in the Directory of Important Wetlands in Australia (Environment Australia 2001).

Environmental Water Requirement: Based on the presence of different vegetation components, the EWR for Lake Newland can be described as:

- For the entire year, the groundwater level needs to be in direct contact with the spring source.
- For three to six months of the year, saturated soil or surface water depth <200 mm needs to be maintained in the basin for *Sarcocornia* and *Tecticornia*.
- For six months of the year, a water depth of 20–30 mm needs to be maintained in the basin for *Ruppia*.
- Where present, a surface water depth >250 mm needs to be maintained for at least 16 weeks for *Chara*.
- For at least three months of the year (one in three years), no surface water should be present, but the groundwater table needs to maintain damp soil within the parts of the basin where *Tecticornia* and *Sarcocornia* are located.
- For at least three months of the year (at any time), the groundwater table needs to be maintained within 1 m of the *Baumea* zone.
- For at least three months of the year (at any time), the groundwater table needs to be maintained within 2–3 m of the *Melaleuca* zone.
- For at least two months of the year (at any time), the groundwater table needs to be maintained within 3–4 m of the *Gahnia* zone.
- For at least three months of the year over spring (one in three years) the groundwater table needs to be maintained within 250 mm of the *Baumea* zone.
- For at least three months of the year over spring (one in 10 years) the groundwater table needs to be maintained within 250 mm of the *Melaleuca* zone.

7.7. POELPENA WETLAND



Description: Poelpena wetland consists of a single large elongate basin that is likely to be intermittently inundated. Poelpena swamp is the representative site.

Hydrology: Recharge appears to be via direct rainfall and groundwater discharge.

Vegetation: Vegetation mapping by SKM (2009) shows fringing vegetation of *Melaleuca brevifolia* with an understorey of *Gahnia filum,* with some limited areas of red gum (*Eucalyptus camaldulensis*). DENR floristic mapping shows an understory of Samphire (*Tecticornia* sp.) covering a significant portion of the swamp basin (Government of South Australia, 2012b).

Other significant environmental values: None known.

Environmental Water Requirement: Based on the presence of different vegetation components, the EWR for Poelpena swamp can be described as:

- For three to six months of the year, saturated soil or surface water depth <200 mm needs to be maintained in the basin for *Tecticornia*.
- For at least three months of the year (one in three years), no surface water should be present, but the groundwater table needs to maintain damp soil within the parts of the basin where *Tecticornia* is located (for recruitment).
- For at least three months of the year (at any time), the groundwater table needs to be maintained within 2–3 m of the *Melaleuca* zone.
- For at least two months of the year (at any time), the groundwater table needs to be maintained within 3–4 m of the *Gahnia* zone.
- For at least three months of the year over spring (one in 10 years) the groundwater table needs to be maintained within 250 mm of the *Melaleuca* zone.
- To maintain the water regime within the limits of red gum adaptability (as indicated by the historic groundwater regime).

8. SCENARIO TESTING

Environmental water requirements (expressed as groundwater regime) have been determined for each of the major groundwater dependent ecosystems in the two Prescribed Wells Areas on the Eyre Peninsula. These requirements are expected to maintain or improve the current environmental values so that they are sustainable into the future with a low level of risk. It is recognised that during dry periods, groundwater resources available for environmental values may not always meet the recommended regime. This is seen as a natural occurrence and the biota have adapted to survive varying periods where water availability is lower than desirable. However, risks to groundwater dependent ecosystems are expected to increase if these periods are extended, or made more frequent, beyond what these systems have historically experienced.

8.1. INFLUENCES ON GROUNDWATER REGIME

The regional groundwater systems of the Eyre Peninsula are highly responsive to rainfall-recharge variations and have high rates of transmissive loss, ultimately discharging into the ocean (Stewart *et al*. 2012). Therefore, any changes in groundwater may be primarily attributable to climate. This is consistent with the findings of Evans *et al.* (2009b) and Love *et al.* (1994) who respectively report that all lenses in the Musgrave region experienced declining water levels of between 1–5 m irrespective of extraction volumes and that decreases in extent of the saturated limestone between 1973 and 1994 are attributable to declines in regional recharge.

Effective provision of environmental water requires a better understanding of the relationship between extraction and water regime.

For example, hydrogeological models for the Uley South lens suggest that pumping of 6 GL from that aquifer results in a maximum decrease in groundwater level of approximately 1 m over summer compared to no pumping. Each winter the groundwater level recovers to the same level as if extraction were not taking place (Zulfic *et al*. 2007; Werner 2010). Lower recharge due to decreased rainfall can also result in decreasing groundwater levels, such as has been observed over the PWA in recent years. In some cases, the coupled effect of groundwater extraction and lower recharge volumes can have a greater impact upon groundwater dependent ecosystems.

It is noted that the Caroonda wetland, which occurs over the Uley South groundwater lens, is now considered functionally extinct as a wetland based upon die off of *Baumea juncea* stands, suggesting that its environmental water needs were not met at some point in the recent past (VanLaarhoven and Nicol, unpublished data). However, without a better understanding of the relationship between extraction and groundwater regime it is not possible to attribute this change in ecosystem state (aquatic to terrestrial) to recent low rainfall periods, water extraction or a combination of both.

8.2. SALINITY

Salinity levels are a contributing factor to GDE health and need to be considered in light of the following scenario testing methodologies that focus on relationships between the environment and groundwater level.

All biota, except for extreme halophiles, have a tolerance to salinity beyond which they will experience stress and ultimately perish (Hart *et al*. 1991; Metzeling *et al*. 1995; Nielsen et al. 2003). In many cases the literature does not provide specific information on salinity thresholds and therefore it is necessary to use published data from similar taxa or knowledge of presence and/or abundance of a given species within habitats of varying water quality to estimate salinity tolerance or preferences. If salinity threshold data is found in the literature it is often LC50 data (i.e. lethal dose for 50% of the test population). The acceptance of LC50 data poses two significant difficulties: 1) LC50 is not a conservative approach to ecosystem management (targets should be considerably lower in order to protect species in the wild); and 2) chronic exposure (longer than 4 day exposure used in LC50 trials) may have deleterious effects at levels that may be assumed to be 'safe'. A species' response to salinity is also unlikely to be linear. It may be that there is little or no apparent effect over a range of values leading up to a threshold and then rapid change at or around the threshold value. Furthermore, salinity changes in a given habitat are likely to be linked to other stressors such as lower water availability and changed nutrient status. Therefore, changes in salinity form a significant component of the EWRs that act in concert with the requirements for water detailed above.

Salinity in the GDEs is most likely to be a function of the salinity of the groundwater, the water balance (i.e. relative inputs of groundwater and rainfall) and the relative rates of evapo-concentration of surface water. During periods of low rainfall, recharge is also lower, likely leading to a lowering of the groundwater table and increased salinity of the groundwater. This suggests that the GDEs are at risk of increased salinity during and immediately after periods of low rainfall and recharge.

The salinity tolerances for the different species (Table 5) provide a theoretical order in which the species would be lost if salinity increased over time in a given GDE. However, critical life history stages, ecological interactions and processes may significantly alter this predicted order of response. That is, the effects of salinity are part of an interconnecting set of ecological interactions and processes, including those listed below, that act together to determine whether a species will persist or not:

- baseline condition, including degree of redundancy
- ability to avoid stressors
- dispersal mechanisms
- critical life history requirements (e.g. diadromous life cycles)
- indirect trophic effects (e.g. habitat provision, predation, competition)
- level of dependence on specific habitat or food resources.

