Eyre Peninsula Groundwater Dependent Ecosystem Data Analysis: Wetland condition data for Lake Pillie and Sleaford Mere

A report for Natural Resources Eyre Peninsula, Department of Environment and Water, Port Lincoln, South Australia.

Prepared by: Kerri Muller NRM Pty. Ltd.

Authors: Dr. Kerri Muller and Dr. Jason Nicol
with Dr. Alison Charles from Water Technology Pty. Ltd.

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To contact the authors:

Dr. Kerri Muller
Kerri Muller NRM Pty. Ltd.
PO Box 203 Victor Harbor SA 5211

E: km@kmnrm.com.au

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Executive Summary

Wetlands are an important feature of the Eyre Peninsula landscape, providing temporary or permanent surface water habitats for a range of flora and fauna, including migratory birds. It is thought that all wetlands in the Southern Basins and Musgrave Prescribed Wells Areas (PWAs) are Groundwater-Dependent Ecosystems (GDEs) that need to be considered under the Water Allocation Plan (the WAP), except for Big and Little Swamps that have their own surface water catchments. Principles and policies for water-sharing aim to maintain these GDE Wetlands at a low level of risk with regard to possible impacts of groundwater extraction.

Adaptive management of our groundwater resources relies on regular and strategic monitoring. The Eyre Peninsula Natural Resources Management Board have previously invested in extensive investigations into regional groundwater dynamics, but this is the first time that the WAP has required the monitoring of GDEs, in response to community feedback on the WAP.

GDE Wetland condition was assessed between December 2016 and September 2018 to establish a baseline for two monitoring sites: Lake Pillie and Sleaford Mere. Sleaford Mere is located close to current licensed groundwater extractions, whilst Lake Pillie was established as a 'control site', being outside of the expected zone of influence of any current licensed extraction.

The groundwater table changes in level in response to recent rainfall and particularly heavy rain in winter. Analysis of winter rainfall at Port Lincoln showed a long-term drying trend since the 1890s when records began. This is reflected in the groundwater levels that have shown a decline since the 1950s for bores near both Lake Pillie and Sleaford Mere, well before the implementation of water allocation policies (EP NRMB 2016a).

Vegetation at Sleaford Mere forms distinct bands from the water's edge to the higher elevations, grading from sedges (*Baumea juncea*) to cutting saw grass (*Gahnia filum*) to paper barks (*Melaleuca halmaturorum*). These communities are low in diversity, highly tolerant of drought conditions and are likely to change very slowly in response to changing groundwater. It is expected that as the *Melaleuca* canopy grows denser and darker that the *Gahnia* and *Baumea* will decline and ultimately be replaced with different understorey species that prefer those conditions.

Vegetation at Lake Pillie also grades from samphires to *Melaleucas*. Many of the *Melaleucas* in the monitoring site at Lake Pillie appear to be less than 10 years old, suggesting that the vegetation has responded to historic drying by changing in character towards a drier, *Melaleuca*-dominated system. This is consistent with anecdotal evidence that the wetland has dried from a permanent to an intermittent wetland over the last 15-20 years.

There were no consistent differences in wetland condition between sites with or without nearby groundwater extraction. This suggests that current licensed groundwater extraction, at the rates permitted by the WAP, is not a source of significant risk to the GDE Wetland condition compared to that predicted for climate change over coming decades. The two wetlands are, however, of very different type, which weakens the value of Lake Pillie as a control site. Future changes in these tolerant plant communities are likely to be slow, if they occur.

Furthermore, the current monitoring program design is generally sound but is not directly answering the WAP evaluation question of whether these GDE Wetlands are changing in condition and if this change is linked to groundwater extraction. Given this, recommendations are made to change the vegetation survey methodology and extend the sampling to more wetlands within both PWAs (sampled less often) to better understand changes over time, likely relationships to climatic factors and confirm the appropriateness of WAP policies for protecting these regionally and internationally important wetlands.

1. Introduction

Wetlands in the area covered by the Southern Basins and Musgrave Prescribed Wells Areas Water Allocation Plan (the WAP) are considered to be *groundwater dependent ecosystems (GDE)*, receiving seasonal, intermittent or continuous groundwater contribution. This means that the WAP needs to consider the environmental water requirements of the groundwater-dependent wetlands through its water-sharing policies and principles. Two wetlands are known to be exceptions, Big and Little Swamps, which are dependent on surface water catchments (EP NRMB 2016a).

There are different types of GDE wetlands in the PWAs including lakes, damplands and springs. Some are saline wetlands, such as Lake Newland, Lake Pillie and Sleaford Mere, whereas others are freshwater-brackish systems such as Myrtle Swamp and Lake Hamilton. Several wetlands contain significant springs such as the Weepra Spring at Lake Newland and the springs that discharge into Sleaford Mere (Doeg et al., 2011).

Wetlands are also characterised by the permanence of their standing water. Groundwater levels across the PWAs vary seasonally, being closer to the surface during the wetter months (winter-spring) and dropping to deeper levels in the drier months (summer-autumn). When groundwater levels are high enough to discharge to the surface, the wetland has standing water to that level. When groundwater levels drop below the base of the wetland, there is no standing water but the sub-surface soils may be saturated. The hydrological regime of a given wetland is, therefore, a function of the relationship between the elevation of the wetland, the shape of the wetland and the spatio-temporal changes in regional groundwater levels (EP NRMB 2016a).

Generally, the wetland GDEs within the PWAs are shallow with respect to observed changes in groundwater levels, and thus they are vulnerable to relatively small changes in groundwater level that may not significantly affect other water users. As such, they are susceptible to groundwater development and/or periods of low recharge, that usually coincide with lower rainfall, higher temperatures and higher rates of evapotranspiration, which result in lowered groundwater levels and/or increased salinity.

Lake Pillie and Sleaford Mere are the two wetlands currently used to monitor the effectiveness of the policies in the WAP aimed at allocating a sustainable level of take. Sleaford Mere is a permanent saline lake, whereas Lake Pillie is a seasonal or intermittent saline wetland. Both wetlands are situated in the Southern Basins PWA, which has a Mediterranean climate with a pronounced ‘wet winter’ period between May – August during which mean monthly rainfall exceeds mean monthly potential evaporation. Figure 1 displays the annual rainfall recorded at Westmere station (BoM Station 18137, located 19 km south west of Port Lincoln within the Southern Basins PWA). Rainfall ranges between 337 and 1023 mm/yr with a long-term average annual rainfall of 569 mm (for the period 1907 to 2014, as used in the WAP, Figure 1). The red line in Figure 1 displays the cumulative deviation from average annual rainfall, an upwards trend represents a period where rainfall was above the long-term average rainfall, and a downward trend indicates a drier than average period.

It can be seen that rainfall was generally below average from the 1930s until 1950, with a pronounced wetter period from 1951 to 1992. Since 1992 rainfall at this station has generally been below the long-term average, and the annual variability has not been as extreme as it was historically. Whilst there have been years of above average rainfall since 1992, none have experienced rainfall in excess of 700 mm, whereas historically, annual rainfall totals were frequently greater than 700 mm.

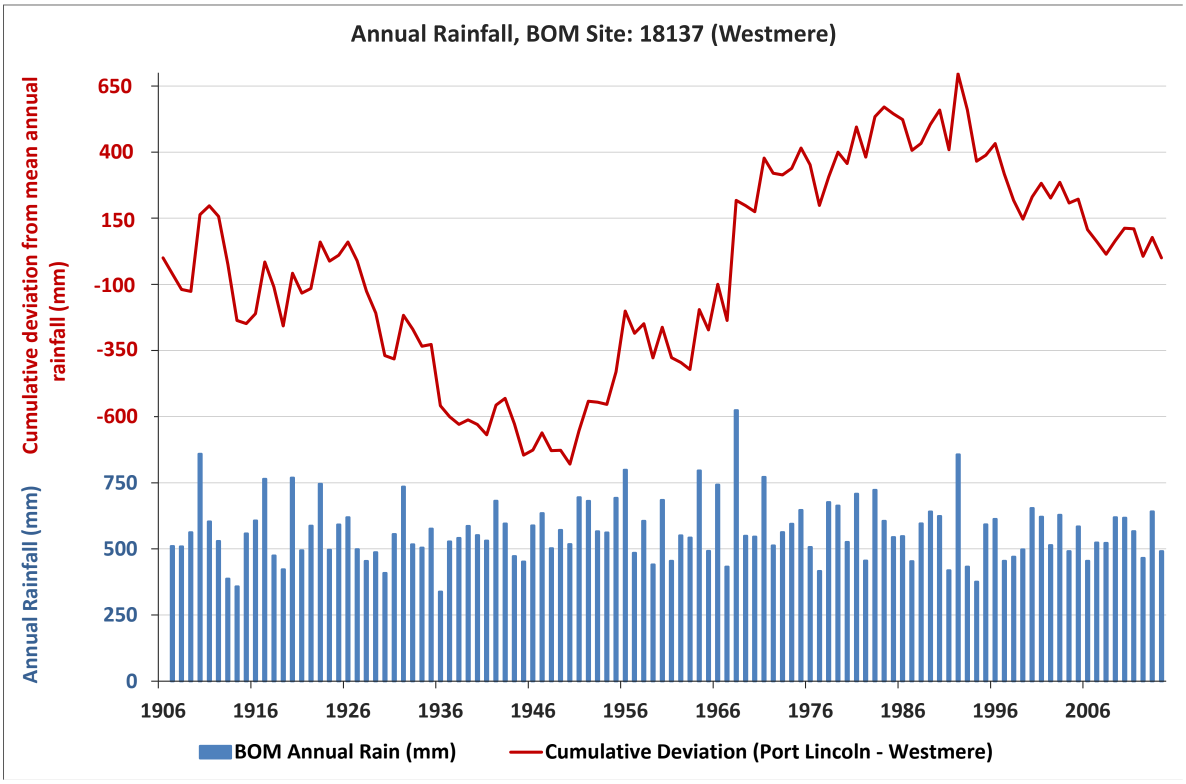


Figure 1: Annual rainfall and cumulative deviation from mean annual rainfall for Westmere BoM weather station (taken from the WAP; EP NRMB 2016).

