Monitoring, Evaluation, Reporting and Improvement (MERI) Plan for the Southern Basins & Musgrave Prescribed Wells Areas WAP

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Executive Summary

This Monitoring, Evaluation, Reporting and Improvement (MERI) Plan presents design and implementation principles aimed at measuring and assessing hydrogeological, ecological and water use parameters for Eyre Peninsula's Prescribed Wells Areas, while also assessing the effectiveness of the Water Allocation Plan (WAP) in meeting its objectives.

A series of evaluation questions have been developed to assess the effectiveness of the policies of the WAP in meeting its objectives (as outlined in Section 8 of the WAP). These have been categorized into three guiding principles for water planning to achieve water security for individuals, sustainability of water resources and equity through a rules-based system for all users (including Groundwater Dependent Ecosystems as a user) and include:

- To what extent has the WAP been effective in allocating groundwater extraction for consumptive purposes?
- To what extent has monitoring of compliance with conditions on water licences, water resources works approvals and permits been effective in managing groundwater resources?
- To what extent has the WAP been effective in managing groundwater use within sustainable levels?
- To what extent has the WAP been effective in minimising the risk of seawater intrusion?
- To what extent has the WAP been effective in minimising the risks to groundwater salinity?
- To what extent has the WAP been effective in minimizing the impact of authorised groundwater extraction on other groundwater resources (adjacent or overlying), GDEs and existing users of groundwater?
- To what extent has the WAP been effective in meeting the community's expectations?

As the objectives of the WAP are specifically related to minimising the impacts on the these systems, should evidence for a decline in the resource become apparent, the reason for such declines will be investigated as part of the evaluation process to determine which interventions are the most appropriate, effective and efficient.

Under the NRM Act, the Board must review the WAP at least once during each period of ten years following adoption of the plan. Consequently, a comprehensive mid-term review to evaluate the effectiveness of the WAP and accompanying MERI plan will be undertaken with a view to address any improvements required. However, it should be noted that this MERI plan is a dynamic document which will be updated as a result of knowledge gained through the MERI process.

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1. Introduction

Planning for a monitoring and evaluation program is essential for achieving efficient and effective outcomes (Markiewicz and Patrick, 2016). This has been assessed and documented for Eyre Peninsula's prescribed wells areas in Werner *et al.* (2011).

Monitoring, Evaluation, Reporting and Improvement (MERI) can be broken down into four key components (Department of Environment, Water and Natural Resources, 2014):

- *Monitoring*: To watch – in the MERI context, it means routine collection of quantitative or qualitative information for the purposes of reporting and/or evaluation.
- *Evaluation*: A structured process of inquiry to discover the worth or relevance of plans, policies, activities, assumptions, decisions or other factors impacting the achievement of planned outcomes.
- *Reporting*: Routine communication of monitoring and evaluation outcomes to stakeholders for the purposes of accountability and informed decision making.
- *Improvement*: "Closing the loop" to ensure that findings of monitoring, evaluation and reporting are considered in decision making with respect to planning or implementation.

Key steps to the development of a successful MERI framework include:

- program theory, program logic and evaluation questions
- integrated monitoring and evaluation plans
- strategies for data collection, management and analysis
- strategies for learning, reporting and communication
- implementation plans

This MERI Plan incorporates all of the above components to develop a comprehensive program aimed at measuring and assessing hydrogeological, ecological and water use parameters, while also assessing the effectiveness of the WAP in meeting its objectives.

2. Context setting

The *Natural Resources Management Act 2004* (the NRM Act) requires the Eyre Peninsula Natural Resources Management Board (the EPNRM Board) to prepare and review the Water Allocation Plan (WAP) for the Southern Basins and Musgrave Prescribed Wells Areas (PWA). Consequently, the EPNRM Board has prepared a new WAP to replace the two previous WAPs for the Southern Basins PWA and the Musgrave PWA, which were adopted in 2000 and 2001 respectively (see Figure 1).

Figure 1: Musgrave and Southern Basins Prescribed Wells Areas on the Eyre Peninsula

By managing the take and use of water from the groundwater resources within the Southern Basins and Musgrave PWAs within the limits set by the WAP, this MERI Plan aims to meet the following objectives:

- Allocate water for licensed consumptive purposes, including (but not limited to) public water supply, irrigation, recreation and mining, in a manner that allows for the long term viability of the water resource

- Minimise the impact of the authorised taking of water on:
    - other water resources (adjacent or overlying water resources)
    - groundwater dependent ecosystems (GDEs)
    - existing users of groundwater
- Minimise the risk of seawater intrusion due to the taking of authorised water in coastal aquifers
- Minimise the risk of increasing groundwater salinities from the authorised taking of water.

In minimising the impact on GDEs the ecological objective of the WAP (see section 3.1.2 of the WAP) is the maintenance and protection of GDEs such that there will be a low level of risk (i.e. no significant detrimental impact) to the present and future health and maintenance of these ecosystems due to the extraction of groundwater for consumptive use.

In preparation of the WAP it is a requirement to ensure provisions are in place to assess the capacity of the resource to meet the demands for water on a continuing basis. Furthermore, a WAP must make provisions for regular monitoring of the capacity of the resource to meet those demands (see section 76 of the NRM Act) and to allow for the evaluation of WAP's effectiveness in achieving its objectives (see section 81 of the NRM Act). DEWNR is responsible implementing the WAP and MERI Plans on behalf of the Minister.

The adaptive management approach outlined in the WAP is wholly dependent on regular and strategic monitoring which will provide information on the status and condition of the resources and provide indications of usage levels and the impacts of climate variability. This MERI Plan has been developed as a dynamic document, which will be updated as a result of knowledge gained throughout the MERI process.

3. Evaluation Questions

Under the NRM Act, the Board must review the WAP at least once during each period of ten years following adoption of the WAP. However, a comprehensive mid-term review to evaluate the effectiveness of the WAP and accompanying MERI Plan will be undertaken with a view to address any improvements required. This review will address the key evaluation questions outlined in this chapter.

MERI is a process designed to support and inform decision making, good governance and knowledge management in the NRM context. The key driver for MERI is adaptive management (Holling, 1978).

As the objectives of the WAP are specifically related to minimising the impacts on the aforementioned systems, should evidence for a decline in the resource become apparent, the reason for such declines will be investigated as part of the evaluation process to determine which interventions, if any, are the most appropriate, effective and efficient.

This MERI Plan includes a series of evaluation questions that have been developed to assess the effectiveness of the policies of the WAP in meeting its objectives (as outlined in Section 8 of the WAP). These have been categorized into three guiding principles for water planning to achieve:

1. Water security for individuals
2. Sustainability of water resources
3. Equity through a rules-based system for all users (including GDEs as a user)

Water security

To what extent has the WAP been effective in allocating groundwater extraction for consumptive purposes?

Annual reviews of the Eyre Peninsula Demand and Supply Statement will provide an assessment of the effectiveness of the WAP in allocating groundwater extraction for consumptive purposes.

To what extent has monitoring of compliance with conditions on water licences, water resources works approvals and permits been effective in managing groundwater resources?
DEWNR Water Licensing will be responsible for all WAP-related compliance issues. Annual extraction data from metered wells will enable us to evaluate whether licensed water extraction remains within the bounds of annual water allocations.

Sustainability

To what extent has the WAP been effective in managing groundwater use within sustainable levels?

Evaluation of annual storage assessments will allow us to determine whether storage in the resources have remained stable, remained within the bounds of historical levels (thereby continuing the long term viability of the resources) or declined.

To what extent has the WAP been effective in minimising the risk of seawater intrusion?

Regular monitoring of salt water interface wells (Appendix 2) will provide data on the current status of the interface. A mid-term review will allow any significant movement of the interface to be identified.

To what extent has the WAP been effective in minimising the risks to groundwater salinity?

Regular groundwater salinity monitoring will provide data on the condition of the resource (Appendix 2). Annual groundwater status reports will evaluate this data and determine whether salinity of the resource has increased and, more importantly, has it increased to a level which is unacceptable for the purpose of the water use.

Equity

To what extent has the WAP been effective in minimizing the impact of authorised groundwater extraction on other groundwater resources (adjacent or overlying), GDEs and existing users of groundwater?

Evaluation of GDE monitoring data (Appendix 1) will provide an assessment of the impact of groundwater extraction on the health and maintenance of GDEs.

The publication of annual groundwater status reports, combined with regular licensee surveys, will be used to determine whether the WAP has been successful in minimising the impact on existing groundwater users.

To what extent has the WAP been effective in meeting the community's expectations?

A biennial survey of license holders and additional key stakeholders will be undertaken to determine whether the broader community believes that the WAP has been effective in meeting its objectives.

4. Monitoring Program

The objectives of the WAP, key evaluation questions and monitoring objectives and monitoring activities have been summarised in Figure 2. Using the principles of adaptive management, this diagram outlines the relationships and links between each of these components of the MERI Plan.

As a result of the different monitoring requirements for each of the monitoring activities, the MERI program has been split into the following categories:

1. Groundwater level monitoring
2. Groundwater salinity monitoring
3. Groundwater extraction
4. Climate parameters
5. Groundwater dependent ecosystem condition
6. Annual storage calculations
7. Community survey

4.1 Groundwater Level Monitoring

Groundwater level trends give an indication of the state of the balance between the natural discharge processes and extraction (outputs) and the variable recharge from rainfall (inputs).

Water level trends of the Quaternary Limestone aquifers in Southern Basins and Musgrave PWAs are strongly connected to rainfall (refer to Figures 9b and 10 in WAP). Water level declines are observed when discharges from the aquifer (which may also include extraction) are higher than the recharge entering the aquifer. Conversely, water level rises are observed when recharge exceeds the groundwater discharge.

A selection of wells in the existing monitoring network will be monitored by DEWNR every six months for the purposes of continuing to monitor long term and seasonal trends in groundwater level variations (Appendix 2). A subset of these wells will be monitored with a data logger to provide a more continuous data record and allow for future optimisation of the water level monitoring network. This data will be telemetered to allow near real time visualisation of the data on the WaterConnect website.

Monitoring water level trends also gives early warning of levels potentially reaching critical limits. For example, levels falling toward sea level (0 m AHD) would indicate a higher risk of sea water intrusion which can occur if levels continue to fall. A select number of wells located adjacent to the coast in the Uley South Public Water Supply (PWS), Coffin Bay PWS and Lincoln South PWS consumptive pools will be monitored for this purpose. Ideally these wells will be constructed with long screens or as nested piezometers to aid in the measurement of salinity profiles.