Table 5. Salinity tolerance of surrogate taxa

Taxa	Salinity tolerance
Wilsonia backhousei	Common in brackish and coastal areas, probably has high salinity tolerance but requires periods of lower salinity. Reported extreme salinity tolerance (VRO Website 2).
Samphires	*Tecticornia* spp. are more salt tolerant than *Sarcocornia* spp. (J. Nicol, SARDI, pers. comm.).
Melaleuca halmaturorum	Highly salt tolerant although impact of multiple stressors is not well understood (*sensu* Ladiges *et al*. 1981; Raulings *et al*. 2007; Salter *et al*. 2007; Morris *et al*. 2008; Robinson *et al*. 2008; Salter *et al*. 2008; Salter *et al*. 2010a; Salter *et al*. 2010b).
Gahnia trifida and *G. filum*	No information regarding salinity tolerance for *G. filum* but it appears to persist well in drier conditions. *G. trifida* is common in coastal/brackish environments and reported to be extremely salt tolerant and has high waterlogging tolerance (VRO Website 3).
Baumea juncea	5.8 ppt TDS resulted in significant biomass reduction (47% - Bailey *et al*. 2002). No information regarding the impact of multiple stressors. Reported high salinity tolerance (VRO Website 4).
Triglochin striatum	Is common in brackish to saline wetlands. Reported to be extremely salt tolerant (VRO Website 5).
Hydrocotyle spp.	No data located, but believed to be intolerant of salinity due to locations where they have been recorded (J. Nicol, SARDI, pers. comm.).

Taxa	Salinity tolerance
Phragmites australis	Died at 15 ppt TDS, dieback at 12 ppt TDS (Bailey *et al.* 2002), although it has been observed growing in water with over 20 ppt TDS at Goolwa (J. Nicol, SARDI, pers. comm.).
Ruppia spp.	Maximum salinity tolerance depends on species (*R. megacarpa* 46 ppt TDS, *R. polycarpa* 125 ppt TDS, *R. tuberosa* 230 ppt TDS) (Brock 1979; Brock 1981a; Brock 1981b; Brock 1982). Higher salinity (>35 ppt TDS) resulted in delayed seed germination and turion sprouting in the Lake George population of *R. tuberosa* (J. Nicol, unpublished data).
Chara spp.	Depends on species (*C. fibrosa* 9 ppt TDS, *C. globularis* 7.5 ppt TDS, *C. corallina* 8 ppt TDS, *C. vulgaris* 4 ppt TDS). The charophyte *Lamprothamnium papulosum* (which looks superficially like *Chara*) is reported to have a salinity tolerance of 210 ppt TDS (Bailey *et al.* 2002)
Eucalyptus camaldulensis	Bell (1999) found that seedlings could tolerate waterlogging with saline solutions equivalent to 1700 mg NaCl, however, tolerance varies widely with provenance (Marcar *et al*. 2002) and thus site-specific studies need to be undertaken to determine salinity tolerance of a given population.
Eucalyptus petiolaris	No data located

8.3. SCENARIO TESTING

Even under natural conditions, there will be dry periods where the EWRs recommended for surrogate taxa may not be provided every year. Life history strategies traits, as described in Table 6, allow taxa to persist through these naturally sub-optimal climatic conditions. Through this understanding of the ways in which plants establish and persist, we can predict the likely impacts on environmental values if the EWRs are not met over a given time period and the relative chances of recovery if water availability subsequently increases.

The likely impact of poor water availability can be assessed by examining the “vital attributes” of plants (Noble and Slatyer 1980). Vital attributes are those life history characteristics that are vital to its role in vegetation replacement sequences. These attributes include the method of arrival or persistence of the species at a site during and after a disturbance, the ability to establish and grow to maturity in the developing community and the time taken for the species to reach critical life stages.

Aquatic plants can persist through periods of reduced water availability as long-lived adults (e.g. Samphires), underground organs (e.g. rhizomes of *Phragmites australis* or *Baumea juncea*) or from the seed bank (e.g. *Hydrocotyle* sp.). Small patches of emergent plants may persist where localised soil moisture remains due to; high organic matter, dense thatching acting as mulch, groundwater seepage and/or rainfall run-off. Given suitable soil and water quality, rhizomes and other underground organs may persist for several years, reshooting when favourable conditions return to readily form new stands of healthy plants.

The seed bank is defined as the reserves of viable seeds and spores that persist in or on the soil surface and litter layers (Thompson and Grime 1979; Roberts 1981). A viable seed bank ensures plant populations recover after disturbance or loss that may be caused by sustained drawdown. In many cases, the seed bank is the only life stage to survive desiccation. Therefore the seed bank is vital for recovery of plants that have experienced disturbance such as extended periods of low water availability or salinities beyond the tolerances of adult plants (Casanova and Brock 1990; Brock and Britton 1995; Brock and Rogers 1998; Leck and Brock 2000; Nielsen *et al*. 2007). If a viable seed bank exists, then re-establishment of those plants contained with the seed bank is not reliant on migration or dispersal from other aquatic habitats, which in the case of the wetlands of the Eyre Peninsula, is a significant issue given the relative isolation from other wetlands and dry temperate climate. Once established from seed, many aquatic plants can rapidly increase their populations to fill the available niche via asexual reproduction (*sensu* Grace 1993).

If seed is available and the water regime is suitable, amphibious plants such as *Hydrocotyl*e sp. are likely to germinate *en masse.* In this case, the seed bank may become exhausted and the plant is at risk of local extinction if the germinants perish unless they have evolved a persistent seed bank (i.e. not all of the viable seed germinates at one time) (sensu Thompson and Grime 1979). The very narrow riparian and littoral bands in most of the wetlands suggests that most niches are unsuitable or sub-optimal for the more aquatic taxa and that competition within the most optimal elevation bands may be high. Given its habit and high dependence on the fresher areas of wetlands directly influenced by spring discharge, *Hydrocotyle* sp. is likely to be a very poor competitor in the Eyre Peninsula wetlands. They would be unlikely to re-establish if lost, particularly if disturbance occurred when juveniles dominated the population.

The charophytes are more tolerant of competition, are more readily dispersed and highly opportunistic. They are able to form stands in roadside spring-fed pools (Saunders pers. comm.) and other isolated habitats. Therefore it is likely that *Chara* spp. and related plants could re-establish after sustained drawdown.

The species composition will vary in seed banks within and between wetland groups (e.g. Nicol and Ward 2010), thus some level of diversity will be retained in the seed bank even if disturbance occurs. However, Brock *et al.* (2005) have shown that elevated salinity reduces seed bank germination and as salinity increases, the time required for germination also increases (Sim *et al*. 2006; Nicol and Ward 2010). A longer hydroperiod may be required for plants to complete their life cycles if salinity increases. Leck and Brock (2000) and Brock (2011) show that seed banks significantly decline in diversity and numbers of germinants after ten to twelve years. Therefore, periods of low water availability of ten years or more may significantly reduce plant diversity.

Reeds such as *Phragmites australis* and *Baumea juncea* have long-lived seed banks and underground storage organs that can persist when above-ground tissue dries off. They are both relatively tolerant of competition and will occupy different niches. *Phragmites australis* is cosmopolitan and readily dispersed by wind or animals and thus has a robust mechanism for re-establishing in permanent or ephemeral wetlands if local populations are lost. However, the only known stand of *Phragmites australis* within the PWAs is at the lower end of Merintha Creek near Coffin Bay (see Section 7.3). The wetlands on Eyre Peninsula are also spatially isolated from other wetland systems (e.g. Cooper Creek, Yorke Peninsula, Fleurieu Peninsula) by large areas of arid country or stretches of ocean that may prevent effective dispersal. Therefore, *Phragmites australis* populations on Eyre Peninsula are more vulnerable to loss than other more connected populations (e.g. along large river systems). *Baumea juncea* on the Eyre Peninsula will be less readily dispersed and more susceptible to regional extinction if it is lost from the wetlands that contain it.

