Verification of water allocation science program: Groundwater dependent ecosystems in Prescribed Wells Areas of the Eyre Peninsula

DEWNR Technical report 2014/04

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Foreword

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Allan Holmes
CHIEF EXECUTIVE
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Acknowledgements

It is readily acknowledged that this work was only possible as a result of the considerable efforts of wetland scientist Vic Semenuik. The understanding presented in Semenuik & Semenuik (2007) was pivotal to much of the work. Dr Semenuiks' foresight in installing shallow observation wells and encouraging continued monitoring of these was especially noteworthy. Similarly, the pro-active actions of board staff to continue this monitoring are highly valued; at the time of writing these hydrographs constitute one of the best wetland water table records in the State. EP NRM Board staff member Rob Coventry is acknowledged for his role in ensuring continuity of this monitoring record and in addition is thanked by the authors for his support for the project.

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External peer review was provided by Dr Jason Nicol, Plant Ecology Sub-program Leader, South Australian Research and Development Institute. In the process of review, Dr Nicol also suggested some improvements to the proposed monitoring methods (in particular Table 4), which were fully incorporated. Dr Nicol is acknowledged for this contribution, which was greatly appreciated by the authors.

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Summary

As part of the state-regional collaborative program for Verification of Water Allocation Science (VWASP), this report presents design and implementation principles for establishing a monitoring program for groundwater dependent ecosystems within Prescribed Wells Areas on the Eyre Peninsula. Prepared in partnership with the EP NRM Board, this report follows from the groundwater dynamics pilot study presented in White et al. (2014) and explicitly expands on recommendations on GDE monitoring identified in Doeg et al. (2012).

There are four sections within the report:

(1) Conceptual models of potentially competing water delivery mechanisms supporting ecosystems are presented. Such understanding is important, because alternative water supply mechanisms are one of the critical covariates that must be understood if the role of groundwater – and therefore extractive uses – can be isolated as drivers of vegetation condition.

(2) Technical design principles for a groundwater-dependent ecosystem monitoring program are presented. Where possible, some potential methods for site establishment of monitoring are provided, but a lack of prior data collection means that some elements of the proposed methods should be seen as a pilot study. Included are sections on study populations, study and sampling site establishment, re-visit frequencies and data analysis.

(3) A number of representative sites suggested in Doeg et al. (2012) were prioritised using a group of specific selection criteria and weightings. Methods are explained such that were priorities of the Board to differ from the proposed, re-application of the principles could be undertaken. One possible prioritisation is provided along with the rationale for site selection.

(4) Summary data based on field inspections of the target sites are presented, with explanations of the opportunities, challenges and different environmental data that might be gained from monitoring at each site.

The monitoring and evaluation program suggested would seek to answer questions such as:

- What are the critical characteristics of water table dynamics that are associated with a given plant functional group being maintained in good (or degraded) condition?
- For a given range in water table dynamics, which plant functional groups are most likely to be present?

By answering these questions it will then be possible to comment on the likely ecological implication (with a focus on dependent vegetation) due to changes in water table dynamics – whether these are driven through changes in climate or due to extractive activities.

In order to answer these questions, a minimal monitoring program may require up to ten 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's five to ten yearly review intervals.

While implementing the proposed or similar program will provide considerable improvement in understanding over time, an opportunity to immediately develop a base level of quantitative understanding was identified during the project. The coincidence of multiple long-term observation wells and mapped vegetation associations allows for an analysis of water tables with vegetation at the time of mapping. A rapid, low cost survey of such locations could be combined with a desktop study to greatly improve understanding over a short period of time.

Context statement

During the recent development of the Water Asset Database for the Eyre Peninsula (Denny and Berens, 2013) a number of knowledge gaps relating to groundwater dependent ecosystems (GDEs) were identified, which were prioritised for further investigation. The first knowledge gap concerned the distribution of phreatophyte vegetation associations. Phreatophytes, being plants that have roots that can penetrate the capillary fringe and saturated zone, are at least in part dependent upon groundwater to persist. This dependence means they are potentially vulnerable to groundwater extraction and understanding their spatial distribution is critical to determining the level of risk presented by a given development. White et al. (2014) investigated the groundwater dependence of vegetation across the region using time series analysis of remote sensing imagery to indicate rates of transpiration indicative of active groundwater use.

The other priority knowledge gap identified was the subject of this investigation: the lack of quantitative understanding of the interaction between groundwater dependent ecosystems, water table dynamics and extractive pressure. The geographical focus of this investigation was the Musgrave and Southern Basins Prescribed Wells Areas (PWAs) of the Eyre Peninsula, due to the availability of existing data. Groundwater dependent vegetation of both wetlands and phreatophytes were considered. Other groundwater dependent biota (e.g. stygofauna) are likely to be present in the region and possibly within both PWA (Doeg et al. 2012) but it was beyond available resources to investigate these.

The aim of this technical report is to build from prior understanding of the function and environmental water needs for GDE in the region (Semenuik & Semenuik 2007; Doeg et al. 2012) to propose a monitoring approach for the EP NRM Board that can begin to develop a quantitative understanding of environmental water needs and corresponding responses to changes in groundwater dynamics.

The work presented within this report was funded by the National Partnership Agreement on Coal Seam Gas and Large Coal Mining Development (NPA) via the Eyre Peninsula Natural Resources Management (EP NRM) Board, with a substantial in-kind contribution towards the project provided by staff of the Science, Monitoring and Knowledge Branch, Department of Environment, Water and Natural Resources (DEWNR).

1. Introduction

1.1. Groundwater dependent ecosystems and water use on the Eyre Peninsula

Groundwater dependent ecosystems (GDEs) of the Eyre Peninsula are important biodiversity assets that face multiple anthropogenic sources of 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 natural systems have evolved under conditions of variability in water tables and exhibit a certain amount of resilience, additional pressure imposed through the extraction of water for human uses (or as a result of climate change) inevitably alter the characteristics of water availability for environmental uses. This can be expected to result in measurable ecological consequences. For ecosystems dependent upon groundwater, the ecological consequences of changes in water table dynamics are among the most critical to understand if they are to be effectively managed.

Extractive use of groundwater on Eyre Peninsula (Figure 1) is largely for potable town water supplies, though some extraction for irrigation also occurs along with stock and domestic use. Concerns around the need to protect the ability of supplies to meet critical human needs resulted in the prescription of some key groundwater resources as early as 1987. Within the prescription framework, WAPs set out the policies for sustainable use of prescribed water resources and must take account of environmental water needs in doing so. Ensuring an acceptable level of environmental condition is maintained while providing for other water supply needs involves complex decisions, which include economic and social considerations. Any trade-off in environmental condition is a decision for the community as a whole, including government, but knowledge of possible outcomes is crucial. The role of environmental science is to inform this discussion with evidence that increases understanding of how the environment is likely to respond to a given extraction regime. This understanding is essential if planning and policy development is to prove capable of avoiding unnecessary or unacceptable changes to ecosystem composition, structure and function. Information on precise water requirements for groundwater dependent ecosystems in South Australia, including the EP NRM region, is scarce, particularly with regard to changes in ecological characteristics. This report outlines a possible program to commence the collection of quantitative data for two classes of groundwater dependent ecosystems; phreatophyte woodlands and wetlands.

The natural climatic variability is one of numerous covariates that may affect ecological responses (e.g. soil type and disturbance history), all of which complicate the task of understanding the role of water availability as a determinant of ecological condition. Human extractive water uses are superimposed on natural variability and may result in complex spatial and temporal interactions and non-linear dynamics:

- Extractive pressure is usually highest where good quality water is present in exploitable quantities. These characteristics tend to also support areas of ecological importance.
- Human pressure on supplies in the region are greatest under conditions of drought, when impacts on water resources are pronounced (Alcorn, 2009, McMurray, 2006), and stresses on natural ecosystems are highest.

Although detailed knowledge of hydrological and ecological processes of water dependent ecosystems is lacking, considerable progress has been made in mapping and classifying GDEs. Generating the conceptual understanding that is a pre-requisite to quantitative interpretation has also begun. This study aims to provide guidance for the next logical step in building understanding, and as such relies upon a range of prior research:

- Semenuik & Semenuik (2007) undertook 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.
- Vegetation distribution of spatial data from Biological Surveys of South Australia
- Two wetland inventories undertaken by the former Department for Environment and Heritage (Seaman 2002; Wainwright 2007);
- Doeg et al. (2012), who selected representative wetlands from the groups developed in the earlier work by Semenuik & Semenuik (2007) within the Musgrave and Southern Basins PWAs, and articulated some general environmental water requirements (EWRs) and conceptual models of wetland function;

- Three prior studies of phreatophytic vegetation, each using contrasting methods: SKM (2009), the Australian Groundwater Dependent Ecosystems Atlas http://www.bom.gov.au/water/groundwater/gde (2012), and time series Landsat data analysis presented in White et al. (2014).

Thus the aim of this report is to follow-on from the groundwater dynamics pilot study presented in White et al. (2014) to provide a set of design principles for monitoring representative wetlands identified in Doeg et al. (2012). Some additional high value sites and phreatophyte woodlands not identified in Doeg et al. (2012) were identified during the project and, as these may provide other possible sites, are also discussed.

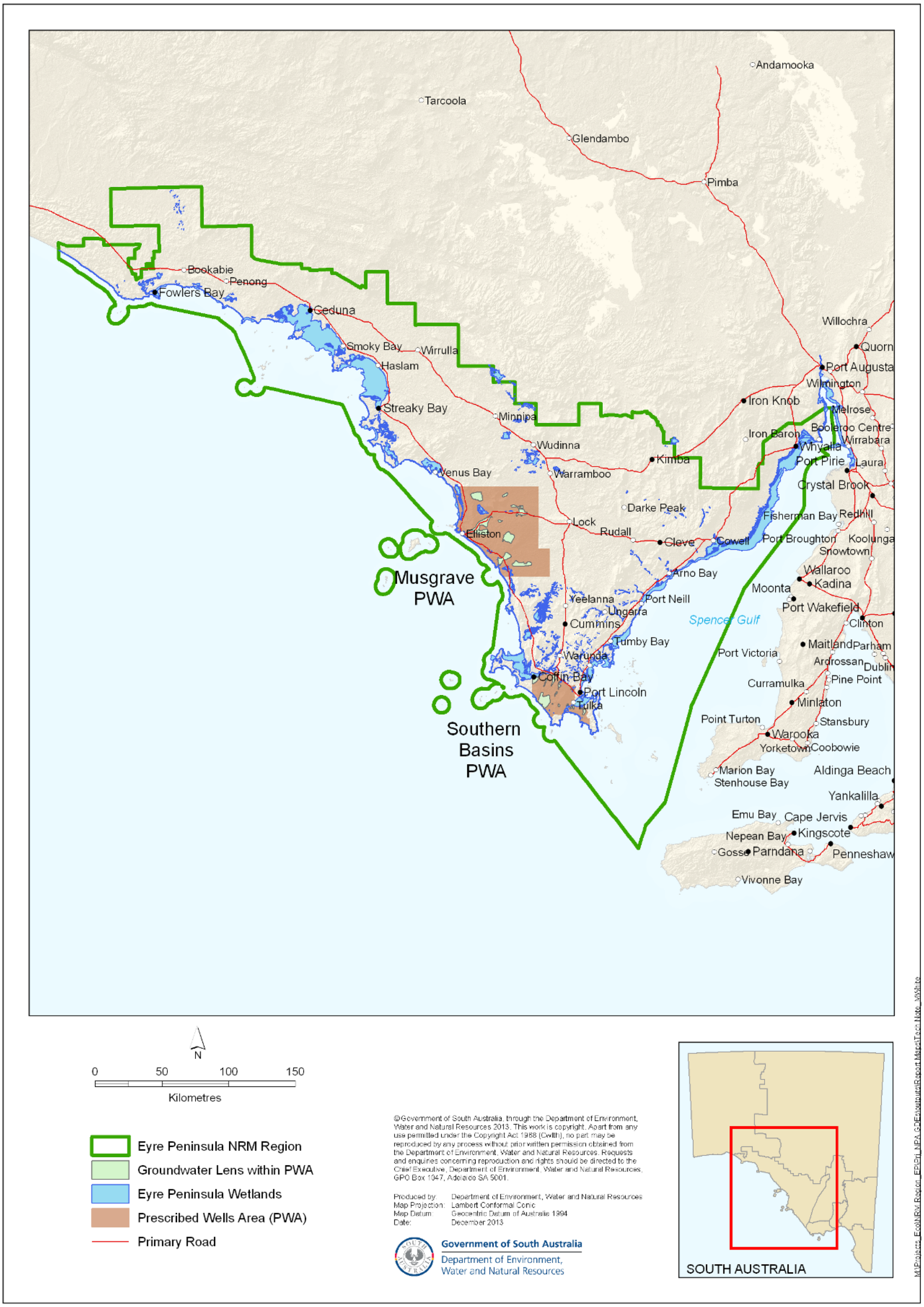


Figure 1. Locality of wetlands of the Eyre Peninsula and groundwater lenses within the Prescribed Wells Areas

1.2. The South Australian Verification of Water Allocation Science Program

In partnership with all regional NRM Boards, the Department of Environment, Water and Natural Resources (DEWNR) seeks to establish and continually improve understanding on how the environment responds to varying levels of water availability and the interaction between environmental condition and human extractive uses. This program (known as 'VWASP') is in the early stages of developing a quantitative understanding of what biological characteristics the environment might exhibit for a given level of water availability. Such understanding will greatly improve planning capability, allowing for better informed and more transparent trade-offs between human and environmental needs for water, based on improved certainty of the likely outcomes of each.

As in other parts of the world, quantifying environmental water requirements is an emerging science and foundational activities such as proposed herein are critical. Much of the current activity under the program is informing the establishment of programs to collect concurrent biological and water-availability data. Such baseline monitoring provides the pre-requisite information needed to advance the science across the state. Research is also on-going into the most effective measures of biological performance through collaborations with SARDI, CSIRO and The University of Adelaide.

As increasing volumes of data accumulate, emphasis will be directed to the development of predictive models that can be coupled to groundwater model outputs. This will allow for projected hydrological changes that may result from various extraction or climatic scenarios to be used to predict the state a water dependent ecosystem will take within these constraints. Managers are then in a position to evaluate different scenarios in terms of their likely ecological consequences.

1.3. Working hypotheses for mechanisms of water delivery

In a landscape where saline wetlands predominate, such as the Eyre Peninsula (Wainwright 2008), any source of low salinity water is crucial for species intolerant of high salinities. Of overriding interest to water allocation planners though is the interaction between human users and the environment as this is where some influence on the delivery of water can be exerted. On Eyre Peninsula this leads to interest in ecosystems reliant upon Quaternary aquifers of low salinity. Among the points for consideration, when seeking to link a given groundwater (or other) supply to ecological condition are:

- Virtually all ecosystems rely on a combination of water sources (rainfall, runoff, groundwater) and determining the specific role of a given source may require extremely detailed water balance and ecophysiological studies
- Even ecosystems without a direct reliance on an exploited groundwater resource can still provide information on water requirements that is applicable in exploited ecosystems. In designing any monitoring program, it is critical to have both control and impact sites. In some situations, it may be desirable to monitor sites that cannot be impacted by development, precisely for this reason – as it provides a point of comparison.

With these points in mind, it is important to establish a plausible link between a given environmental asset and an exploited resource, and the level of confidence in both the importance of this supply and the system model that makes the dependence explicit. Doeg et al. (2012) presented a conceptual model linking wetland vegetation with the Quaternary aquifer, where the interaction of water table dynamics and wetland basin morphology (elevation profile) generates observable plant zonation. Such processes have a well established basis in wetland science and can be viewed as a base model, but a number of possible alternative sources of freshwater may interact with this process and moderate supplies. If the role of Quaternary supplies alone are to be understood, the link between this source and the biological response must be of high certainty, making it necessary to consider the relative merits of this and any competing scenarios.

Field inspections suggested some possible alternative mechanisms affecting water delivery to non-salt tolerant vegetation, which add some complexity to the models presented in Doeg et al. (2012). While the subtle differences in the working models do not necessarily alter monitoring design for vegetation response, determining the exact mechanism of water delivery will require adequate design consideration and potentially additional data collection to determine support for these different possibilities. The additional conceptual supply models are presented below, along with an additional phreatophyte model. For phreatophytes the process is relatively straightforward, with water tables or their capillary fringe being within the root zone of the vegetation. It is also possible that understorey species benefit from the presence of phreatophytes through the process of hydraulic lift (Section 1.3.3).

For wetland systems, Doeg et al. (2012) suggested a conceptual model with two possible outcomes for the interaction of water and dependent biota:

(1) Variable groundwater levels interact with wetland basin profiles to determine the hydrological regime of a wetland, which represents a surface discharge point for groundwater (gaining system).

(2) Wetlands that 'pond surface runoff from rainfall that is destined to evaporate or recharge the underlying aquifer' (Doeg et al. 2012 pg. 18). This represents a recharge point for groundwater (losing system).

Three potential water sources are thought to have the potential to create enduring conditions of relatively low salinity. This can create ecological benefits over timeframes of weeks to several months, or longer during growing seasons. Any of these may contribute part of the water balance supporting aquatic plant functional groups on Eyre Peninsula. All of the following models can be viewed as alternative working hypotheses and considered along with the more general model presented in Doeg et al. (2012):

(1) *Localised perched groundwater systems*: Perching-ponding of local rainfall: accumulation of rainfall in topographic lows may provide conditions of enduring seasonal saturation where deep vertical infiltration is impeded. This pathway includes only local-scale flow or seepage – that is, surface or shallow sub-surface saturated movement of water over a scale up to that of a hillside. Such small flow systems cannot support extractive use, but could complicate observed vegetation zonation. This process is put forward as a possible alternative explanation for the 'donut' pattern of non-halophytic wetland vegetation which is often observed fringing saline lakes: clay substrates or even saline groundwater may prevent deep infiltration of ponded rainfall. This may result in extended periods where soils are saturated with low salinity water from rainfall which supports wetland vegetation. Capillary rise from any low salinity lens may occur up to metres below the surface and could help maintain vegetation during drier seasons as saline aquifer levels lower.

(2) *Quaternary regional quaternary aquifer*: There are at least two ways this source may provide low salinity groundwater to root zones:

    a. Shallow discharge points – via (near) surface discharge creating zones of low salinity water in the root zone can maintain wetland vegetation. This includes the elevation based model presented in Doeg et al. (2012) but also a situation where freshwater displaces saline water in a 'dilution front'.

    b. Deeper access by phreatophytes – deep root systems of certain species enable them to access groundwater that would not normally reach the surface at any time e.g. from up to tens of metres depth. This pathway may also provide ecologically significant volumes of water to understorey species through the process of hydraulic lift redistributing water to near surface soil profiles.