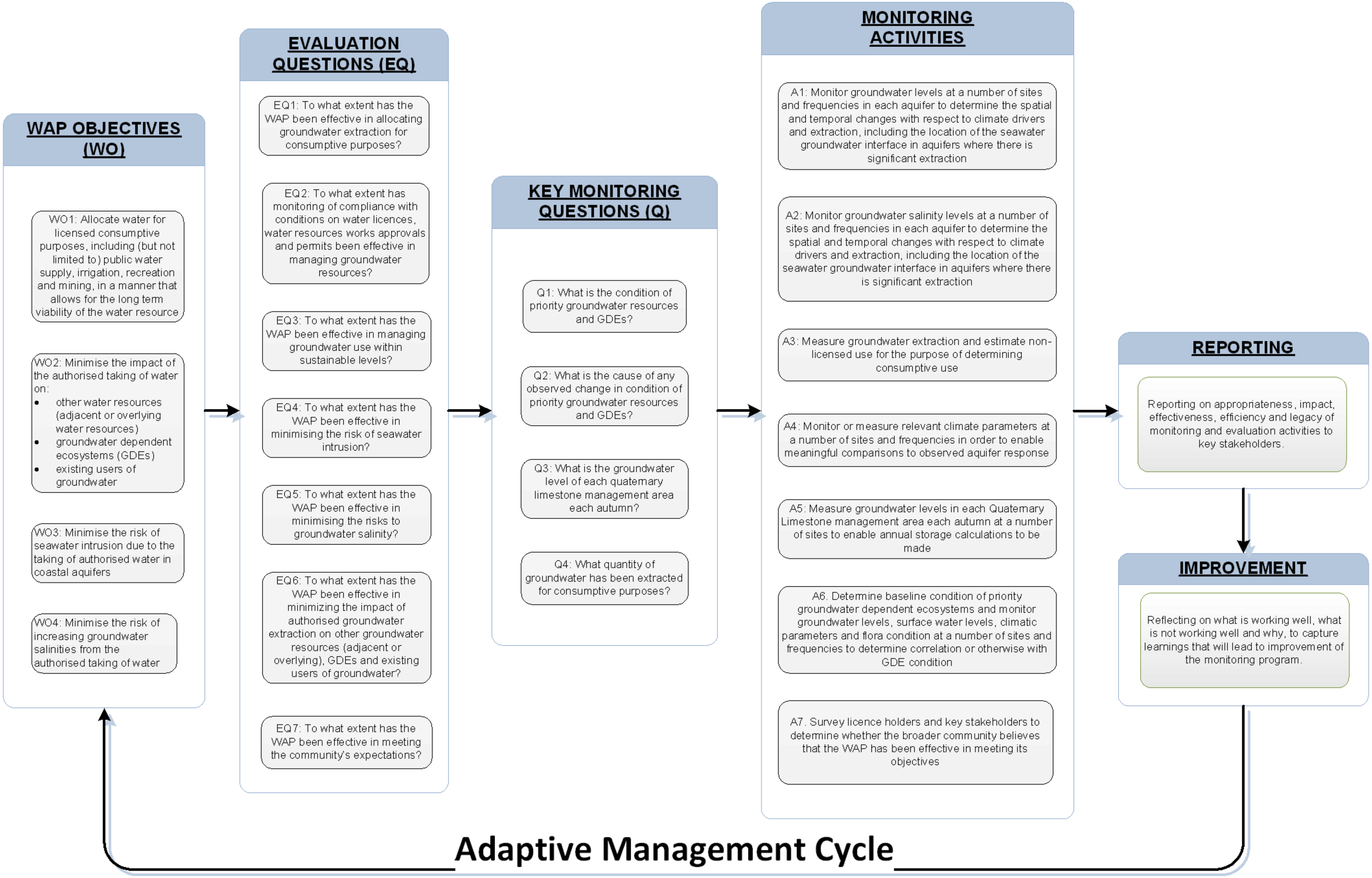

Figure 2: WAP MERI adaptive management cycle

Groundwater levels are important for the health of GDEs and changes in level may explain why changes in the condition of GDEs occur (see section 3.4.1 of WAP and Appendix 1 for further detail).

4.2 Groundwater Salinity Monitoring

As with water levels, salinity trends can give an indication of the state of the balance between the discharge processes (that can increase groundwater salinity by evapotranspiration in areas of shallow watertables) and the recharge inputs from rainfall that can freshen groundwater.

Salinity trends can also assist in preventing unsustainable extraction levels by giving an early warning of sea water intrusion or the upconing of saline groundwater which may underlie the fresher groundwater being pumped.

Salinity in production wells from which significant volumes are extracted can vary rapidly. Over-extraction from production wells can disturb stratification in an aquifer, causing upward coning of higher salinity water into production zones.

Because the processes that add or remove salt from aquifers are slow, the rate of change in groundwater salinity is also slow. Therefore, in most cases the monitoring frequency for salinity does not need to be as frequent as that for water levels. A network of wells have been identified for salinity monitoring annually (Appendix 2). Furthermore, in a select number of the wells located adjacent to the coast in the Uley South PWS, Coffin Bay PWS and Lincoln South PWS, the salinity gradient will be monitored annually by using a downhole probe (or sonde).

It should be noted that other groundwater quality parameters (e.g. nutrients, metals etc.) may be monitored periodically by the EPA where the groundwater is used for public water supply.

4.3 Groundwater Extraction

Groundwater in the PWA can be extracted and used for licensed (e.g. irrigation, town water supply and mining) and non-licensed (e.g. stock and domestic) purposes. The volume of water available for licensed use in the Quaternary Limestone aquifer is varied annually depending on the aquifer storage level.

As part of the WAP process, it is a requirement that demand for stock and domestic water must be estimated for each consumptive pool. Notwithstanding this requirement, the logistics and cost of measuring stock and domestic extractions would be cost prohibitive. While stock and domestic water use is not licensed in the PWAs, it is important to account for this use because both licensed and non-licensed demands are met from the consumptive pools.

The methods used and results with regard to estimated stock and domestic water demand for the PWAs are documented in Stewart *et al*. (2012), Stewart (2013) and are outlined in the WAP. These volumes are fixed for the life of the WAP.

All licensed extraction points from which water is extracted must have a suitably calibrated meter to measure the annual extractions and to determine if they are within the allocation limit. The extraction data is also useful for assisting the calibration of groundwater models where they exist.

Where a water allocation in excess of 100ML/yr has been granted, additional salinity and water level data can be collected in accordance with conditions on a water resources works approval, should the Minister require the holder of the approval to provide this information. Principle 35 in the WAP provides the Minister with the power to request this information via an Annual Water Use Report.

4.4 Climate Parameters

Climate data, primarily in the form of rainfall data, is important for establishing an understanding of long term rainfall-recharge relationships, but is not used for determining the volume of water available for licensed purposes annually.

The Bureau of Meteorology currently operates three rainfall stations in and around the Southern Basins PWA (Coffin Bay, Port Lincoln – Big Swamp, Port Lincoln – Westmere) and seven rainfall stations in and around the Musgrave PWA (Elliston, Elliston – Three Lakes, Elliston – Oaklands, Elliston - Lambing Station, Mount Wedge, Lock – Terrah Winds and Lock – Keriody).

In addition to this, pluviometers that measure rainfall total as well as rainfall intensity are located in the Polda Basin, Uley South Basin and Coffin Bay. Additional sites have recently been installed in Uley Wanilla and Lincoln South basins as part of the new WAP. The number of rainfall stations and their locations is sufficient to provide a reliable estimate of the rainfall falling on the recharge areas of the various consumptive pools, but is not used to calculate annual water allocations.

4.5 Groundwater Dependent Ecosystem Condition

Wetlands and phreatophytes (especially red gum forests and woodlands) have been identified as priority GDEs on Eyre Peninsula (Doeg *et al*. (2012), Semeniuk and Semeniuk (2007), SKM (2009)). However, the baseline condition of priority GDEs on Eyre Peninsula has not yet been determined. Methods for determining these have been outlined in Appendix 1.

The water needs of GDEs are described in section 3 of the WAP and the principles for the maintenance and protection of GDEs are included in sections 6 and 7. In order to evaluate the success of these provisions, a program targeting priority GDEs in management areas where extraction is occurring and at representative control sites will ensure baselines are established.

This will enable critical hydrogeological and ecosystem parameters to be monitored, including:

- Establishing a baseline and monitoring changes in groundwater level and salinity for wetlands and groundwater dependent vegetation;
- Establishing a baseline and monitoring changes in vegetation species condition, composition and abundance for wetlands and groundwater dependent vegetation.

The groundwater monitoring referred to in previous sections has been well established since 1940 in the Uley Wanilla Basin and became widespread later in the Southern Basins and the Musgrave PWA areas in the 1960s.

By contrast, this WAP includes the first targeted GDE monitoring to be developed for the PWAs. This has required the determination of a GDE monitoring program scope, a rationale for site selection and program for baseline establishment to be defined prior to establishing the GDE monitoring program outlined in Appendix 1 and has drawn heavily on Semeniuk and Semeniuk (2007), Doeg *et al.* (2012) and Deane and White (2014).

4.6 Annual Storage Calculations

A detailed methodology for calculating the annual storage volumes for the various Quaternary Limestone aquifer consumptive pools, and in turn the water available for licensed requirements, is outlined in Chapter 8 of the WAP.

In order for the allocation methodology for the Quaternary Limestone aquifer consumptive pools outlined in the WAP to be successful, a select number of monitoring wells are required to be monitored annually in autumn when the water table is normally at its lowest seasonal elevation before winter recharge occurs.

4.7 Community Survey

License holders and other key stakeholders will be surveyed biennially to determine whether the community believes the WAP has been successful in meeting its objectives.

5. Data collection, management, analysis and synthesis

Appropriate management of environmental knowledge enables the right information to be available to the right users in the right format at the right time – both now and in the future. For an effective long-term monitoring program to be achieved, all monitoring data must be collected, maintained and analysed in a systematic and thorough manner.

All data collected through this MERI plan will be managed as part of DEWNR's Information Management Framework. A summary of the type of information collected, where it will be stored and how it can be accessed has been summarised in the following table.

Information type	Output format	Storage location	Access
Groundwater level data	Database tables, spreadsheets	WaterConnect	www.waterconnect.sa.gov.au
Groundwater salinity data	Spreadsheets	WaterConnect	www.waterconnect.sa.gov.au
GDE monitoring data	Data sheets, spreadsheets, images	Local DEWNR database	
Community survey responses	Data sheets, documents	Local DEWNR database	
Annual report cards	Documents	Enviro Data SA	data.environment.sa.gov.au
Groundwater status reports	Documents	WaterConnect	www.waterconnect.sa.gov.au

6. Learning, reporting and disseminating

Annual groundwater status reports for the Southern Basins and Musgrave PWAs will be prepared by DEWNR and published on the WaterConnect website at www.waterconnect.sa.gov.au.

Annual report cards that assess the condition and trend of priority GDEs will be produced and published on the Natural Resources Eyre Peninsula website at www.naturalresources.sa.gov.au/eyrepeninsula.

Results of the biennial community survey into the community's perception of the WAP in meeting its objectives will be published on the Natural Resources Eyre Peninsula website.

As increased knowledge of Eyre Peninsula's groundwater systems drive the need to adapt our monitoring approach, the MERI Plan may be revised to reflect these changes. The community will be notified of any changes and an updated MERI Plan will be published on the Natural Resources Eyre Peninsula website.

Furthermore, as guided by the NRM Act, the EPNRM Board must review the WAP at least once during each period of ten years following adoption of the WAP. Consequently, a comprehensive mid-term review to evaluate the effectiveness of the WAP and accompanying MERI Plan will be undertaken with a view to address any improvements required.