These data indicate that above or below average rainfall trends can persist for up to 40 years, possibly longer, which is a similar time period to the residence time in regional groundwater systems (e.g. Uley Basin), highlighting the need for effective and adaptive management of these water resources (EP NRMB 2016a).

It is thought that up until the 1950s - 1960s (over 20 years prior to formal water management in the region), the groundwater levels were significantly higher in some aquifers, most likely due to the wetter than average period from 1950 to 1958. In some areas, the groundwater was expressed as surface water in wetlands that are no longer present or have changed ecological character. For example, in Uley South there were surface water wetlands (waterholes) such as Paradise Swamp, that have been dry since the 1960s and now support tussock grasslands (EP NMRB 2016a). There is also anecdotal evidence that Lake Pillie has transitioned from a permanent surface water wetland to a basin being colonised by terrestrial plants in the last 15-20 years (EP NRMB 2016a).

Adaptive management of the taking and use of groundwater, as outlined in the WAP, depends on regular and strategic monitoring. Groundwater dynamics on Eyre Peninsula have been extensively studied and the scientific evidence suggests that groundwater levels in unconfined aquifers are governed mainly by the amount and intensity of incident rainfall, the nature of the surface geology, and by type and density (or absence) of vegetation (Stewart et al. 2012).

Limits for extraction in the WAP have been set at levels that will maintain groundwater-dependent ecosystems (GDEs) at a low level of risk. It is acknowledged, however, that GDE health may be more strongly linked to climatic variables than the impacts of the limited groundwater extraction permitted under the WAP and that adverse climate impacts (e.g. high temperatures, lower or more variable recharge rates) are likely to increase over coming decades due to climate change.

Rainfall and groundwater monitoring in the PWAs has been undertaken for decades but this is the first time the WAP has required targeted GDE monitoring. Natural Resources Eyre Peninsula (NREP) staff collected GDE Wetland condition data at two WAP monitoring sites between December 2016 and October 2019 following the methods in EP NRMB (2018). Groundwater data was also collected at these same sites in 2018 and 2019. Two new observation wells were installed at Sleaford Mere and Lake Pillie in May 2018 for this project and thus groundwater data is only available since 2018 for these wetlands site. Additional long-term groundwater data for the period 1963 to 2019 for four sites other wells was sourced from DEW.

Sleaford Mere has current groundwater licensed extractions nearby, whereas Lake Pillie was established as a 'control site', being outside of the expected zone of influence of any current licensed extraction. The anecdotal evidence above, however, suggests that Lake Pillie has already been through a drying phase. There may be extraction of water for stock and domestic purposes without a water licence near to either site, which is assumed to be low compared to extraction for licensed consumptive purposes, , and there is a low likelihood of it having any impact on the GDE.

NREP engaged Kerri Muller NRM Pty. Ltd. to:

- analyse and evaluate the GDE Wetland condition data against relevant rainfall and groundwater data to set a baseline that can be used to evaluate WAP policies and inform the five-year and ten-year reviews of the WAP in 2022 and 2027.

In this report, wetland vegetation abundance data collected from quadrats at the two wetlands has been analysed and is discussed in relation to rainfall and groundwater data from the same period. Results from these data analyses will be used to establish a baseline for the Wetland report cards that will be periodically published by NREP in accordance with the Monitoring, Evaluation, Reporting and Improvement (MERI) Plan developed for the WAP (EP NRMB 2016b).

a. Sleaford Mere

Located on the south-eastern tip of the Eyre Peninsula, the Sleaford Mere system consists of two basins, Sleaford Mere and Little Sleaford Mere. Only Sleaford Mere is located in the PWA, however (see Attachment A for map of PWAs).

It is a permanently inundated, shallow saline lake that displays the typical fringing zonation of *Baumea juncea, Gahnia filum* and *Melaleuca halmaturorum*. A diverse community of understorey species, including *Wilsonia rotundifolia,* occurs on the damp littoral edges of the lake. The permanent freshwater soaks provide habitat for a number of restricted plant species including *Hydrocotyle* sp. and *Triglochin striatum*.

Sleaford Mere provides important habitat for a wide range of waders, shorebirds and other waterbirds. It is a site of national and international importance for shorebirds and is nationally important through its inclusion in the Directory of Important Wetlands in Australia.

For permanent wetlands, such as Sleaford Mere, the summer groundwater level needs to intersect with the shore of the wetland or not be below the deepest point of the wetland for long enough to allow evaporation to dry the wetland and increase salinity to above tolerance levels. The Environmental Water Requirements (EWR) for Sleaford Mere (Doeg et al., 2011) states that:

- The groundwater table needs to maintain a depth of surface water of 10-20 cm throughout the year

The freshwater spring communities at Sleaford Mere are not well understood and neither is the spatio-temporal extent of the freshening effect. Rapid assessment suggests that the salinity around the springs at Sleaford Mere were in the order of 3000 EC in October 2011 whilst the main body of the wetland was in the order of 30,000 EC (K. Muller, unpublished data). The freshened area was only a metre in diameter at the time although this is likely to vary with season, wetland water level and comparative ground and surface water qualities. More extensive mapping of the area under freshening influence by the springs and surveying of vegetation and faunal communities associated with the springs, would be required to improve our knowledge.

Springs associated with the Sleaford Mere need to maintain flowing water to support the associated vegetation community. Flowing water at Sleaford Mere also prevents the ingress of salty water into the seepage area, which would rapidly kill off the freshwater community. Therefore, the EWR for the springs area (Doeg et al., 2011) states that:

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

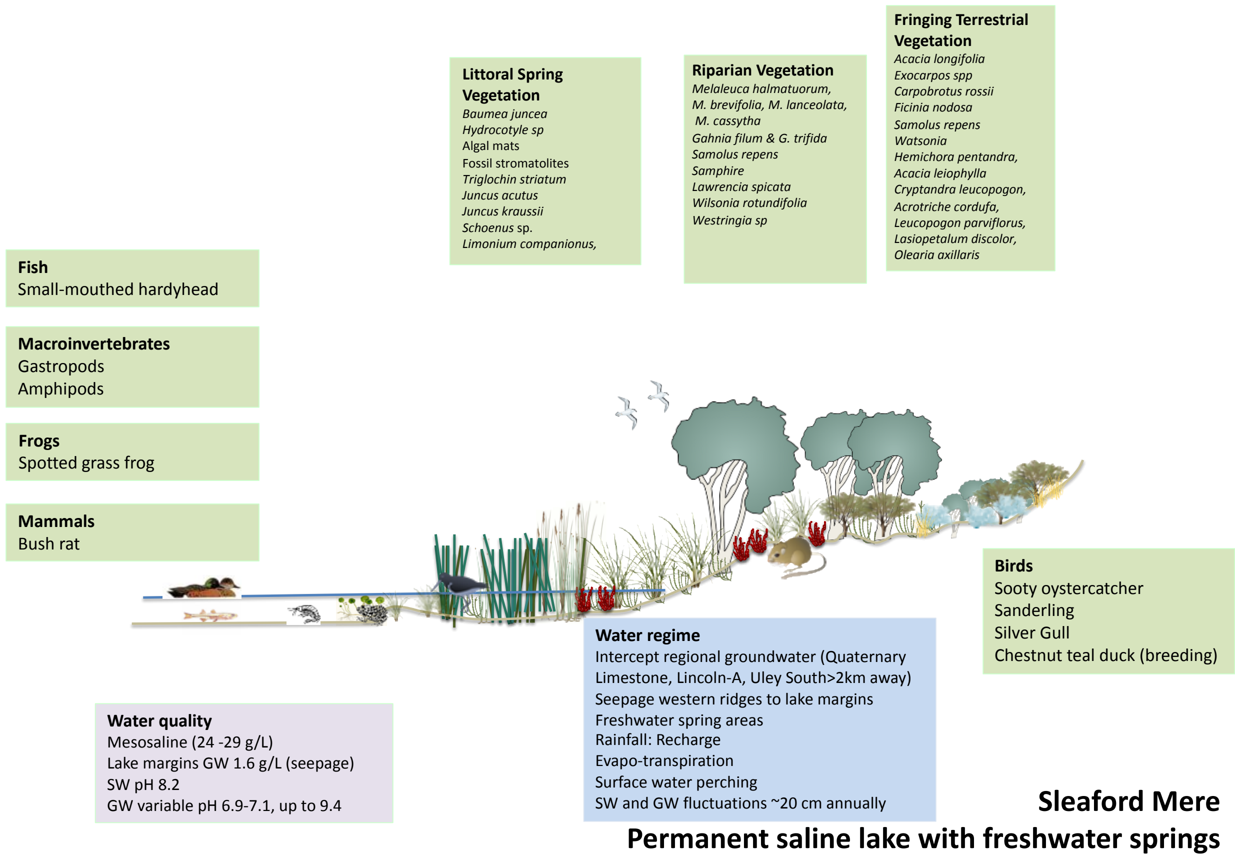


Figure 2: Conceptual diagram of the hydrological processes and flora and fauna of Sleaford Mere.

b. Lake Pillie

The vegetation community at Lake Pillie consist of a simple zonation, with *Wilsonia backhousei* and *Sarcocornia quinqueflora* found on the shoreline and basin floor, and open heath of *Melaleuca halmaturorum* and *Gahnia filum* further up the slope. *Chara* sp., a macroalgae, is found in the basin. Its close proximity to the Coffin Bay Coastal wetlands means that it helps to support 63 waterbird and seabirds species (see Attachment A for map of PWAs).