(3) Surface water runoff: Large volumes of runoff can be contributed from upstream catchments via surface drainage networks in some settings, resulting in large wetland complexes. The scale and presence of flow within defined surface channels distinguishes this from pathway 1. Water may be transported distances of several to tens of kilometres and stored in low-lying topographic features where infiltration losses are minimal (Big and Little Swamps being the major examples, but smaller scale processes may be identified at other sites).

The monitoring and evaluation design proposed aims to quantify variations in ecological response for communities dependent upon Pathway 2a and 2b, consistent with water allocation planning needs (Doeg et al. 2012). Any of the above three water sources may be present at a given site and understanding the separate ecological roles of each requires monitoring capable of distinguishing these potentially complex interactions. Although germination in phreatophytes may not require flooding or saturation (J.Nicol, (SARDI) pers. comm., 3 March 2014), Pathway 1 may create optimal conditions for recruitment if Pathway 3 doesn't occur at the site. Determining the precise source of water is critical if any impacts are to be correctly assigned to human and/or to determine the risk to ecosystems from extractive activities vs natural causes.

1.3.1. Perching-ponding model

In some low-lying areas adjacent to coastal salinas (notably Sleaford Mere and Pillie Lake) small groups or isolated individuals of the amphibious genus *Gahnia* were observed among a largely terrestrial plant matrix. The presence of this species would usually be seen as an indication of conditions of persistent near-surface saturation. However the co-dominance with terrestrial species intolerant of such conditions suggests that neither functional group is precluded or competitively dominant. This suggests conditions are intermediate between favouring terrestrial and aquatic plants. Local rainfall concentration and perching in suitable topographic lows is theorised to create adequate saturation during wet years for plants like *Gahnia* to establish among largely terrestrial/salinity tolerant species. As periods of saturation vary with climatic cycles, dense stands of *Gahnia* that can competitively exclude terrestrial species will not establish, but individuals in suitable micro-habitats can persist.

In suitable areas (e.g. Bramfield lens – Section 3.2.2), this mechanism is also a plausible model for phreatophyte recruitment where plants may germinate on recharge mounds overlying shallow aquifers following heavy rainfall. In saline wetlands where a clear 'donut' amphibious vegetation zonation is observed, ponding of rainfall may flush shallow soil profiles and create a lens of freshwater that supports vegetation. Even if not dependent on surface discharges of Quaternary aquifers, the depth to water may still be critical for environmental water provision. It is important that the nature of dependence on groundwater is clarified to inform appropriate management actions.

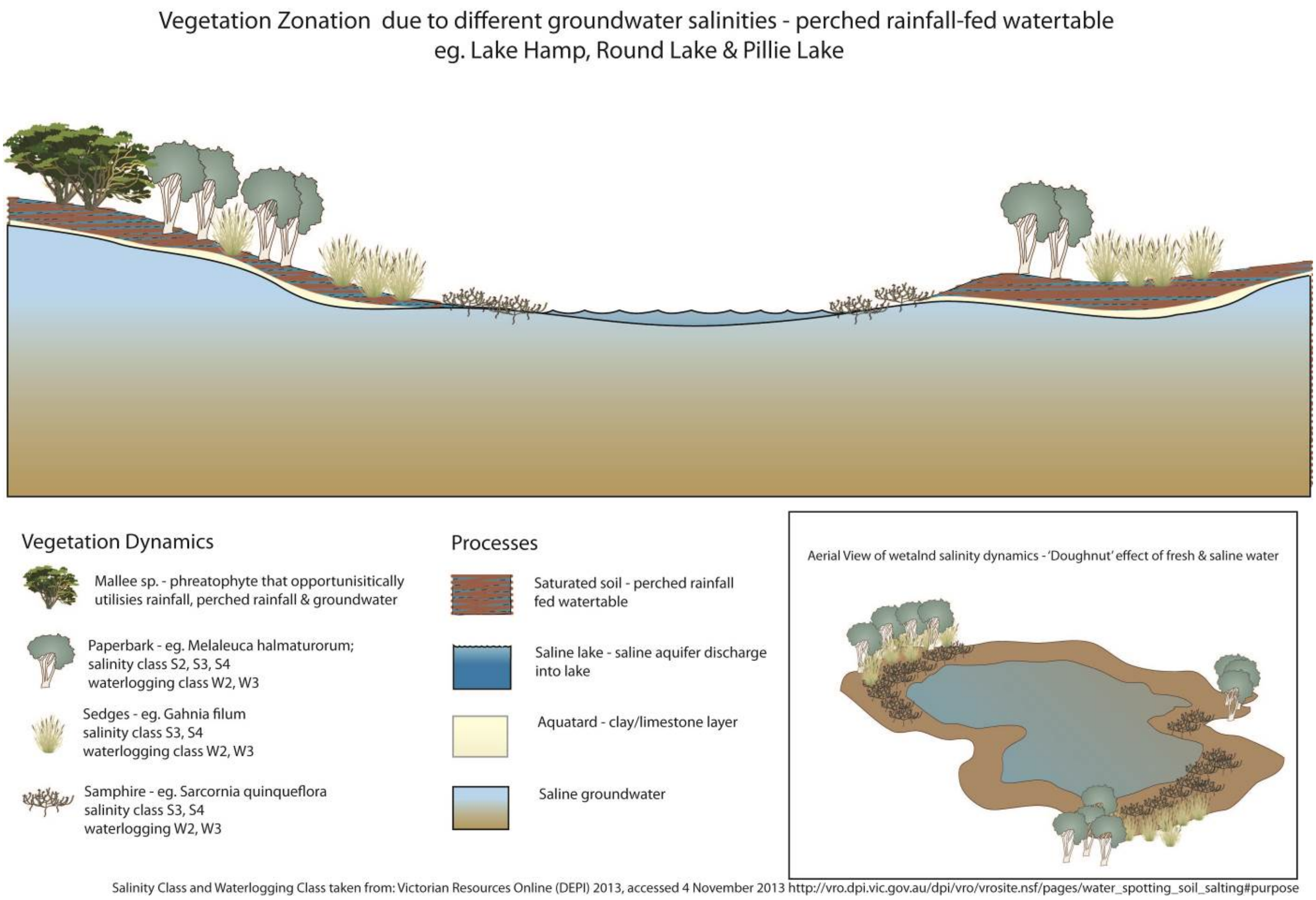


Figure 2. Conceptualisation of the perching-ponding model

1.3.2. Dilution-front model of permanent salt lake sedge zonation

In some locations visited during field investigations Quaternary groundwater via Pathway 2a (Section 1.3) does not appear to generate vegetation zonation purely as a result of inundation or saturation. At saline lake shores where dense stands of sedge species such as *Baumea juncea* and *Schoenoplectus pungens* were present, Quaternary groundwater discharge overlies, displaces or mixes with saline lake water. Non-halophytic sedges occupy the resulting 'dilution front' where the discharging freshwater provides amelioration of the hyper-saline lake waters.

Hence observed zonation appears to result not only as a function of saturation, but also of the resulting reduction in sediment pore water salinity. Where groundwater discharges occur away from lake shores, it appears that only plant functional groups with a tolerance of drying *and* salinity can persist (e.g. *Melaleuca* and *Gahnia* spp). Associations of *Baumea*, *Juncus*, *Cyperus* or *Schoenoplectus* species were only observed at lake edges suggesting a possible ecological role for the saline lake waters, although presence is clearly dependent upon the relatively fresh discharges creating a narrow hydrological – salinity niche.

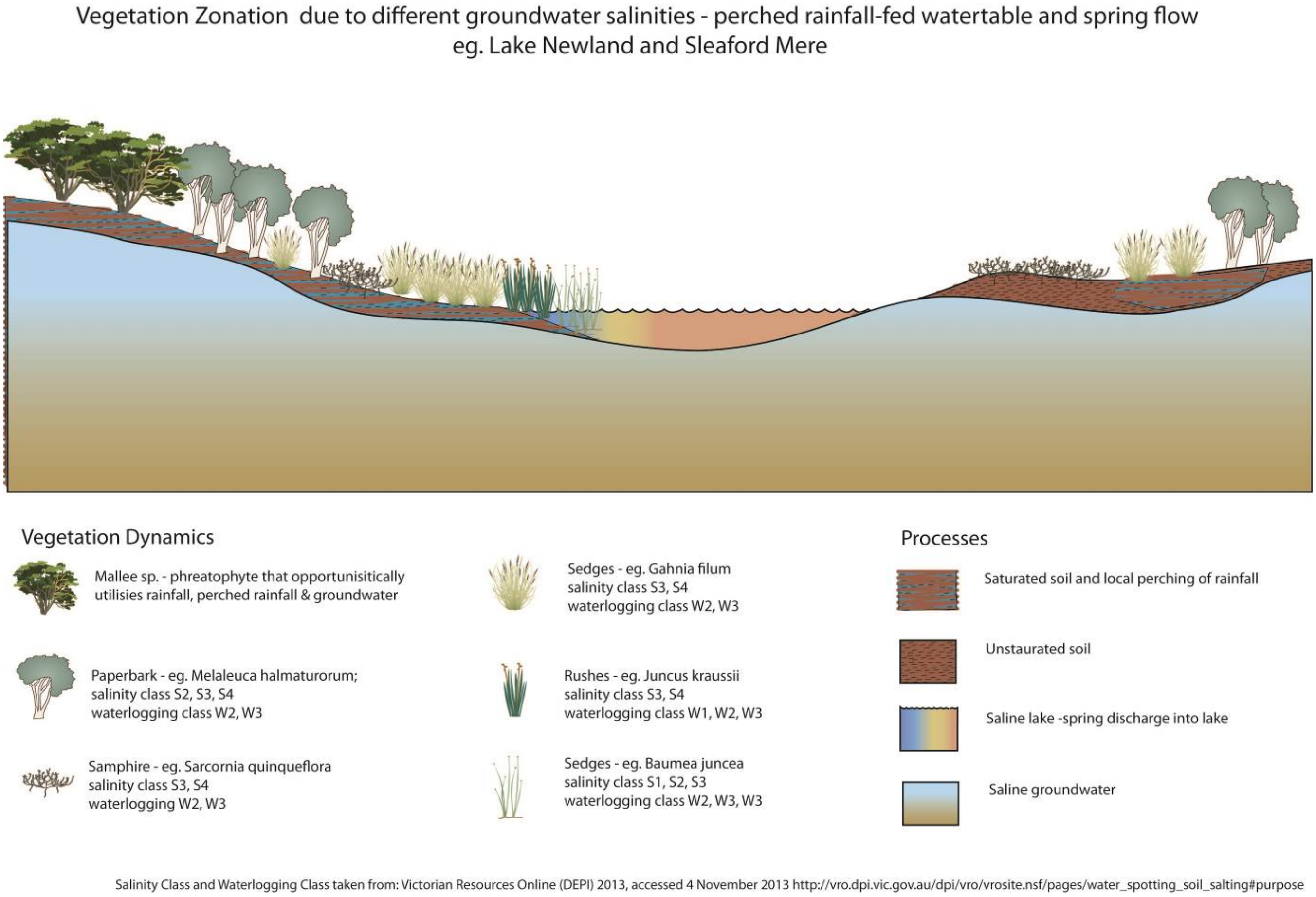


Figure 3. Conceptualisation of the dilution front model

1.3.3. Hydraulic lift phreatophyte model

Phreatophytes introduce some complexity to the use of plant functional groups as approximations of EWR as their precise water requirement is not defined in terms of a surface water depth-duration response as is commonly adopted with amphibious or submerged plants. Many phreatophyte stands exist in locations where surface soils are never completely inundated and it is necessary to determine groundwater dynamics to explain the observed condition.

Groundwater dependence of phreatophyte communities can be identified by the characteristic of continuing to maintain a high level of water use during periods of climatic drought. This indicates a de-coupling of the water source supporting the trees from prevailing climate, most readily explained by groundwater. It is not possible to determine from desktop studies the actual source, but it can to a certain level of confidence be inferred from what is known about the hydrogeology and climate.

Where deep-rooted perennial species can access groundwater well below the root zone of understorey species, hydraulic lift may lead to a productivity supplement to shallow rooted species by re-distribution of water to surface soils where it becomes available for uptake by all species (Caldwell et al., 1998).

This mechanism may be at least partly responsible for the presence of *Gahnia* understorey occurring beneath *Melaleuca halmaturorum* woodlands. Disconnection of *Melaleuca* roots from regional groundwater and subsequent loss of hydraulic lift derived surface soil water supplements is a potential explanation for the loss of *Gahnia* observed at Poelpena during field reconnaissance. It is unlikely that this would be the only source of water, but during dry periods the extra soil water component from hydraulic lift may be critical to support understory plants. In other settings, terrestrial shrub species richness or density may be dependent upon such soil moisture supplements. It is even possible that supplementary pasture productivity takes place due to the occurrence of added soil moisture from paddock phreatophytes.

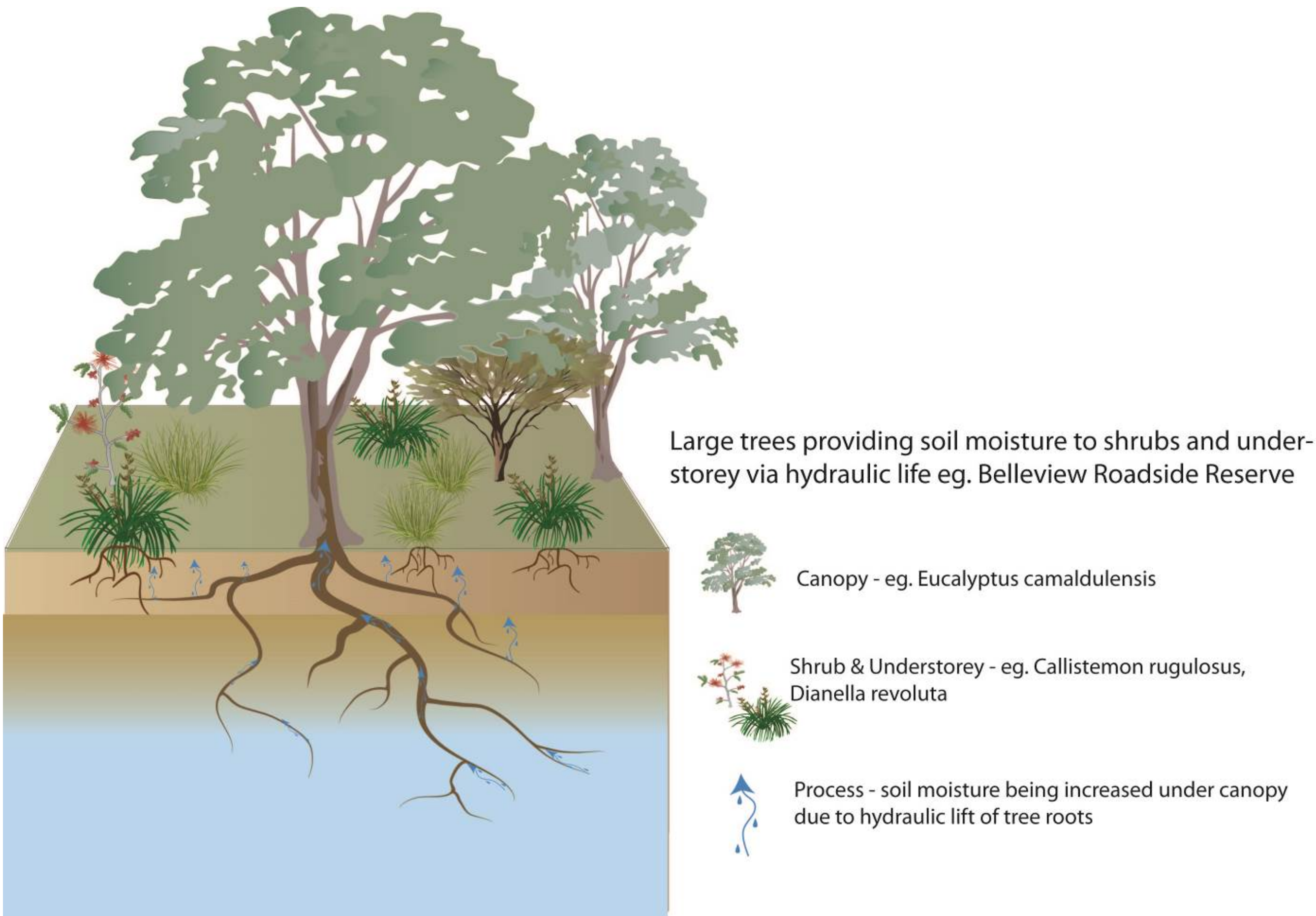


Figure 4. Conceptualisation of the hydraulic lift phreatophyte model

2. Program technical design

Monitoring as a component of adaptive management

Monitoring is a highly resource intensive activity, yet under an adaptive management approach it is indispensible. An adaptive management cycle (attributed to Holling 1978) views management as a highly dynamic process of continual adjustment towards a desired state. The ability to learn while doing and adjust as needed is critical for natural resource management because ecological and social systems are complex and self-organising in nature. Overall responses cannot be easily predicted from those of individual components (Harris, 2007). In the absence of complete understanding, continual adjustments based on observed progress are needed to move towards desired end states. Such adjustment is only possible where adequate monitoring and evaluation are available to assess this progress. Management seeks to continually improve by implementing an explicit series of steps, which can be represented in a cyclic diagram such as shown in Figure 5. Although depicted as being sequential in Figure 5, in reality many of the tasks are concurrent and continuous throughout the process. Monitoring is a good example of such an activity. Adaptive management frameworks provide the context and a means for integration of monitoring activities into more effective overall actions.

The cycle starts by assessing the current landscape and agreeing on a desirable future condition that is to be achieved through management intervention. Existing knowledge is used to model the system response in order to decide on management actions most likely to result in the desired state, along with suitable measures of progress towards this state (performance indicators). Monitoring then provides the information necessary to interpret the success or otherwise of actions to achieve the desired outcomes. The definitive characteristics of true adaptive management are the feedback loops that allow for adjustment of actions undertaken based on observed outcomes and continuous improvement in pre and post intervention system understanding.