7. Planning for implementation

Timeframe	Description	Responsibility	Timeframe
Lincoln North Monitoring	• Lincoln North consumptive pool currently has no monitoring wells within the network and new sites are required. Possible locations within the pool are currently being investigated by the DEWNR Resource Monitoring Unit, which will be verified through hydrological assessments, with installation of equipment estimated to be completed by June 2016.	• DEWNR	• June 2016
Additional telemetered wells	• To strengthen baseline monitoring two new telemetered monitoring wells have been added to the network in Uley Wanilla and Lincoln South. These site will enable additional data to be collected to measure rainfall total as well as rainfall intensity.	• DEWNR • NREP	• Completed
Optimisation of monitoring network	• Classification of the State water monitoring network is currently being implemented through the optimisation project, which was undertaken cognisant of the new EP WAP. Site classification integrates a site status and high level function into the management of the network to ensure that the network continues to support improved and robust decision making. • The optimisation process enables review of the monitoring network to ensure continual improvement and prioritisation of monitored sites in response to evaluation outcomes of the MERI Plan. An EP working group has been established under the optimisation project to undertake future review of the network.	• DEWNR	• June 2016 • Annual if required
Licensing conditions for groundwater monitoring	• Where a water allocation in excess of 100ML/y has been granted, additional salinity and water level data can be collected in accordance with conditions on a water resources works approval, should the Minister require the holder of the approval to provide this information. This matter needs to be considered further and if condition of licence is required for some users, appropriate approvals, systems and processes will be required.	• DEWNR	• June 2016
Saltwater/Freshwater interface	• Improved monitoring of the saltwater interface is proposed for the Uley South PWS, Coffin Bay PWS and Lincoln South PWS. The most effective way of achieving this through utilisation of either downhole probes or sondes. This needs to be investigated, with the suitability of wells assessed and monitoring regime requirements.	• DEWNR	• Year 3
Annual water use reporting	• Annual water use reports may be required (as a condition on a Water Resource Works Approval) and as such standard operating procedures may need to be developed to	• Licensees • DEWNR	• Year 1

Timeframe	Description	Responsibility	Timeframe
	guide this process and to ensure systems are in place to verify compliance with this condition.		
Rainfall total and intensity monitoring	• The Bureau of Meteorology currently operates three rainfall stations in and around the Southern Basins PWA and seven rainfall stations in and around the Musgrave PWA. In addition to this, pluviometers that measure rainfall total as well as rainfall intensity are located in the Polda Basin, Uley South Basin and Coffin Bay, which will be added to through Project 2. The number of rainfall stations and their locations is sufficient to provide a reliable estimate of the rainfall falling on the recharge areas of the various consumptive pools, but is not used to calculate annual water allocations. Processes need to be developed to ensure effective collection and collation of this measure.	• DEWNR • NREP	• Ongoing
GDE monitoring preparation	• Define GDE and Wetland survey requirements and produce field data sheets and booklets in readiness for commencement of monitoring program • Determine data storage requirements and processes that need to be established • Define survey methodologies to be utilised and document this • Identify survey team and provide suitable training and ensure a program is in place to provide ongoing training and support	• NREP	• June 2016
Establish and maintain GDE Monitoring program	• Utilising Site Selection criteria (Appendix 1) identify preferred sites for the GDE, wetlands and Phreatophyte monitoring • Ensure baseline is completed by Spring 2016. • Establish ongoing monitoring program of all identified sites. • Ensure protocols and processes are developed for each monitoring activity to maintain data integrity, improve collection, management, storage and retrieval of data and other information consistently. This needs to be done in close consultation with DEWNR Knowledge Management Unit.	• NREP	• Year 1 (Spring 2016) and ongoing
Annual storage calculations	• The processes used to calculate the annual storage will need to be documented to ensure consistency in application through the life of the WAP. • The level of storage for each water use year will be derived from monitoring data obtained from the nominated groundwater observation wells listed in Appendix 2 and will be calculated using the 3D AquaveoTM Arc Hydro Groundwater software package or an equivalent package.	• DEWNR • DEWNR	• June 2016 • Ongoing

Timeframe	Description	Responsibility	Timeframe
Determining Annual allocations	• Once the annual storage calculations are completed the actual allocation for each year will need to be determined. A gazettal notice will be required annually detailing: • the level of storage of each consumptive pool calculated as a percentage of the reference level storage as determined by the means set out in this Plan; and • the consumptive pool volume of each consumptive pool. • A standard operating procedure needs to be documented with systems in place to ensure gazettal is published on or about 1 June of the preceding water-use year.	• DEWNR	• Ongoing
Standardised data management processes	• Protocols, policies, procedures and standard operating practices need to be identified or developed for each monitoring activity to maintain data integrity, improve collection, management, storage and retrieval of data and other information consistently. This needs to be done in close consultation with DEWNR Knowledge Management Unit	• DEWNR • NREP	• Year 1
Centralised data systems	• Current data storage systems within NREP need to be reviewed, with an aim to centralising data availability to all staff. Consideration also needs to be given to community accessibility to some levels of data, licensing or ownership restrictions. The centralised system needs to have capacity to store all data or have linkages to other existing data storage facilities (e.g. NRIMS etc). It needs to include a glossary, map and advanced search functions to ensure ease of use.	• DEWNR • NREP	• Year 1
Community engagement plan	• A community engagement plan for the WAP will be developed prior to the actual commencement date of 1 July 2016. This will include direction on how changes to the MERI will be communicated	• NREP	• June 2016
Understanding the WAP	• Identified through the WAP consultation process was the need to develop a plain English publication to assist members in the community to read the WAP. This body of work needs to be scoped and produced prior to commencement of the WAP in July 2016	• DEWNR • NREP	• June 2016
Inclusion of WAP activities in Citizen Science Strategy	• A broader Citizen Science Strategy is being developed, which will incorporate wherever possible opportunities for Citizen Scientist to be involved in WAP monitoring activities.	• NREP	• Year 1
Compliance checks	• Throughout the life of the WAP compliance checks of licenses will be required and standard operating procedures will be needed for this, as well as data storage and escalation. These SOPs need to be in line with DEWNRs compliance management system.	• NREP	• Year 1

Timeframe	Description	**Responsibility**	**Timeframe**
Evaluation plan	• Scoping of evaluation requirements for both the WAP and the underpinning MERI plan is required. This should be undertaken in the initial stages of implementation to ensure that the appropriate metrics are incorporated in all project activities. Completed May 2016, with evaluation requirements strengthened in the WAP.	• NREP	• Completed

8. Appendices

Appendix 1: Terrestrial Groundwater Dependent Ecosystems (GDEs) on Eyre Peninsula

Overview

The GDEs of Eyre Peninsula are important biodiversity assets that face many types of human induced ecological stress, such as groundwater extraction, habitat fragmentation and salinisation. These stressors interact with the highly variable semi-arid climate to create an elevated, but uncertain, level of risk to ecosystems.

Although detailed knowledge of hydrological and ecological processes of water dependent ecosystems on Eyre Peninsula is lacking, considerable progress has been made in mapping and classifying GDEs. This monitoring plan builds upon a range of prior research into GDE's on Eyre Peninsula:

- Semeniuk and Semeniuk (2007) undertook the definitive field and desktop studies to develop a wetland classification system based on similarities in structure and function, in the process installing a monitoring network at selected wetlands
- Spatial data on vegetation distribution from biological surveys of South Australia
- Two wetland inventories undertaken by Department for Environment and Heritage (Seaman 2002, Wainwright 2008)
- Doeg *et al.* (2012), who selected representative wetlands within the Musgrave and Southern Basins PWAs and articulated some general environmental water requirements (EWRs) and conceptual models of wetland function
- Studies on phreatophytic vegetation, each using contrasting methods:
    - SKM (2010)
    - the Australian Groundwater Dependent Ecosystems Atlas (GDE Atlas 2012) http://www.bom.gov.au/water/groundwater/gde; and
    - time series Landsat data analysis integrated with the previous two studies (White *et al*. 2014)
- A set of design principles for monitoring representative wetlands (Deane and White 2014)

Using a spatial analysis model based on three independent datasets (NDVI, GDE Atlas and SKM, 2009), White *et al*. (2014) determined the likelihood of vegetation across Eyre Peninsula being dependent on groundwater. They determined four probability based categories (Very High, High, Moderate and Unlikely) of groundwater dependence. This MERI Plan relates only to those elements of groundwater dependent vegetation that lie within the Southern Basins and Musgrave PWAs.

Both the Southern Basins and Musgrave PWAs contain a number of Quaternary aquifers which contain fresh groundwater (below 1000 mg/L) and also areas of brackish or more saline groundwater. The size and extent of the freshwater lenses varies depending on the rainfall patterns. The vegetation found in association with the aquifers also varies greatly across the region, and much of it does not appear to be dependent on groundwater.

Terrestrial wetland groups within the PWAs known to have groundwater dependency are:

- Southern Basins PWA: Pillie wetland group; Sleaford wetland group; and Wanilla wetland group (Figure 3).
- Musgrave PWA: Poelpena wetland; Newland wetland group; and the Hamilton wetland group (Figure 4).

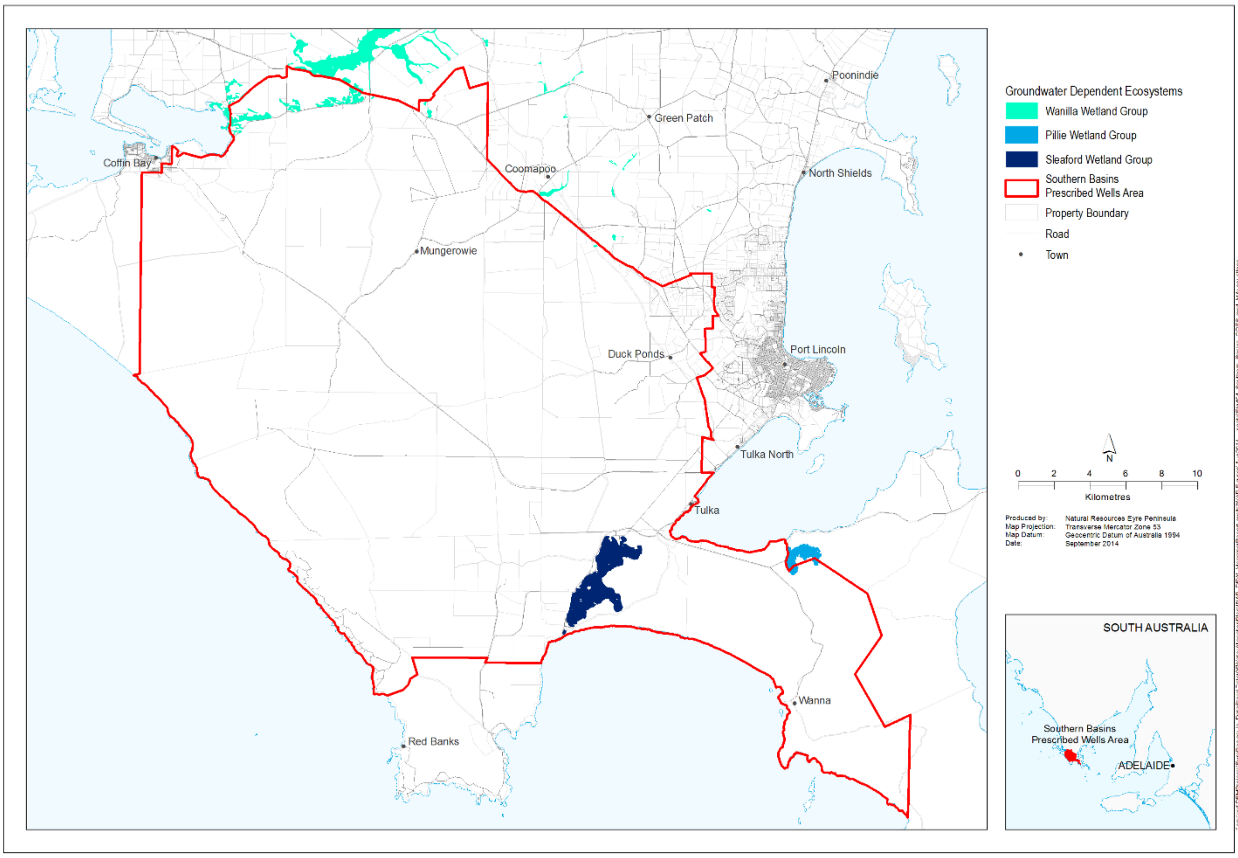

Figure 3: Wetland groundwater dependent ecosystems (GDEs) of the Southern Basins PWA