Lake Pillie, is a dampland, which means the groundwater remains close to the surface through much of the year, providing for extended periods of damp soil with no surface water. In the main, the basin surface of these wetlands is relatively flat, with little variation in surface elevation across the wetland. In these wetlands, the groundwater needs to be close enough to the surface for capillary action to draw the water to the surface. Only in wet years does the water level rise over the surface. Therefore, Doeg et al. (2011) set an EWR that states that:

- The groundwater table needs to maintain at least within 25 cm of the sediment surface of the basin throughout the year.

As stated above, there is anecdotal evidence that Lake Pillie went through a significant drying phase around the time of the Millennium Drought (early 2000s). This is substantiated by the age structure of the *Melaleucas* at the wetland (see results and discussion below).

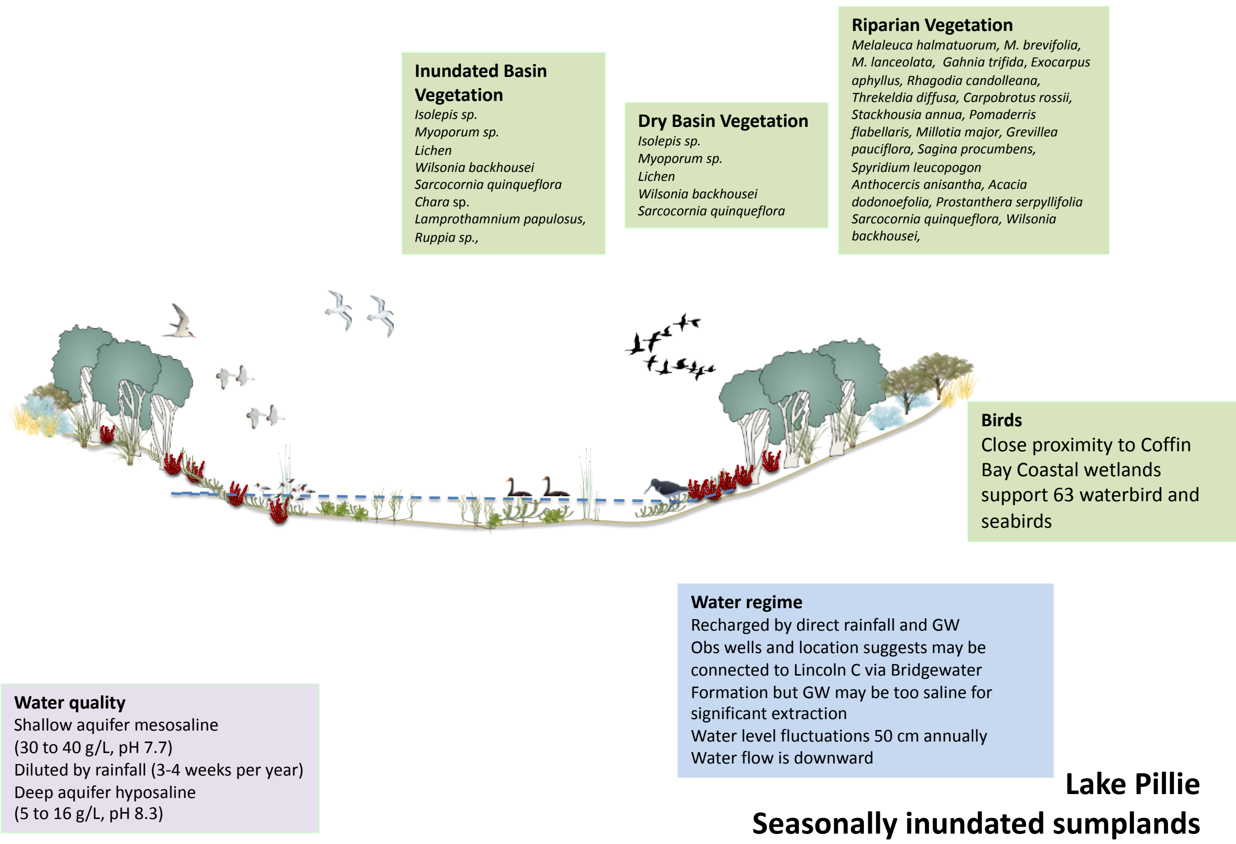


Figure 3: Conceptual diagram of the hydrological processes and flora and fauna of Lake Pillie.

2. Methods

2.1: Summary of survey methods

Fixed quadrat-based vegetation surveys were established in Lake Pillie and Sleaford Mere with quadrat placement based on distribution of the target species (samphire, *Baumea, Gahnia*, and *Melaleuca halmaturorum*).

In Lake Pillie 10 x 10 m quadrats were established in the samphire and *Melaleuca halmaturorum* zones, 3 x 10 m quadrats in the *Baumea* zone and 3 x3 m quadrats in the *Gahnia* zone. Quadrats in the *Baumea* and *Gahnia* zones were positioned at the same elevation and were well replicated (n = 7), which meant they could serve as replicates and statistical analyses could be undertaken to compare change in abundance through time.

The *Melaleuca* and samphire quadrats were positioned at different elevations along two transects, which did not provide sufficient replication (only two quadrats at each elevation) to allow quantitative statistics. The corners of each quadrat were marked to ensure the same area was sampled each survey. The number of plants in each quadrat were counted in December 2016, November 2018, May 2019 and October 2019. In addition, *Melaleuca halmaturorum* condition and demographics were monitored using the technique described in Stewart (2000) and Telfer et al. (2000).

In Sleaford Mere 3 x 3 m quadrats were established in the *Gahnia* zone, 1 x 1 m in the *Baumea* zone and 2 x 2 m in the *Juncus* zone (the salt tolerant rush, *Juncus kraussii* was present in Sleaford Mere). Individual *Melaleuca halmaturorum* trees were tagged and condition and age of individual trees were monitored using the technique described in Stewart (2000) and Telfer et al. (2000). Percentage cover of *Gahnia* and *Baumea* was visually estimated in January 2017 (*Juncus kraussii* numbers were low and recorded). In addition, the number of *Baumea* stems and *Gahnia* flower heads in each quadrat were counted.

Only one survey of *Baumea, Juncus* and *Gahnia* was undertaken due to the density of vegetation making quadrat access difficult and the likelihood of damage to the site by repeat visits (EP NRMB 2018). *Melaleuca* condition was surveyed in January 2017, September 2018 and May 2019, with no change in tree condition detected.

For a detailed description of the methods see (EP NRMB 2018).

2.2: Data Analysis

The change in number of plants through time for *Baumea* and *Gahnia* in Lake Pillie were analysed using single factor univariate Permutational Analysis of Variance (PERMANOVA) using the package PRIMER version 7.0.12 (Clarke and Gorley 2015) with the PERMANOVA+ add on (Anderson et al. 2008). Euclidean distances were used to calculate the similarity matrices for univariate PERMANOVA analyses (McCune et al. 2002, Anderson and Ter Braak 2003). PERMANOVA was used to analyse change in number of plants through time as it makes very few assumptions of the data compared to a traditional ANOVA and can be used for multifactorial designs (Anderson and Ter Braak 2003).

Less data was collected at Sleaford Mere due to the damage being done to the fragile reed beds by trampling to access quadrats. This meant that statistics could not be undertaken to determine if there had been a change over time.

Groundwater hydrographs have been compiled using data from Water Connect and supplemented by more recent data provided by Natural Resources Eyre Peninsula (May 2018-May 2019).

Hydrograph data is presented as groundwater elevation, in Australian Height Datum (mAHD), for wells documented in the GDE Survey Site Establishment report (EP NRMB 2018).

Patched SILO rainfall data for the station at Westmere (#18137) near Port Lincoln was used to calculate the long-term mean winter rainfall (May to Sept.) and the annual number of winter rainfall events ≥10 mm/day. Ten winter rainfall events ≥10 mm/day between May and October are required for recharge to occur (EP NRMB 2016a).

3. Results and Discussion

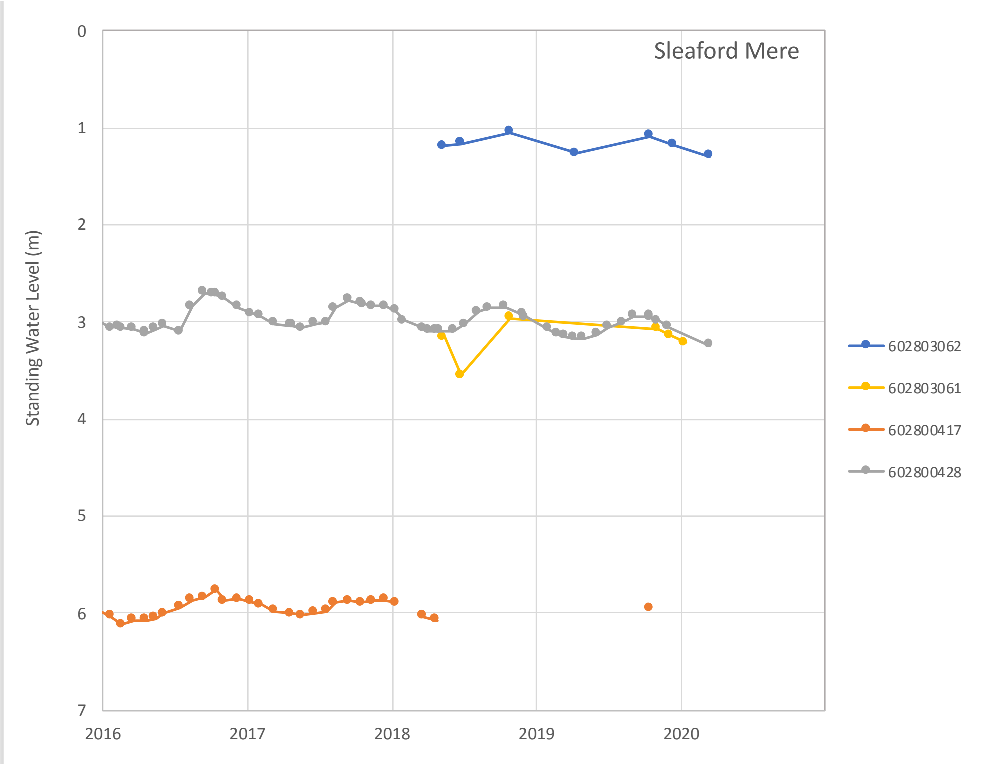
3.1: Changes in vegetation, rainfall and groundwater availability at Sleaford Mere

Only one survey was conducted at Sleaford Mere for most species because it quickly became apparent that accessing the quadrats was causing damage to the vegetation by trampling.