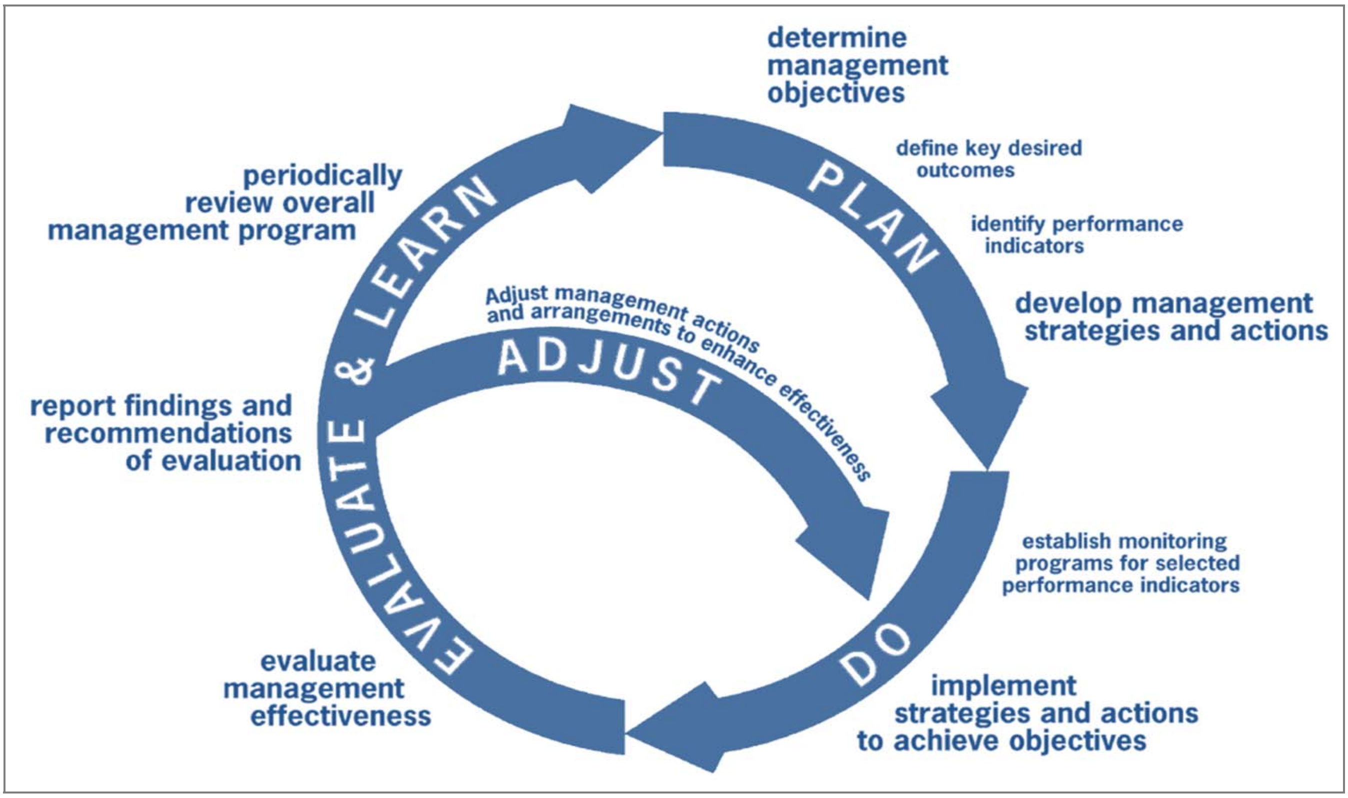


Figure 5. Diagrammatic representation of the adaptive management cycle (from Jones 2005)

It is important that the design of a monitoring and evaluation program is nested within the overall management framework and is explicit from the outset. This includes information that demonstrates what the program aims are and how these can be achieved. This includes having a framework for regular review against these aims, allowing refinement as required in adaptive management. McDonald (2003) reviews the key features of environmental monitoring program design, which include:

(1) defining the monitoring scope – questions to be answered

(2) specifying the study population of interest and the allocation and arrangement of sampling units

(3) establishing the sampling protocols (measurements to be taken and their sampling frequency)

(4) determining the sample size (replication necessary for desired power to detect change).

To these we can add a fifth step:

(5) specifying how data are to be used for evaluation purposes – the analysis and interpretation stage, along with any feedback processes to refine monitoring design and to inform planning.

Each of these components of program design are discussed below.

2.1. Monitoring program scope

The aim of developing a VWASP GDE monitoring program for the Eyre Peninsula is to relate the condition of vegetation associations dominated by aquatic plant functional groups to Quaternary aquifer water table dynamics. Geographically, monitoring recommendations are limited to the Musgrave and Southern Basins PWAs. From a hydrological perspective, the scope is constrained to the Quaternary aquifer (Bridgewater Formation), the source of groundwater that is most heavily developed in the region. Building on Doeg et al. (2012), Section 1.3 establishes some 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. As suggested by Doeg et al. (2012), other GDEs are likely to be present in the region and when resources become available the program scope could be extended to include such systems.

The monitoring and evaluation program proposed seeks to answer the following questions:

- For a given range in water table dynamics, which plant functional groups are most likely to be present?
- What are the critical characteristics of water table dynamics that are associated with a given plant functional group being maintained in good condition (or, alternatively which dynamics lead to degraded condition)?

Monitoring and evaluation in this program seeks to determine the point at which water limitation will lead to a discernible change in vegetation condition. To meet this aim, site selection should be stratified to measure a range of observed conditions for each plant functional group. For this program, aquatic functional group populations observed in November 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 water table 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 water table 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's five-yearly review intervals. It should also be recognised that understanding about sub-lethal and early warning indicators of change will require a longer term investment.

2.2. 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 (see Section **2.4.2** for a discussion of appropriate levels of replication). On the Eyre Peninsula, two major classes of GDE study populations have been identified for monitoring: phreatophyte vegetation associations and wetlands. The size of the study populations is described below.

2.2.1. 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 red gum condition having been reported. Field visits confirmed reported evidence of recent loss of red gums in at least one area (Section **3.2.3**). 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 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 (±57.97 SD) ha. Another phreatophyte of significance in the region is the water gum (or Eyre Peninsula blue gum) *Eucalyptus petiolaris,* which is mapped as occuring in mixed stands with *Eucalyptus odorata* 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.

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 (Section **2.3.2**).

Melaleuca halmaturorum is defined as a facultative phreatophyte, meaning it will use groundwater if present but 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 extirpated 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 Musgrave and Southern Basins PWAs are suggested for monitoring in order to gather evidence for groundwater dependence of both or one of these species.

2.2.2. Wetlands

The sampling population for study wetlands extends to each consanguineous suite (Semenuik & Semenuik, 2007) considered to have a Quaternary groundwater dependence. For this pilot study, constraints in available resourcing have led to the pragmatic decision to limit site selections from amongst the 'representative wetlands' for each relevant suite presented in Doeg et al. (2012). These authors also suggested Poelpena wetland in addition to those identified in the original work (Semenuik & Semenuik, 2007). In the Musgrave PWA representatives of three wetland suites are found and in the Southern Basins PWA, there are two (Table 1).

Table 1. Summary data for wetland suites and representative wetlands considered for monitoring

Wetland suite	PWA	Count	Total area (ha)	Mean ± SD area (ha)	Representative
Hamilton	**Musgrave**	**39**	**1589**	**40±97.5**	**Round Lake**
Poelpena	**Musgrave**	**1**	**343.2**	**N/A**	**Poelpena**
Newland	**Musgrave**	**33**	**2043**	**62±140.2**	**Lake Newland**
Unassigned*	Musgrave	2	2082	1041±1452.4	NA
Sleaford	**Sthn Basins**	**6**	**755**	**126±240.4**	**Sleaford Mere**
Pillie	**Sthn Basins**	**1**	**38.4**	**N/A**	**Pillie Lake**
Wanilla*	Sthn Basins	2	13	7±5.3	Merintha Creek
Greenly*	Sthn Basins	7	296	42±57.2	Big Swamp
Unassigned*	Sthn Basins	23	498	22±42	NA

* Current understanding is that these wetlands have no dependence upon Quaternary aquifer (Doeg et al. 2012) and no GDE monitoring is suggested. Bolded sites are thought to have a dependence on Quaternary groundwater

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.

2.3. Spatial scale: 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). Monitoring 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 observation well (obswell) network. Therefore more than one plant functional group may be present at a study site and referenced to the same obswell network.
- Sampling units – as zones of plant functional groups (PFG) are the variable of interest, this is what needs to be replicated to provide the understanding of water table 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 (Section 2.4)

Owing to differences in climate and other physiographic variables and the large distance between their boundaries, it could be argued that there are two separate study areas corresponding to the two PWAs of the Musgrave and Southern Basins. As discussed, some species are also found in more than one habitat type (e.g. *Gahnia* is found in phreatophyte woodlands and wetlands). An ideal design would see these as grouping factors and have a comparable level of replication assigned to each. This would however mean that all monitoring must be duplicated at both sites and all habitats leading to a large increase in monitoring costs. 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 are probably more realistic from a resourcing perspective. Whether this is valid or not 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 water tables 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 (water table) include land use and physiographic conditions (e.g. climate, soil type, geology).

2.3.1. Establishing 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 water table 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.

This report sets out a range of criteria created for the purpose of developing an objective and transparent site prioritisation for a monitoring program. Criteria are explained below and an implementation of these with the weightings discussed appears in Table 2 allowing the reader to compare relative values between sites, or re-prioritise sites against different decision making criteria, scoring or weightings system.

2.3.2. Site selection criteria

A range of criteria relating to the importance of each site under a range of categories were considered, each category can score between 1 and 3, with higher scores indicating a better return on monitoring investment for the criteria concerned. As not all criteria are of equal interest to resource managers, more critical criteria are assigned a double weighting value of 2, with the total score reflecting this weighted sum.

(1) Plant composition and condition – weighting 1

Rationale: Each site should exhibit a clear dominance by one or more of the amphibious plant functional groups referred to in Doeg et al. (2012). Across all monitoring sites, a range of observed biological conditions for each functional group should be targeted to enable a link between water tables and vegetation (i.e. sites that are 'too dry' or 'wet enough'). Condition in this context refer to relative stem density (i.e. individuals per unit area), presence of understorey or commonly associated species (e.g. *Melaleuca* over *Gahnia*), phenology (flowering, fruiting), evidence of successful recruitment and range of age classes and canopy related indicators such as density, colour and epicormic growth (a known indicator of water stress for eucalypts).

Higher value is given for the determination of a hydrological niche where more than one functional group is observed on a hydrological or salinity gradient or, when functional groups have distinct zones attributed to elevation relating to duration of saturation or depth of inundation.

Higher value is given if physiological limits are observed (assumed to be related to water table variation):

a. sites are no longer able to support plant functional groups that were formerly present OR

b. sites where environmental needs for water are being met

<u>Scoring</u>:

1 = vegetation is dominated by terrestrial types but with some aquatic plant functional groups present in low densities

2 = dense cover of one aquatic plant functional group indicative of a high water demand or association

3 = more than one high density aquatic plant functional group cover OR clear evidence of decline in condition or loss of an aquatic plant functional group

(2) Regional prevalence – (i.e. number of other similar systems of GDE) weighting 1
Rationale: Maximum value is obtained from monitoring data where inference can be made at multiple similar sites. This must be traded off against any values associated with the conservation values of a relatively unique system (Criteria 5).

Scoring:

1= one of only a few similar type of groundwater dependent ecosystem in the PWA or region

2= multiple groundwater dependent ecosystems of similar characteristics are found in the region but are locally restricted

3= ecosystem type is widespread and findings are potentially relevant through much of the PWA or even regionally

(3) Promixity of potential development pressure – weighting 2
Rationale: This criteria establishes how likely is it that the site might be impacted by draw down or be unlikely to experience pressure under existing conditions (indicating good control site potential). Considerations here relate largely to relative position of the site compared with extractive pressure (up or down gradient). Sites may be prioritised either near to the extractive pressure or further away, either in the same groundwater lens or an adjacent one and serving as a control

Scoring:

1 = site unlikely to be subject to extractive pressure at any foreseeable time but not suitable as a control site

2 = site is up-gradient of areas of development pressure OR within an area formerly supporting high volume extraction and with uncertain future pressure

3 = site located within impact zone of high volume extractive pressures OR suitable control site for such sites

(4) Groundwater dependence – weighting 1
Rationale: many of the assumed groundwater dependencies are precisely that – an assumption. Section 1.3 outlines some working hypotheses for different plausible mechanisms for provision of water to ecosystems. This uncertainty represents a risk to the value of any monitoring data gathered in terms of meeting water allocation planning information needs. Scoring is assigned here based on the subjective confidence available to assign a level of dependence. One of the major aims for monitoring is to determine this dependence with higher certainty.

Scoring:

1 = groundwater dependence is considered unlikely based on available information

2 = likely to be dependent upon groundwater resources for at least some part of life history (e.g. recruitment)

3 = high certainty dependence on groundwater resource for persistence

(5) Conservation values – weighting 1
Rationale: Any site with a high level of conservation value ascribed to it is likely to be of disproportionate importance both to the community and biological processes. Additional information will always be useful for management in this context, but such uses are not always immediately evident. The more unique the ecosystem is to the area the more likely it will be of a higher conservation value at larger management scales.

Scoring:

1 = ecosystem is of local biodiversity significance, possibly structurally simplified (e.g. lacking strata or mono-dominant)

2 = ecosystem exhibits some habitat complexity (e.g. presence of multiple vegetation strata) and is of biodiversity conservation importance for the PWA

3 = ecosystem is of regional or higher biodiversity conservation significance

(6) Existence of prior information – weighting 1
Rationale: Previous studies, knowledge and data greatly increase the value of future data collection, allowing for longer time trends to be more readily tested or for model calibration or verification. This includes past vegetation surveys, but most importantly groundwater data.

Scoring:

1 = no prior information available, nearest groundwater data is of unknown applicability

2 = limited vegetation survey data available and/or some groundwater data available

3 = located near to current observation network and/or part of a vegetation monitoring program

(7) Site tenure and access – weighting 1
Rationale: This criterion introduces a logistical element to site prioritisation. This includes both the security of access for ongoing monitoring and the level of access for drill rig and subsequent monitoring activity.

Scoring:

1 = private landholder with no track access

2 = private landholder with good accessibility

3 = public land with any accessibility

(8) Community interest in, or concern for, the ecosystem – weighting 1
Rationale: Ultimately NRM boards are responsible to the community for management decisions. Some landscape elements are more highly prized than others for various reasons. Such sites warrant additional effort because of the value of the resulting community engagement.

Scoring:

1= no widespread public interest known

2= some community interest in conservation, or involvement such as friends groups

3= high conservation value (listed) wetland or woodland community OR high visibility or iconic environmental asset (especially phreatophytic Eucalyptus woodland) with observed decline in condition

(9) Complementary outcomes – weighting 1
Rationale: This criterion seeks to provide a measure of the additional benefits over and above thresholds of environmental response to water availability. In some cases monitoring can help to provide the basic information needed to help determine some functional aspects at a given site or more broadly. Or alternatively the data may be useful for additional studies, opening up potential partnerships with research institutions e.g. Universities.

Scoring:

1= monitoring data only likely to be useful in establishing local environmental water requirements

2= monitoring data may provide insights into key hydrological or ecological processes at the site

3= monitoring data may contribute to multiple research outcomes at the site

(10) Management value – weighting 2
Rationale: Resource management is a complex operation, often operating in data-poor settings. NRM Boards not only need to provide evidence linking resources to environmental condition, but develop an understanding to the range of values that can support such landscape elements under a range of extractive pressures. Monitoring can be a monetary and time expensive activity and provision of information that help the NRM Board in multiple aims represent an increased return on this investment.

Scoring:

1= monitoring and evaluation may provide information relevant to environmental condition at the site in question for observed water table dynamics

2= monitoring and evaluation may help establish or test threshold values predicting good or poor condition that have potential for being transferable throughout similar systems across the PWA

3= monitoring and evaluation can achieve outcomes as under Criteria 2 and in addition provide specific information to test working hypotheses of water delivery

Table 2. Results of site prioritisation

Rank	Site name	PWA	Total	Crit. 1 PFG	Crit. 2 Rep	Crit. 3 Devt*	Crit. 4 GW conf	Crit. 5 Cons	Crit. 6 Prior info	Crit. 7 Tenure	Crit. 8 Community	Crit. 9 Research	Crit. 10 Mgmt value*
1	**Belleview**	M	35	3	2	3	3	3	3	3	3	3	3
2	**Sleaford Mere**	SB	26	3	2	2	3	3	3	3	3	2	2
3	**Pillie Lake**	SB	24	2	2	2	3	3	3	3	2	2	1
4	**Lake Newland north**	M	23	3	2	1	3	3	2	3	3	2	2
4	**Lake Newland south**	M	23	3	1	1	3	3	2	3	3	3	2
6	**Bramfield**	M	22	2	3	3	3	1	1	2	2	2	2
7	**Mount Wedge**	M	21	2	3								
7	**Poelpena**	M	21	2	2	3	3	1	2	2	1	2	3
9	**Lake Hamp**	M	16	2	2	1	2	2	2	2	1	1	1
9	**Round Lake**	M	16	2	2	1	2	2	2	12	2	1	2
NA	**Big Swamp**	SB	22	3	1	2	1	3	2	2	3	3	3

** Selection criteria with a weighting of two in calculations – see above section for explanation of selection criteria and scoring rules*

2.3.2.1. 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:

(1) Sites that appear currently to be maintaining ecological viability (based on observed density, condition and age classes); and

(2) Sites which were evidently under stress or have possibly transitioned from former functional groups to a new assemblage

Time series biological data was not available to determine vegetation condition at potential sites, so the aim has been to assess the apparent condition during field visits in June and November 2013. Sites were compared for compositional similarity with mapping units created by DEH (feature class: "VEG.SAVegetation.shp", accessed Dec 2013) and were assessed relative to one another 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 PFG within the short list of sites that are available is preferable. Once the water table dynamics supporting these 'black and white' areas of the gradient are established, the more complicated 'gray' 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 water table dynamics. A first draft of this should be possible after the first five-year monitoring period.

A total of 11 potential study sites were prioritised for monitoring effort across the Musgrave and Southern Basin PWAs based on field visits (Figure 6 and Figure 7) and the application of the selection criteria to observations. Sites included three wetlands, five phreatophyte areas and three mixed sites offering potential for both habitat types.