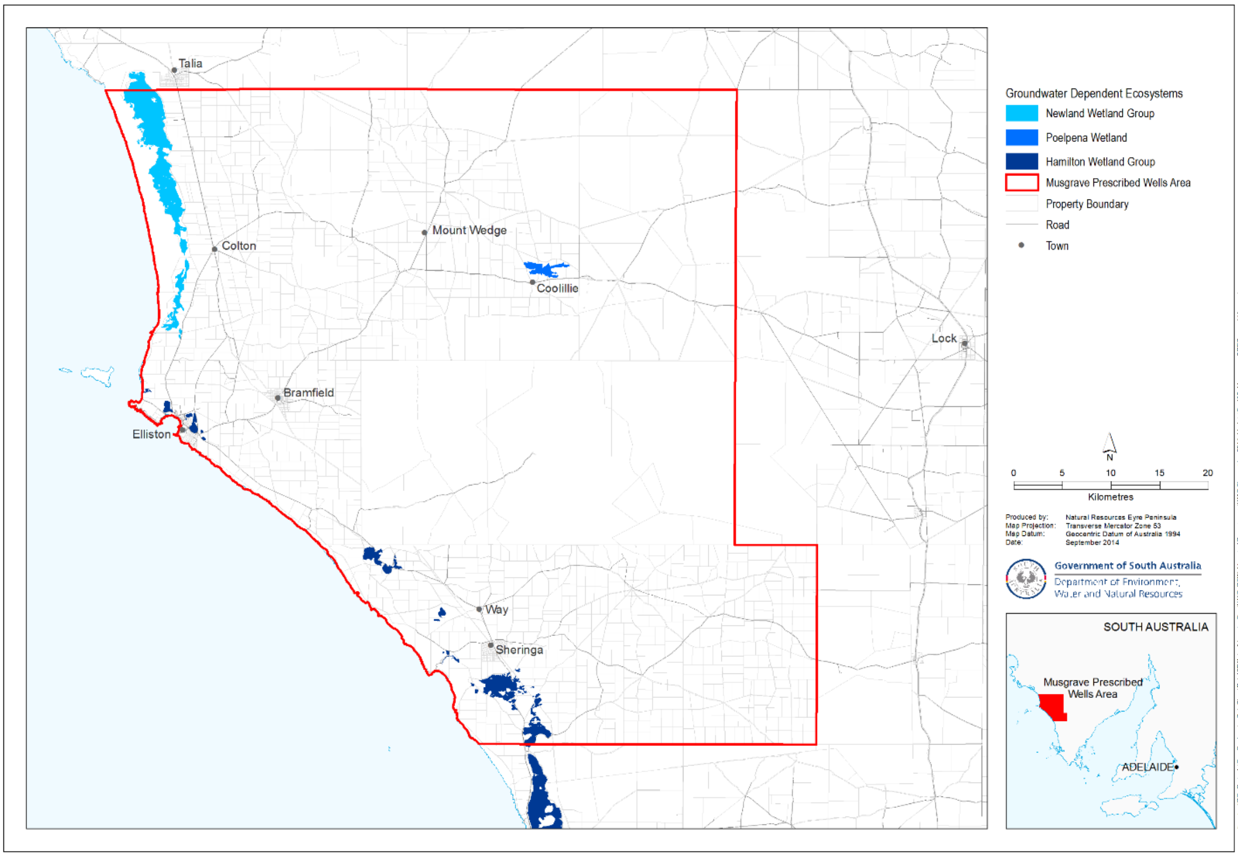

Figure 4: Wetland groundwater dependent ecosystems (GDEs) of the Musgrave PWA

GDE Monitoring Program Scope

The aim of developing a GDE monitoring program for the Eyre Peninsula is to relate the condition of vegetation associations dominated by aquatic plant functional groups to Quaternary aquifer watertable dynamics. Geographically, monitoring recommendations are limited to the Southern Basins and Musgrave PWAs. From a hydrological perspective, the scope is constrained to the Quaternary aquifer, the source of groundwater that is most heavily developed in the region. This program addresses the previously identified working hypotheses as to how the Quaternary aquifer may function to provide a source of freshwater for these vegetation associations.

Biologically, investigations are limited to plant functional groups identified in Doeg *et al.* (2012) as reliant on conditions of persistent saturation that can only result from the presence of groundwater. This study considers only groundwater dependent ecosystem types consisting of phreatophytes and wetlands.

The MERI program proposed seeks to answer the following questions:

1. For a given range in watertable dynamics, which plant functional groups are most likely to be present?

2. What are the critical characteristics of watertable dynamics that are associated with a given plant functional group being maintained in good condition (or, alternatively which dynamics lead to degraded condition)?

This MERI program seeks to determine the point at which water limitation will lead to a discernible change in existing vegetation condition. To meet this aim, site selection is stratified to measure a range of observed conditions for each plant functional group. For the purposes of this program, aquatic functional group populations observed in November 2014 (Deane and White 2014) to be in good condition (as defined later) are assumed to be receiving adequate groundwater supplies, while those in poor condition are not.

Data from the proposed program should, over time, identify clear depth-duration thresholds that would be expected to support a given plant functional group in good condition. However, sub-lethal changes in watertable dynamics that may lead to vegetation being present, but in a degraded condition will be more difficult to determine. Such understanding can only be developed as data accumulate on the range of hydrological and biological variability that maintains sites within their observed condition. Over successive years of such monitoring, measures of acceptable average watertable variations (and confidence intervals) can be established. Any sites where these data indicate these thresholds are being approached should be targeted for more intensive monitoring effort as many insights may be gained into temporal vegetation dynamics as water becomes limiting at such sites. Collection of biological data from more technically difficult physiological measures of plant performance may also be required in such a situation.

In order to start answering these questions, a minimum commitment to this monitoring program may be up to five years to adequately capture varying biological and climatic conditions. A complete data analysis and review of monitoring network adequacy against the design aims is recommended as being undertaken in line with WAP mid-term review. It should also be recognised that understanding about sub-lethal and early warning indicators of change will require a longer term investment.

GDE study populations

The aim of a monitoring program is to collect data at a suitably large representative sample so that generalisations over the entire study population can be undertaken. On the Eyre Peninsula, two major classes of GDE study populations have been identified for monitoring: 1) phreatophyte vegetation associations and 2) wetlands. The size of the study populations is described below.

Phreatophyte communities

For phreatophytic vegetation, the focus of this proposed monitoring program has been on the Musgrave PWA where issues have arisen over recent years with declines in *Eucalyptus* *camaldulensis* (red gum) condition (Deane and White 2014). The study population for phreatophytes in this case includes all mapped stands of phreatophytic Eucalyptus vegetation within the Musgrave PWA, which defines the range of potential sampling sites. Analysis of DEWNR corporate GIS data (feature class: VEG.SAVegetation.shp, accessed Dec 2013) indicates this constitutes 144 stands of red gum, with a total mapped area of 3797 ha. Mean patch size is 26.4 (±58.0 SD) ha. Another phreatophyte of significance in the region is *Eucalyptus petiolaris*, (the Eyre Peninsula blue gum or water gum) which is mapped as occurring in mixed stands with *Eucalyptus odorata* (peppermint box) across the Musgrave PWA. Although less suitable as study plants owing to their relative rarity, these are an important consideration from a conservation perspective and could form the subject of follow up studies.

Red gums 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). They 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 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 Southern Basins and Musgrave PWAs are not riparian, 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 generalised 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.

As red gum stands of widely differing observed condition were identified within the Musgrave PWA, control sites (where no apparent degradation has occurred) can be identified from among this study population on an assumption of no impact.

Sampling sites have been selected on the basis of observed condition during field survey with current status being determined by qualitative comparison of relative: canopy density, colour and thickness; stem density; and the range and relative condition of age classes present. An additional criterion of proximity to extractive pressure (high for impact sites, low for controls) was added.

Melaleuca halmaturorum is defined as a facultative phreatophyte, meaning it will use groundwater if present. However, presence of the species alone is not diagnostic of groundwater being available. The species is often, though not always, found in an association with *Gahnia trifida* or *G. filum* at varying density within the region. A total of 94 patches of this association are mapped within Musgrave PWA for a total area over 4300 ha (mean patch size: 46±194.3 ha). Anecdotal evidence from field inspection where *Gahnia* has been almost entirely cleared while *M. halmaturorum* persists suggest a possibility that under some conditions *Gahnia* may rely on the moisture supplement created via hydraulic lift from *M. halmaturorum* when groundwater is within its root zone. Similar moisture supplements may apply to other shallow rooted vegetation found in association with phreatophytes in the region. It is important when managing for possible ecological impacts of water planning decisions, that any dependence on Quaternary aquifers can be established for both *M. halmaturorum* and *Gahnia* spp independently and in association. Hence while *M. halmaturorum* is not a focus of phreatophyte monitoring, some sites where it is present in both the Southern Basins and Musgrave PWAs are suggested for monitoring in order to gather evidence for groundwater dependence of both or one of these species.

Wetlands

The sampling population for study wetlands extends to each consanguineous suite (Semeniuk and Semeniuk 2007) considered to have a Quaternary aquifer groundwater dependence. Following preliminary investigations and community consultation, two wetland suites were selected from Southern Basins PWA:

- Sleaford wetland group (6 wetlands totaling 755 ha)
- Pillie wetland group (1 wetland totaling 38.4 ha)

The value of monitoring a wetland increases when more than one plant functional group is present. In particular, contiguous zones where multiple plant functional groups merge into one another offer good opportunities for data collection on both groundwater and multiple plant groups. The aim is to establish the variation in conditions across the hydrological gradient that leads to vegetation zonation and the detection of the different thresholds between plant functional groups. The most efficient approach is to direct monitoring effort to places where the turnover of species / communities is great over a small area. This allows small numbers of groundwater wells to be linked to observations of a number of different plant functional groups.

Spatial scale: GDE program extent, study sites and sampling units

Spatial scale can be defined by study grain and extent. Grain is the size of the minimum sampling unit (e.g. quadrat), while extent is the overall area over which the study is undertaken (Downes *et al*. 2002). This MERI program seeks to provide data from which we can infer the relationship between groundwater and vegetation condition across the study extent. Successful inference requires adequate replication to estimate variability at the scale at which questions are posed. In this case a zone of a given plant functional group is the level for replication, but this is slightly complicated as some functional groups may be found in either phreatophyte or wetland landscape settings (e.g. *Gahnia* may be an understorey species or form a monocover where it is the only species present). It is assumed that wherever a given species is observed, its water requirement (plant functional group) will be comparable.

For program design consistent terminology is required:

- **Study sites** – Each separate location where data will be collected is referred to as a study site. Each study site requires at least one measurement of groundwater dynamics and one biological response. Study sites can be either based on phreatophyte or wetland habitats. If conditions warrant, more than one study site may be present at a single GDE, but the term 'study site' implies the presence of a dedicated groundwater monitoring network. Therefore more than one plant functional group may be present at a study site and referenced to the same monitoring network;
- **Sampling units** – as zones of plant functional groups (PFGs) are the variable of interest, this is what needs to be replicated to provide the understanding of watertable response across the different habitats in which it is observed for the study extent. Within each sampling unit, multiple measurements of vegetation response are necessary in order to obtain a level of confidence in the precision of this point estimate – the variance. Each PFG at a study site can be viewed as a sampling unit, and replicate measurements taken at each sampling unit are referred to as sub-samples.