Repeated measures were taken for the *Melaleuca* data to detect changes in tree condition. No changes were detected in the surveyed trees. There are multiple factors that are likely to explain the lack of change seen in the data:

1. the trees appear to be one, relatively young cohort (one age class) thought to have recruited after a fire at Sleaford Mere nineteen years ago (known as the Tulka fire, February 2001) and still have many decades of life expectancy
2. the monitoring methods used are better suited to studying demographics rather than distribution and thus yielded no trends because the trees are all of one age class
3. the trees are very tolerant, and the conditions are close to ideal for *Melaleuca,* thus they are unlikely to show any change in health or decline to the point of loss from the quadrat in a short period. Changes, if they occur, are likely to occur over decades not years.
4. Groundwater levels have a distinct seasonal pattern but have dropped since the 1950s (Figure 4). Well 602800417 has been dry since mid-2018, suggesting that the drying trend is continuing. The winter rainfall and winter rainfall-recharge events have also declined since records began in 1890s (Figure 5) but the *Melaleuca* condition data suggests that although the water availability is declining, it is still within the tolerance of the trees because they have not declined in health.

The vegetation community at Sleaford Mere is currently a very stable one. Unless a major disturbance occurs, there is unlikely to be changes in the *Melaleuca* other than progressive maturation of the trees. As this occurs, the canopy will become dense and reduce light penetration to the *Gahnia* and other plants living underneath. The *Gahnia* are likely to decline as the *Melaleuca* canopy matures, independent of the groundwater allocation policies. The *Gahnia* may move down the elevation gradient or it may become contracted if the *Baumea* outcompetes it on the waterside of its zone.



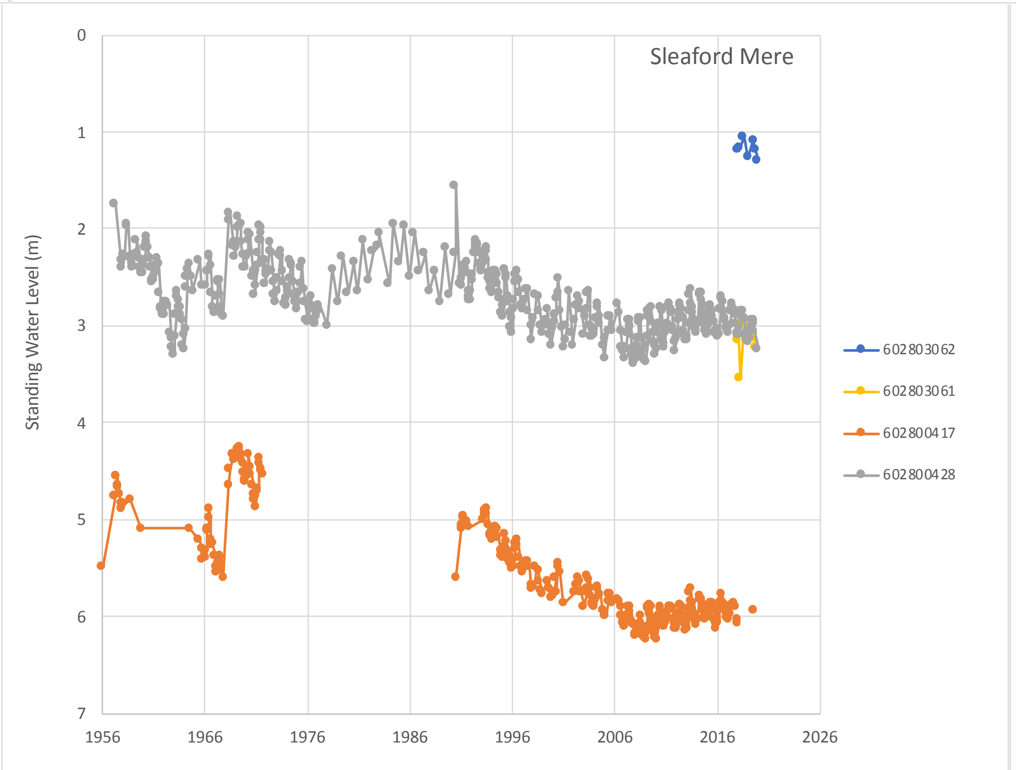


Figure 4: Groundwater levels at Sleaford Mere from a mixture of regional and newly installed wells at the site showing the long term trend (1956 to current; top) and recent levels (since 2016; bottom).

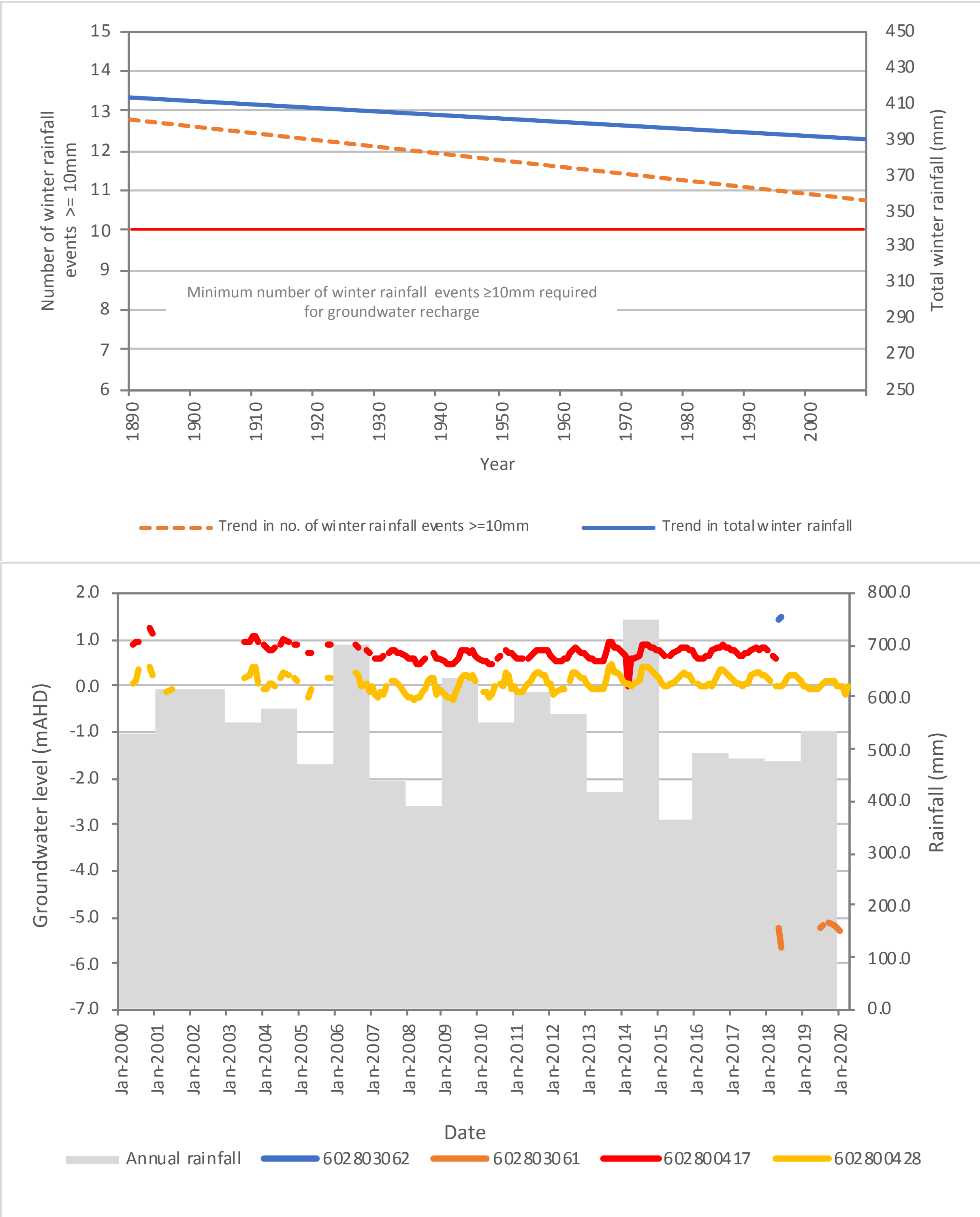


Figure 5: Long term trends in winter rainfall (May to Sept. 1890 to present) and annual number of winter rainfall-recharge events ≥10mm/day at Westmere Station (18137), near Port Lincoln (top) and trends in groundwater level and annual rainfall since 2000 for Sleaford Mere.

3.2: Changes in vegetation, rainfall and groundwater availability at Lake Pillie

Groundwater

The long-term hydrograph (Figure 6Figure 6) shows the groundwater levels near Lake Pillie fluctuate seasonally in response to rainfall patterns and that groundwater levels have dropped over the last six decades, which is consistent with the long-term trends in winter rainfall and winter rainfall events large enough to generate effective recharge Figure 5(Figure 7). The significant drop between the late 1980s and the mid-1990s appears to be a step-change over a shorter period that may be related to below average rainfall in the early 1990s.

Samphire

The Samphire data were collected from six quadrats on v-shaped transects down the elevation gradient. This means that data collected at quadrats 1 and 4 were at the highest elevation, those from quadrats 2 and 5 were intermediate and those from quadrats 3 and 6 were at the lowest elevation (nearest the middle of the basin).

Figure 9 shows the number of plants in each quadrat for each survey from December 2016 to October 2019. These data show that there was a high level of spatial and temporal variability in the samphire plant numbers over time and across the quadrats. Due to the monitoring design having only two (duplicate) transects statistical analyses could not be undertaken and the data were not analysed further.