Considering the additional decision points logic above, a prioritised list for the program by PWA could be as follows:

Musgrave

- **High – Belleview** red gum woodland - Mount Wedge – provides the impact site information for comparison with the Belleview site and should be considered equally important. Historical obswells in the area should be investigated prior to committing to a new well (TIN014, TIN015 – last monitored 1995)
- **High – Poelpena** provides a point of comparison in between the decline in condition at Mount Wedge. Red gums in the area near the homestead appear to be in good condition, despite being sparse due to (presumably) having been cleared during establishment of Poelpena Station. Hence water table data from the site provides an additional data point for comparison with Belleview to verify adequate availability to support red gum. The site also provides a point to assess the loss of *Gahnia* from *Melaleuca* woodlands and the state of the woodlands themselves. This forms a possible impact site for both species for comparison with the Lake Newland data. Multiple wells are found in the Poelpena area, and a detailed search and condition inventory is recommended prior to deciding on any need for any additional wells at the site.
- **Lower – Bramfield** provides an additional source of information on an adequate water regime to support red gum woodlands in Musgrave and may provide insights into recruitment processes over time. It is lowest priority of the Musgrave sites.
- **High** – both **Lake Newland** sites provide information on water requirements to maintain mixed wetland sedges and *Melaleuca* woodland with *Gahnia* understorey in good condition from the Musgrave PWA

- **Lower – Round Lake** offers opportunities similar to Lake Newland as controls for any impact observed at Poelpena for *Gahnia* and *Melaleuca* associations.
- **Limited – Lake Hamp** is of limited value, but offers similar opportunities to Round Lake

Southern Basins

- **High – Sleaford Mere and Pillie Lake** – to provide information on high conservation value sites with multiple plant functional groups (mixed sedges, *Gahnia*) and phreatophyte communities (mallee, *Melaleuca*) in good condition wihtin the Southern Basins PWA.
- **High – Big Swamp** was included in this analysis to demonstrate that it ranks highly (equal sixth) against the other sites for monitoring value, despite being equivocal in terms of groundwater dependence (and therefore at a disadvantage in this analysis). It is likely this would rank among the highest monitoring priorities if the groundwater reliance criteria were removed (see Appendix for a discussion of potential investigations at this site).

In addition to the pre-determined representative wetlands (Doeg et al. 2012) and phreatophytes, four sites were considered of very high potential value for monitoring. Additional information would be required in order to make a categorical statement as to their value, but it warrants investigation. Before a final decision is made on allocation of resources to monitoring, all of these sites should at least be considered (Table 3).

Table 3. Additional sites of potentially high value for monitoring in the Southern Basins PWA

High value sites – Southern Basins			
Site	**Type**	**Vegetation**	**Rationale**
Stands of *E. petiolaris*	P	*Eucalyptus petiolaris*	High conservation value phreatophyte, widespread in region
Big Swamp	P/W	red gum mixed sedges	Field visit beyond scope – but potential for high value information on plant function group water requirements to be gained
Little Swamp	P/W	red gum mixed sedges	Field visit beyond scope – but potential for high value information on plant functional group water requirements to be gained
Unnamed wetland	W	*Gahnia trifida, Baumea juncea* sedgeland	Large wetland on western side of the Uley South lens within the SA Water supply reserve, near Shoal Point. Wetland was only observed during desktop mapping and would require a field visit to quantify if it would be a site for future monitoring.

Figure 6. Sites visited within the Musgrave Prescribed Wells Area in 2013

Figure 7. Sites visited within the Southern Basins Prescribed Wells Area in 2013

2.4. Design and monitoring protocols for sampling units and sub-samples

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. This section outlines some general design considerations for sampling, with additional details on site orientation and location in Sections **2.4.3** and **2.4.4**.

2.4.1. Relating obswell data to vegetation condition

Vegetation responses are complex and observable condition may not change greatly over a wide range of water table 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). Studies of this nature would be well suited to post-graduate research student, but such specialised monitoring is unlikely to be realistic for most NRM purposes. Hence the proposed focus for this program is the use of surrogate measures of condition such as species density, abundance and condition measures such as canopy (Table 4).

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 water table can be approximated by a level surface, the variation in water table 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 water table 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.

The approach suggested for this program is to designate a rectangular study-site boundary centered on the main observation well. Within this area, either fixed or random vegetation sampling units can be used, provided the elevation of each sub-sampling unit to 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. This option has benefits as only requires a single groundwater monitoring well. The use of additional groundwater monitoring wells will increase confidence in localized standing water levels through improved accuracy of interpolated groundwater levels across the surface to match vegetation quadrat elevations. 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 water tables 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 providing precise measurements. This is recommended as part of initial site set up.

The number of obswells required will depend on relative levels of variation in the water table and land surface. For flat terrain, a single obswell may be adequate. Monitoring data from eight randomly selected obswells near to Poelpena Station located up to several kilometres apart indicated water table 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 m 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 water table elevation. The significance of such an error will depend upon how large this is compared with water table fluctuations. Small-scale variability may be considerably less but this needs to be determined to establish whether a uniform water table elevation can be assumed. The use of a single well to estimate the water table 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 water table slope near the site. This should be within a few hundred metres of the obswell and referenced to a common datum.

Where a clear topographic gradient is present within the study site, water tables will also likely exhibit some subdued level of slope. At least three obswells would be required along a diagonal, or five obswells are recommended in a cross or similar orientation to estimate 3-dimensional variation (Figure Figure 7). A topographic gradient will most likely occur at wetlands with water tables being near-surface, it would be expected that most obswells will be shallow (<2 m). All additional obswells would be relative to the main obswell, which should be deeper to ensure saturated conditions in the well, even during dry periods. For deeper water table 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 water tables 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.

It is suggested that in any location where Quaternary groundwater may not be the only source of water creating an observed vegetation zonation (see the working hypotheses under Section 1.3), nested piezometers should be installed. This would involve co-locating a shallow obswell (perhaps less than one metre) adjacent to the main obswell (of up to five or more metres depth). Designing an appropriate installation may require some information on soil profiles or possibly 1–2 years of water table 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 water table (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 (See Section 1.3).

Finally a low-cost, manual-read rain gauge located as close as possible to the study site is recommended 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 water tables 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.

2.4.2. Monitoring variables and temporal frequency

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

- Explanatory (independent) variables: the three-dimensional variation of water availability over time as a result of Quaternary aquifer water table dynamics
- Response (dependent) variables: 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 4 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 are 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 pilot data collection can be run at each site.

Table 4. Main response variables and covariates, and methods for monitoring

Variable	Sampling unit and sub-samples	Measurement	Variable to be estimated	Site replication
Stem density	Sampling unit: 1 ha plot Sub-samples: 20 x 50 m 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, with 6 or more ideal for statistical purposes
Mean height	For sedges an estimate of mean height can be obtained	Height per sub-sample	Mean height (±CI) - Mean elevation of each	Sub-samples at same points

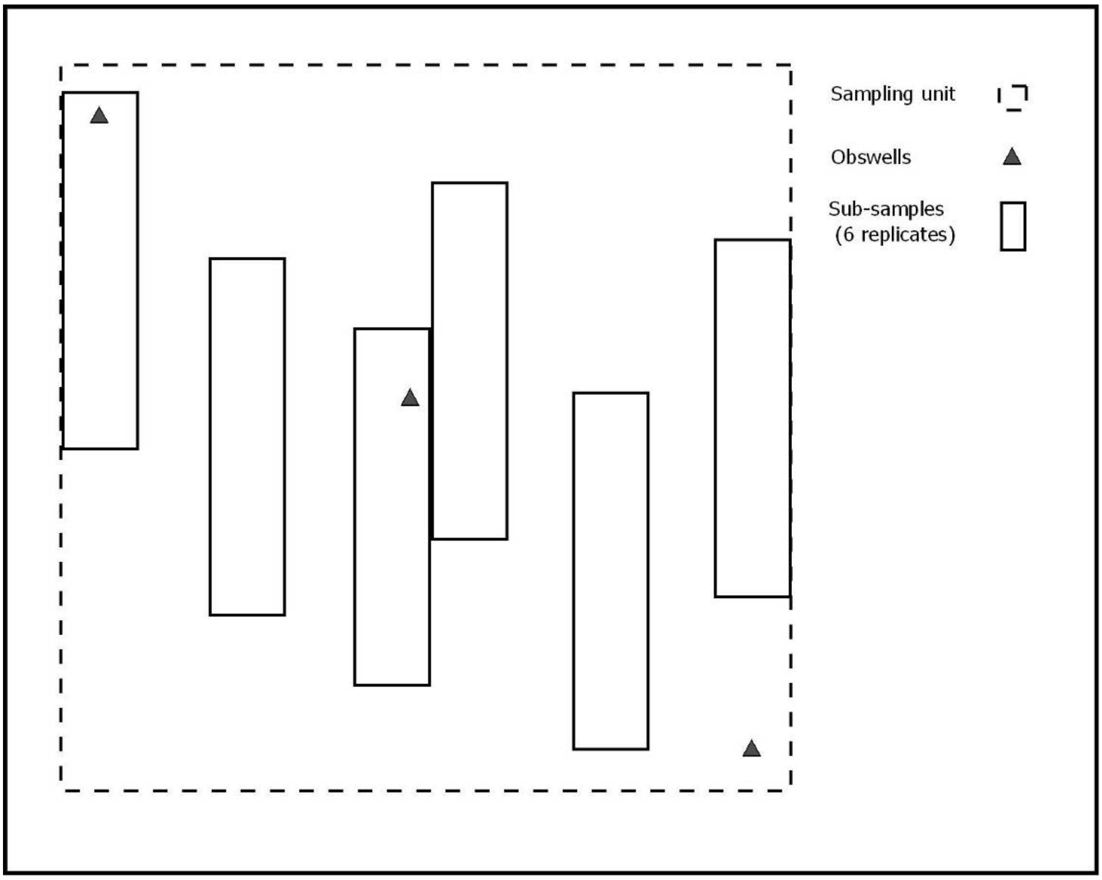
	by measuring the height of six plants within each sub-sample.		quadrat relative to groundwater datum	as above
Canopy condition	Sampling unit: 1 ha plot Sub-samples: 30 trees randomly assigned across stem density quadrats	Souter et al. (2010) Nicol et al. (2010)	Ordinal condition scores (widely used in 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	Six or more is ideal
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
Sedges	Sampling unit: 1 ha plot Sub-samples within each distinct zone: 1 m^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	Six or more is ideal
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	pH, salinity, nutrients, soil	Quantitative soil	Various soil parameters to	As suggested

chemistry and hydraulics	strength, infiltration rates for each soil horizon	chemical descriptors	characterise site soils to allow for inter-site comparison	by soil mapping (at least one per mapping unit)

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

2.4.3. 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 red gum condition method (Souter et al., 2009) is recommended. For 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 8) 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.



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 obswells may not be necessary, if only one well is used, centre position is preferred. Avoid areas damaged during drilling when positioning sub-samples.

Figure 8. Example of a sampling unit and sub-sample design for phreatophytes

For *Melaleuca*, an initial sampling unit suggested is 0.5 ha, notionally 50 x 100 metres (provided the width does not introduce too much uncertainty in elevation), centred on the main obswell. The long axis should be oriented along the water table 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.

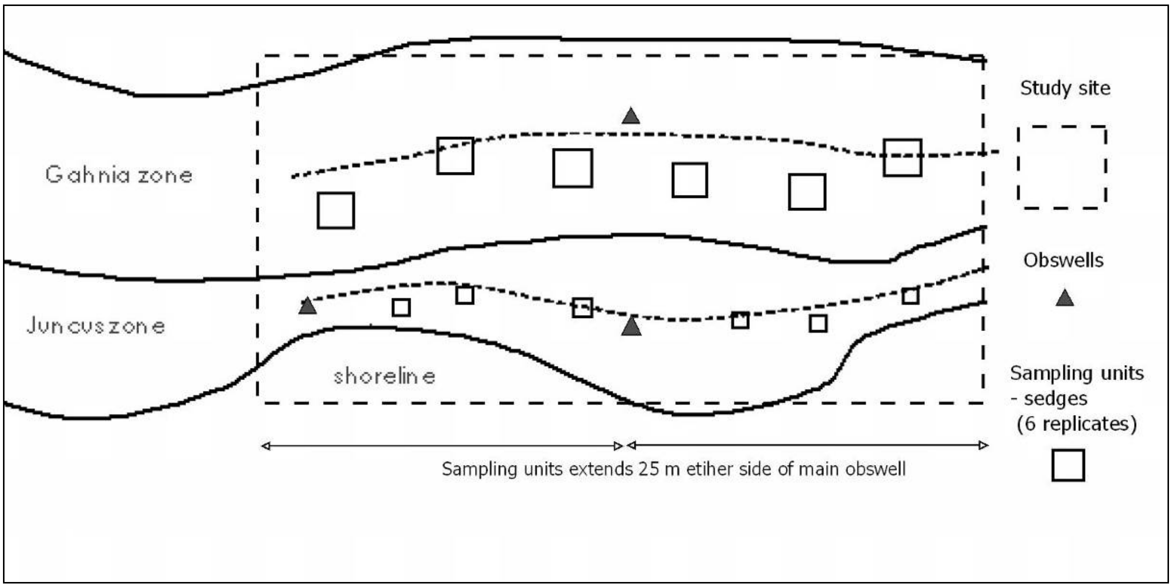
2.4.4. Sampling protocols and sampling unit orientation for wetland study sites

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 where narrow zones rather than broader habitat patches that were observed in phreatophyte associations. A maximum 25 metre 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 9). 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. 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.



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.

Figure 9. Study site setup for hydrological gradient (e.g. Sleaford Mere)

Another wetland situation that may be encountered is a dense mono-cover stand of a single species, most typically *Gahnia filum* or *G. trifida*. A 3 x 3 metre 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-transects should be established along the gradient of interest, either connecting observation wells of two elevations, or no more than 50 metres up and down gradient from a single obswell. 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 10 m apart (to provide a good level of separation) is recommended with at least six 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 (i.e. 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.

Table 5. 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 obswell*	3 x 3 m quadrat 6 replicates	Usually found near wetlands
Gahnia mono-cover-linear zone	W	50 linear metre zone centred on obswell*	3 x 3 m quadrat 6 replicates	Wetland shore zones
Gahnia understorey	P	20 x 20 m centred on obswell*	3 x 3 m quadrat 6 replicates	May be wetland area or general topographic low
Red gum, *E. petiolaris*	P	100 x 100 m centred on obswell*	20 x 50 m quadrats 6 replicates	Long axis of quadrats should be along water table contours. Understorey monitoring recommended if natural woodland
Melaleuca (± Gahnia understorey)	W/P	50 x 100 m centred on obswell*	10 x 50 m quadrats (Mh) 6 replicates	Orient both sampling unit and quadrats along water table contours
Mallee eucalypts	P	100 x 100m centred on obswell*	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 50 m up and down gradient of obswell*	X x 1 m subtransects every 0.2 m change in elevation 6 replicates	Orient main transect across water table contours and sub transects along.

*All recommendations to centre on obswells assume that the obswell 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 obswell installation should be avoided.

2.4.5. Re-visit frequency

For each study site a small groundwater network is proposed, with at least one well being instrumented with a data logger recording at hourly intervals. The reason for such a high sampling frequency is to seek information on water use from water table fluctuations e.g. using the White method (White, 1932).

For the non-instrumented wells, manual water level recording is necessary with monthly sampling ideal. At a minimum quarterly sampling is suggested, roughly seasonally to provide adequate variation over the year for use with interpreting vegetation sampling. Sampling periods would then be: Apr–May, Jul–Aug, Oct–Nov, and Jan–Feb. Frequency should never be less than twice per year aiming to capture seasonal highs and lows in Mar–Apr and Aug–Sep.

Vegetation sampling could be notionally undertaken annually in spring, but sampling frequency can be adjusted for some parameters. If resourcing cannot extend to annual sampling for all vegetation parameters, density (sedges, phreatophytes) could be recorded initially and then perhaps 2–3 yearly (sedges), or 5 yearly (phreatophytes), where changes in density are of interest. Phenological state and recruitment success would ideally be done annually in late spring.

2.4.5.1. Salinity and general water chemistry

Salinity should be measured at the time of obswell 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 an obswell 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 at the same time as when 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 (Section 1.3). Sampling for this could initially be based on salinity only and would be done at the end of winter early spring as water tables 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.

2.4.5.2. 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 year re-sampling frequencies would at least allow some analysis of any change in vegetation over the sampling period and comparison with the water table data.

2.4.5.3. Phreatophytes

Ideally the 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 population 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.

2.5. 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. This is discussed below.

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 water table 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 water table (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 modeling questions well suited to (generalised linear or additive) mixed modeling approaches, which can account for nesting and auto-correlation (non-independence) and covariates in the model structure (Pinheiro & 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 4, section 2.4.2) 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 water tables do not explain much of the variation in condition, or where comparable water table 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 water table 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. Water tables 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 PWA in White et al. (2014) includes an approach for presenting water table 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 water tables 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.

3. Field based site investigations

3.1. Wetlands

3.1.1. Pillie Lake

3.1.1.1. Description

Pillie Lake is a seasonal, coastal salina of high ecological value (Williams, 1985) located in a depression of Quaternary calcarenite dunes around 10 km to the south of Port Lincoln (De Deckker et al. 1982). The wetland is classified by Semenuik & Semenuik (2007) within the Coffin Bay suite.

3.1.1.2. Hydrology and water quality

Pillie Lake is ephemeral, with both rainfall and seasonal groundwater discharges contributing to the water balance (De Deckker et al. 1982). Quaternary aquifer discharges are likely the major groundwater contribution, although some local flow systems in adjacent dunes also likely contribute. During field visits there was no evidence of any freshwater discharges that might be associated with the low salinity Quaternary aquifer, and nor was any standing water observed, the water table being measured at 24 cm below the lake surface. Semenuik & Semenuik (2007) seem to suggest that the system is a recharge feature ("Water flow in the basin is downward" pg. 18) but this is difficult to reconcile with the depressional landscape setting or constant presence of shallow groundwater, which suggest it represents a discharge system.

Regional groundwater data records for the period 1992–2009 range between 1400–2700 µS/cm but are relatively few in number (observation wells FCN008, FCN010 and FCN057, completed within the Bridgewater formation and located within 1 km of the lake). Semenuik & Semenuik (2007) record a much higher range and hypothesise the presence of two aquifers, differentiated by their salinities, with a hyper-saline surface system of 30–40 000 mg/L overlying a lower salinity deeper system of 5–16 000 mg/L (note the different units: mg/L are approximately equal to 0.6 µS/cm). The presence of hyper saline shallow water tables was also recorded by field surveys, but it seems unlikely these represent a separate hydrogeological system. Drilling records for obswell FLN010 70 m to the west of the lake (Figure 12) records do not indicate the presence of any confining layer that would support the presence of a hyper saline perched shallow system, stratographic logs indicating Bridgewater formation sediments are continuous from the surface to around 20 m for wells in the area – that is a single hydrogeological unit. The high salinity gradient may reflect the evaporative losses from the lake creating density driven separate layers, with limited vertical mixing from convection, however this remains speculative and the alternative of a separate aquifer cannot be ruled out.