Owing to differences in climate and other physiographic variables and the large distance between their boundaries, it could be argued that there are really two separate study areas corresponding to the two PWAs of the Southern Basins and Musgrave. As discussed, some species are also found in more than one habitat type (e.g. *Gahnia* is found in phreatophyte woodlands and wetlands). For this proposed monitoring program and for immediate water allocation planning purposes, cautious use of data from one area to infer responses across the region will be applied. The validity of this decision will not be known until data can be evaluated and levels of consistency in response can be observed.

Minimum levels of replication are essential to ensure between-site variations not related to watertables can be accounted for within data analysis and interpretation. Covariates that may affect observed vegetation response and confound the response to the major explanatory variable (watertable) include land use and physiographic conditions (e.g. climate, soil type, geology).

A rationale for site selection

Each potential study site for a monitoring network brings a range of possible values for managers to consider in final design decisions. Monitoring a degraded site can give information on unacceptable watertable levels, but cannot provide information on water requirements to maintain good condition. Other questions relate to whether the source of groundwater used by vegetation is the same as is extracted for human needs. Monitoring can help clarify some of the key processes supporting vegetation and help to target more detailed quantitative investigations to discern finer detail about the relationship between groundwater and dependent ecosystems, provided the questions are understood during the design phase.

A monitoring program design requires consideration of the value of the information each site presents for management and an explicit process of prioritisation against current and foreseeable management priorities is recommended. Potential sites can be matched to specific information needs in an objective manner, producing the best value network with clear information objectives for the monitoring program. This also helps to establish the context set out for each sampling site within the program.

Additional decision points for program design

Best practice design principles would incorporate a power analysis to determine a suitable number of samples (replication) for a given effect size of interest (how large a difference in condition do we need to be able to detect) based on the variability in response and a specified level of statistical certainty (Downes *et al*. 2002). As there is effectively no information upon which to conduct a power analysis, monitoring proposed herein fills the role of a pilot program contributing this critical information to future program refinement.

Establishing these two criteria (effect size and power) should be viewed as a critical element of the first review and data analysis phase.

Final sites suggested herein fall into two categories:

- Sites that appear currently to be maintaining ecological viability (based on observed density, condition and age classes); and
- Sites which were evidently under stress or have possibly transitioned from former functional groups to a new assemblage.

Time series biological data were not available to determine vegetation condition at potential sites, so apparent condition was assessed during field visits in June and November 2013 (Deane and White 2014). Sites were compared for compositional similarity with mapping units created by Department of Environment and Heritage (feature class: "VEG.SAVegetation.shp", accessed Dec 2013) and were assessed relative to each other based on observed density and qualitative condition indicators.

Although replication is a sound scientific aim, in such a resource and information limited situation as presents, this should not be prioritised at the expense of improved coverage of gradient extremes. Where duplication does occur within a given GDE class or vegetation association, it should be at opposite ends of the condition gradient, hopefully allowing for unambiguous interpretation – in other words where there is either adequate water supply or not. Hence aiming for the best and worst examples of each plant functional group (PFG) within the short list of sites that are available is preferable. Once the watertable dynamics supporting these 'black and white' areas of the gradient are established, the more complicated 'grey' area supporting sub-optimal vegetation condition can commence. A first step in this should be the specification of conceptual models that characterise the different states for each plant functional group association including ranges in biological state variables and watertable dynamics.

Design and monitoring protocols for GDE sampling units and sub-samples

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 a no pumping scenario. 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 (Doeg *et al*. 2012).

The Caroonda wetland, which occurs over the Uley South groundwater lens, is 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 the associated low rainfall periods, water extraction or a combination of both (Doeg *et al*. 2012).

Once study sites have been selected, orientation of sampling units is the next step in spatial design. Site design needs to align biological condition with observed groundwater dynamics. This should be done with an understanding of how vegetation measurements will be taken and on which variables.

Relating watertable monitoring data to vegetation condition

Vegetation responses are complex and observable condition may not change greatly over a wide range of watertable conditions. Ideally, quantitative monitoring would incorporate physiological monitoring parameters (soil moisture or pre-dawn water potential to determine water stress; sap flow and water balance or eddy covariance to estimate water use).The proposed focus for this program is the use of surrogate measures of condition such as species density, abundance and condition measures based on canopy (Table 2).

All vegetation sampling units are measured over a patch of ground (e.g. quadrat), which must be matched to groundwater measurements taken at individual point locations. Ideally, each vegetation sample would be associated with an independent measure of groundwater variation, but in reality this would require an unfeasibly large number of observation wells. By assuming that over small scales, the watertable can be approximated by a level surface, the variation in watertable between vegetation sampling locations can be estimated using differences in land surface elevation (topographic variation). The spatial scale and geometry of the area over which the assumption of a level surface can be applied is important; designs should maximise across-gradient dimensions (e.g. along contours) to match each sub-sample to the lowest possible variability in groundwater levels. The spacing and number of vegetation samples that can be reliably related to the watertable measurement at each observation well is limited by local variation and depends on factors such as the slope of the land and potentiometric surface as well as aquifer properties.

Table 2: Main response variables and covariates, and methods for monitoring.

Variable	Sampling unit and subsamples	Measurement	Variable to be estimated	Site replication
Stem density	Sampling unit: 1 ha plot Sub-samples: - 20 x 50m quadrats (Eucalyptus) - 10 x 50 m quadrats (Melaleuca)	Number of individuals Phenology Diameter breast height (Eucalypts)	For each quadrat: - Mean density (±CI) - Proportion exhibiting given phenology - Mean diameter - Mean and range of elevation of quadrats relative to groundwater datum	At least 3
Mean height	For sedges an estimate of mean height can be obtained by measuring the height of six plants within each sub-sample.	Height per subsample	Mean height (±CI) - Mean elevation of each quadrat relative to groundwater datum	Sub-samples at same points as above
Canopy condition	Sampling unit: 1 ha plot Sub-samples: 30 trees randomly assigned across stem density quadrats	Souter *et al.* (2009) Nicol *et al.* (2010) Telfer *et al.* (2000)	Ordinal condition scores (widely used in the Murray- Darling system) - Mean elevation of each quadrat relative to groundwater datum Other methods include - Hemispherical photographic analysis canopy photograph -Changes in NDVI through time (limited to patches of adequate size).	30 trees
Understorey	Sampling unit: 1 ha plot Sub-samples: 10* by 1m quadrats and / or line intercept methods	Nicol *et al.* (2010),	Proportional cover (presence / absence in each 1 x 1 m cell) - Mean elevation of each quadrat relative to groundwater datum	At least 6
Recruitment, senescence	All sampling units	Number of standing dead individuals; number of recruits	Count data per sampling unit (density) It may be necessary to locate sites based on observed recruitment (that is, mapping areas of successful recruitment) and monitoring survivorship by repeat sampling the same sites.	measure at each unit

Variable	Sampling unit and subsamples	Measurement	Variable to be estimated	Site replication
Sedges	Sampling unit: 1 ha plot Sub-samples within each distinct zone: 1m^2 quadrats randomly assigned relative to a centreline for each zone	Number of individuals (density) OR % cover. Phenology	- Mean cover of each sedge - Mean density of sedges - Mean elevation of each quadrat relative to groundwater datum	At least 6
Rainfall	Single rain gauge per site	Total rainfall in mm since last sample	Rainfall is a critical water balance component. Total rainfall between vegetation monitoring helps aid interpretation of condition and establish relative importance	1 per site
Water chemistry	Samples from surface soil profiles and deeper groundwater	Chemical analysis for stable isotopes, nutrients	Provides a baseline information on groundwater chemistry for inter-site comparison and for use in establishing water source	All accessible wells in the vicinity of the site.
Soil texture	Description of soil horizons noting organic matter, sand-silt-clay fraction of each layer, rooting depth, presence of any hardpan	Various descriptive soil parameters, depths in cm, % of sand-silt-clay.	Soil textures and depths to characterise site soils to allow for inter-site comparison	As suggested by soil variability (at least one per mapping unit)
Soil chemistry and hydraulics	pH, salinity, nutrients, soil strength, infiltration rates for each soil horizon	Quantitative soil chemical descriptors	Various soil parameters to characterise site soils to allow for inter-site comparison	As suggested by soil mapping (at least one per mapping unit)

** Actual number of contiguous 1m cells should be based on a species-accumulation (collectors) curve – see Nicol et al (2010)*

The approach suggested for this MERI program is to designate a rectangular study site boundary centred on the main monitoring well. Within this area, either fixed or random vegetation sampling units can be used, provided the elevation of each sub sampling unit can then be related to the groundwater datum. If a digital elevation surface of the study area is created as part of site establishment, any sampling point can subsequently be related to the groundwater datum. Fixed transects are likely to be the most effective approach as repeatedly laying out sampling plots will add considerable time to each sampling visit. Fixed plots are also preferred for determining trends (Austin 1981, Bakker *et al*. 1996, McDonald 2003). Referencing of watertables and vegetation sampling units to a common datum is also simplified if a fixed sampling unit is adopted. This will require the use of a total station, differential GPS or other surveying method capable of a measurement precision within a few centimetres.

The number of monitoring wells required will depend on relative levels of variation in the watertable and land surface. For flat terrain, a single well may be adequate. Monitoring data from eight randomly selected monitoring wells near to Poelpena Station located up to several kilometres apart, indicated that watertable depth varied between 0.1 and 1.7 mm per metre of linear distance. If this level of variation is consistent over small scales, a 100 metre sampling unit with a centrally located well would be no more than 50 m from any vegetation site, but this may introduce an error of almost 9 cm in watertable elevation. The significance of such an error will depend upon how large this is compared with watertable fluctuations. Small scale variability may be considerably less but this needs to be determined to establish whether a uniform watertable elevation can be assumed. The use of a single well might be adequate, but ideally at least one or more existing wells completed in the same aquifer can be monitored to provide an indication of watertable gradient near the site. This should be within a few hundred metres of the well and referenced to a common datum.

Where a clear topographic gradient is present within the study site, watertables will also likely exhibit some subdued level of slope. At least three monitoring wells would be required along a diagonal, or five wells are recommended in a cross or similar orientation to estimate 3-dimensional variation (Figure 8). A topographic gradient will most likely occur at wetlands with watertables being near-surface, and it would be expected that most wells will be shallow (<2 m). All additional wells would be relative to the main well, which should be deeper to ensure saturated conditions in the well even during dry periods. For deeper watertable situations (e.g. phreatophyte woodlands), multiple wells are unlikely to be realistic from a resourcing perspective. In such situations, efficient use of existing wells may be critical, although expert hydrogeological advice could be used to establish likely variation over the study site. Ongoing refinement to the monitoring program should include a review of variations in watertables at each site. If, over time, data confirm the assumption of a near-level surface, a decrease in monitoring effort or redeployment of continuous monitoring instruments is justifiable.