The large increase in samphire plant numbers between December 2016 and November 2018 show that there was a mass germination event during that period in quadrats 5 and 3. Groundwater levels showed a seasonal pattern but did not show any interannual trend during these years in either the shallow or deep observation bores (Figure 6). Rainfall was relatively higher from winter 2016 onwards than it had been in early 2016, which may explain the germination response, even though long-term winter rainfall trends have steadily declined since records began in 1890 (Figure 5).

There was high mortality of these seedlings between November 2018 and May 2019 in quadrat 3 that was not observed in the other quadrats. This did not correlate with strong changes in water availability at the wetland scale and may reflect seasonal patterns in rainfall and groundwater recharge (e.g. spring germination of samphires) and/or interannual variability in soil moisture (e.g. high rainfall years supporting germination of plants that do not persist through following dry periods).

Baumea juncea

Figure 8 shows that there was very high spatial variability in *Baumea juncea* plant numbers between the quadrats (as shown by the large error bars ± 1 S.E.), but low temporal variability across sampling dates. This suggests that there has been no significant change in plant numbers over time, which was confirmed by PERMANOVA (PERMANOVA: *Pseudo* $F_{3,27} = 0.041$, $P = 0.99$).

Baumea juncea is the most drought-tolerant of all the *Baumea* species and thus changes are likely to be slow, if they do occur. All the plants recorded were live. If there is a decline in water availability over time, it is likely that the first sign will be dead culms or retreat from the drier elevations, but this may not be detected in these quadrats.

Gahnia filum

The *Gahnia* data were collected and analysed in a similar way to the *Baumea* data. Once again there was high spatial variability but low temporal variability with no significant change in abundance through time in the seven quadrats (PERMANOVA: *Pseudo* $F_{3,26} = 0.647$, $P = 0.61$).

Melaleuca halmaturorum

The Melaleuca data are presented in

Figure 10. Plant numbers have been plotted using a log scale due to the large numbers of plants. Thousands of seedlings were recorded at the highest elevation (quadrats 1 and 4) between December 2016 and September 2018 and very little mortality has been recorded since. The germination appeared to occur at the same time as the Samphires but there was not the discernible mortality that was seen in the Samphire data.

All the trees sampled were young, being in the three youngest age classes (

Figure 10.). Most of the trees at Lake Pillie appear to be <10 years old with no older trees present. It is hypothesised that the lower rainfall during the Millennium Drought (especially 2007 and 2008) created a drying niche for the *Melaleucas* to enter the Lake Pillie plant community (given that groundwater levels track recent rainfall closely; Stewart et al., 2012) and that these trees germinated in the relatively wet period that followed from winter 2009.

This drying regime seems to have continued (Figure 5) with standing water not having been observed in the lake for the last two winters (2018 and 2019) when it was seasonally inundated prior to that.

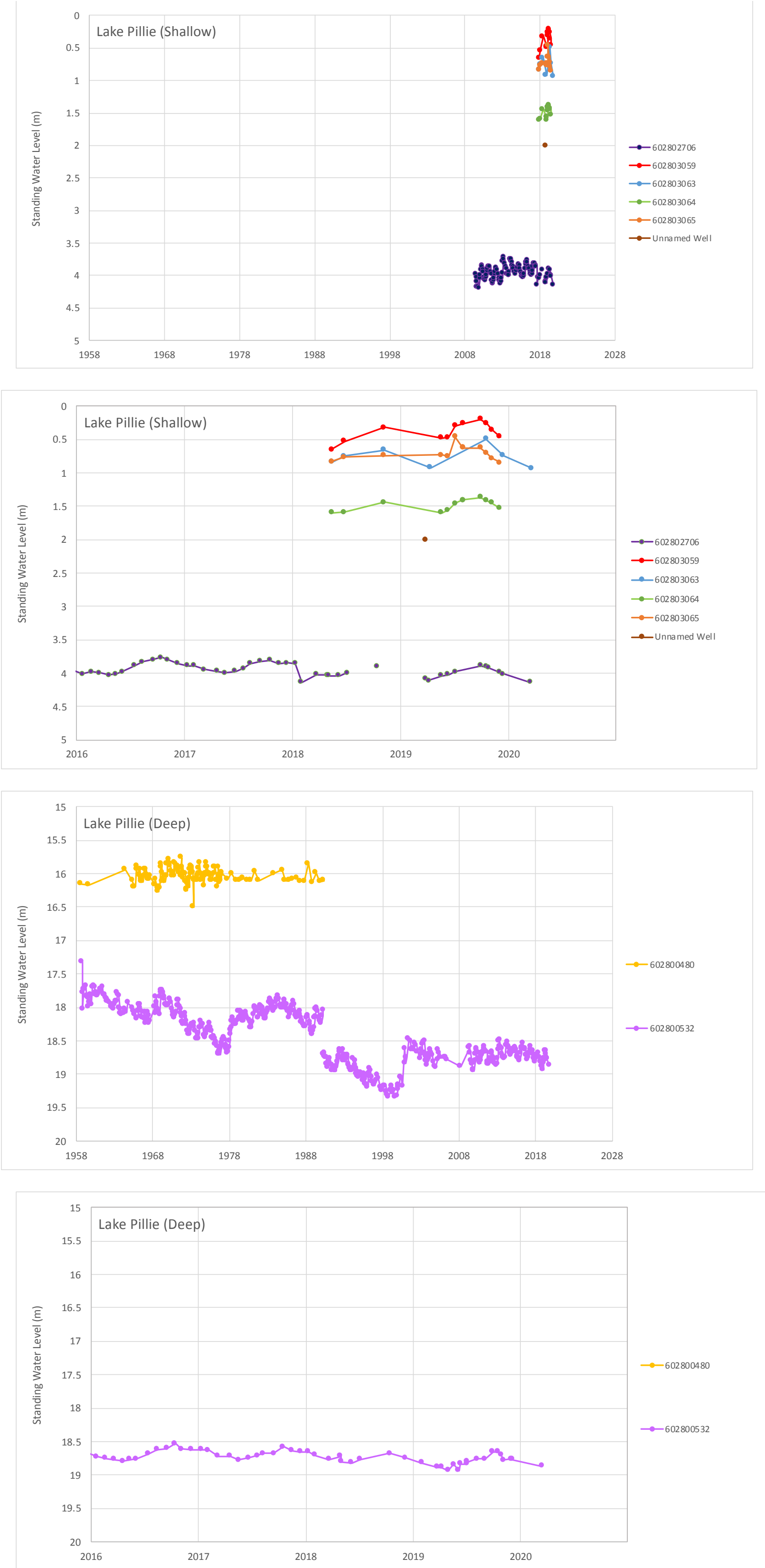


Figure 6: Groundwater hydrographs from shallow (top two graphs) and deep (bottom two graphs) observation bores at Lake Pillie. Note the Unknown well in the legends is well 6028-2722.

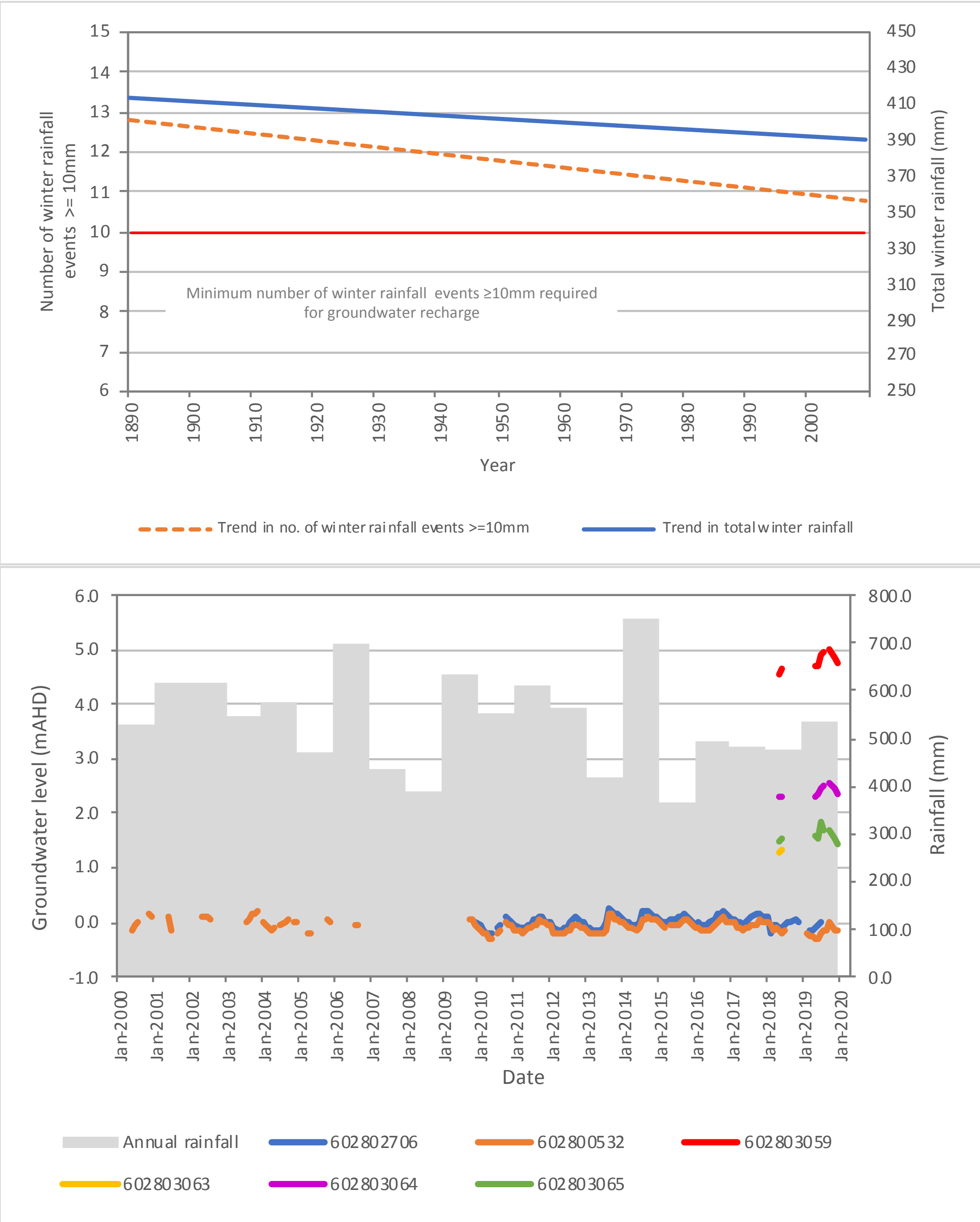


Figure 7: Long term trends in winter rainfall (May to Sept. 1890 to present) and annual number of winter rainfall-recharge events ≥10mm/day at Westmere Station (18137), near Port Lincoln (top) and trends in groundwater level and annual rainfall since 2000 for Lake Pillie.