3.1.1.3. Vegetation

A detailed field survey undertaken in the late 1970s during a period of shallow inundation recorded both charophytes and a species of the salinity-tolerant aquatic macrophyte genus *Ruppia* as being present in the lake, along with a number of aquatic invertebrates including ostracods and cladoceran copepods (De Deckker et al. 1982). During the field visit in November 2013 the lake itself was largely devoid of vegetation, with scattered samphires on lower surfaces, and isolated patches of *Melaleuca* on raised areas within the lake. The latter appear to most likely have formed on windblown deposits of sediment where initial vegetation establishment facilitates further deposition rate allowing increased vegetation to establish in a positive feedback mechanism.

Fringing vegetation was contiguous in cover, but patchy in composition, with changes in association evidently in response to variations in soil and/or topography and resulting changes in water and nutrient availability. Compositionally a number of plant functional groups of interest occur, a mixed *Melaleuca* stand comprising *M. brevifolia* and *M. halmaturorum* fringing the lake on three sides with phreatophyte mallee to the east of the lake (DEWNR corporate spatial data - feature class: VEG.SAVegetation.shp, accessed Dec 2013) (Figure 12). A stand of tall sedgeland of around 30 ha is reported in the mapping layer, reportedly dominated by *Gahnia filum*. Observed cover of *Gahnia* during November 2013 was extremely sparse and most individuals appeared to be re-shooting from fire damage (Figure 10). The only record a large stand of *Melaleuca* is found to the south of the lake and presents the greatest opportunity for monitoring owing to the presence of a current observation well with a period of continuous record extending back over 50 years.

Figure 10. Sparse *Gahnia* in the northern wetland area that appeared to be recovering from fire

3.1.1.4. Development pressure

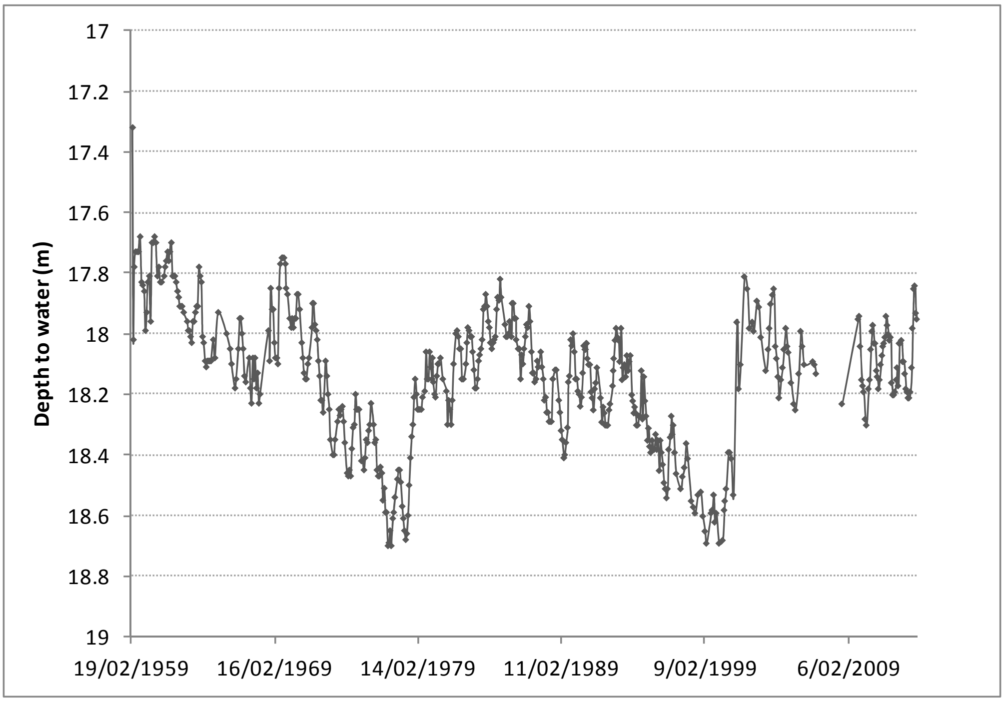
In this area the Quaternary aquifer contributes to the Lincoln Lens reticulated supply. Landuse surrounding the lake is conservation park and it would seem unlikely that any development of the resource other than for management of such lands (e.g. for firefighting storage or to provide potable supplies at campgrounds) would occur in addition to the town water supply demand.

3.1.1.5. Monitoring

What could be gained from monitoring at the site?

From an environmental perspective; salt lake dynamics, especially frequency, depth and duration of inundation could be related to the invertebrate community dynamics, which is of conservation interest. Surface saturation to the north of the site could be used to help explain the reason for the decline in the *Gahnia filum* association and track any trajectory of recovery, assuming this was to occur. A well designed obswell network and concurrent water chemistry sampling program may help to determine the relative importance of the different potential sources of water supporting the species (that is local runoff/rainfall vs Quaternary aquifer discharges). While valuable information, this is beyond the proposed scope of the program.

The real potential or monitoring at this site relates to the immediate opportunity to establish the current vegetation condition against water table fluctuations over a long antecedent period. This would be of value as a baseline data point to help interpret the condition of *M. halmaturorum* throughout the region. If pumping is to be re-instated, vegetation condition monitoring of the *M. halmaturorum* may become of interest. If pumping is not to proceed, the site will still have value as a climatic control for temporary saline lakes and other Southern Basins sites, provided vegetation monitoring was run concurrently for a period allowing the relationship between them to be established.



NB – well was rehabilitated in September 1990 leading to a shift in datum. This hydrograph corrected by 0.65 m.

Figure 11. Quaternary aquifer monthly hydrograph 1959–2013 near Pillie Lake (obswell FLN-008)

What options are there for monitoring?

To the south east of the lake however the long-term, current obswell FLN-008 (Figure 11) provides an excellent opportunity to collect data on the density and condition of the mapped *M. halmaturorum / Gahnia* association. This would provide a critical long period-of-record site for use in determining the relative condition of such associations across the Southern Basins Prescribed Wells Area. Moreover, it will require only an initial vegetation survey to establish this baseline level of information.

In terms of the lake community itself, the remnant *Gahnia filum* community at the northern end of the site could be monitored, but extant individuals had all been burned and were only commencing to re-shoot. The sparse density of individuals and the presence of terrestrial species within this zone suggest that the site would provide limited information relevant to program aims.

The site is of high conservation value and water table data from the network installed by Semenuik & Semenuik (2007) could be analysed against the record from FLN-008, which has a continuous record extending back to 1960. This would characterise water table dynamics at the site of the lake itself. It is not immediately apparent what value the Semenuik & Semenuik (2007) wells can provide other than inundation of the lake itself. Even though there is conservation value of the lake's flora and fauna, this data is not relevant to the aims of the current program.

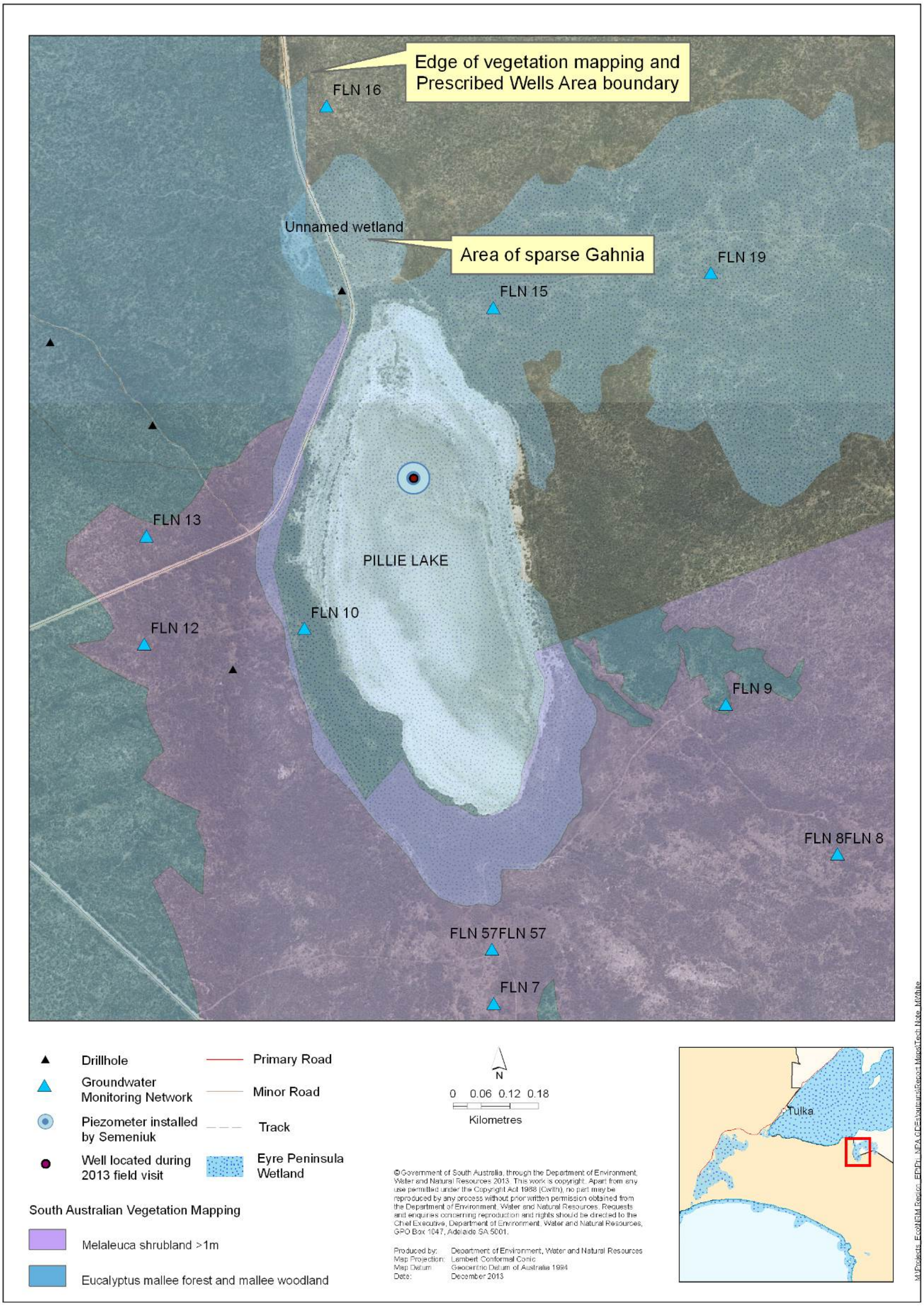


Figure 12. Map of Pillie Lake

3.1.2. Sleaford Mere

3.1.2.1. Description

This site is a large coastal salina and is the representative wetland for the group of the same name (Semenuik & Semenuik, 2007, Doeg et al. 2012). During a site visit in November 2013 the system was a large shallow lake, of almost marine salinities (~40 mS/cm).

3.1.2.2. Hydrology and water quaility

The main Lake at Sleaford is permanent with water levels reported by Semenuik & Semenuik (2007) to vary around 20 cm annually, with surface and groundwater reported to co-vary. It would seem likely that lake levels are largely maintained by seawater seeping through coastal dunes as the southern tip, as the main lake is only around 300 m from the ocean. Semenuik & Semenuik (2007) report pH 8.2, describing this as typical of limestone aquifers. It is also the mid-range value for salinity of coastal waters in Australia (ANZECC and ARMCANZ, 2000) this is perhaps the more probable reason for the observed value.

The water balance of the site, particularly at the fringes of the lake, is complex and thought to include contributions from rainfall and localised runoff, the marine seepages through the dune system separating the salina from the coast, 'seepage from adjacent ridges' (Semenuik & Semenuik 2007), which include discharges from the low salinity Bridgewater formation. There appears to be in particular a flux from this Quaternary aquifer entering from the northern margin of the main lake (Figure 15).

3.1.2.3. Vegetation

Other than a small stand of the emergent sedge (*Baumea juncea*) no submerged vegetation was observed, though Semenuik & Semenuik (2007) report the presence of charophytes. Fringing vegetation consists of a number of different associations, including some known wetland sedges, shrubs and trees. Where present, aquatic species were typically sparse and interspersed with species classes as terrestrial dry. The exception was one patch in the northern part of the lake that presents a good hydrological gradient with clear monocover zones of *Baumea juncea*, *Gahnia trifida* grading into a mixed *Melaleuca* shrub/woodland (Figure 13). Behind this to the north are zones of mallee dominated vegetation and Allocasuarina woodland. Hence a clear gradient is observed from amphibious emergent through to terrestrial species over a linear distance of 50–100m.

A complication for interpreting the environmental conditions supporting this hydrological gradient is the presence of the saline lake water; the Baumea zone was confined to a zone of shallow inundation in hyper-saline surface water – a position it is perhaps unlikely to prefer over time. The ambient salinity of the lake water, while lower in the zone of discharge is clearly too high for *Baumea juncea*, being around 20–30 000 µS/cm, hence discharging Quaternary water with a conductivity of only around 2000 µS/cm must perform a dilution effect to maintain the good observed-condition of the vegetation (the 'dilution front' model presented in Section 1.3.2). Considerable insights into processes at the site could potentially be gained by installing a network of shallow piezometers, supported by existing obswells and possibly a new deeper well located on a nearby firetrack among the mallee. Possible network design for the site is discussed below.

Figure 13. Environmental gradient of *Baumea juncea*, *Gahnia trifida* and *Melaleuca* shrub/woodland.

3.1.2.4. Development pressures

This aquifer has a history of use as a town supply and monitoring data goes back to 1957 from a reasonable network of obswells located around the north-western edge of the site. These present a good opportunity to extend records back and potentially, once a relationship between the new environmental obswells was established, could provide a surrogate measure of environmental water needs.

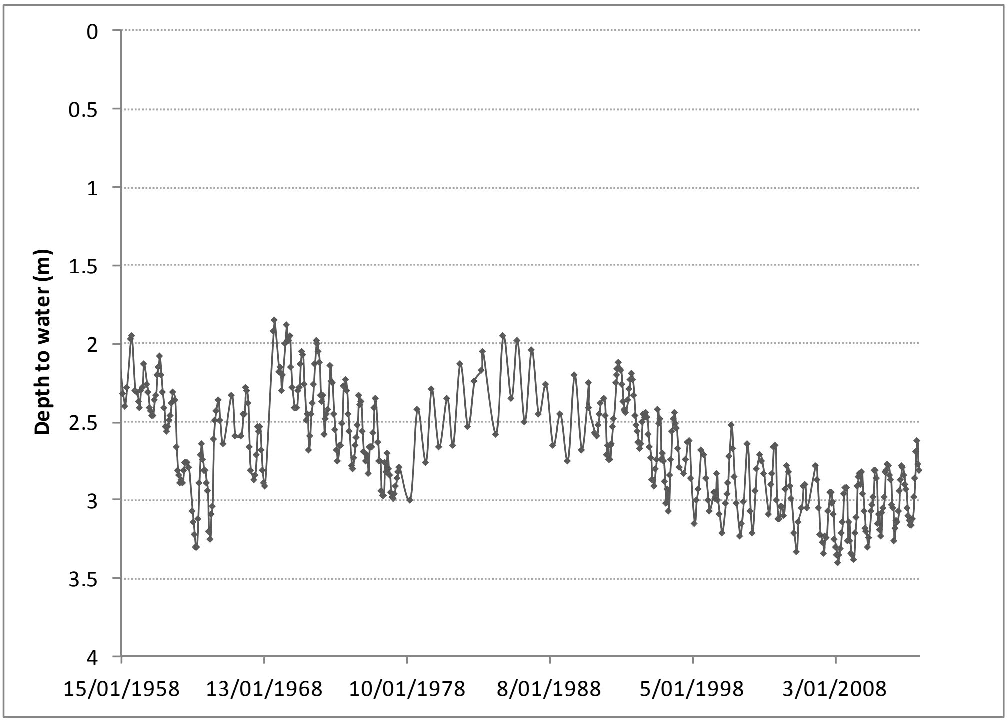
3.1.2.5. Monitoring

What could be gained from monitoring at the site?

Sleaford Mere has the clearest zonation in plant functional groups observed at any reference wetland. This zonation is also clearly driven by discharging freshwater from the Quaternary aquifer. Hence it presents a good opportunity identified to delineate water table dynamics of this aquifer which supports different species and functional groups.

The Quaternary aquifer has also been the source of potable town supplies and presumably retains this potential. Establishing vegetation monitoring at the site will help to determine any resulting change to vegetation zonation should pumping re-commence.

Although the site biologically presents good characteristics for monitoring, the feedback between discharging freshwater and overlying hyper-saline lake waters presents some complications. Given ambient salinity of the lake is near marine, neither *Gahnia* nor *Baumea juncea* would be expected to occur without the freshwater discharge into the root zone from the Quaternary aquifer. Hence the extent and condition of this small patch exists in a narrow niche space, balancing between freshwater inputs and saline lake water. This is an example of the dilution-front model of water dependence (Section 1.3.2) and is the area of the wetland most obviously dependent on the Quaternary aquifer.



Note: Well was rehabilitated in September 1990 without any apparent shift in datum. One anomalous data point corrected.

Figure 14. Quaternary aquifer hydrograph 1957–2013 near Sleaford Mere (obswell SLE-052)

What options are there for monitoring?

The clear environmental gradient of this site is ideal for monitoring for the aims of the program, but is not directly accessible by vehicle, requiring equipment to be carried around 200 m from the nearest vehicle access. While this should be possible, it imposes some constraints:

- Wells would have to be hand-augered
- Maximum depth would depend on sediments encountered, but would be restricted to a maximum of perhaps 2–3 metres
- Construction techniques would be limited to equipment and materials that can be carried in by hand.

Surface substrates appear to be suited to manual installation of this nature and it is likely that even shallow wells would adequately cover the range of water-table variation at the site.

A small network of three wells (one fitted with a datalogger) should provide adequate cover for a study site that included two or three sampling units dominated by individual species (*Gahnia, Juncus* and possibly *Baumea*).