Samphires and Paperbark (*Melaleuca halmaturorum*) tend to form stands behind the riparian and littoral zones of more permanent wetlands. In more intermittent wetlands (e.g. Round Lake), Samphires may occur on the basin side of the Paperbarks and extend into the basin. In these cases, it is likely that there is no continuous band of *Baumea juncea* (occurs in fresher and wetter patches) and the Samphires form the basin vegetation. Samphires and Paperbark are highly tolerant of desiccation but they do require damp, saturated or flooded soils to recruit. Typically they have long life spans, a high tolerance of dry conditions and are highly tolerant of competition in their respective niches. However, in the case of Eyre Peninsula wetlands, they may be affected by extended periods (decades) of reduced groundwater levels.

Gahnia spp. is generally considered a poor recruiter and may need extended periods of inundation or specific cues for recruitment (J. Nicol, SARDI, pers. comm.). So although it appears tolerant of competition, little is known about its recruitment and dispersal mechanisms.

Therefore, the relative sensitivities of the surrogate taxa can be assessed in terms of their ability to withstand periods of below optimal environmental water regimes.

While conclusions can be made for the majority of plant species, with the exception of *Gahnia* spp., little is known about the tolerances of fauna in the study area. The obvious exception is fish, which have a requirement for permanent water to be present. With little opportunity for dispersal and colonisation between wetlands, any period with no surface water would be likely to result in localised extinctions of fish.

Table 6. Vital attributes of surrogate plant taxa

Taxon	Dispersal	Recruitment	Persistence	Competition	Vulnerability
Hydrocotyle spp.	Seed in mature inflorescences	Shallow inundation or damp soil	Seed bank, Desiccation intolerant, may germinate *en masse*	Poor in narrow riparian zone	High
Baumea juncea	Seed bank Seed in mature inflorescences Vegetative growth	Damp soil or shallow inundation for seed germination. New shoots will grow out from water's edge to depth or salinity threshold	Seed bank, Desiccation tolerant (underground rhizomes, thatching to protect young shoots)	Strong if established	Medium
Chara spp.	Multiple dispersal vectors (including fauna) Seed bank Seed in mature inflorescences	Germinate underwater	Seed bank, Mulching of young shoots	Strong because can germinate underwater and form dense beds	Medium
Triglochin striatum	Seed bank Seed in mature inflorescences	Damp soil or shallow inundation for seed germination	Seed bank, Desiccation tolerance unclear	Medium, can form dense bands but short compared to competitors thus easily shaded	Medium
Melaleuca halmaturorum	Wind	Damp soil	Highly desiccation tolerant, long-lived adults Aerial seed bank (serotiny)	High. Long-lived and tall, Seedlings grow to match water levels	Low
Samphires (*Sarcocornia* spp. *Suaeda australis* and *Tecticornia* spp.)	Seed bank	Damp soil	Seed bank, highly desiccation tolerant.	Low – long-lived and highly desiccation tolerant	Low
Phragmites australis	Wind Vegetative growth	Waterlogged soil	Desiccation tolerant (underground rhizomes, thatching to protect young shoots)	Low – long-lived seed banks and underground storage organs, good disperser	Medium
Ruppia spp	Seed bank Animals (e.g. waterfowl)	Inundated soil	Seed bank and turions (small bulbs present on *R. tuberosa* and *R. polycarpa*)	Highly salt tolerant and germinates rapidly when sediment is inundated. Poor competitor in fresh environments	Low
Gahnia spp.	Unknown	Damp soil	Desiccation tolerant	Unknown	Low

8.4. GDE RISK ASSESSMENT EXAMPLE

In the following hypothetical example there are two wetlands - Wetland A: An intermittent wetland connected to the regional groundwater at 2.4 m AHD; and Wetland B: A permanent wetland lower in the landscape (1.0 m AHD) containing a freshwater spring connected to the regional groundwater at 2.1 m AHD. Within the aquifer that feeds these two wetlands are a series of wells from which groundwater is extracted. (Figure 14) shows a hypothetical hydrograph for groundwater levels in the aquifer over a 17 year period without extraction (natural - blue line) and with extraction (red line). The steps used to determine the risks for Wetlands A and B under the extraction scenario are detailed below.

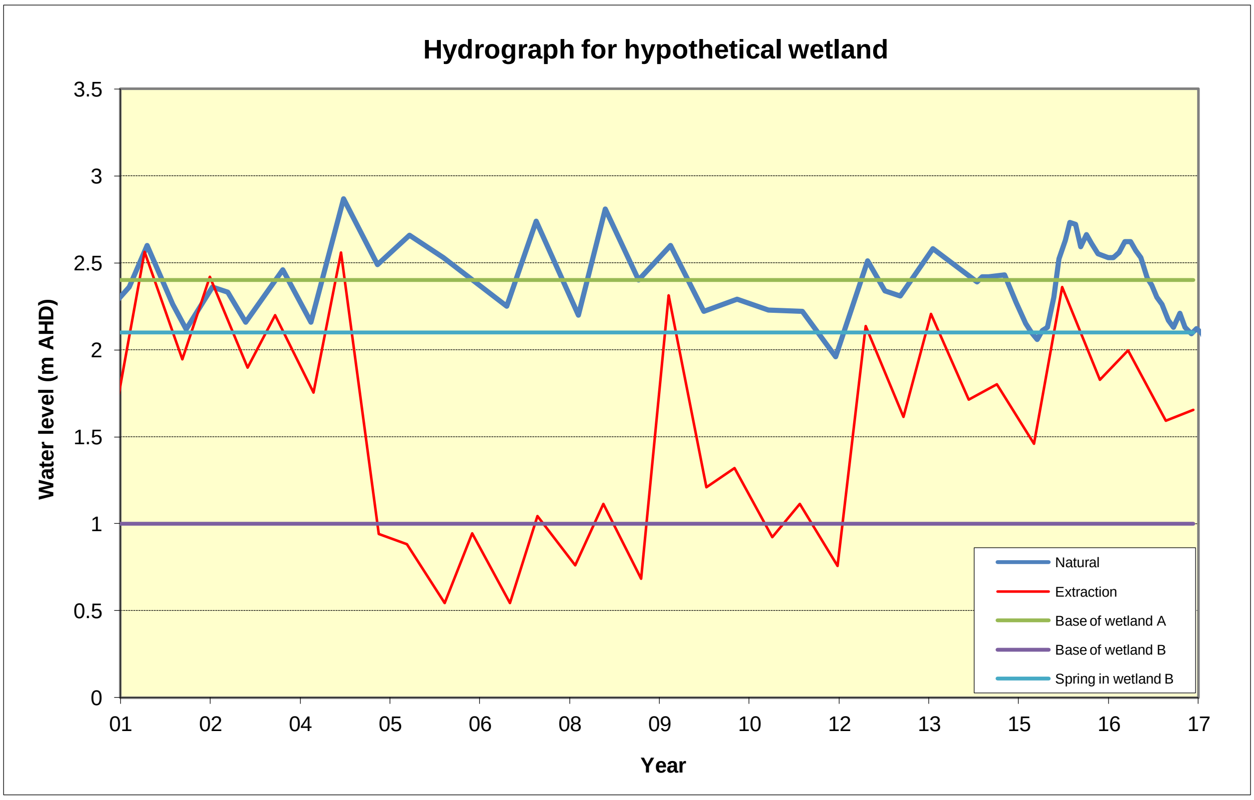


Figure 14. A hypothetical hydrograph for the aquifer underlying Wetlands A and B with (blue lines) and without (red lines) extraction

Under natural conditions (dark blue line), the groundwater level is higher than the base of intermittent Wetland A on a number of occasions, representing when surface water is present. The natural level always remains above the base of Wetland B (purple line), so permanent surface water is present. Apart from three occasions, the natural groundwater level is always in contact with the level of the spring in wetland B (green line), so water flow from the spring is almost always maintained.