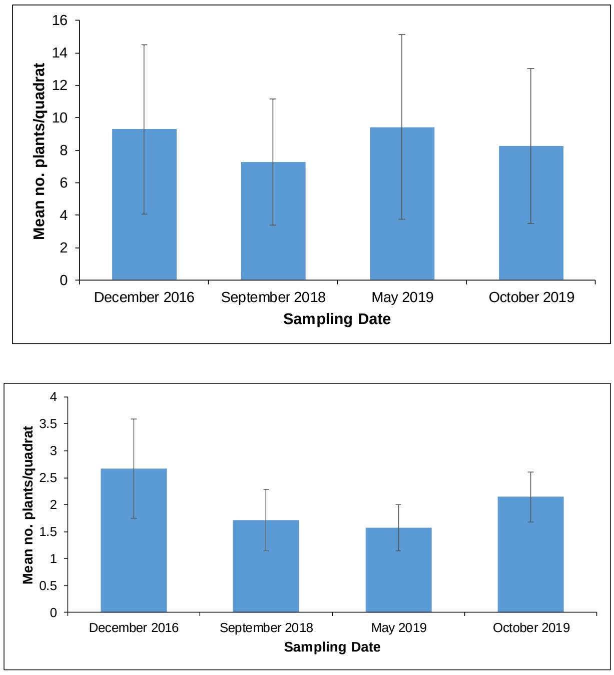


Figure 8: Number of Baumea juncea (top) and Gahnia filum (bottom) per sampling date at Lake Pillie. Error bars ± 1 S.E.

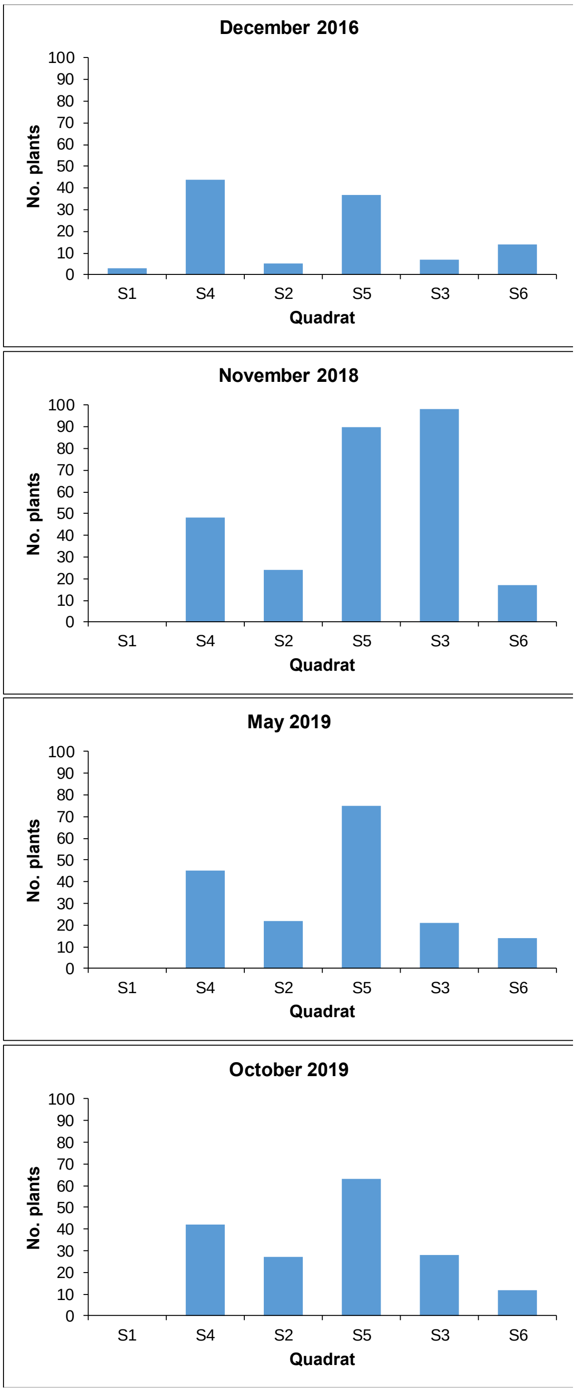


Figure 9: Number of samphire plants in each quadrat at Lake Pillie at four sampling times: December 2016 (a), November 2018 (b), May 2019 (c) and October 2019 (d).
Note that S1 and S4 are at highest elevation, S2 and S5 are intermediate and S3 and S6 are at the lowest elevation.

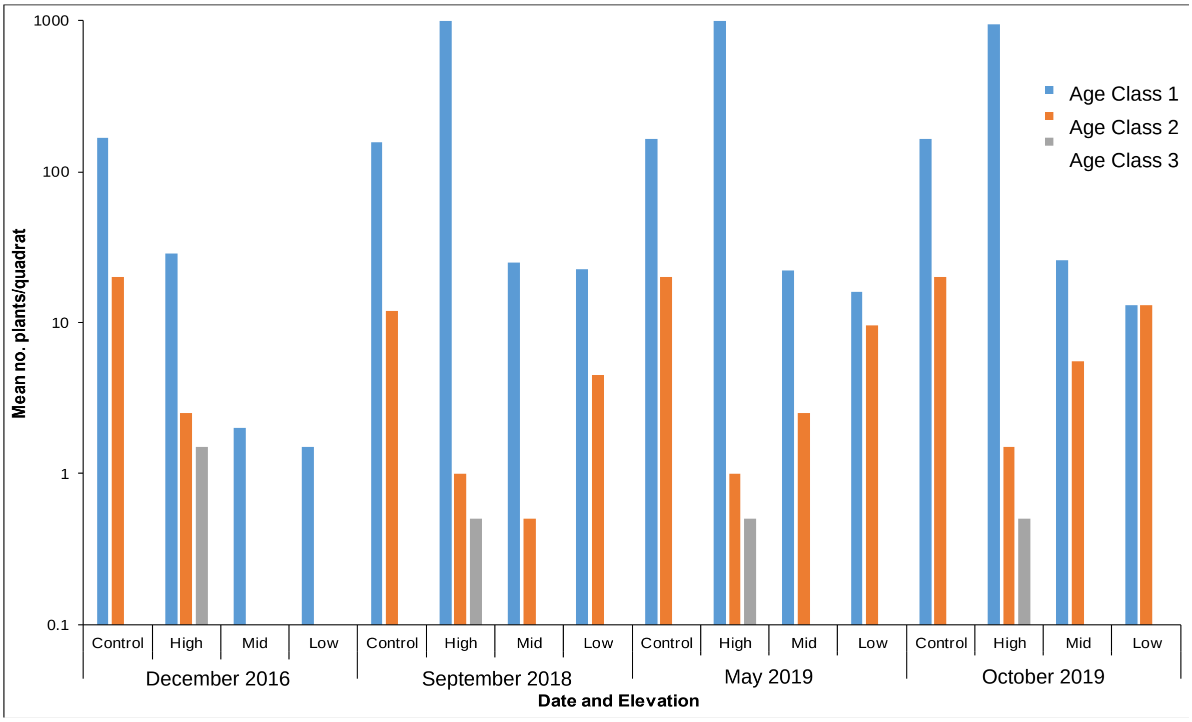


Figure 10: Number of Melaleuca trees in each quadrat at Lake Pillie at four sampling times: December 2016, September 2018, May 2019 and October 2019. Note the three age classes all represent young trees (age class 1: 1–2 year old trees; age class 2: 2–5 years old; and age class 3: 5–7 years old) with the oldest trees sampled being in Age Class 3 out of 7 possible Age Classes.

4. Conclusions

- Effective evaluation of the WAP needs to answer the following question:
  Are GDEs in the PWAs changing in condition and if so, do these changes show increased risk from nearby groundwater extraction?
  The current monitoring design is generally scientifically sound and based on proven methods, but it is not directly answering this question as the data are collected at the wrong spatial scale. It can only provide evidence of change in the given quadrats over time. It cannot provide evidence of changing distribution along the elevation gradient, which is the most likely change in vegetation that would occur if groundwater availability declined. The monitoring program can, therefore, be improved – see Recommendations below.

- Sleaford Mere – the vegetation data was only collected once for most species due to the need to prevent damage to the vegetation caused by more intensive sampling. The current data is a snap-shot of plant numbers in the quadrats that were sampled but do not constitute a baseline against which the evaluation question can be answered for Sleaford Mere. The *Melaleucas* at Sleaford Mere are young and still maturing in canopy extent and density and thus are unlikely to show changes using the current methods. Furthermore, the plant communities at Sleaford Mere are floristically simple, highly tolerant of drought conditions, very stable and only likely to show change over longer time periods (e.g. decades not years). It is expected that the *Melaleucas* will form a closed canopy over time, which is likely to shade out the *Gahnia* and *Baumea*, regardless of groundwater extraction rates. New understorey species that prefer living under dense *Melaleuca* canopies are likely to colonise.