In locations where Quaternary groundwater is not the only source of water creating an observed vegetation zonation (see the working hypotheses under GDE Monitoring Program Scope), nested piezometers may be installed. This would involve co-locating a shallow well (perhaps less than one metre) adjacent to the main monitoring well (of up to 5 or more metres depth). Designing an appropriate installation may require some information on soil profiles or possibly 1-2 years of watertable data from the deeper well before the nested piezometers can be installed. The aim is to capture only the top of the saturated profile. The shallow well would read only surface soil profiles intercepting the upper level of the watertable (either A horizons or those above any texture contrast in the profile). By careful installation and separation of shallow and deeper groundwater at the site, water samples can be drawn from both wells periodically to help discern any contribution of ponded or perched rainfall from discharged Quaternary (or deeper) groundwater as the source of saturation in shallow profiles.

Rainfall data from as close to the site as possible will be used to check local water balance inputs. This will provide additional insights on local climatic conditions prior to sampling and to help explain variations in vegetation patterns or phenological states where watertables do not provide any clear evidence. Such data can also be proportionally de-accumulated to a daily record using the nearest BOM daily read climate station to provide more detailed recent climatic history at each site.

Monitoring variables and temporal frequency

If independent effects of watertable variation are to be determined, data must be collected on:

- **Explanatory (independent) variable**: the three-dimensional variation of water availability over time as a result of Quaternary aquifer watertable dynamics.
- **Response (dependent) variable**: ecological dynamics of plant functional groups.
- **Response covariates**: rainfall, water chemistry (salinity, nitrogen, phosphorus), soil texture and soil chemistry, land use, topography, elevation

Variables such as vegetation condition and depth to groundwater require time series data, though the frequency of recording will vary depending on individual dynamics. Other variables are more stable through time and can be grouped to establish basic site characteristics to be incorporated in data analyses. Table 3 summarises the major variables of interest, suggested sampling units, replication frequency and other key points. What is essential across the entire monitoring program is a consistent approach so that data is comparable both within and across region. Some potential sampling approaches are presented for the range of conditions observed from the field visit, but a final decision should be made once site selection is complete and a pilot data collection can be run at each site.

Table 3: Sampling units and sub-samples for each observed plant functional group association

Plant Functional Group	Type	Sampling unit	Sub-sample	Comments
Gahnia **mono-cover patch**	W	20 x 20 m centred on well*	3 x 3 m quadrat 6 replicates	Usually found near wetlands
Gahnia **mono-cover linear zone**	W	50 linear metre zone centred on well*	3 x 3 m quadrat 6 replicates	Wetland shore zones
Gahnia **understorey**	P	20 x 20 m centred on well*	3 x 3 m quadrat 6 replicates	May be wetland area or general topographic low

E. camaldulensis, E. petiolaris	P	100 x 100 m centred on well*	20 x 50 m quadrats 6 replicates	Long axis of quadrats should be along watertable contours. Understorey monitoring recommended if natural woodland
***Melaleuca* (± *Gahnia* understorey)**	W/P	50 x 100 m centred on well*	10 x 50 m quadrats (Mh) 6 replicates	Orient both sampling unit and quadrats along watertable contours
Mallee eucalypts	P	100 x 100 m centred on well*	10 x 50 m quadrats 6 replicates	Understorey should be monitored in all *Eucalypt* phreatophyte settings
Phreatophyte understorey (mallee or red gum)	P	2 or more linear transects 50m up and down gradient of well*	X x 1 m sub-transects every 0.2 m change in elevation 6 replicates	Orient main transect across watertable contours and sub transects along.

**All recommendations to centre on monitoring wells assume that the well has been placed in the middle of the patch of interest. If not, some offset is recommended. Similarly sampling in any area where damage to vegetation has occurred during well installation should be avoided.*

Sampling protocols and sampling unit orientation for phreatophyte study sites

Published and currently utilised methods are preferred in this program for reasons of comparability with other locations in the State. The Living Murray river red gum condition method (Souter *et al*. 2009) is recommended. For river red gum phreatophytes, the suggested sampling unit is a 1 ha area (Souter *et al*. 2009). A slight variation to the published method is suggested whereby a sampling unit is marked out as being one hectare in area, with individual rectangular quadrats (Figure 5) used as sub-sampling plots. Individual trees within each quadrat should have their condition evaluated following Souter *et al*. (2009) but also stem density, diameter at breast height and phenology (budding, flowering, fruiting). Use of such multiple sub-samples allows for the variance to be determined, which may be more critical than mean values.

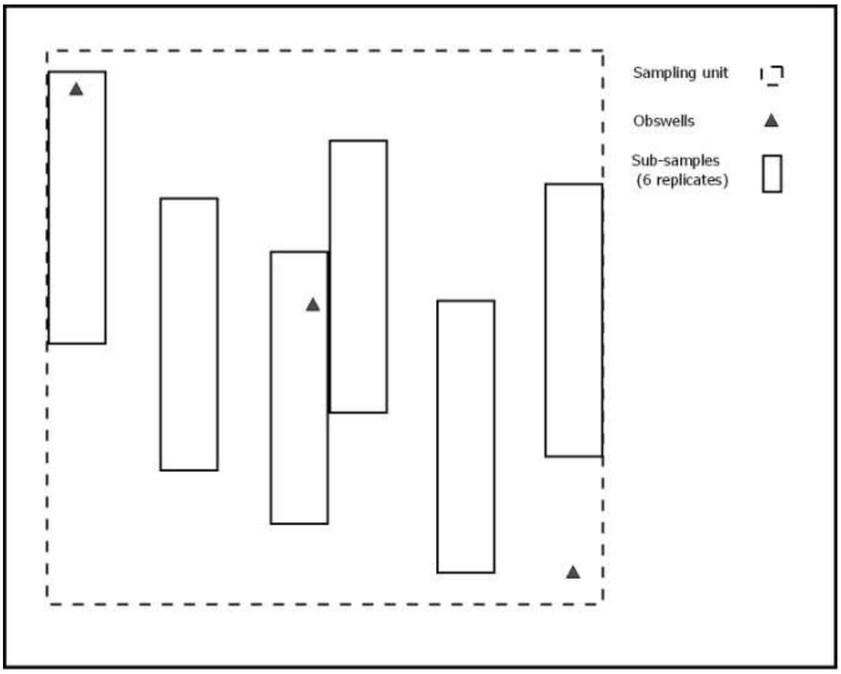

Figure 5: Example of a sampling unit and sub-sample design for phreatophytes. Red gum sampling unit size recommended at 100 x 100 m, Melaleuca 50 x 100 m oriented along potentiometric contours. Here groundwater flow would be left to right (or vice versa). Multiple wells may not be necessary, if only one well is used, centre position is preferred. Avoid areas damaged during drilling when positioning sub-samples.

For *Melaleuca*, an initial sampling unit suggested is 0.5 ha, notionally 50 x 100 m (provided the width does not introduce too much uncertainty in elevation), centred on the main obswell. The long axis should be oriented along the watertable potentiometric surface contour to minimise within plot variability. As for red gums, six sub-samples should be collected within the sampling unit, with sub-samples reduced from 20 x 50 m for red gum to 10 x 40 m for *Melaleuca*. Where present, *Gahnia* density should be monitored using separate sub-samples of 3 x 3 m dimensions. Mallee woodland and understorey can follow the *Melaleuca* sizes, with understorey data collected using the Nicol *et al*. (2010) methods. Sampling protocols and sampling unit orientation for wetland study sites

For wetlands a study site may include multiple sampling units referenced to a common observation network. Clear vegetation zonation was observed at a number of sites, where different plant functional groups graded one into another along a hydrological gradient. These were narrow zones rather than broader habitat patches that were observed in phreatophyte associations. A maximum 25 m width of the vegetation zone either side of the main observation well is a recommended approach allowing for flexibility in locating sampling units and sub-samples.

Each functional group zone represents a sampling unit and within each sampling unit, sedges can be sub-sampled based on six or more quadrats located randomly relative to a centreline of the zone. This should be oriented along the zone, which is also presumed to represent a depth-to-water contour (Figure 6). Quadrat size can be determined based on the size of the vegetation present. A size of 1 x 1 m is probably adequate for *Baumea spp.*, though larger sedges such as *Schoenoplectus pungens* or *Juncus kraussii* 2 x 1 or 2 x 2 m dimensions may be more appropriate. For sampling *Gahnia* density, 3 x 3 m is suggested as a starting point.

Record the number of individuals rooted within the quadrat (assuming individual culms represent individuals), any phenological indicators (budding, flowering, fruiting) and a general measure of growth status (e.g. vigorous, moderate, poor, dead NB condition classes must be clearly defined before sampling and with common standards agreed between observers) based on qualitative observations such as presence of any discoloration/dieback, new shoots. Percentage cover for each quadrat could be considered as a surrogate density measure, but the density of individuals provides a more objective means to compare between sites and determine productivity under different water supply conditions. For species such as *Baumea juncea* which may be very dense, of reasonably uniform cover and with only individual culms present, a smaller area can be used to estimate the total density, possibly as small as 0.1 x 0.1 m. If this is done, the equivalent value for 1 x 1 m should be reported along with the individual totals for any number of smaller areas used to estimate density at this scale.

If zones of tree species (mallee, *Eucalyptus* or *Melaleuca*) are present as part of the hydrological gradient, these should be sampled using the phreatophyte methods, probably requiring one or more additional obswells.

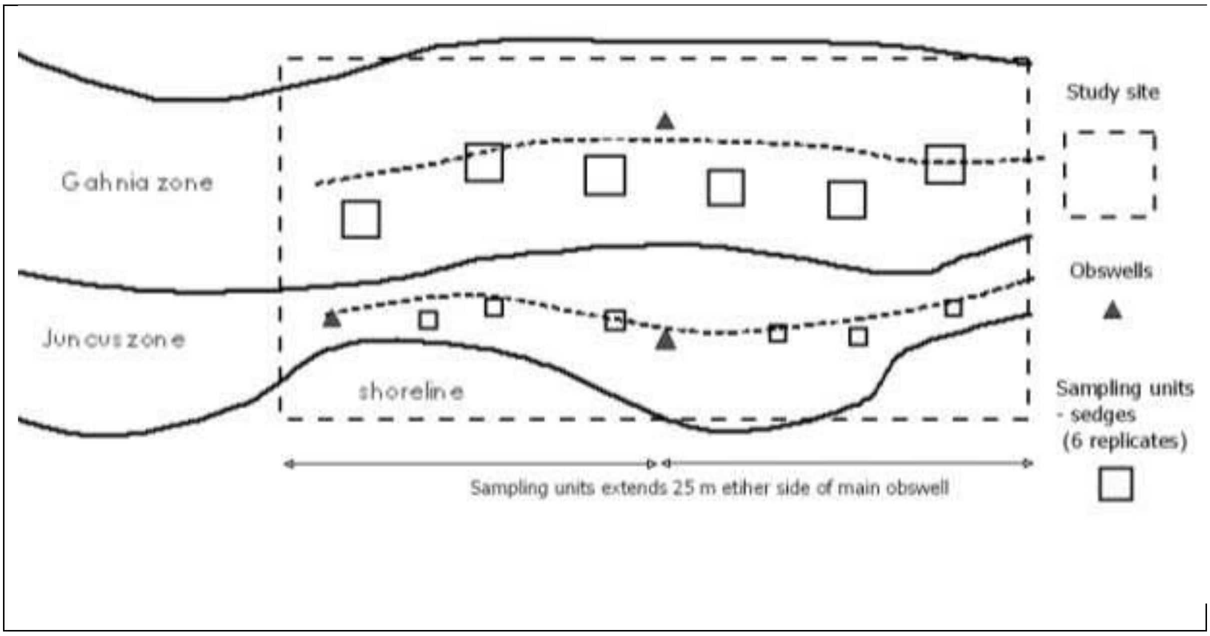

Figure 6: Study site setup for hydrological gradient (e.g. Sleaford Mere). Suggested sedge sampling quadrat dimensions: *Gahnia* 3 x 3 m; smaller sedges (*Baumea juncea*), 1 x 1 m and moderately sized individuals (e.g. *Juncus kraussii*) use 1 or 2 x 2 m.