With extractions (red line), the groundwater intersects with the surface of Wetland A on much fewer occasions (and not since year 4), so the frequency of surface water is greatly reduced and there is an extended period with no surface water. The extracted groundwater trace also falls below the level of the permanent Wetland B, meaning there are now periods with no surface water present (e.g. years 5 and 6). The groundwater falls below the level of the spring more often, with extended periods where the springs would not be flowing.

In making this risk assessment, the following assumptions have been made:

1. The plants will respond based on the vital attributes described above
2. Competition will not limit establishment or persistence of any plant species
3. Salinity will remain within the tolerances of each plant
4. Changes in hydrology will occur quickly, negating the ability of plants to move down gradient during the analysis period, that is, the risk will be assessed for the gradient at which each plant currently occurs (this is based on observations of *Baumea juncea* loss at Caroonda wetland in Uley South). The exceptions are *Ruppia* spp. and *Chara* spp. which are highly dispersive, annual species that will colonise areas where the water regime is suitable.

Step 1: Identify surrogate plant taxa and their relative elevations.

The EWRs presented in this report are based on the water requirements of surrogate plant species (Table 4). Therefore the first step in determining the risk to the plants is to identify which of the surrogate plant species occur at what elevation within a given wetland. For the purposes of this hypothetical, plant assemblages and their relative elevations typically seen in intermittent and permanent wetlands on Eyre Peninsula have been used for Wetlands A and B (Table 7).

Table 7. Surrogate plants present at Wetlands A and B and their relative elevations

Wetland feature	Wetland A (m AHD)	Wetland B (m AHD)
Hydrological feature		
Springs	-	2.1
Wetland base	2.4	1.0
Plant taxa		
Gahnia spp.	2.9	2.6
Melaleuca halmaturorum	2.7	2.4
Baumea juncea	2.6	2.2
Samphires	2.5	2.3
Hydrocotyle spp.	-	2.1
Ruppia spp.	2.45	2.0
Chara spp.	-	1.75

Step 2: Analyse relevant hydrographs against EWRs

Next, the hydrograph in Figure 14 is analysed for capacity to meet the EWRs for each of the surrogate plants over time. The key EWR components are water depth (level), duration, timing and frequency of inundation (Table 4) at the elevation where each plant occurs.

For example, *Melaleuca halmaturorum* requires groundwater within 2-3 m of surface for three months of the year and within 250 mm of surface (no surface water) once every 10–25 years. With the relative elevations of 2.7 m at Wetland A and 2.4 m at Wetland B to meet the EWR, the groundwater needs to be at or above 0.7 m and 0.4 m for three months each year respectively and at 2.45 m and 2.15 m for 3 months every 10–25 years (based on the requirement of groundwater within 250 mm of the surface for recruitment).

Similarly, for *Baumea*, the groundwater level needs to be at 1.6 m and 1.1 m for three months at least once every three years in Wetlands A and B respectively (based on the relative elevations of 2.6 and 2.2 m) and at 2.35 m and 1.95 m for three months once every three years for recruitment (but no rarer than once every five to ten years).

A given plant species will persist in the wetland at a low level of risk if all of its EWR components are met all of the time. If one or more of its EWR components are not met then the risk to that plant increases over time. How long the EWR component cannot be met before the plant becomes locally extinct requires application of knowledge of the plants' vital attributes, as well as evaluation of the periodicity of meeting given EWR components. In some cases, expert knowledge will need to be applied to analyse the level of risk to a given plant or other wetland characteristic under a set of given scenarios.

The resultant tables (Table 8 and Table 9 below) show whether the different EWR components are met over time in the hypothetical wetlands under the extraction scenario. It is assumed that the climate is able to support all the EWRs if no extraction occurs during this period (NB: this may not be the case in reality if the climate is drying).

Step 3: Determine the ecological risk over time
By utilising the vital attributes and the results of the hydrological analysis in Step 2, the ecological risk over time can be analysed (*sensu* Muller 2011). The risk over time is expressed in diagrammatic form (for example, see Figure 15) using the following process and depictions:

- The surrogate plant taxa (and selected other faunal species) are listed down the first column
- Increasing time since loss of EWRs is across the top of the diagram.

A green coloured band is used to represent the time and relative duration that the EWRs for that plant is within acceptable tolerances (e.g. groundwater within 250 mm of the surface, suitable recruitment intervals).

A dark green block indicates all the EWR components in the relevant wetland remain within the surrogate's tolerances (no stress). The progressively lighter shades of green qualitatively show decline in EWR components met, or the degree to which they are met and thus show an increase in stress to the point of complete loss. Lighter greens show lower proportions of environmental water requirements being met; that is higher risk of loss or significant decline.

No Stress		Increasing stress			Complete loss

Figure 15. Ecological risk over time diagram key

Results of hypothetical example

In preparing this hypothetical example, it has been assumed that the EWRs for all the taxa are met under the no-extraction scenario and thus this is a hypothetical assessment of the increased risk attributable to extraction.

Wetland A

Overall, the effect of extraction is to make Wetland A much more intermittent. Instead of receiving groundwater to the wetland surface in 15 out of 17 years when extraction was not occurring, Wetland A only received groundwater to the wetland surface in three out of 17 years when extraction was occurring. When the groundwater did break the surface in years 1, 2 and 4 it was for very brief periods and would be likely to result in smaller area of surface water. Notwithstanding this, over the 17-year period of assessment, the EWRs for the most tolerant plants (*Gahnia* spp., Paperbark) will be met at all times under the extraction scenario (Table 8 and Figure 16).

Table 8. Analysis of the hydrological capacity to meet the EWRs for plants in Wetland A if extraction is occurring

Plant taxa	Year																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Gahnia spp.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Melaleuca halmaturorum	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Baumea juncea	✓	R	R	✓	L D F R	L D F R	L D F R	L D F R	F R	L D F R	L D F R	F R	F R	F R	F R	F R	F R
Samphires	✓	L D F	L D F R	✓	L D F R	L D F R	L D F R	L D F R	L D F R	L D F R	L D F R	L D F R	L D F R	L D F R	L D F	L D F	L D F
Ruppia sp.	✓	L R	L R	✓	L R	L R	L F R	L F R	L F R	L F R	L F R	L F R	L F R	L F R	L F R	L F R	L F R

Key to symbols: tick (✓) = all the EWR components met for the corresponding year; L = water level unsuitable; D = duration unsuitable; F = frequency unsuitable; T = timing unsuitable and R = water needs for recruitment not met in that year

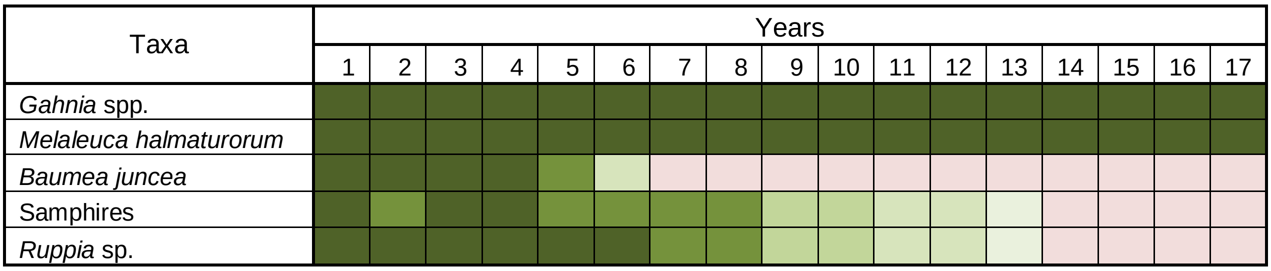


Figure 16. Ecological risk over time diagram for the hypothetical Wetland A under extraction

Water levels were adequate to support maintenance of *M. halmaturorum* in each year (the level did not fall below 0.7 m, or when it did, it was for less than nine months). However, levels were too low to support recruitment (R) in all but two years when the timing may not be suitable. The 17 year assessment period is too short to determine whether the recruitment component of the *M. halmaturorum* EWR has been met because the maximum recruitment interval is 25 years. If the groundwater trends repeated over the next 17 years, both *M. halmaturorum* and *Gahnia* spp. would be at risk from failed recruitment, although adults would be expected to persist on the groundwater, which never drops below the reach of their mature roots for more than nine months (i.e. that component of the EWR is met).