- Lake Pillie – this wetland appears to have been on a drying trajectory since at least the 1950s, well before the introduction of water allocation policies. There are multiple lines of evidence including the long-term groundwater hydrograph showing a significant lowering of the groundwater levels, the long-term drying trends in winter rainfall and the lack of *Melaleucas* more than c. 10 years old. As for Sleaford Mere, the current plant communities at Lake Pillie are very stable and tolerant of current conditions, representing the plants that have withstood the drying regime or colonised opportunistically as the wetland has dried out. These plants likely are able to withstand significant further drying of the wetland water regime before showing signs of decline.

5. Recommendations

It is recommended that the GDE Wetland monitoring methods are changed from the current quadrat-based methods to a belt transect method (sensu Grant et al. 2004) to better answer the evaluation question, which is:

Are GDEs in the PWAs changing in condition and if so, do these changes show increased risk from nearby groundwater extraction?

This will contribute to answering the broader evaluation question from the WAP MERI (EP NRMB 2016b), which is:

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

To answer these questions, it is important to look at changes in distribution of plant species along the elevation gradient. The current quadrat-based method is not well suited to studying distribution or answering this evaluation question.

It is recommended that EP NRMB switch to a methodology using belt transects and re-establish the baseline. Belt transects run from the highest elevation at which water-dependent vegetation grows to the middle of the basin (Grant et al., 2004). Every 1m along that line, the presence/absence of each plant species is noted anywhere across the width of the transect (i.e. one value for each species each metre) until the centre of the basin is reached or until there are no more plants down the elevation gradient. The belt transect can vary in width, usually 2-10m wide. It is recommended that EP NRMB use 5m to 7m wide belt transects for the GDE wetlands.

It is also recommended that EP NRMB survey GDE Wetlands less frequently but visit more wetlands. It would be ideal to survey as many wetlands in the PWAs as possible over the next 12-14 months, or at least one representative of each wetland group as described by Semeniuk and Semeniuk (2007). This data would then form the baseline against which any changes in vegetation bands or community composition can be evaluated against climatic changes and/or groundwater extraction using belt transects. This is important because Lake Pillie does not represent a robust control site for Sleaford Mere. Surveying more wetlands, less often, with belt transects will provide more robust evidence and more lines of evidence for answering the evaluation questions than the current monitoring design.

Rationale for changing monitoring methods

1. The current methods are generally scientifically robust but are not answering the question at the whole of PWA scale or at the wetland scale. The number of quadrats is powerful enough to detect changes over time in those quadrats but there are not enough quadrats to answer the monitoring question, which requires an understanding of how distribution along the elevation gradient is changing. For example, if a species declines in a quadrat over time, the current method will not provide evidence as to whether that species has moved up or down the elevation gradient or been lost from the wetland in response to changing groundwater levels.
2. Belt transect advantages:
   a. Provide evidence at a whole of wetland scale – less quantitative at a small scale than quadrats but will give more information at a whole wetland scale and will answer the evaluation question more directly and robustly. Many quadrats would be needed to yield the same level of information at a whole wetland scale that the belt transect method can.

   b. Provide evidence at a regional scale – using drones to collect belt transect data at more wetlands than just Lake Pillie and Sleaford Mere across the PWAs (Figure 12 and 11) will yield regional trends and provide more robust evidence for whether wetlands close to groundwater extraction are changing at a different rate to those only subject to climatic factors and regional groundwater trends.

   - Less resource intensive at the wetland scale - Drones can be deployed to fly the georeferenced same path. Images can be stitched together to form a remotely sensed “belt transect” that can be compared through time. This will be highly beneficial for Sleaford Mere, where the vegetation is more fragile and susceptible to trampling during on-ground sampling, to look at changes in distribution of *Melaleuca* and *Gahnia* and for establishing more sites across the region. The wetlands are floristically simple, therefore, scoring presence or absence of species at 1 m intervals will be relatively rapid once data templates have been developed. It is expected that each belt transect will require a half day to establish and then c. 1-2 hours for repeated surveys using georeferenced drone images. It is expected that any changes in vegetation distribution due to future changes in groundwater levels are likely to be long-term, therefore resampling can be done every 5-7 years. The vegetation at most GDE wetlands are slow responders because they are highly tolerant species and are currently well within their tolerance bands.

   c. Track vegetation changes along the elevation gradient - belt transects record the presence or absence of each species at 1 m intervals down the elevation gradient. This enables managers to track movement up or down the elevation gradient in response to changes in groundwater levels, if they occur. The quadrat method will only give evidence of the density of the selected plant species at the selected locations.

   d. Generate a species list – unlike the quadrats which have been established in specific vegetation bands (e.g. samphire, *Baumea*, *Gahnia* and *Melaleuca*), belt transects will generate a species list for the wetland along the elevation. This can be used to identify less common species (e.g. *Wilsonia rotundifolia*), colonisation by new species (e.g. pest plants or more drought tolerant species) and to evaluate the water regime down the elevation gradient based on the water requirements of the different species (Doeg et al. 2011). Change in the plant community through time and comparisons between wetlands (on a presence-absence basis) can also be undertaken using multivariate statistics (e.g. nMDS ordination, clustering) (McCune et al. 2006).

e. Elevation can be determined along the transect and the change in distribution of species can be documented horizontally and vertically.

Lake Pillie recommendations:

- Establish four x 5m wide belt transects around the wetland. Options for selecting locations include: using existing quadrat locations, or using compass bearing north, south, east and west.
- Take GPS co-ordinates and place peg in ground at beginning of transect
- Conduct on-ground surveys along these belt transects to establish a base line and check that the drone methods align well with on-ground surveys. Note there is a low likelihood of causing damage to vegetation by conducting ground surveys at Lake Pillie compared to more sensitive sites such as Sleaford Mere.
- At the same time, fly drones along the same georeferenced path to establish correlation between presence/absence data from ground surveys and drone surveys
- There are very few species at Lake Pillie, therefore, recording presence or absence will be rapid.

Sleaford Mere recommendations:

- Undertake same methods for belt transect establishment as for Lake Pillie but only use the drone and do not conduct ground surveys to prevent damage to more sensitive wetland vegetation.

Additional wetlands recommended:

- For additional wetlands: Establish a minimum four x 5m wide belt transects around the wetland using compass bearings north, south, east and west, unless there is a reason to select a particular line (e.g. changes in vegetation or ease of site access or congregation around a feature) in which case the transects would be equally located around the shore from that point.
- Semeniuk and Semeniuk (2007) grouped wetlands on the Eyre Peninsula based on their topographical, hydrological and ecological character (Attachment A). It is recommended that at least one wetland from each group be selected for vegetation surveys, although, using these drone survey of belt transect methods, it may be possible to survey all the surface water wetlands in the PWAs. Each wetland would only need to be flown with drones every 5-10 years, although best to establish baselines at all sites in the next 24 months. The exception are the Wanilla Group of wetlands that are creek systems close to Coffin Bay that are less likely to answer the evaluation question because they are different geomorphologically to the other GDE wetlands and they are close to Coffin Bay where groundwater extraction by SA Water has ceased under the WAP.
- Those wetlands that are near to current groundwater extraction can be compared to other 'reference' wetlands that are not near to current groundwater extraction to answer the evaluation question.

- Lake Newland is a high priority for surveying as a reference site due to high value ecological assets, especially around Weepra Springs.
- Wetlands in the Hamilton Wetland Group near Sheringa and around Elliston are likely to provide an additional site for GDE wetlands that may be affected by groundwater extraction, in the latter case for town water supplies, and could be compared with Lake Hamilton itself unless there are other wetlands that are more similar in terms of geomorphology or landscape position.

Further investigations into watering history

Anecdotal evidence and regional groundwater data suggest that some of the GDE Wetlands in the PWAs are undergoing long-term drying, in some cases since the 1950s. It may be possible to reconstruct their watering histories, to a certain extent, to add further lines of evidence to the WAP evaluation by:

- examining surface water imagery (e.g. Water Observations from Space) for periods when the groundwater was expressed at the surface and/or
- using the drone or other methods to determine the bathymetry of the wetlands, especially the elevation of the wetland base, and relate this to changes in groundwater elevations to show when the groundwater levels were higher or lower than the wetland base over time.

The relative differences in elevation between the wetland base and the groundwater levels will illustrate whether the wetland had standing water and for what periods (see Figure 11 for example). This could be confirmed using Water Observations from Space.

This watering history and aerial observations could also be used to confirm the age of *Melaleucas* at the different wetlands.

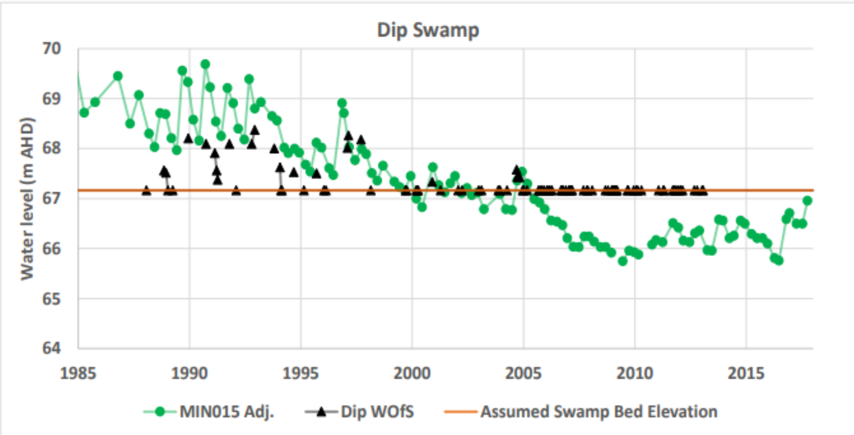


Figure 11: Example hydrograph for Dip Swamp showing changes in groundwater levels from an adjacent bore (green) and surface water expression detected using Water Observations From Space relative to the elevation of the bottom of the wetland basin.
Figure taken from Cranswick and Herpich (2018).

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Attachment A: Locations of GDE Wetlands in the PWAs.