Another wetland situation which may be encountered is a dense mono-cover stand of a single species, most typically *Gahnia filum* or *G. trifida*. A 3 x 3 m quadrat is recommended for all *Gahnia* density and phenology monitoring as a starting point. The sampling unit dimensions can be decreased to 20 x 20 m in such situations centred on the obswell. As for all vegetation samples, ensure that an independent estimate of the elevation for each sub-sample with respect to the groundwater datum is recorded.

For understorey plants in woodland phreatophyte stands, the methods of Nicol *et al*. (2010) are suggested. Multiple parallel linear transect should be established along the gradient of interest either connecting observation wells of two elevations, or no more than 50 m up and down gradient from a single well. Data are collected from sub-transects, located at elevation intervals that appear to represent changes in vegetation association (0.2 m can be used as a default value). If topography is relatively flat the establishment of transects at suitable elevation intervals or at least 10metre apart (to provide a good level of separation) is recommended with at least 6 quadrats for the study site. Quadrats within which plant data is recorded are established perpendicular to the main transect and comprise contiguous 1 x 1 m cells. The total number of cells should be determined through the use of species accumulation curves (a.k.a collectors curves see Nicol *et al*. (2010)). The state variable of interest (presence, life history stage) should be recorded as a score out of X, where X is the number of cells in which the variable is observed.

Re-visit frequency

Quarterly sampling (Apr-May, Jul-Aug, Oct-Nov and Jan-Feb) will provide adequate variation over the year for use with interpreting vegetation sampling.

Vegetation sampling will be undertaken annually in spring. Phenological state and recruitment success will be done annually in late spring.

Salinity and general water chemistry

Salinity will be measured at the time of well installation or vegetation sampling site set up and during any water level or vegetation sampling visit using a water quality meter. While the general rule for sampling water quality of groundwater via a well is to firstly purge three well volumes, this can take an unrealistically lengthy period of time. It is suggested that the initial salinity be taken on arrival at a site just after the water levels are recorded. If refilling of the well is rapid, then three purges could be completed recording the salinity at each re-filling. If wells are so slow to refill as to make multiple purging inefficient, then data on this can be collected during vegetation sampling visits when other activities can be undertaken while wells refill.

The other situation where water chemistry data may be valuable is to gather evidence in support of any competing hypotheses as to the importance of Quaternary groundwater in supporting vegetation. Sampling for this could initially be based on salinity only and would be done at the end of winter early spring as watertables reach their highest. A nested piezometer may be necessary to ensure only the surface layer of water is sampled. The aim of the salinity sampling would be to determine whether it appears likely that a shallow layer of rainfall is perched above the regional groundwater system.

Wetlands

At a minimum, biological data collection can consist of an initial visit to gather baseline data and establish the sampling units and locate the permanent quadrats for sub-samples. Sites would ideally be visited at least in line with the five yearly review of water allocation plans and conducted towards the end of spring-early summer. In some situations, such as where vegetation condition decline was a real concern, annual or 2-3 yearly re-sampling frequencies would at least allow some analysis of any change in vegetation over the sampling period and comparison with the watertable data.

Additional monitoring of the freshwater herb, *Hydrocotyle* sp. (Water pennywort; Figure 7) will be incorporated into a GDE citizen science monitoring program. Specimens were found in Sleaford Mere in October 2011 in an area where the salinity was much lower (5,000 EC) than in the bulk of the saline lake (30,000 EC; Muller unpublished data). It is assumed that this freshening of the surface water indicated a discharge site for fresh groundwater. Water pennywort is an amphibious plant that resounds to changes in water level over seasons and years by changing the length of its stems or changing leaf form. Its preferred habitat is permanent, shallow freshwater with an average depth between 2-10 cm (Doeg *et al.* 2012). Water pennyworts are at risk from drying out or high lenity levels if the groundwater inputs they depend on decline or fluctuate beyond their tolerance. It is not known whether these plants occur in other wetlands on Eyre Peninsula. They are an excellent indicator of fresh and permanent wetland habitats and may occur within a larger, saline wetland system. Wetland visitors are encouraged to familiarise themselves with this plant and report sightings in order to better map freshwater discharges to GDEs.

Figure 7: The freshwater herb, *Hydrocotyle* sp. (Water pennywort) is an indicator of fresh and permanent wetland habitats and may occur within larger, saline wetland systems on Eyre Peninsula.

Phreatophytes

Ideally, vegetation sampling methods would be applied twice per year, around mid-autumn to detect the dry season condition and at the end of spring, early summer to determine condition at the end of the recharge season. If only one sampling event is possible, then the end of the dry season would provide a better indication of maximum stress across the different communities and any surviving juveniles would be most likely to recruit to adult populations having survived an initial summer. If capturing the vegetation in its best condition, detecting relative differences in phenological stages (e.g. flowering) or where monitoring understorey shrubs and herbs are of most interest, late-Spring to early-Summer sampling is preferable. As with wetland sampling five yearly samples for changes in density would be a minimum useful re-visit frequency.

GDE monitoring site selection

Following preliminary investigations and community feedback, a range of GDE sites were selected from both Musgrave and Southern Basins PWA's for monitoring.

Fringing vegetation condition will be monitored at Sleaford Mere and Lake Pillie (Southern Basins), with red gum condition monitored at Big Swamp (Southern Basins PWA), Bellevue, Bramfield and Polda (Musgrave PWA).

GDE Data Storage

For an effective long-term monitoring program to be achieved, all monitoring data must be collected, maintained and analysed in a systematic and thorough manner. Failure to follow the appropriate survey protocols, variation in interpretation or definition between data collectors, the incorrect or incomplete recording of data, or the loss of data can mean that it is not possible to carry out the appropriate analysis during, or at the completion of the project, or that the analysis is confounded. As such it is vital that one person be responsible for coordinating the annual surveillance program across the various groups involved. Data collected for all surveys within each surveillance period of the monitoring program will need to be stored and maintained by a single nominated person (e.g. Natural Resources Eyre Peninsula – Monitoring, Evaluation and Reporting Officer).

Data collected will need to be stored and maintained at two levels:

1. As a hard copy booklet/s containing the complete set of records for each survey; and
2. As an electronic document in a data base format appropriate for statistical analysis.

Prior to each survey all of the required data sheets for each survey should be collated into record booklets for each survey team. Following each survey, these booklets need to be collected and centrally stored. One person should be responsible for both the provision and collection of prepared record booklets for each of the surveys person (e.g. Natural Resources Eyre Peninsula – Monitoring, Evaluation and Reporting Officer).

At the completion of each annual surveillance period, data from each survey should be entered into a database for electronic storage and to facilitate the process of analysis and reporting.

GDE Data Analysis and Interpretation

Perhaps the most important point to recognise in a monitoring program design is that data collection and the development of understanding must be considered during the design phase. Data collection without analysis is of little value and part of designing a monitoring program is specifying precisely how the data are to be used.

The aim of data analysis is to determine the key elements of environmental variation that explain the greatest amount of variation in ecological condition, focusing on watertable dynamics. The nature of the analysis itself can be time series (e.g. the annual proportion of flowering plants as some function of groundwater dynamics) or represent some time-integrated responses of both watertable (e.g. mean depth to water) and vegetation (e.g. stem density, proportion of flowering plants).

The latter approach may prove more beneficial for more exploratory analyses. Both are largely statistical modelling questions well suited to (generalised linear or additive) mixed modelling approaches, which can account for nesting and auto-correlation (non-independence) and covariates in the model structure (Pinheiro and Bates 2000, Zuur *et al*. 2009). Rapidly responding state variables such as proportion of flowering plants may be more suited to time series analysis, while providing explanations as to condition measures such as stem densities may require more time-integrated measures.

The vegetation state variables are quite straightforward: density, canopy condition, phenology (e.g. proportion of quadrats/individuals with flowering). Potentially influential covariates are many (Table) but many change little over time (e.g. soil variables) and such information can be accumulated over a number of years and built into analyses as they become available. Where watertables do not explain much of the variation in condition, or where comparable, watertable dynamics lead to widely differing observed condition for vegetation, covariates such as soil type or micro-topography are a likely explanation.

Decisions must be made on how to incorporate rainfall and watertable data as this will be a focus of analysis. Options for rainfall include total depth collected at the sites rain gauge can be de-accumulated against the nearest daily weather station to provide a means for comparison with long term records and therefore extension back in time. Watertables can be summarised using an analogous approach to that used to describe surface water flow regimes, focusing on key aspects of magnitude, duration, frequency, seasonality and rates of change. Example variables for use in analysing vegetation response include annual maximum and minimum depths to water; number of days above or below a critical threshold (e.g. rooting depth); inter-annual variability in all statistics; intra-annual/seasonal rates of change.

The pilot study undertaken at a saline wetland in the Musgrave Prescribed Wells Area (White *et al*. 2014) includes an approach for presenting watertable data where a groundwater depth-duration curve is calculated. Where two time series are available for comparison that have led to opposite responses in vegetation, statistical approaches such as the Kolmogorov - Smirnov test can be used to identify where these differ the most. Where the two time series have been recorded at sites where the same vegetation type is maintained at noticeably different ecological states, the major differences in the two curves can be interpreted for their likely ecological importance (e.g. duration of time at the surface compared to maximum depth).

Finally, it should be kept in mind that major influences on plant zonation are not only due to variations in water availability in terms of saturated soils, but also their resistance to the extent and duration of conditions of low moisture availability. Soil moisture monitoring during periods when watertables are low and climatic stresses highest may ultimately dictate whether a given plant functional group can persist at a site or not. The incorporation of soil moisture variation in modelling may require dedicated research to improve our understanding of plant tolerances not only to saturation, but also to drying.