Resources permitting, a drill rig mounted on a 4WD should be able to access the site via an old fire track, and a well drilled to around 5 m should provide good coverage of the water table, filling the gap between SLE-052 with a record extending to 1957 (Figure 14) and the proposed environmental networks. This would create the possibility for two additional sampling units to be established to study Melaleuca and mallee vegetation dynamics.

> *Note that at the time of the visit in November 2013 an old chain gate had been cut and access was possible at the eastern end of the track. If the chain were to be replaced, then vehicle access would require a key to be obtained, presumably from SA Water.*

On the western bank, a large area is mapped as closed sedgeland dominated by *Gahnia trifida*. On inspection of this area in November 2013, it had dense patches of *Gahnia* associated with highly organic soils. The distribution may have been due to microtopographic variations, but this was not obvious. Potential exists to install two shallow obswells within a patch of *Gahnia,* and at a nearby site where it is not present to investigate this zonation.

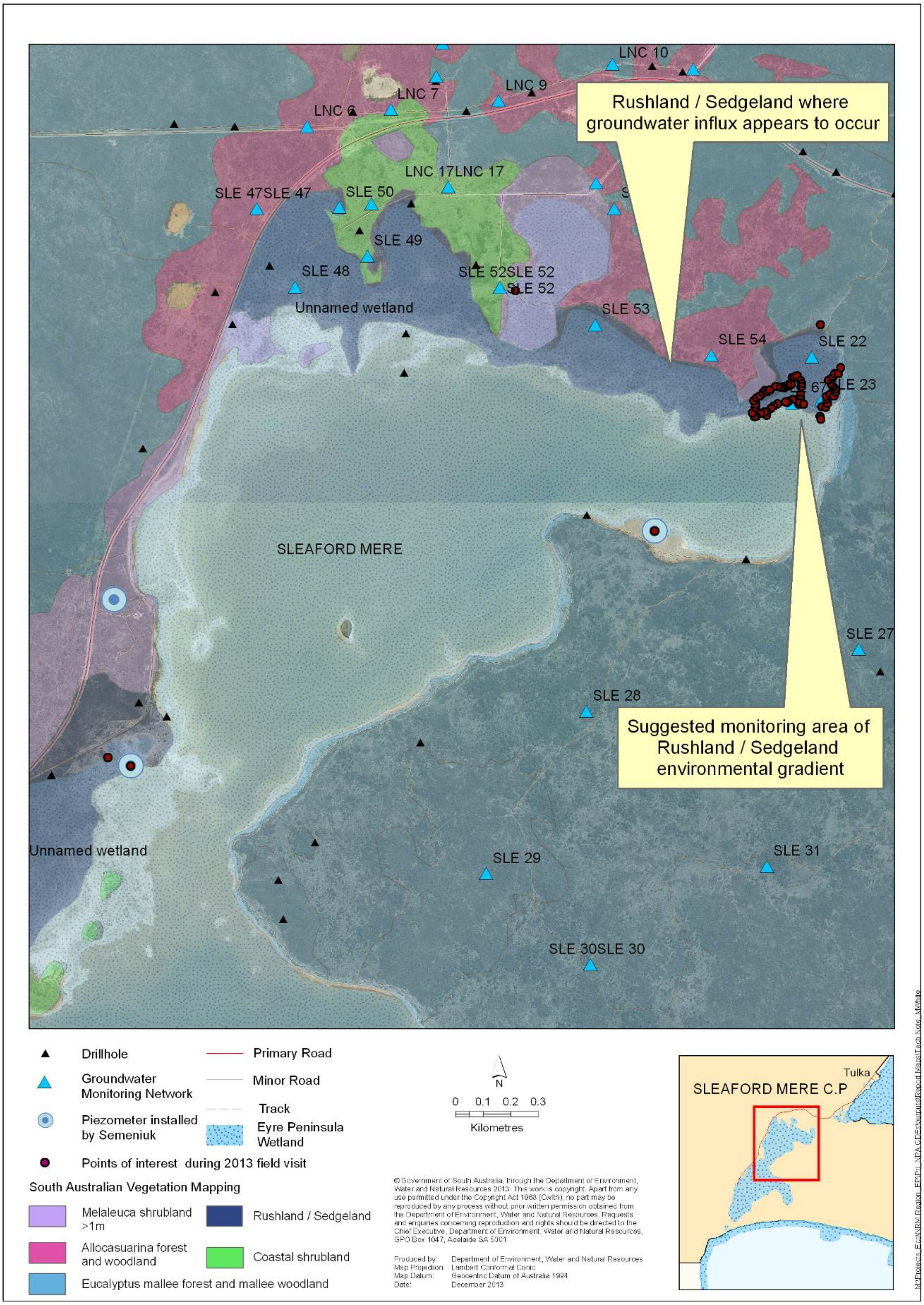


Figure 15. Map of northern section of Sleaford Mere

3.1.3. Round Lake

3.1.3.1. Description

This is an individual wetland within a system of coastal salinas that form the Lake Hamilton wetland complex, within the Hamilton suite wetlands classification of Semenuik & Semenuik (2007). The site is within five kilometres of the sea and nested within a largely agricultural landscape matrix, where cropping predominates. There are two salt lakes at the site and fringing vegetation is more extensive around the north-western part of the lake.

3.1.3.2. Hydrology

Round Lake is located in a karstic geological setting and seasonally inundated (Semenuik & Semenuik 2007). The water balance of the site is a combination of perched rainfall, local runoff from limestone ridges and via spring points on the east and potentially marine vents on the west (Semenuik & Semenuik 2007).

3.1.3.3. Vegetation

Both lakes have fringing zones of *Melalueca* and *Gahnia*, though the stands are much larger around the smaller, northern lake than Round Lake itself (Figure 16).

3.1.3.4. Development pressures

This wetland is located on the boundary of the Musgrave PWA and is not subject to any known extractive pressures.

3.1.3.5. Monitoring

What could be gained from monitoring at the site?

The site presents an opportunity for an additional data point to interpret the optimal saturation required to support dense *Gahnia* vegetation within the Musgrave PWA area. It is of low development impact and may provide a control for other comparable lake systems that may be potentially subject to extraction related water stress.

This site features similar values to the Lake Newland north study-site proposed below. Hence it would provide an additional source of data to confirm and help refine estimates of the preferred water regime for *Gahnia* and *Melaleuca* within the Musgrave PWA.

What options are there for monitoring?

Round Lake proper (the southernmost lake at the site) has a small, but dense stand of *Gahnia* adjacent to the road on the western edge of the lake (Figure 16). This is located on crown land and appears in reasonable condition.

A shallow hand-augered obswell network may be adequate to establish the water table dynamics at this site. A single, deeper well could be drilled to provide an indication of Quaternary aquifer dynamics and determine whether this, or accumulated local rainfall, supports the stand. Subject to negotiating access, the smaller northern basin has an area where both *Gahnia* and *Melaleuca* are present to the west of the lake near the main road. A small network at this site would make it possible to monitor both vegetation types at the same study site. Another potential advantage for the more northerly site is the presence of an old obswell (WAY-043) less than a kilometre to the north along the main road. If this well can be located and is still serviceable it would provide an additional data point for the network. If monitored concurrently with a new network at Round Lake north, it also provides the potential to compare current water table dynamics with those in the period 1972–82 when WAY-043 was actively monitored (the well was also monitored on three occasions during the mid 1990s). WAY-044 has a similar monitoring record, but is located over 4 km to the east of the lakes.

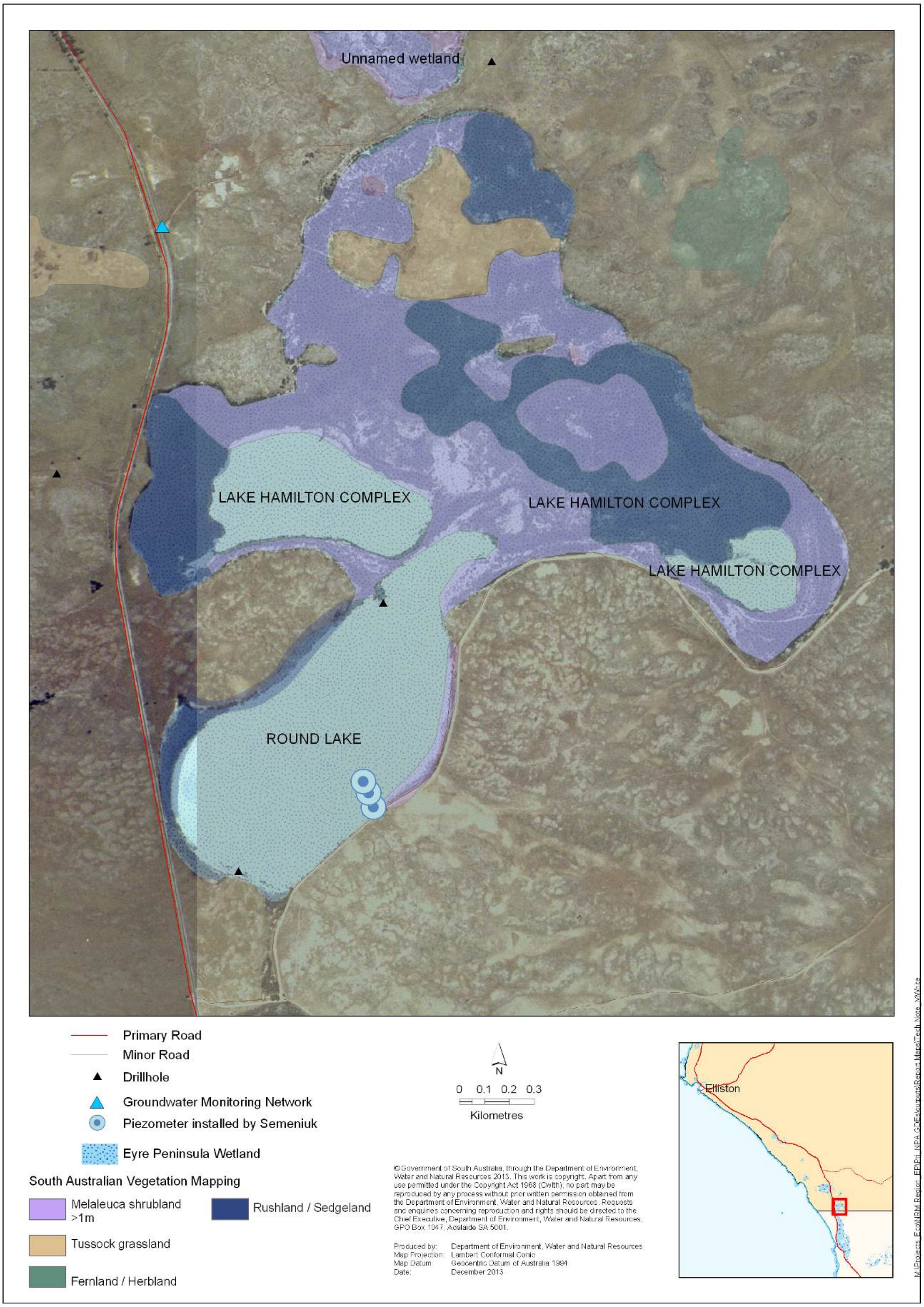


Figure 16. Map of Round Lake

3.1.4. Poelpena

3.1.4.1. Description

Some discrete wetland areas exist and were mapped as part of the Eyre Peninsula Wetlands DEWNR spatial layer. A desktop study digitised an approximate maximal extent for the wetland area from remote imagery that encompassed the smaller wetlands (note this was adopted in White et al. 2014). This larger mapping unit was confirmed as not representative of a rue wetland area during the field visit in November 2013 – the majority of the area being a farmed (cropping) landscape (Figure 19).

Note: Dark soil area originally mapped within the Eyre Peninsula wetlands layer (foreground), higher elevated cropping area incorrectly mapped as part of wetland.

Figure 17. Poelpena wetland during field visit – November 2013

3.1.4.2. Hydrology

As stated above, it was not apparent on field inspection that the area mapped as a wetland in fact functions as an aquatic habitat under current climatic conditions. No evidence of recent widespread surface inundation was found. Some localised topographic depressions may have flooded during the previous winter, but this could be explained by rainfall. Parts of the area recently mapped as wetland appeared several metres higher in elevation than surrounding areas mapped as paddock.

3.1.4.3. Vegetation

The two major vegetation groups of interest are mapped in the 'SA Vegetation' spatial database (VEG.SAVegetation, DEWNR 2013) as red gum woodland and *Melaleuca* shrubland. While the mapped units were broadly correct in terms of overstorey, *Melaleuca* was mapped as overlying *Gahnia*, yet this species appears to no longer exist at the site. Only a single, small individual *Gahnia* plant was identified in a broad search of the mapped units.

3.1.4.4. Monitoring

What could be gained from monitoring at the site?

Given the evidence that water table dynamics seem adequate to support red gum, but are incapable of supporting *Gahnia* and perhaps marginal for *Melaleuca*, any monitoring implemented could provide some indication as to what these dynamics are. That is, given it is evident that groundwater dependent ecosystems are either in decline, or have already declined from previous composition – what are the characteristics of the water table that led to the loss of *Gahnia*? Ideally a nearby site where *Gahnia* was extant could be paired with the site and water table dynamics compared. Round Lake was a site that has a stand of *Gahnia* that appeared in reasonable condition and occurs within the lake.

The other opportunity, by choosing to monitor this site, would be if water tables were to recover and Gahnia was to re-establish at the site.

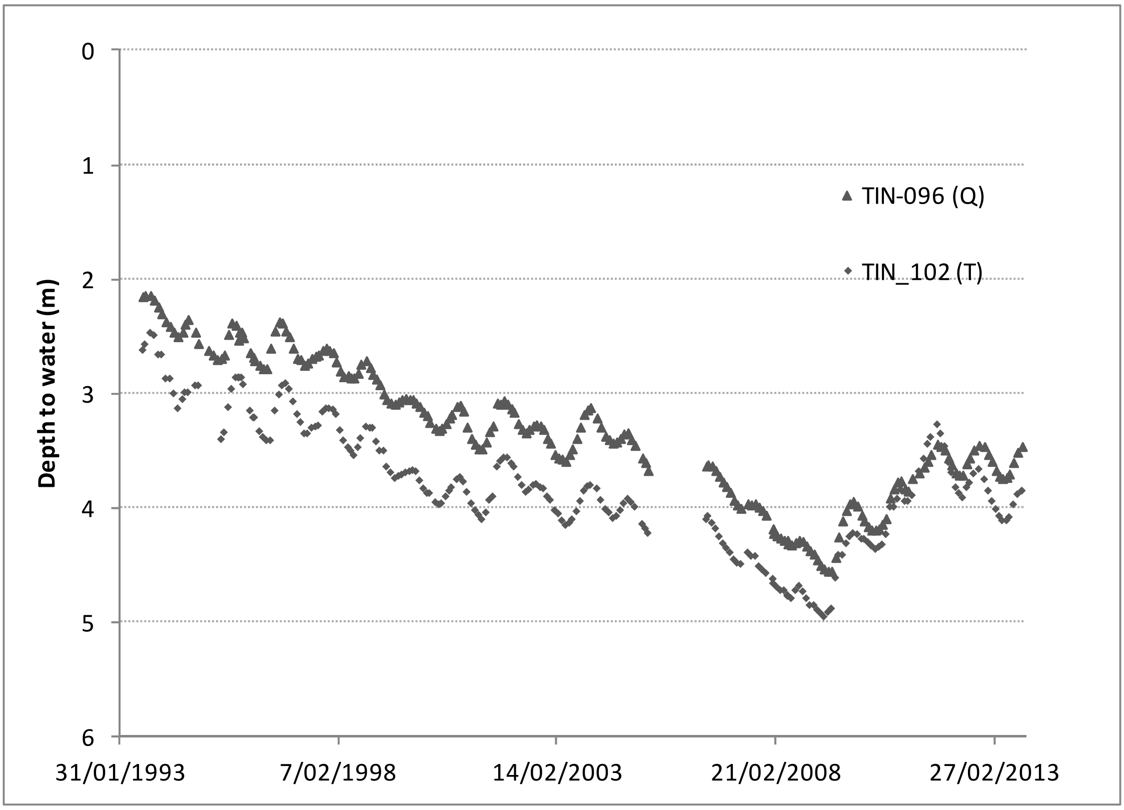


Figure 18. Groundwater hydrographs 1993–2013 for obswells near Poelpena (TIN-096 & 102)

What options are there for monitoring?

There are multiple current and historical observation wells completed in both the Quaternary and Tertiary aquifer surrounding the area mapped as a wetland, including within the fringing phreatophyte vegetation. Many of these historical wells were unable to be located during field investigations and may have collapsed or been backfilled. One historic well that was located (TIN-069) was in poor condition and in need of rehabilitation. This is likely not the best use of monitoring funding though and installing new wells to add value to existing monitoring may be more effective. Obswell TIN-096 has an almost continuous record extending back to the early 1990s (Figure 18) and was also operational between 1963 and 1982 – this presents some possible opportunities for linking monitoring records back through time. Unfortunately it is located on the road and some distance from any vegetation of interest (Figure 19). TIN-102 is among both mallee and *Melaleuca* vegetation and has more potential to reference vegetation monitoring to (Figure 19). The database indicates this well monitors the Tertiary aquifer, but has dynamics almost identical to TIN-096 (Figure 18) suggesting the use of this well as a local datum may be realistic provided some additional shallow obswells were installed to reference the unconfined aquifer.