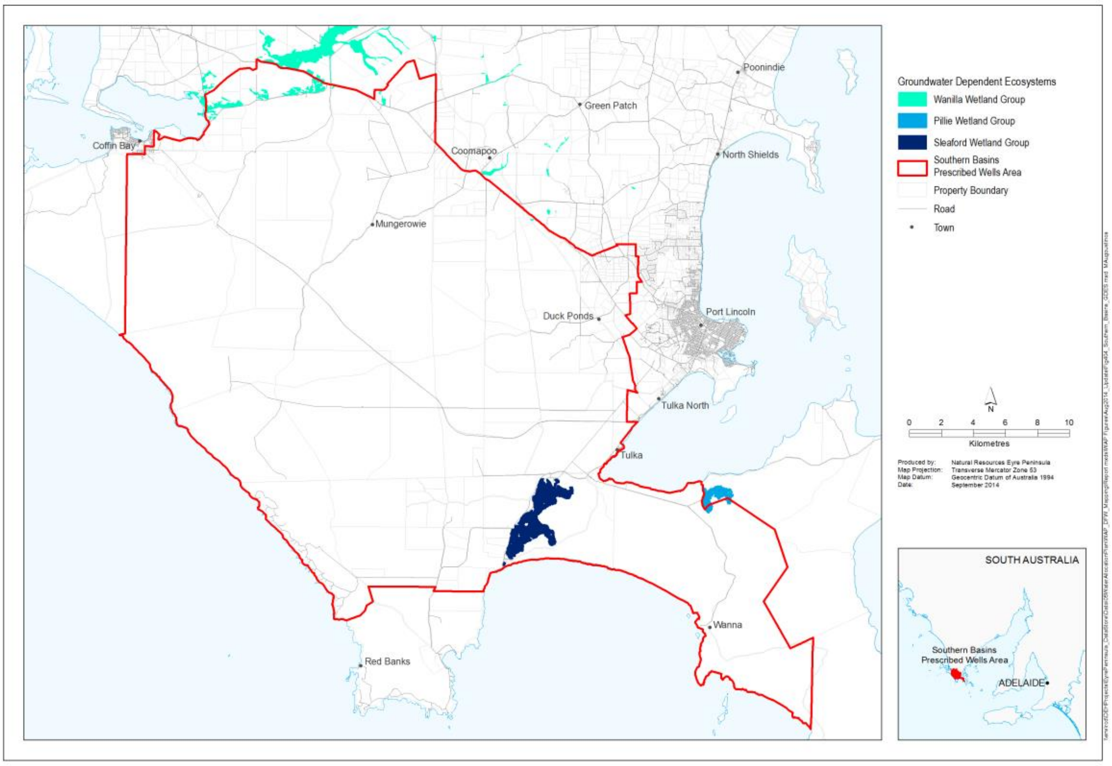

Figure 12: Wetland groundwater dependent ecosystems (GDEs) of the Southern Basins PWA.

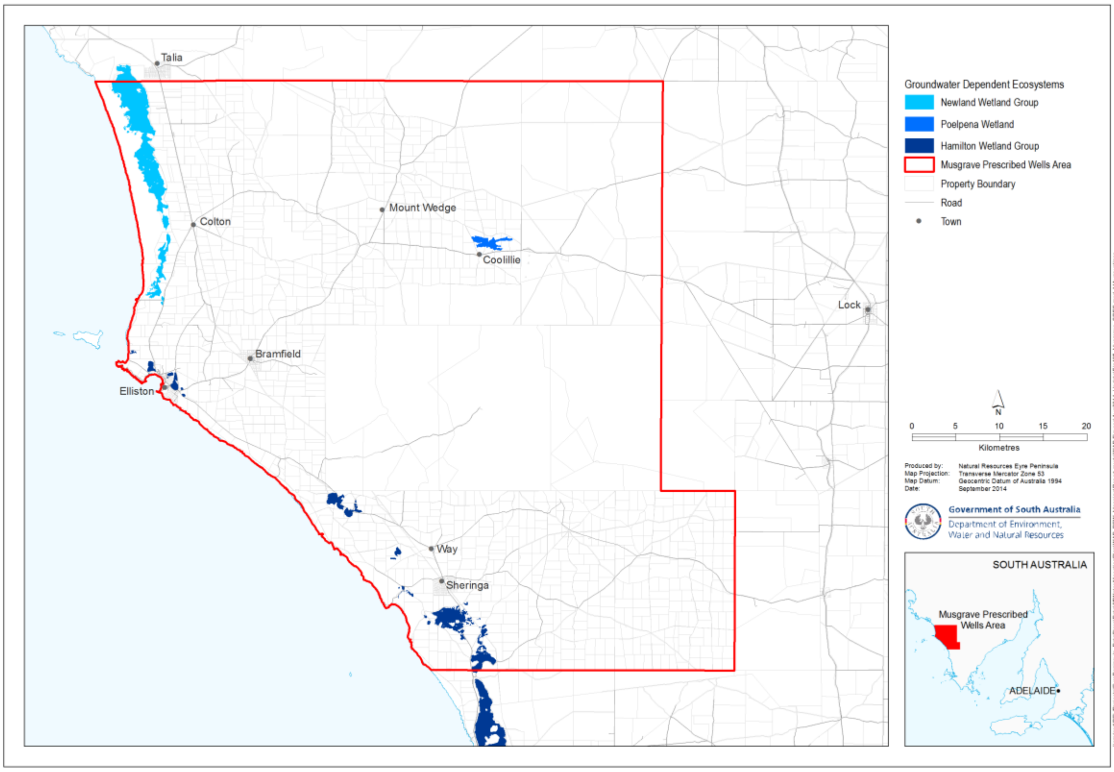

Figure 13: Wetland groundwater dependent ecosystems (GDEs) of the Musgrave PWA.

Attachment B: Eyre Peninsula Wetland Groupings

Semeniuk and Semeniuk (2007) grouped wetlands on the Eyre Peninsula based on their topographical, hydrological and ecological character. The wetland groups found within the PWAs that are known to have groundwater dependency are described below and displayed in Figures 24 and 25.

SLEAFORD WETLAND GROUP: Located on the south-eastern tip of the Southern Basins PWA (Fig. 24) and consisting of two basins, Sleaford Mere and Little Sleaford Mere. Sleaford Mere is a shallow, saline, permanent wetland and a site of national and international importance for shorebirds (Environment Australia 2001). Little Sleaford Mere is ephemeral. Together these basins provide important habitat for a wide range of fauna including waders, shorebirds, other waterbirds, and frogs. The water regime appears to be dependent on direct rainfall and groundwater recharge from the supporting Quaternary Limestone aquifer (Lincoln South management area). Permanent freshwater soaks occur at the northern end of Sleaford Mere.

WANILLA WETLAND GROUP: Consists of a number of short channels originating in the Lincoln Hills that flow into waterlogged flats in the northern section of the Southern Basins PWA (Fig. 24). These channels have flow periods of approximately five months (Semeniuk and Semeniuk 2007). The two main wetlands are Merintha Creek and Wanilla. They appear to be recharged by direct rainfall and runoff from Lincoln Hills and lose water to the groundwater (Uley North management area). However, changes in regional groundwater levels may affect flow and thus they are included as environmental values.

PILLIE WETLAND GROUP: Consists of a number of small elongate dampland basins on the south-eastern tip of the Southern Basins PWA (Fig. 24). The selected representative site is Lake Pillie, although there is anecdotal evidence that it has become more terrestrial in character over the last 15 years (Hyde pers. comm.). The water regime appears to be dependent on direct rainfall and groundwater recharge from the supporting Quaternary Limestone aquifer (Lincoln South management area).

HAMILTON WETLAND GROUP: Includes a single large elongate basin (Lake Hamilton) and a number of smaller associated basins along the coastal edge of the Musgrave PWA (Fig. 25). All are seasonally inundated. The selected representative sites are Lake Hamilton and Round Lake. Lake Hamilton is listed as a nationally important wetland in the *Directory of Important Wetlands in Australia* (Environment Australia 2001) and is a good example of a wetland type occurring within a biogeographic region in Australia. The water regime for Lake Hamilton is dependent on several pathways. Fresh surface water from the eastern and western limestone ridges discharge into the lake from multiple sources, predominantly two large springs at the northern end. There is saline surface water on the western side of the lake with salinities in the order of 2-3 times seawater concentration. It is thought that this may be due to saline springs discharging into the lake (Nosworthy pers. comm.) or tidal channel connections (Semenuik and Seminuik 2007). The water regime of Round Lake appears to be dependent on direct rainfall and groundwater recharge from the supporting Quaternary Limestone aquifer (Sheringa management area).

NEWLAND WETLAND GROUP: Consists of a complex of large wetland basins within the Musgrave PWA (Fig. 25), with the main body of water, Lake Newland, being a relatively permanent salt lake with freshwater springs. Parts of the lake system dry over the summer period. Lake Newland is one of the most ecologically important wetlands on the Eyre Peninsula. According to Wainwright (2008) it attracts bird species considered vulnerable in South Australia and has an important role as a drought refuge for waterfowl. Wainwright (2008) considered Lake Newland to be of 'international importance for banded stilt' and of 'national importance' as a summer feeding habitat for the vulnerable hooded plover. It is also listed as a nationally important wetland in the *Directory of Important Wetlands in Australia* (Environment Australia 2001). Fresh water is delivered into the Newland Lake by rainfall and groundwater (Semeniuk and Semeniuk 2007) from the supporting Quaternary Limestone aquifer (Bramfield management area). The saline lakes become shallower and more saline in summer, but are freshened by winter rain and a number of fresh water springs and seepages, which enter the lakes at their edges.

POELPENA WETLAND GROUP: Consists of a single large elongate basin to the east of the Musgrave PWA (Fig. 25) that is likely to be intermittently inundated. Poelpena Swamp is the representative site. Recharge to the wetland appears to be via direct rainfall and groundwater discharge from the supporting Quaternary Limestone aquifer (Polda management area).