The water levels (L) as well as the duration of suitable water levels (D) are not sufficient to meet the EWRs for *Baumea juncea* from years five to eight or from years 10–11, failing the annual frequency requirement. The threshold of three sequential years of not meeting the persistence requirement means that by year seven there is significant risks that *B. juncea* will become locally extinct at this wetland.

Recruitment of *Baumea juncea* is only supported in years one and four. The EWR states that recruitment only needs to occur every three years to be optimal but no less than once every five to ten years for persistence of the stand. This means that even if persistence flows were met, by year 14 there is a risk that the natural senescence of the species would be complete and the loss of the species may occur at this location. The rapidity and severity of the decline will be strongly influenced by the salinity regime that results from the drying of Wetland A (see Table 5 for salinity tolerance).

For Samphires, the water regime is too dry in most years in terms of level and duration. Their requirement for annual watering means that the frequency component is not met in year 2, nor from years five to 17. Recruitment needs to occur once in every three years (with a threshold of one in 10 years) and thus the recruitment component of their EWR (R) is not met in years seven to 14. There is also a greater than 10 years gap between recruitment requirements being met in year four and year 15, which will lead to significant risk to the loss of the population. It may be possible for Samphires to persist on run-off from the local catchment given they are more desiccation tolerant than *Baumea juncea,* but this would represent a high level of risk of local extinction.

Ruppia spp. is likely to intermittently inhabit the wetland when water requirements are met in years one and four. The water requirements for successful recruitment is for a frequency of not greater than one in 10 years, meaning that *Ruppia* spp. may be lost from Wetland A by year 14 and will be reliant on dispersal from another wetland to re-establish.

Wetland A may become very saline over time and may reach levels that are lethal for the more vulnerable taxa such as *Baumea juncea.* This would be an important additional risk to consider as an overlay to the water availability assessment conducted here.

Wetland B

If extraction is not occurring, Wetland B is a permanent wetland with a maximum depth of 1 to 1.5 m depth (Figure 6). By contrast under the extraction scenario, the wetland dries in years five to seven and for parts of years eight, nine, 11 and 12. This does not affect provision of the EWRs for *Gahnia* spp. and *M. halmaturorum*, which are met at all times under the extraction scenario given that the groundwater does not drop below the reach of their mature roots (Table 9). This was also the case for Wetland A. The recruitment needs for *M. halmaturorum* are not met in all years but are met over the full time period because water levels are high enough at least once in every ten years to support recruitment, therefore the population is not expected to show decline over the 17-year assessment period.

Table 9. Analysis of the hydrological capacity to meet the EWRs for plants in Wetland B if extraction is occurring

Plant taxa	Year																
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Gahnia spp.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Melaleuca halmaturorum	✓	✓	✓	✓	R	R	R	R	✓	R	R	R	✓	R	✓	R	R
Baumea juncea	✓	✓	✓	✓	L D R	L D R	L D F R	L D F R	F	F R	L D F R	F	F	F R	F	F	F R
Samphires	R	R	L D R	R	L D R	L D F	L D F	L D F	F R	L D F	L D F	L D F	F	L D F	F R	L D F	L D F

						R	R	R		R	R	R		R		R	R
Hydrocotyle spp.	D F R	D F R	D F R	D F R	L D F R	L D F R	L D F R	L D F R	D F R	L D F R	L D F R	D F R	D F R	L D F R	D F R	L D F R	L D F R
Ruppia spp.	✓	✓	✓	✓	L D R	L D R	L D R	L D R	✓	L D R	L D R	✓	✓	L D R	✓	L D R	L D R
Chara spp.	✓	✓	✓	✓	L D R	L D R	L D R	L D R	✓	L D R	L D R	✓	✓	L D R	✓	L D R	L D R

Key to symbols: tick (✓) = all the EWR components met for the corresponding year; L = water level unsuitable; D = duration unsuitable; F = frequency unsuitable; T = timing unsuitable and R = water needs for recruitment not met in that year

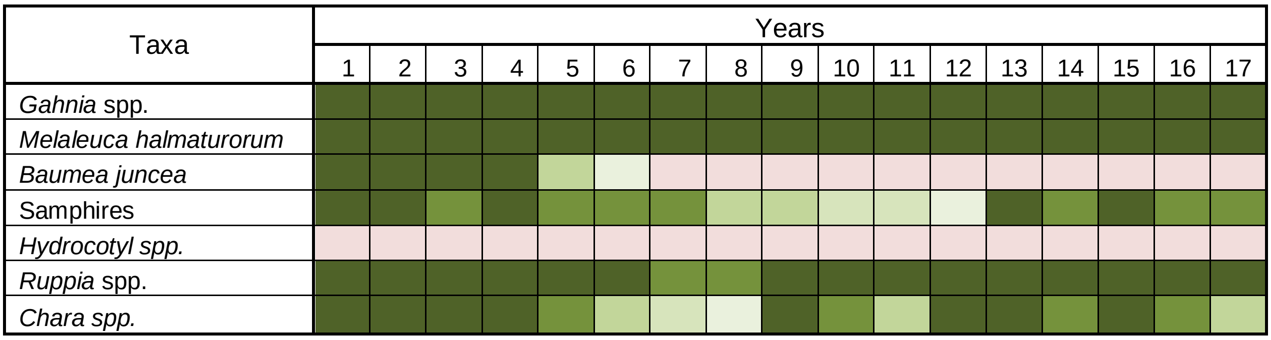


Figure 17. Ecological risk over time diagram for the hypothetical Wetland B under extraction

The overall outcomes for *Baumea juncea* are very similar in Wetland B as they will be in Wetland A. The main differences are that the EWRs for *Baumea juncea* are met more often in the later years, however the threshold of meeting persistence requirements at least once every three years is not occur in years seven and eight. As for Wetland A, this will lead to significant risks to the species persistence in this wetland and it is likely to become locally extinct.

Water requirements for *B. juncea* recruitment are met in the majority of years and would be sufficient to promote a robust and resilient population if persistence water requirements were achieved.

The EWRs for persistence and recruitment of Samphires are met more often in Wetland B than in Wetland A if extraction is occurring. However, the water regime is still suboptimal in Wetland B for Samphires, particularly from years six to 12 where the species is expected to not persist within the wetland other than in the seedbank. The successful recruitment event in year 13 is expected to lead to the re-establishment of the species.

For the entire year, the groundwater level needs to be in direct contact with the spring source for the EWR of the springs to be met. In Wetland B that means the groundwater level needs to remain at or above 2.1 m AHD at all times. This occurs for all but a few weeks in year 12 under the no extraction scenario, suggesting that the springs EWR is effectively met assuming that this short drop in groundwater level below 2.1 m AHD does not prevent re-establishment of spring discharge when levels recover. However, if extraction does occur, the springs are disconnected from their groundwater source most of the time, suggesting that spring flows will be intermittent in years one to four if discharge flows recommence each time the groundwater level reaches the critical 2.1 m AHD threshold. The springs are disconnected from year five onwards, with only brief recovery to 2.1 m AHD in years nine, 12, 13 and 15 which may or may not re-establish discharge. Based upon these regular and probably on-going losses of spring discharge, the complete suite of EWRs for *Hydrocotyle* spp. are considered unlikely to be met at any time given that *Hydrocotyle* spp. depend on permanent standing water (20–100 mm) in the immediate vicinity of the springs. Consequently, it is expected that *Hydrocotlye* spp. will be lost from Wetland B (Figure 17).