Appendix 2: Location of Groundwater Monitoring Wells in Musgrave and Southern Basins PWA's

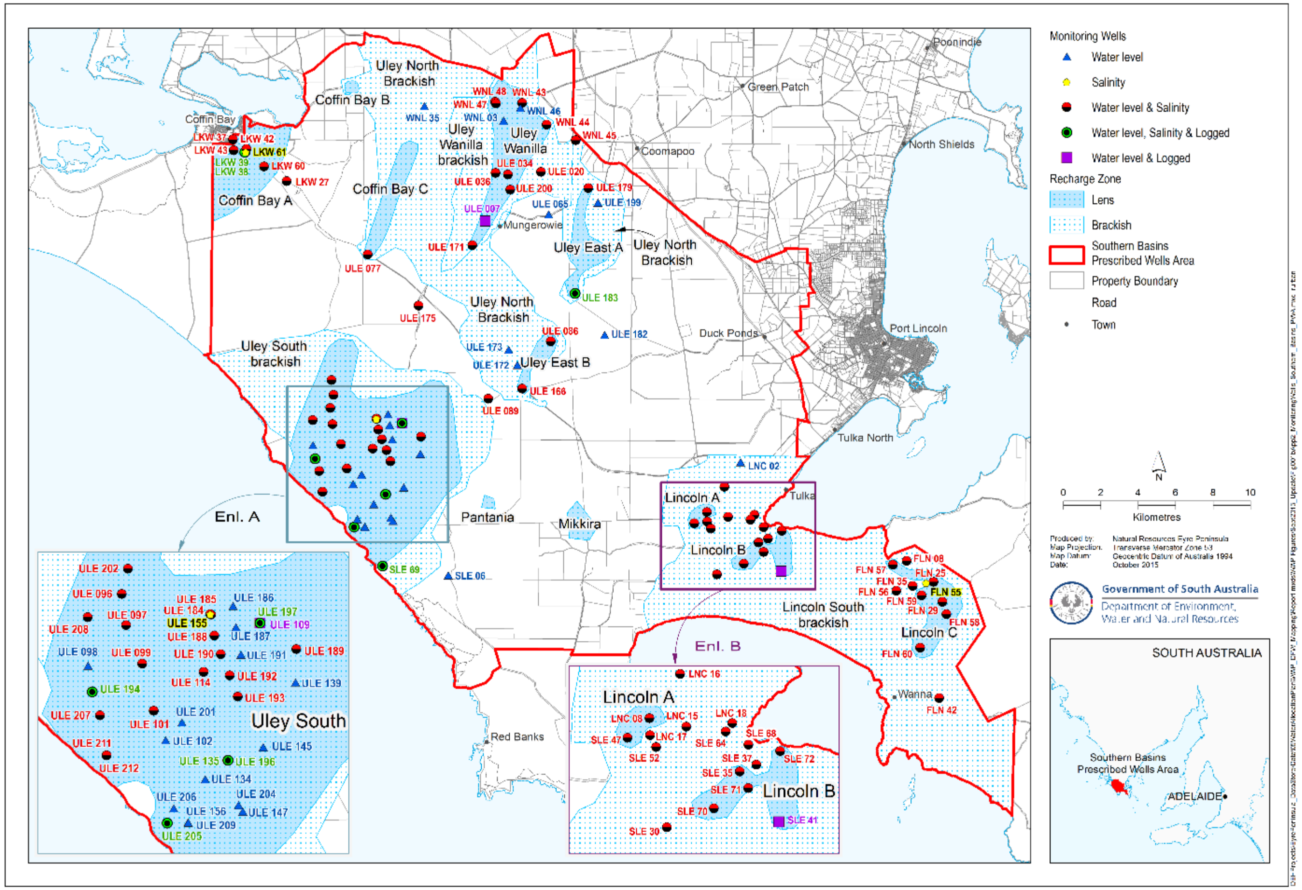

Figure 8: Monitoring wells in the Southern Basins Prescribed Wells Area

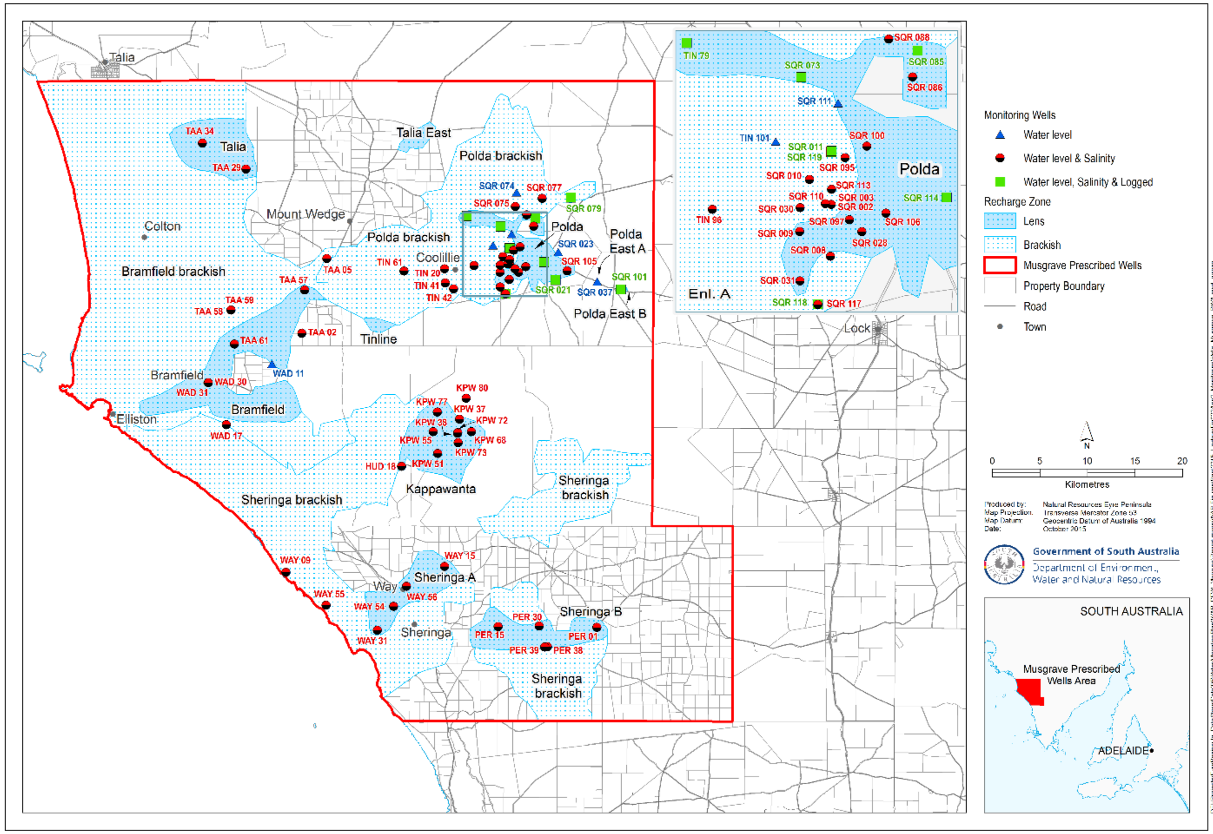

Figure 9: Monitoring wells in the Musgrave Prescribed Wells Area

9. 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.

Allocation: See 'Water allocation'.

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

Australian Height Datum (AHD): the datum adopted for vertical control, measured in metres. Zero metres AHD is approximately mean sea level.

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

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

Consumptive pool: The water that will from time to time be taken to constitute the resource within a particular part of a prescribed water resource for the purposes of Chapter 7 of the Natural Resources Management Act 2004, as determined by this Plan.

DEWNR: Department of Environment Water and Natural Resources (Government of South Australia)

Discharge: Discharge is the process whereby groundwater leaves the aquifer, either through groundwater leakage to surface water bodies (e.g. baseflow), or spring seepage.

Ecosystem: A dynamic complex of plant, animal, fungal and microorganism communities and the associated non-living environment interacting as an ecological unit.

Environmental Water Requirements (EWR): The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk

Groundwater: Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground.

Groundwater Dependent Ecosystem (GDE): an ecosystem that require access to groundwater, on a permanent or intermittent basis, to me*et al*l or some of its water requirements to maintain the community of plants and animals, and the ecological processes and ecosystem services they provide.

Groundwater extraction: The process of taking water from an underground source, either temporarily or permanently.

Groundwater soaks: Surface water expressions of groundwater that occurs where the groundwater intersects with the surface, and the pressure of the groundwater is sufficient to move water to the surface. Groundwater soaks may be permanent where the groundwater is in constant contact with the surface providing a permanent water source, or may only be temporary with flow ceasing when the groundwater level drops below the surface.

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

Hydraulic lift: A process by which some deep-rooted plants take in water from lower soil layers and exude that water into upper, drier soil layers. Occurs during hot, dry periods, when the surface soil dries out to the extent that the lateral roots exude whatever water they contain, potentially resulting in the death of the lateral roots. In the absence of water outside the lateral roots, ground water is drawn up through the deep taproot to the laterals and exuded into the surface soil, replenishing that which was lost.

Hypogean: 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.

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

Land: According to the context, (a) land as a physical entity, including land under water; or (b) any legal estate or interest in, or right in respect of, land; and includes any building or structure fixed to the land.

Lens: A discrete occurrence of relatively fresh groundwater, where groundwater salinity is less than 1 000 mg/L.

Licence: see 'water licence'.

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

Megalitre (ML): one million litres.

Minister: The Minister responsible for the administration of the *Natural Resources Management Act 2004*.

Model: A conceptual or mathematical means of understanding elements of the real world that allows for the assessment of certain conditions.

Monitoring: The systematic measurement of variables and processes over time to address a clearly defined set of objectives.

NDVI: Normalised Difference Vegetation Index.

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

Phreatophyte: A type of plant that exhibits a high rate of transpiration by virtue of a taproot that extends down to the watertable.

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

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

Plant Functional Group (PFG): The set of species co-existing in a given community constitute a functional group if they have similar functional characteristics related to one ecosystem service.

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.

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

Prescribed well: A well declared to be a prescribed well under section 125 of the *Natural Resources Management Act* 2004.

Prescribed Wells Area (PWA): An area of land within which wells are prescribed.

Public Water Supply (PWS): Potable water that is distributed to residential and commercial customers by a water utility via a reticulated system.

Recharge: Recharge is the process whereby groundwater is replenished by water draining into the groundwater system. Recharge does not include water held in the soil in the unsaturated zone that may be evaporated, taken up by plants, or discharge at topographic lows. Groundwater can be recharged from rainfall, irrigation infiltration or leakage from surface water bodies (e.g. stream, channel, lake). Recharge to unconfined aquifers occurs over a wide area directly above the aquifer.

Resource capacity: The capacity of a groundwater resource, calculated by multiplying the recharge area (km^2) by the recharge rate (mm). Also known as the total amount of water available for consumptive demand and non-consumptive demand, that is, total demand.

Sinkhole: A hole formed in soluble rock, especially in a limestone formation, caused by water erosion and providing a route for surface water to disappear underground.

SWL: Standing water level

Stock water use: The taking of water to provide drinking water for stock other than stock subject to intensive farming.

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: or, (ii) 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.

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

TDS: Total dissolved solids

Telemetered: Wireless transmission of data which is available online via WaterConnect.

Unconfined aquifer: An aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

Upconing: In a stratified aquifer, especially a coastal aquifer with fresh overlying sea water, upconing is the upward migration of the saline interface in hydrostatic compensation for a falling watertable in and around a pumped well.

Water allocation: An allocation of water under the terms of a water licence in accordance with Chapter 7 Part 3 Division 2 of the Natural Resources Management Act 2004, and includes the water available in connection with a Water Access Entitlement.

Water Allocation Plan (WAP): A plan prepared by a natural resources management board and adopted by the Minister in accordance with the Act.

Water licence: A licence granted by the Minister under section 146 of the NRM Act.

Water quality: The physical, chemical and biological characteristics of water. It is most frequently used by reference to a set of standards against which compliance can be assessed. Common standards used are those for drinking water, safety of human contact and the health of ecosystems.

Water regime: The extent, duration, frequency, timing and depth of inundation or soil saturation.

Watertable: the upper surface of an unconfined aquifer at which the soil or rocks are permanently saturated with water. The watertable separates the groundwater zone, that lies below it, from the capillary fringe, or zone of aeration, that lies above it.

Water-use year: A water use year runs from 1 July to 30 June in the following calendar year.

Well: As defined by the *Natural Resources Management Act 2004*, means (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.

Wetland: An area that comprises land that is permanently or periodically inundated with water (whether through a natural or artificial process) where the water may be static or flowing and may range from fresh water to saline water and where the inundation with water influences the biota or ecological processes (whether permanently or from time to time).

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