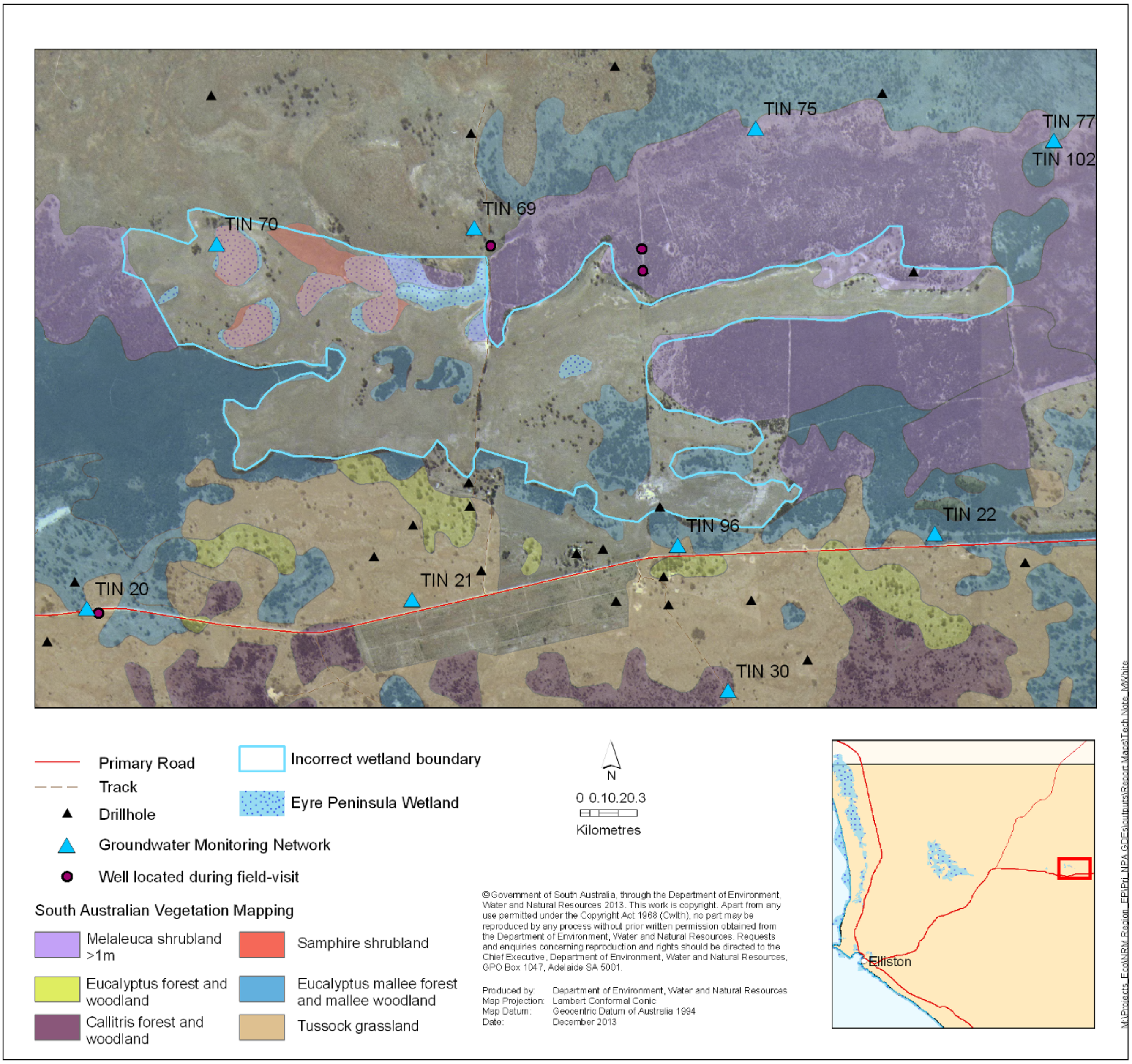


Figure 19. Map of Poelpena

3.1.5. Lake Newland complex

3.1.5.1. Description

This large complex of coastal salinas receives water from a complex system of springs occurring in two regions of the lake complex: north and south. The ecology of the two northern and southern areas, one along the eastern shore of the southernmost lake, the other to the south of the northern most lake, manifests quite differently.

A clear zonation occurs along the southern lake's eastern shore, with *Melaleuca* and *Olearia* overstorey at the inland edge of the discharge zone, grading to *Juncus kraussii*, *Cyperus* spp. and *Schoenoplectus pungens*. *Schoenoplectus pungens* seems to have a hydrological niche that largely overlaps with *Cyperus* spp. (Figure 20), but the *Cyperus* spp. forms dense stands and more typically is found in deeper water. As the depth gradient also coincides with a salinity-dilution gradient, these zones likely reflect the interaction of a salinity and water regime. In places where spring discharge appeared lower in flux, salt couch replaced the sedge community described above as *Juncus kraussii* in the environmental gradient.

In the northern section of the lake complex, springs seemed to favour development of extensive and dense *Gahnia* monocover, with patches of deeper water where dense charophyte beds were observed (Figure 21). In a number of locations, small tributaries have formed in the limestone, draining north into the lake (Figure 24). These create complex habitat within the drainage line and in a narrow fringing area (Figure 22).

Figure 20. Rushland/sedgeland not mapped along the edge of Lake Newland at Three Springs

Figure 21. Dense monoculture of *Gahnia* on edge of spring seepage

Figure 22. Channelised spring with narrow fringing band flowing into northern Lake Newland

3.1.5.2. Hydrology

Semenuik & Semenuik (2007) suggest that the hydrology of Lake Newland recharged via groundwater or perched rainfall. Being around 2 km from the sea and below sea level, the permanent surface water covering around half the lake area (Wainwright, 2008) is likely to be largely of marine origin. Despite this prevailing marine influence on hydrology, the system is extremely complex and various features of the site are totally reliant upon relatively fresh groundwater outflows, and or local accumulations of perched rainfall. These occur from spring discharge points and via seepage from adjacent dune systems that form the seaward-boundary of the site and localised runoff (Semenuik & Semenuik, 2007).

3.1.5.3. Monitoring

Why would you monitor the site?

(1) To understand the relationship between GW discharge and ecology

The conservation values of this complex are well appreciated and the freshwater discharges clearly add considerably to the observed ecological complexity and biodiversity. Recognising this, a desirable goal for management of Lake Newland into the future might be to understand the complex relationship between the Quaternary discharges and the ecological patterns which result. The aspirational goal would be to predict the extent and condition of groundwater dependent vegetation at the site for a given observed hydrograph. White and Lewis (2011) have developed methods capable of establishing the relationship between groundwater spring discharges and the resulting area of wetland that is supported for Great Artesian Basin (GAB) Springs in the Far North region of South Australia. Such methods would appear part of a possible solution to this question at Lake Newland. The challenge at this site is more technical, as the diffuse discharge at Lake Newland is in contrast with single point-sources in GAB springs. Hence groundwater (and other) monitoring data would need to provide information to estimate the volumetric discharge as some function of the observed variables. Mass balance approaches using the ionic signature of ambient groundwater and lake water may prove useful.

(2) To characterise the near-surface salinity and saturation regime supporting the extensive stands of *Gahnia* monocover

The extensive *Gahnia* stands near the northern lake suggest the salinity and water regime are clearly within the species preferred range, monitoring the water levels and saturation at multiple sites would provide valuable information to begin to define these quantitatively.

While the salinity of the groundwater at the discharge point suggests it is not a viable source of water for high volume uses, it may be fresher, closer to recharge areas. Extractions anywhere within the aquifer may impact on the flux to the wetland, so developing a monitoring record of the driving head toward the lake system may be important for management in future.

What options are there for monitoring?

The site presents good access for a small drill rig. Shallow wells to a few metres depth (as springs are thought to be permanent) should cover the range of variation.

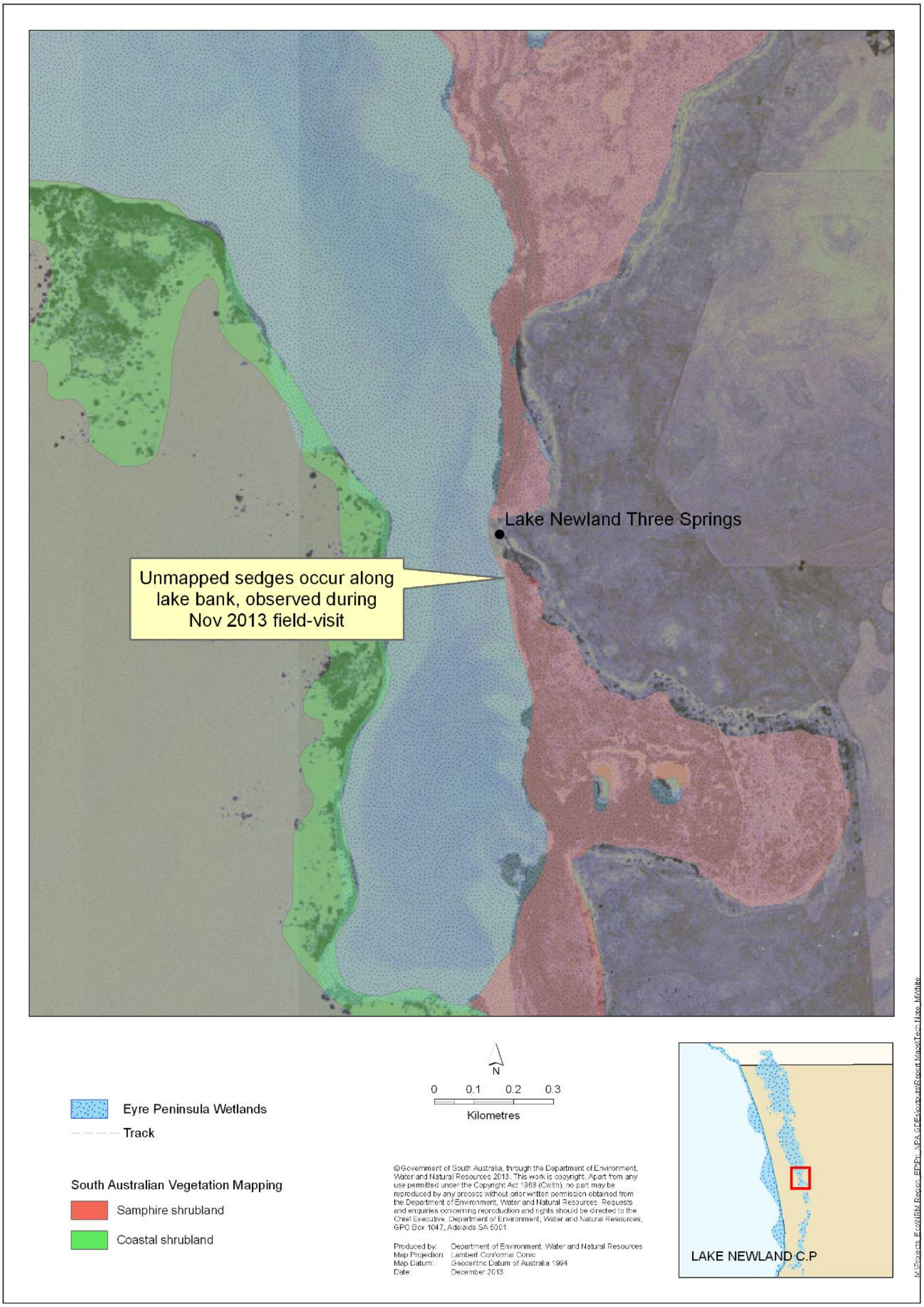


Figure 23. Suggested monitoring Three Springs area, southern section, Lake Newland complex

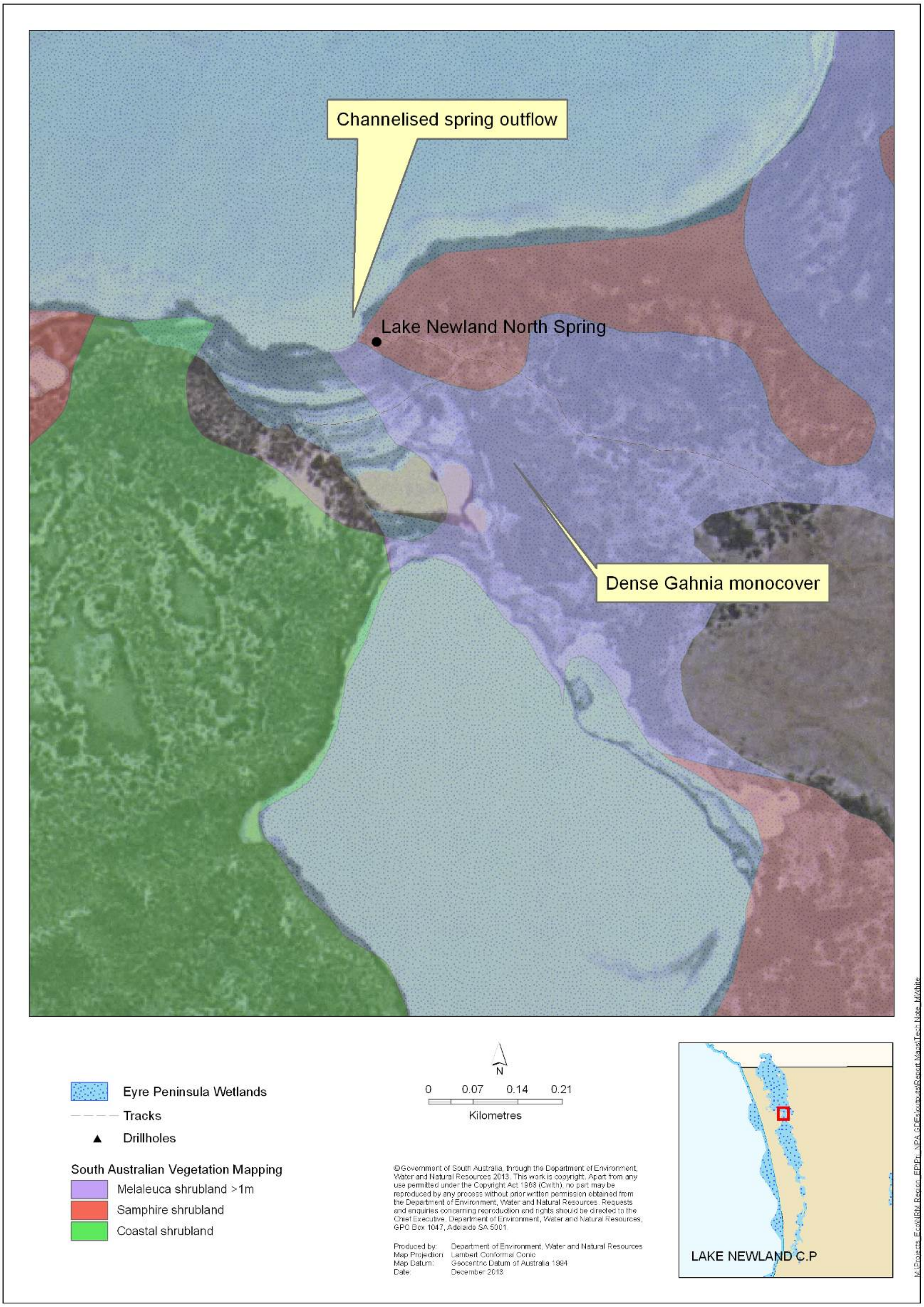


Figure 24. Suggested monitoring area for the northern section, Lake Newland complex

3.2. Phreatophyte associations

3.2.1. Belleview (Bushland monitoring site), Bramfield Lens

3.2.1.1. Description

This is a small (~17 ha) patch of remnant Eucalypt woodland, with the most intact understorey observed at any location, the canopy overlying mixed native shrub association including *Pittosporum, Casuarina, Dianella* and *Callistemon* spp.

Figure 25. Belleview roadside reserve showing dense and intact *Eucalyptus* woodland

Figure 26. Belleview reserve, note existing obswell (bottom right)

3.2.1.2. Monitoring

Why would you monitor the site?

There are a number of reasons for monitoring this site:

(1) Monitoring would provide a good opportunity to investigate the water requirements of a relatively natural mixed phreatophyte association. Assuming the current good condition is maintained in future, this site would allow for the range of water table variability supporting a relatively natural community to be determined. This would provide some guidance to inform any future change in development of the Bramfield lens resource.

(2) Monitoring provides a possible control site for similar monitoring of phreatophytes in stressed or potentially stressed areas within the Polda lens.

(3) Existing monitoring and production wells provide opportunities to access older monitoring data to extend the monitoring record at the site back over the recent antecedent period and provide an indication of water table variation at the site that has supported existing vegetation.

(4) The site has many characteristics that would support a high precision water use study, where actual tree water source volumetric use was estimated, including the groundwater component. Such information is invaluable for modelling scenarios to inform water resource planning for any type of landscape scale water management scenarios.

(5) Monitoring would provide the complementary benefit of value adding existing bushland monitoring data and allow some additional interpretation of community based data collection methods.

What options are there for monitoring?

Existing monitoring infrastructure could simply be re-activated, with the well in the best condition fitted with water level logger device. An additional purpose built well located within the lowest elevation within the red gum patch instrumented with a data logger would provide scope for a range of investigations to be conducted on vegetation structure, abundance and potentially water use (for example using the method of White, 1932). Installation of a small network of shallow wells within the denser areas of vegetation at the bottom of the gradient could provide insights on three-dimensional variations in water table dynamics. An additional well mid-way between the existing wells and the new logged well near the upper edge of the patch would also aid in the interpolation of water tables.