The EWR analysis in Table 9 shows the EWR components for *Ruppia* spp. are not met in four out of 17 years and in 10 out of 17 years for *Chara* spp. This analysis is done for the elevations they occupied in Wetland B if extraction was not occurring. Both of these plants are highly dispersive and opportunistic and are likely to be able to shift down the elevation gradient to where their preferred niches lie if some surface water of suitable depth and permanency occurs. Thus Figure 17 shows that both plants persist until year five and then re-establish in years nine and 12 when the groundwater levels increase and surface water returns. The differences in the responses of *Ruppia* spp. and *Chara* spp. are based on their different elevations and water depth requirements and the requirement of *Chara* spp. to germinate underwater.

This assessment clearly shows the relatively high sensitivity of taxa such as *Hydrocotlye* sp. and *Baumea juncea* and relatively low sensitivity of *Gahnia* spp. and *M. halmaturorum* as indicators of change away from the EWRs at a wetland scale.

9. OPTIONS FOR MANAGEMENT

There are a number of mechanisms that can be used to meet any environmental objectives stated within the Musgrave and Southern Basins WAPs. The most commonly used options include 1) varying the quantity of water available for allocation (environmental water provisions (EWPs) and extraction limits); 2) managing the permissible location of extractions (buffer widths around ecosystem assets); or 3) developing policies that can be varied based on triggers.

The implementation of any policies relating to these three options should be in light of meeting the environmental objectives stated in the WAP. This report provides knowledge and a process for assessing the risk of meeting these objectives.

9.1. EXTRACTION LIMITS

Groundwater level and regime is the major driver of groundwater dependent ecosystem (GDE) condition across the Prescribed Wells Areas (PWA) – these levels can be responsive to both climatic and extraction processes. The use of extraction limits is a method by which the risk to GDEs has been managed in a number of existing Water Allocation Plans.

This report provides an understanding on the relationship between changes in the groundwater regime and risks to the dominant aquatic ecosystems within the Prescribed Areas, however to be most effective this knowledge needs to be coupled with an understanding on the relationship between extraction and groundwater regime – a relationship which is currently poorly understood at the scale and resolution required to effectively inform risks to GDEs.

Groundwater studies have shown that the groundwater systems within the PWA tend to be much more responsive to climatic variables than groundwater extractions. This is evidenced in the work presented in Stewart et al. (2012) which shows that due to high transmissivity values, the extraction of groundwater from the lenses within the PWA result in minimal drawdowns, as well as the work presented in Evans *et al.* (2009b) which indicates that all lenses in the Musgrave PWA have experienced declining water levels irrespective of extraction levels. Note however that while expected to be minimal, there is little evidence on how extraction may influence the rate or magnitude of these reductions.

In light of this, at this stage, knowledge and understanding of the relationships between extraction and groundwater regime is too coarse to be used explicitly for the purpose of managing the localised risks to GDEs. However, extraction limits when used to balance the groundwater budget with respect to recharge vs extraction and outflow will still be an effective management tool in preventing regional declines in groundwater levels which may influence risks to GDEs.

Given these uncertainties in the understanding of the relationship between extraction and regional response in the groundwater regime, management options such as buffers (see Section 9.2) are likely to be more appropriate and effective at this time.

9.2. BUFFER ZONES

Extraction of groundwater can cause cones of depression within a watertable, the shape of which is determined by the transmissivity and heterogeneity of the aquifer. These localised drawdowns can have significant impacts upon any GDEs that are within the drawdown zone. A number of existing Water Allocation Plans manage this localised impact of groundwater development through implementing buffer zones around GDEs within which extractions are limited or prohibited.

Low-volume groundwater extractions from the groundwater lenses in the Musgrave and Southern Basins PWAs are unlikely to result in cones of depression (as would typically be seen in sedimentary aquifers) due to generally high transmissivities of the karstic Quaternary Limestone aquifer. However, broad drawdowns are likely where there is an area of concentrated, high-volume extraction, such as that historically observed in the Uley South well field.

Information presented by Stewart et al. (2012) can be used to determine the likely extent of cones of depression around extraction points which, when coupled with the risk assessment process outlined in this report, can be used to manage the risks to GDEs due to extraction.

9.3. TRIGGER LEVEL MANAGEMENT

Policies within WAPs are generally aimed towards meeting a stated social, economic or environmental objective. The environmental water requirements stated within this report and the process outlined for assessment of increased risk to the environment if these water requirements are not met can be used to determine triggers for varying extraction rules so that stated objectives of the WAP can be met. For the Musgrave and Southern Basins PWA, the most relevant trigger will be the target groundwater level/regime required to maintain GDEs at the desirable level of environmental risk stated during the development of EWPs.

The use of trigger levels in groundwater management can be confounded by external factors not attributable to extraction, but rather due to climatic variability or climate change. There is potential that extraction may exacerbate risks to GDEs due to its altering of the groundwater regime, but it is also possible that EWPs will not be met in some years solely due to the influences of climate. This is of particular relevance for the Eyre Peninsula where it appears as though the most significant driver of groundwater level is climate, rather than extraction (as evidenced through the findings of Evans *et al*. 2009b).

To most effectively implement this policy option there is need for a better understanding of the influence of extraction on groundwater levels in relation to the influence of climate.

10. ASSUMPTIONS, KNOWLEDGE GAPS AND MONITORING

10.1. ASSUMPTIONS

In determining the EWRs for the GDEs on the Eyre Peninsula, a number of assumptions have been made. Often, there are little data to support these assumptions, in which case the best scientific advice is used. The major knowledge gaps are listed below.

1. **Wetlands are groundwater dependent unless there is distinct evidence to the contrary.** For many of the wetlands on the Eyre Peninsula, there is some uncertainty as to the major source of water. While considerable advances in our knowledge of the groundwater systems have been made through the EP Groundwater Allocation, Planning & Management (GAPM) Program, detailed descriptions of the source of water for each GDE have not been determined. For example, there is conflicting evidence regarding the dependence of Big and Little Swamps on the regional groundwater system (SKM 2009 vs. Semeniuk and Semeniuk 2007a). For these remaining wetlands, it is assumed that there is some dependency upon regional groundwater. Thus if part or all of that groundwater were made unavailable, it is assumed the ecological character of these wetlands could decline or the wetland feature may cease to exist (Lamontagne 2002).

2. **The water requirements of surrogate taxa are largely met through groundwater processes.** All of the surrogate taxa may partially utilise rainfall as a water source, but the proportion and regime of this dependence is largely unknown. This assumption is appropriate in light of predicted reductions in future rainfall, with each species likely to become increasingly reliant on groundwater as a source.

3. **Stated EWRs have historically occurred at the environmental sites.** It is assumed that the groundwater regime as recommended for each of the GDEs has historically been provided at each of the sites for the majority of the time. While there is a network of observation bores across the Eyre Peninsula, few of these have been located close enough to the environmental assets to validate the stated environmental groundwater requirements.

4. **EWRs for surrogate taxa represent the suite of species present.** It was not feasible to establish water requirements for all the groundwater dependent taxa present in the PWAs so a suite of surrogate taxa was selected. EWRs were determined for these groups with the expectation that if the requirements for these groups were met, then the water needs for other, potentially less common, taxa would also be met. It is possible that the chosen surrogate species are more tolerant to changes in water regime than other taxa they are expected to represent.

5. **EWRs for the representative GDE in a wetland group represent the suite of wetlands present.** Many of the wetland groups are represented by a single main wetland with associated smaller wetlands (e.g. the Hamilton group). The water regime and the flora present at these smaller wetlands have generally not been established and so EWRs have only been developed for a representative of the wider wetland group.

6. **EWRs for each taxon are the same across the study area.** The study area is large and has variable climatic conditions such as temperature and rainfall. It is assumed that the water requirements of each of the surrogate taxa are the same across the study area and different geographic sub-groups of the taxon with different water requirements have not arisen over time.

7. **EWRs for fauna will be met by setting EWRs for vegetation.** Migratory and some terrestrial fauna depend on groundwater availability over different seasons and during dry periods (Hatton and Evans 1998). These include fish, birds using wetlands for feeding and breeding, as well as terrestrial animals such as kangaroos that drink at wetlands, near-shore marine discharges or springs. It is assumed that the provision of a suitable water regime to meet the requirements for the range of water dependent vegetation, from aquatic to terrestrial, inhabiting the representative GDEs identified in this report will satisfy the water requirements for these dependent fauna.

10.2. PRIORITY KNOWLEDGE AND DATA GAPS

Groundwater regime at representative wetland compliance points. For the GDEs examined here, EWRs have been determined at particular points or vegetation zones around or in the basin. The distribution of groundwater monitoring bores does not necessarily correspond to these points. For individual wetlands or wetland groups, the NRM Board should consider establishing compliance points should be established to monitor groundwater (see Section 10.3). This could be achieved through either installing an appropriate monitoring bore network at compliance points, or potentially through relating the height of the existing network of groundwater observation wells to ground levels relative to the shape and elevation of the wetland basins (e.g. take differential GPS readings of the top of the bore casing and on the edge and middle of the wetland basin).

Water sources maintaining ecosystems. It has been assumed that mapped GDEs have some level of groundwater-dependency unless there is contrary evidence. Investment in direct assessments (e.g. for phreatophytic vegetation: pre-dawn water potential/water balance analysis and/or stable isotope analyses) would provide greater understanding of the level of groundwater dependence and potential for vegetative GDEs to switch water resources if alternative water (e.g. ponded rainfall or seawater intrusion) is available. Other methodologies are well documented in the GDE Toolbox (SKM 2007).

Water requirements, life history mechanisms and hydro-ecological relationships of water dependent biota. Much of the information used in documenting the water requirements and implications of not meeting the recommended water requirements by varying degrees is based on expert opinion. Investing in gaining a better understanding on the hydro-ecological relationships for surrogate and non-surrogate taxa will add confidence to the documented implications. Of particular relevance are:

- ***Gahnia*.** Little is known about the recruitment and dispersal mechanisms, so the potential impacts of not providing the EWRs are unclear.
- ***Eucalyptus petiolaris (water gums).*** There is very little information regarding the ecology and ecophysiology of this species which is assumed to be phreatophytic

Distribution of less well mapped GDEs – phreatophytes, springs, marine discharges and hypogean/hyporheic ecosystems. The freshwater spring communities are not well understood and neither is the spatio-temporal extent of the freshening effect of spring water entering more saline environments. Rapid assessment suggests that the salinity around the springs at Sleaford Mere were in the order of 3000 EC in October 2011, whilst the main body of the wetland was in the order of 30 000 EC (K. Muller, unpublished data). The freshened area was only a metre in diameter at the time, although this is likely to vary with season, wetland water level and comparative ground and surface water qualities. The NRM Board should consider undertaking more extensive mapping of the area under freshening influence by the springs and surveying of vegetation and faunal communities associated with the springs is required, not just in Sleaford Mere but also in Lakes Newland and Hamilton and other spring-fed systems.

Very little is known about the location or ecological functioning of marine discharges. Discharges in Kelledie Bay can be readily observed and anecdotal evidence suggests that discharges occur in other locations such as Proper Bay (Tulka) and where the Uley South lens meets the sea. Mapping of the locations of marine discharges and determination of what freshening effect the groundwater has in terms of spatio-temporal extent and biotic composition is required to better inform the potential environmental implications of WAP policy options.

Leijs and Mitchell (2009) have identified stygofauna within the Prescribed Wells Area through sampling observation bores and caves, however this sampling is patchy. Little is known about the water requirements of stygofauna, so knowledge of their distribution is likely to be of limited use until the requirements of these ecosystems are better understood.

Other biota of GDEs. While vegetation surveys are the most common, relatively little is known on the other components of the environment, particularly macroinvertebrates, amphibians and reptiles. Spotted grass frogs were heard calling at Sleaford Mere in January 2011 (J. VanLaarhoven, pers. obs.) and unidentified black tadpoles were observed around the springs in October 2011 (K. Muller, pers. obs.). This suggests that Sleaford Mere supports resident frog populations that are likely to be isolated and unable to migrate to more favourable habitats should conditions at Sleaford Mere deteriorate. Similarly, Fairy terns were observed fishing in October 2011 at Sleaford Mere (K. Muller, pers. obs.), presumably for Small-mouthed hardyheads, which had been previously observed. Small-mouthed hardyheads have been observed in Lakes Hamilton and Newland as well (Wainwright 2007; Semeniuk and Semeniuk 2007a,b). Confirmation of the groundwater-dependent fauna present in the different GDEs and their water regime and salinity tolerances will provide more confidence in stated EWRs, or may lead to their refinement.

Ecosystem components of unsurveyed wetlands. A number of wetlands have little or no data on their biological composition – therefore the suitability of the wetlands used in this report to represent their water requirements is unknown.

10.3. MONITORING, EVALUATION, REPORTING AND IMPROVEMENT (MERI)

The knowledge presented within this report aims to provide a basis for making informed Water Allocation Planning decisions with respect to associated environmental implications. While the process has used the best practices and information available at the time of writing, there have still been significant knowledge gaps that have had to be managed (see Section 10.1 - Assumptions) to provide a useable and useful product. A targeted monitoring program will help to fill these knowledge gaps and validate the information basis upon which this report has been developed. It is essential that this monitoring program includes a transparent process for both evaluating monitoring results and reporting them in a way that implicitly informs the validation and development of the Musgrave and Southern Basins WAPs policy options.

Prior to implementation, the following questions should be addressed to guide the development of a comprehensive monitoring plan:

1. What is the policy question to be informed?
2. What data is required to inform the question and how should it be measured (specific metrics)?
3. How will the data be used (evaluated and communicated) to inform or change a WAP policy?
4. What mechanisms will be used to adapt or change a policy position? (e.g. triggers within a WAP? New iterations of the WAP?)

5. Where and how will it be reported?

For the purposes of this report, the primary policy question addressed can be broadly stated as:

- How do we account for the environment when balancing the triple-bottom-line during the development of Environmental Water Provisions?
  - i.e. What are the risks to GDEs from changes in the groundwater regime caused through the application of WAP Policies?

The secondary question is:

- How does the groundwater regime respond to various extraction scenarios (volume/location)?

The following section discusses the broad monitoring requirements of the primary question, whereas the monitoring required to inform the secondary question requires specific and detailed knowledge of groundwater systems and is outside the scope of this report.

Recent WAPs (e.g. Marne; draft Eastern Mount Lofty Ranges; draft Western Mount Lofty Ranges) in South Australia have developed knowledge that has more transparently informed the environmental implications of Environmental Water Provisions (EWPs) than has previously been achieved. This has been through the development and reporting of hydro-ecological relationships that link ecological risks to changes in water regime as brought about through water extraction. The data required to generate these relationships is often also the data required to test the delivery of EWPs with regard to meeting the environmental objectives of the WAP.

In recent WAPs in South Australia, this data collection has been achieved through applying the principles of the VWASP (Verification of Water Allocation Science Program), which promotes the consolidation of monitoring of both the hydrological *drivers* of ecological change and associated ecological *responders*.