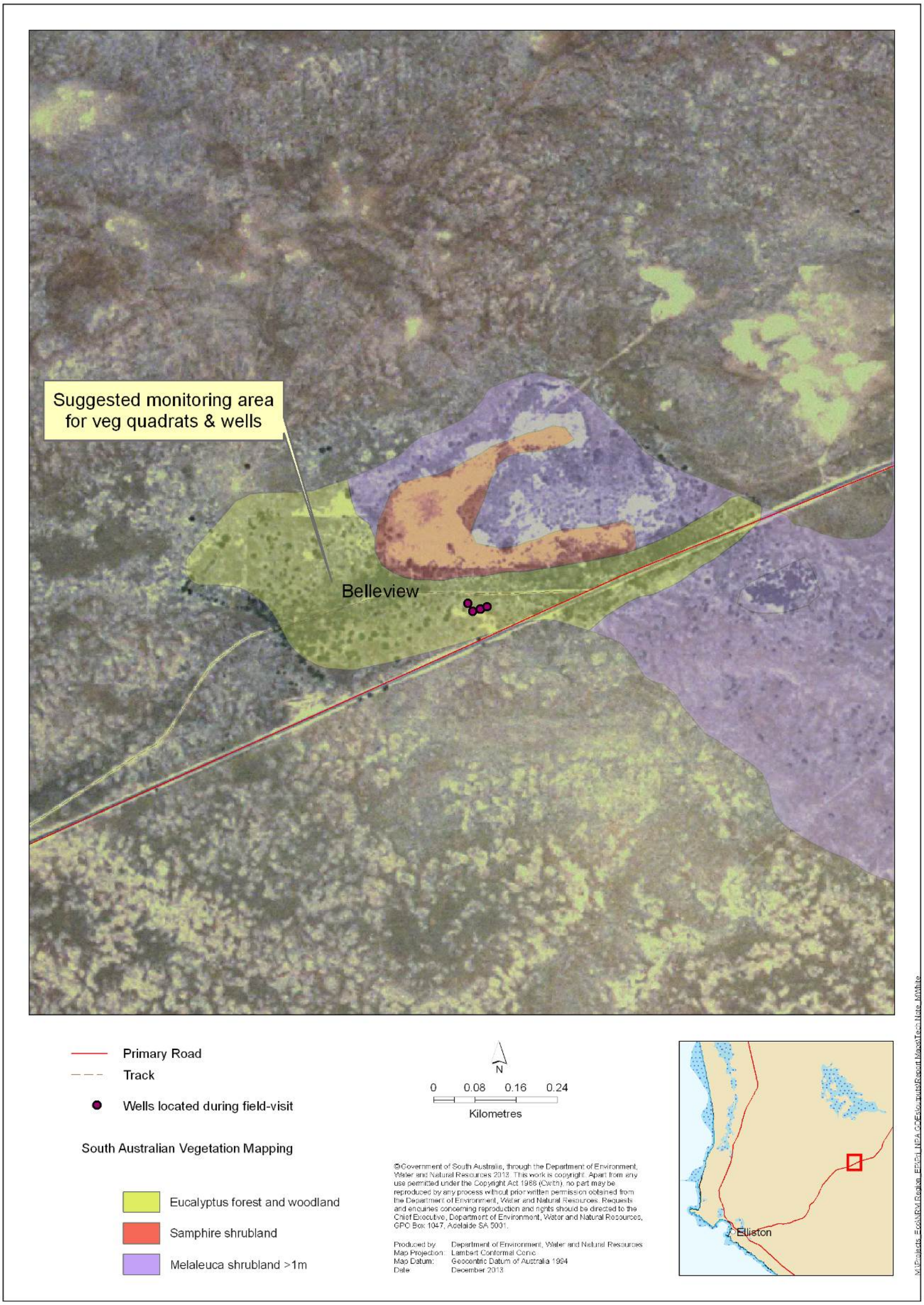


Figure 27. Belleview roadside reserve

3.2.2. Red gum woodland, Bramfield lens

3.2.2.1. Description

A grazed site under private tenure with a red gum woodland patch. This site is located in a natural depression and following periods of high rainfall maintains conditions of saturation which persist for around a week before infiltrating. Rainfall intensities adequate to produce the ponding are thought to occur around every thirty years. Evidently red gum germination occurs on the draw down phase, and presumably seedlings recruit to the population when juvenile root extension can keep pace with the wetting front as it recharges to local groundwater. Anecdotal evidence for the recruitment theory was observed during field visits for this project, where seedlings of similar height were observed at a similar elevation in roughly concentric circles at the edge of the patch. Presumably this represents zones where appropriate soil moisture conditions and reduced competition from adults combined to support episodic recruitment following periods of unusually high rainfall.

3.2.2.2. Hydrology

Unknown: Ponded water is believed to periodically recharge the local water table and the gradual decline of water levels following ponding may support red gum recruitment.

3.2.2.3. Vegetation

Red gum woodland or forest overlying pasture grasses – no real shrub layer over most of the patch (Figure 28). This pattern may be due to grazing pressure, though *Eucalyptus* recruits are present hence it is possible that mulching from eucalypt leaf litter plus competition for light and water may be major factors.

Figure 28. Red gum woodland near Bramfield

3.2.2.4. *Monitoring*

What options are there for monitoring?

There are a range of private wells in the vicinity of the stand that may form part of a network, but this would be subject to negotiation with the landholder. The combination of opportunistic reading of local private wells and the installation of a new well instrumented with a continuous water level logger would be optimal. Depending on soil profiles, a number of shallow wells could be installed along the elevation gradient to provide a more complete indication of shallow inundation.

Site establishment should involve creation of a digital elevation model (DEM) based on a grid that covers the study area. The location of vegetation (individuals in the case of phreatophytes or quadrats or other area based sampling unit for wetlands) can subsequently be mapped onto the grid and elevation derived. The DEM should ideally be referenced to the Australian Height Datum, but if this is not feasible then use of the same datum as the groundwater monitoring data is adequate for local scale interpretation. This then allows fluctuations in the water table to be interpreted for each sample or individual, providing an assumption of a horizontal water table is reasonable. In cases where this assumption does not hold (on sloping sites) it may be necessary to create a groundwater surface based on information from multiple obswells.

Vegetation monitoring could follow Souter et al. (2009) undertaken twice yearly within timing to coincide with mid to late autumn and late spring. Late spring samples should also record any recruitment and the elevation relative to the datum.

Investigations could include size-elevation mapping using diameter at breast height and total height. The aim of such an investigation would be to gain insights into conditions supporting recruitment.

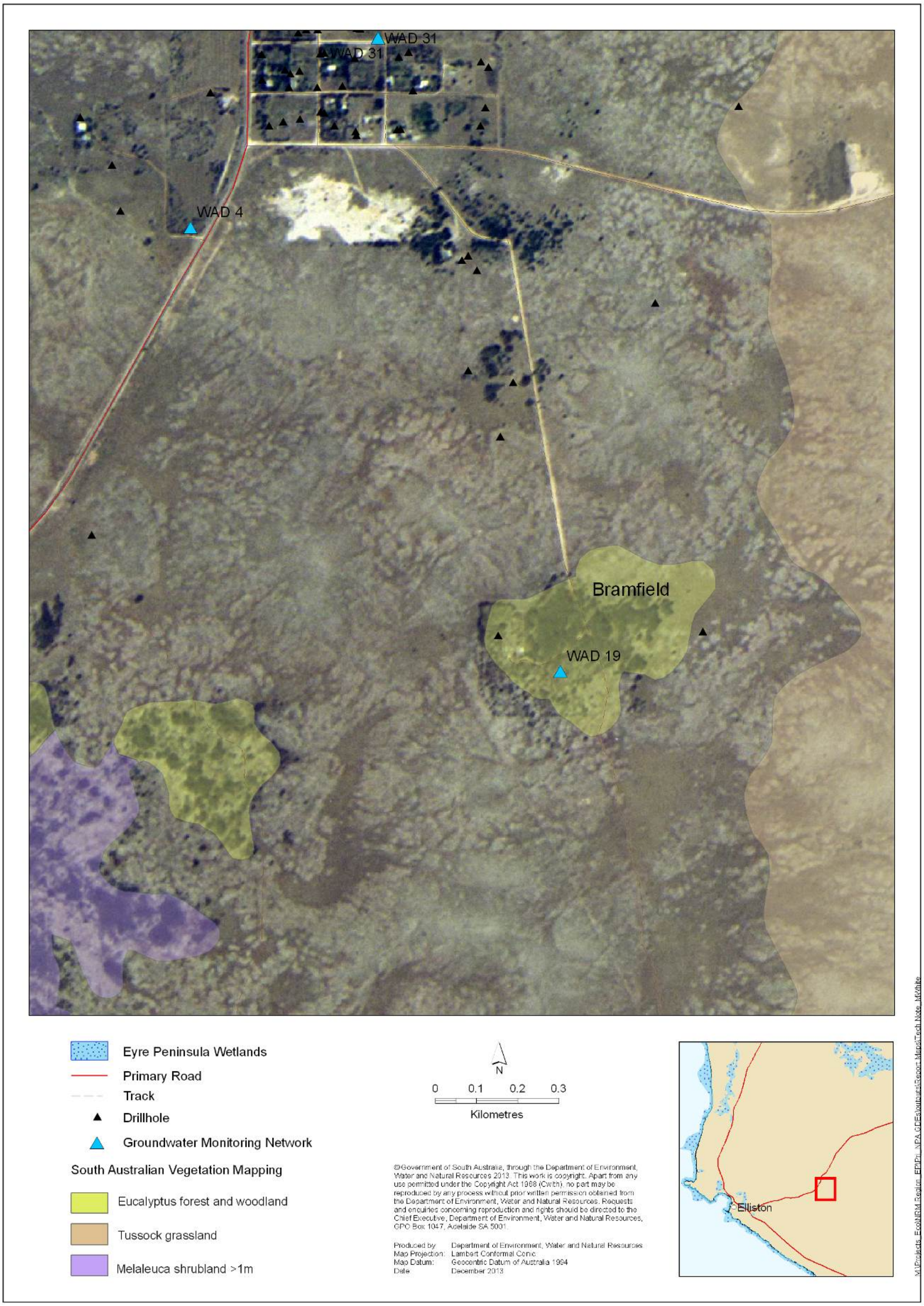


Figure 29. Red gum woodland near Bramfield

3.2.3. Red gum woodland, near Mt Wedge

3.2.3.1. Description

A grazed site under private tenure with an open red gum woodland patch. Red gums located near the roadside are sparse individual paddock trees while a more dense patch appears to occur east of the roadside (**Figure 32**). Community concern has been expressed about the recent dieback (~5 yrs) of the red gums within this area.

3.2.3.2. Hydrology

Unknown: The two wells on the map are not part of the current obswell monitoring program (Figure 32).

3.2.3.3. Vegetation

Red gum woodland overlying pasture grasses – a sparse shrub layer occurs which may reduced be due to grazing pressure, though different age classes of *Eucalyptus* are present. Recent dieback has been seen in the juvenile/young adult trees (Figure 31).

Figure 30. A combination of mature dead trees and almost dead, near Mt Wedge (November 2013)

Figure 31. Recent dieback of young adult trees near Mt Wedge (November 2013)

3.2.3.4. Monitoring

Why would you monitor this site?

Any monitoring implemented could provide some indication of water table dynamics and any correlation with red gum dieback that is being experienced. It will provide a point of reference for water tables that are not adequate to maintain the species in viable condition

What options are there for monitoring?

Vegetation monitoring could follow Souter et al. (2009) – undertaken twice yearly to coincide with mid to late autumn and late spring. Subject to landholder permissions, the ideal place for this is as close to TIN014 as possible, yet remaining within the patch of red gum shown in Figure 32. The first site priority should be to determine the potential to rehabilitate TIN014 and recommence monitoring. There is a continuous water monitoring record from 1967–82 with some additional data points around 1995 that could be compared with current levels.

Any new well would ideally be installed in the centre of the vegetation monitoring site according to guidelines in Section 2.4. If access to the property is not possible, then a well adjacent to the roadside (near either TIN014 or the arrow in Figure 32) should provide ease of access and maintenance. Ideally it would be possible to link the new data collection with the TIN014 obswell and monitoring could occur in the patch of red gum at a site close to the historical well and based on a new logged obswell.

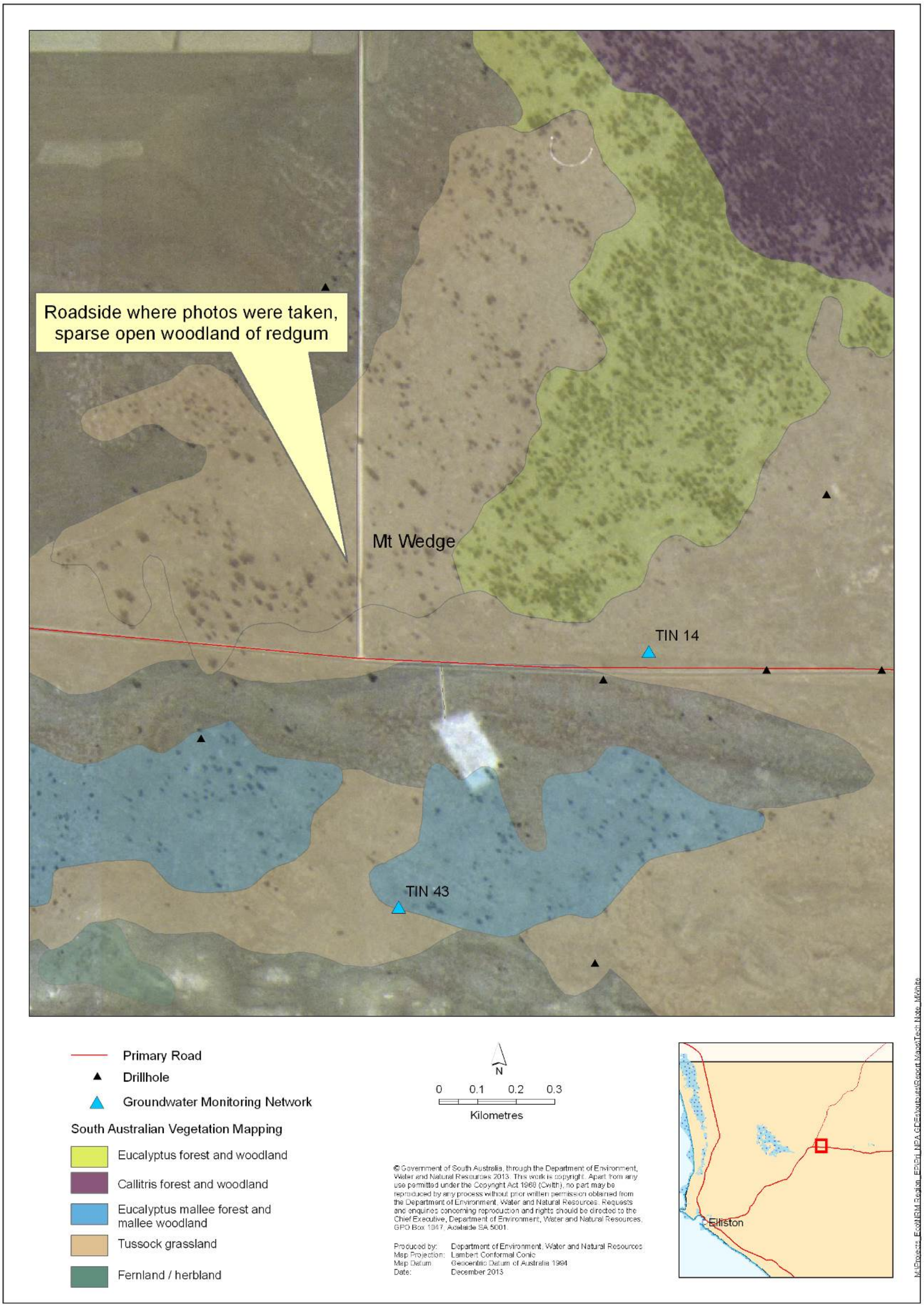


Figure 32. Dieback area of red gum near Mt Wedge

4. Conclusions

In undertaking this project the most practical observation from the authors perspective was that there are already existing opportunities to rapidly develop a basic quantitative understanding of groundwater dependence for some plant functional groups. Eyre Peninsula has a significant number of existing and historical monitoring well records located across a range of phreatophytic vegetation associations. Many wells are currently operational, with some having periods of record that extend back decades. Significantly, monitoring records were identified where the data collection period encompasses the time of vegetation mapping. As the date of vegetation mapping is known these data can be used to characterise the dependence of the mapped speices on groundwater. By collating pre-vegetation mapping water table dynamics at multiple sites, average water table dynamics and confidence intervals can be rapidly developed. This constitutes a useful empirical model of an acceptable range of variation to support the vegetation of interest.

It is possible to increase the information provided by undertaking comparative vegetation surveys. Experience at Poelpena during this project suggests the amphibious sedge *Gahnia* has been lost from the site in the period since it was mapped in 1997. Many sites may similarly have transitioned from the vegetation associations mapped during the 1990s and where observation well records span this period information on critical thresholds may be evident in the record. Where vegetation in the contemporary landscape remain as mapped, it is reasonable to assume that the water table conditions have remained within the tolerance of the mapped vegetation. Vegetation surveys need only be presence absence, and could largely be conducted from a vehicle. What is proposed is a low cost, largely desktop investigation that could yield a disproportionate amount of useful management information over a short period of time. This work could commence immediately. It should be noted however that few wetlands will have this type of historical groundwater data, and monitoring detailed in this report will be necessary to develop a quantitative understanding.

Other opportunities exist in the numerous observation wells identified among the areas of interest that are currently no longer monitored, but have a long historical data records that may also allow further insights to be developed. A first step in any planned establishment of monitoring should involve a review of the state of nearby wells. Those found to be in adequate condition to resume monitoring could be re-commissioned immediately and any new vegetation study sites orientated to take greatest advantage of this additional data point. Historical records can be used to verify simple water-table models that may be able to interpolate the period between original monitoring and currently observed behaviour. Methods exist to incorporate development in such models to gain an initial understanding

From an NRM Board perspective, while there is clearly a need to monitor known groundwater assets in PWAs, other sources of data that provide insights for little investment should not be overlooked. Similarly, theorised lack of groundwater dependence at high-value sites such as Big and Little Swamp, are not consistent with the presence of species with known groundwater dependence such as red gum. Even if such individuals are only reliant on local bank-flux or small lenses, they still provide potentially valuable water-requirement information.

5. Appendix

Big Swamp and Little Swamp

Description

These large seasonal lake and riparian vegetation systems were classed within the Greenly Suite by Semenuik & Semenuik (2007). Both swamps are believed to rely on surface water inflows.

Development pressure:

As surface water runoff and rainfall are believed to be the major water balance components, farm dam development in contributing tributaries represent a major constraint. In general this is believed to be fairly limited when modelled on annual timesteps (Alcorn 2009), although dry years are the most affected. Alcorn (2009) does not consider the effects of farm dams on the water balance of Big and Little Swamps and a water balance study would be a means to not only determine any impacts occurring but also test the possibility that groundwater plays some role in wetland water balance as suggested by Semenuik & Semenuik (2007).

Monitoring

Why would you monitor the site?

These sites appear to support some of the most consistent wetland vegetation in the region. Even if the water source is considered to be largely surface water, these sites still present the best opportunities to establish the dimensions of the hydrological niche supporting wetland vegetation in the region.

Recommended investigations for Big and Little Swamps are:

(1) Digital elevation of banks and bathymetric survey of underwater areas to determine the full supply volume and stage-inundation relationships (this may most simply be undertaken as an airborne LIDAR survey during full draw down).

(2) Determine the cease to flow depth (sill level) for each basin and establish water-level monitoring for each to determine the depth of inundation and spatial distribution of extent of sub-surface saturation (assuming a perched water table in wetland benthic sediments)

(3) Map existing vegetation zones onto the digital model of the sites and determine the elevation of any sharp transitions in plant assemblages.

(4) Conduct water balance modelling to evaluate the relative importance of the different hydrological gains and losses.

The aim of these investigations is to understand the system adequately to project any possible impacts that may result under future scenarios.

What options are there for monitoring?

These sites were not a target for the November 2013 field visit, but a short visit was made to inspect Big Swamp as a potential site for the investigation of plant functional group hydrological niches irrespective of water source. These systems were identified by Semenuik & Semenuik (2007) as losing water predominantly through vertical losses. Hence those authors consider the swamps in part reliant on groundwater in so far as it prevents the loss of accumulated surface water through deep infiltration. This is analogous to the proposed conceptual model in Section 1.3.

6. Units of measurement

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

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

2. Shortened forms

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

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