Through monitoring hydrological *drivers* and ecological *responders* over time, it is possible to validate and/or refine the relationships (EWRs) between groundwater regime and quality and changes in the associated dependent ecosystems, animals and plants, as well as helping to define the link between groundwater extraction regimes and groundwater levels maintaining GDEs.

Environmental water requirements presented in this report are based on:

1. Representative wetlands
2. Obligate phreatophytes (e.g. red gums and water gums)
3. Springs
4. Hypogean and hyporheic ecosystems
5. Marine discharges

Very little is known about the distribution, prevalence and EWRs for the hypogean/hyporheic and marine discharge ecosystems that should be the subject of a more detailed investigation (mapping, biotic components, EWRs) prior to the implementation of a monitoring program.

10.3.1. WETLANDS AND SPRINGS

Subject to validation of the assumption that representative wetlands are suitable surrogates (see Sections 10.1 and 10.2) for the wider range of wetlands within the Prescribed Wells Area, then monitoring of these representative wetlands will be the most efficient way of validating and refining the

EWRs stated within this report, as well as reporting on the environmental objectives of the WAP. Table 10 shows the representative wetlands, hydrological components and priority ecosystem components for monitoring.

The aim of monitoring at these sites is to be able to attribute changes in ecosystem condition to changes in the groundwater regime. This can be achieved through monitoring time-series groundwater level and quality at the same location as measurements of ecosystem condition (e.g. vegetation condition and recruitment). This data can be used to generate hydro-ecological relationships that can be used to validate and/or refine the water requirements and ecosystem risks presented within this report, which have been largely derived through the use of expert opinion.

Coupled with an understanding of how extraction influences groundwater levels and quality (which may need to be the focus of a separate investigation), this can be used to report the effectiveness of policy options with regard to meeting WAP objectives and to refine our understanding of how WAP policy options interact with risks to wetland condition.

In the case of springs, a more detailed mapping program may be required prior to the development of a monitoring plan due to the current paucity of information on their distribution.

Table 10. Monitoring needs for representative wetlands

Representative wetland*	**Driver****	**Responder**** (see Section 7 for preliminary species list)
Sleaford Mere	Water depth and salinity (Surface and Groundwater)	• Aquatic and fringing vegetation. • Vegetation and biota associated with fresh groundwater inputs at the northern edge of the wetland.
Lake Pillie	Water depth and salinity (Surface and Groundwater)	• Aquatic and fringing vegetation.
Round Lake	Water depth and salinity (Surface and Groundwater)	• Aquatic and fringing vegetation.
Lake Newland	Water depth and salinity (Surface and Groundwater)	• Aquatic and fringing vegetation.
Springs	Water depth and salinity (Surface and Groundwater)	• Aquatic and fringing vegetation.

*Monitoring the drivers at the Greenly and Wanilla Groups of wetlands would provide suitable information for determining groundwater dependence

**Subject to the development of a detailed monitoring plan

10.3.2. OBLIGATE PHREATOPHYTES (RED GUMS AND WATER GUMS)

Red gums in the PWA have been mapped through the use of remote techniques (remote sensing; depth to groundwater mapping), however there are still unknowns on the actual water use strategies of these assumed obligate phreatophytes. This limits the ability to accurately define the risks of changes in the groundwater regime as may be brought about through extraction.

Similar to the approach taken with wetlands, the goal in monitoring phreatophytes is to determine the relationship between changes in the groundwater regime and red gum/water gum condition (both individuals and populations), so that the influences of groundwater extraction can be assessed.

The first step in this process requires investigation into the water sources maintaining red gum/water gum health (e.g. rainfall/regional groundwater/combination) to ensure that changes in condition can to some degree be attributed to changes in access to suitable groundwater.

Once an understanding of the level of dependence on the groundwater regime has been established then, similarly to the monitoring regime for wetlands, measuring 1) groundwater regime and quality; and 2) red gum condition (individuals and population) will enable the derivation of hydro-ecological relationships. An initial survey of tree condition and response to recent water availability as been conducted in the Polda region using techniques based on Muller (2006) and Souter *et al*. (2010). The results could be used as a baseline and subject to the development of a detailed monitoring program. Initial recommendations are that tree health condition and response surveys should occur every November and March in line with the beginning and end of the effective rainfall period on Eyre Peninsula.

The number of locations at which this should be conducted should also be one of the outcomes of a more detailed monitoring program.

Some of the specific questions to be answered by a robust monitoring and investigation program are:

- What water do the trees use (e.g. perched rainfall, regional groundwater, combination)?
- Do the trees respond in a predictable way to groundwater trends? For example, do they switch water sources during different seasons or at times of high and low groundwater availability? Can sinker roots track groundwater drawdown? If so, what is the maximum groundwater drawdown rate that can be tolerated?
- At what salinity concentrations do trees undergo stress? Is this concentration different for seedlings compared to mature trees?
- What are the recruitment mechanisms of the trees? (e.g. how often does a given stand need to recruit to maintain a resilient demography?).

APPENDIX

ATTENDEES AT WORKSHOP

Jason VanLaarhoven (Chair, DFW, Aquatic Ecologist)

Dr. Darren Alcoe (DFW, Hydrogeologist)

Glen Scholz (DFW, Principal Aquatic Ecologist)

Scott Slater (DFW, Aquatic Ecologist)

Jonathan Clarke (EPNRMB)

Prabodh Das (EPNRMB)

Arkellah Hall (DENR)

Paul Wainwright (DENR)

Dr. Jason Nicol (SARDI)

Dr. Kerri Muller (Kerri Muller NRM)

Tim Doeg (Consultant)

UNITS OF MEASUREMENT

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

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

Shortened forms

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

GLOSSARY

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

Aquatic biota — An association of interacting populations of aquatic organisms in a given water body or habitat

Aquatic ecosystem — The stream channel, lake or estuary bed, water and/or biotic communities and the habitat features that occur therein

Aquatic habitat — Environments characterised by the presence of standing or flowing water

Aquatic macrophytes — Any non-microscopic plant that requires the presence of water to grow and reproduce

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

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

Biodiversity — (1) The number and variety of organisms found within a specified geographic region. (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems

Biota — All of the organisms at a particular locality

BoM — Bureau of Meteorology, Australia

Bore — See 'well'

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

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

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

DENR — Department of Environment and Natural Resources (Government of South Australia)

DfW — Department for Water (Government of South Australia)

DHS — Department of Human Services (Government of South Australia)

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

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

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

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

EP — Eyre Peninsula

EPNRMB — Eyre Peninsula Natural Resources Management Board

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

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

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

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

Hypogean — Located under the earth's surface; underground.

Hyporheic zone — The wetted zone among sediments below and alongside rivers; it is a refuge for some aquatic fauna

k selection — selection occurring when a population is at or near the carrying capacity of the environment, which is usually stable: tends to favor individuals that successfully compete for resources and produce few, slowly developing young and results in a stable population of long-lived individuals.

Macro-invertebrates — Aquatic invertebrates visible to the naked eye including insects, crustaceans, molluscs and worms that inhabit a river channel, pond, lake, wetland or ocean

m AHD — Defines elevation in metres (m) according to the Australian Height Datum (AHD)

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

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

Native species — Any animal and plant species originally in Australia; see also 'indigenous species'

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

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

Population — (1) For the purposes of natural resources planning, the set of individuals of the same species that occurs within the natural resource of interest. (2) An aggregate of interbreeding individuals of a biological species within a specified location

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

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

PWA — Prescribed Wells Area

r selection — Selection occurring when a population is far below the carrying capacity of an unstable environment: tends to favor individuals that reproduce early, quickly and in large numbers so as to make use of ephemeral resources and ensure that at least some offspring survive.

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

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

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

Viable population — A population that has the estimated numbers and distribution of reproductive individuals to ensure the continued existence of the species throughout its existing range in the planning area

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

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

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

WDE — Water dependent ecosystem

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

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

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